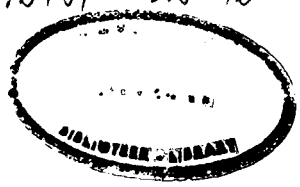

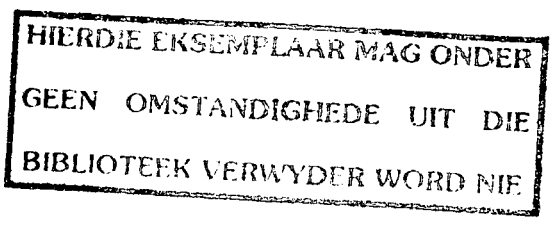

GRAIN YIELD AND BREADMAKING QUALITY OF WHEAT LINES WITH LEAF RUST RESISTANCE GENES *Lr29, Lr34, Lr35*, AND *Lr37*

by

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Ek, Benida Grobbelaar, verklaar dat die verhandeling wat hierby vir die graad Magister Scientiae Agriculturae aan die Universiteit van die Oranje-Vrystaat deur my ingedien word, my selfstandige werk is en nie voorheen deur my vir 'n graad aan 'n ander universiteit of ander fakulteit ingedien is nie. Ek doen voorts afstand van die outeursreg op die verhandeling ten gunste van die Universiteit van die Oranje-Vrystaat.

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CONTENTS

CHAPTER 1

INTRODUCTION

Rust is a common disease of wheat (*Triticum aestivum* L.) worldwide (Singh, 1992a). Leaf or brown rust, caused by *Puccinia recondita* Rob. ex Desm. *f. sp tritici,* is probably the most important rust disease of wheat (Samborski, 1985). Leaf damage caused by *P. recondita* reduces the quantity and composition of assimilates available for grain development, thus resulting in lower yield and quality. Yield losses due to leaf rust usually vary from 5-15% or more, depending on the level of resistance and stage of crop development when initial infection occurs (Liu & Kolmer, 1997).

Leaf rust, according to Drijepondt, Pretorius, van Lill, & Rijkenberg (1990), can lower the grain yield, kernel size, hectolitre mass, and protein content. The reduced yield and protein content will, in turn, reduce the income of farmers, millers and bakers. Crop protection is thus necessary for the maintenance of production capacity, the stability of cultivar yield, and the prevention of negative effects on quality (Hoogenboom, 1993).

Genetic resistance to rust diseases is highly preferable because it is considered to be the most effective and environment-friendly method of disease control (Liu & Kolmer, 1997; Singh & Huerta-Espino, 1997). According to Hoogenboom (1993) the value of resistance breeding is emphasized by the positive ratio between input and return. Despite the value of resistance to rust diseases, the respective pathogens, and particularly the leaf rust fungus, often mutate to overcome sources of resistance. This regular breakdown of resistance demands an ongoing search for new and effective sources (Kloppers, Pretorius & van Lill, 1995). Plant breeders are thus forced to add new resistance genes to their breeding material, and to develop strategies that will prevent the pathogen from stepwise adaptations.

High yield has always been considered to be the most important characteristic of a wheat cultivar. More recently, grain quality has become equally important, with significant economic implications in the production and marketing of grain. Therefore, when breeders decide to use particular genes for disease resistance in their

programmes, information on negatively or positively associated quality characteristics is important.

The genes *Lr29*, *Lr34*, *Lr35* and *Lr37* are valuable sources of resistance to leaf rust. However, the effect of these genes on yield and quality characteristics of South African wheat cultivars is largely unknown. Knowledge of any advantageous or deleterious effect associated with these genes will assist the wheat breeder in selecting appropriate leaf rust resistance sources.

The aim of this study was to determine the effect of specific leaf rust resistance genes in two different genetic backgrounds on the breadmaking quality and yield of wheat.

CHAPTER 2

LITERATURE REVIEW

This overview is directed towards the importance of wheat quality and its measurement. Furthermore, yield components are briefly discussed and the respective leaf rust resistance (*Lr*) genes and associated quality characteristics are addressed.

2.1 QUALITY TRAITS

Wheat quality can be defined as the suitability of the cultivar for the intended procedure and product manufactured from the grain. Milling performance, dough rheology and the baking quality are the main criteria used to describe wheat quality. Quality testing thus provides important information that is used to facilitate selection during breeding. Furthermore, prediction of inherent end-use quality is important to the miller, baker and breeder as it affects income directly (Peterson, Graybosch, Baenziger & Grombacher, 1992; Graybosch, Peterson, Shelton & Baenziger 1996).

According to Graybosch *et al.* (1996) flour is expected to produce a strong dough with adequate loaf volume and desirable appearance. Bread quality is largely determined by the quantity and quality of flour proteins. Quality is mainly controlled genetically whereas quantity is largely influenced by environmental or related factors (McGuire, & McNeal, 1974; Fowler & De la Roche, 1975a; Baenziger, Clements, McIntosh, Yamazaski, Starling, Sammons, & Johnson, 1985; Peterson, *et al.,* 1992).

2.1.1 Protein quantity

Protein quantity of wheat is considered important due to various reasons. Protein is an important nutrient in the human diet and the content is also of significance in the functional uses of flour (Eliasson, 1990). Thus, wheats that do not have a high or acceptable protein quantity are undesirable for domestic consumers (McGuire & McNeal, 1974). The protein content in wheat can vary from 6% up to as much as 27%. Most commercial samples in South Africa, however, contain between 8-16% protein. A

protein content lower than 11% is insufficient for the production of well-leavened bread (Koekemoer, 1997).

Most of the difference in breadmaking quality between flours are explained by variation in the protein content. Protein content and breadmaking quality of flour are positively correlated, but selection for a higher protein content is hampered by a negative relationship with kernel yield (Schepers, Keizer & Kolster, 1993).

Fowler & De la Roche (1975b) found that most of the variation in loaf volume can be explained by variation in protein quantity. Flour protein content and SDSS volumes were often correlated with quality parameters (Graybosch *et al.*, 1996). A significant correlation was found between loaf texture and glutenin content. Loaf texture and flour protein content were, however, negatively correlated (Peterson *et al.*, 1992; Graybosch *et al.*, 1996).

2.1.2 Protein quality

Differences in breadmaking quality can also be attributed to differences in protein quality. Dough development is influenced by protein quality, which emphasises the importance of protein quality in cultivar breeding (Fowler & De la Roche, 1975b).

Protein quality is almost as important as protein quantity in baking (Campbell, Wrigley, Cressey & Slack, 1987). Total wheat protein can be divided into five groups: albumins (soluble in water), globulins (soluble in salt solutions), gliadins (soluble in aqueous ethanol), glutenins (soluble in dilute acid or alkali) and insoluble fractions. Gluten, consisting of gliadins and glutenins, is the predominant wheat protein and is unique to wheat. Much of the variation observed in flour quality may result from variation in gluten content (quantity) and composition (quality). According to Eliasson & Larson (1993) the unique visco-elastic properties of wheat flour are a result of glutenin residues. The genes coding for gliadins are located on chromosome 1 and 6 whereas those coding for glutenins are located on chromosome 1 (Graybosch *et al.*, 1996).

Glutenin constitutes up to 50% of the total protein in wheat flour. The amount of glutenins increases with an increase in protein content (Eliasson & Larson, 1993).

Glutenins are, furthermore, divided into low molecular weight (LMW) and high molecular weight (HMW) subunits. The HMW glutenins are coded by genes on the long arm of chromosome 1, whereas LMW glutenins arise from genes linked to gliadin genes on the short arm of chromosome 1 (Graybosch *et al.*, 1996).

In the early generations of a breeding programme, the small amounts of available seed usually preclude extensive quality testing. However, sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) can be used to determine the HMW banding patterns for protein quality in early-generation lines. An advantage of this technique is the small amount of flour required (Lorenzo & Kronstad, 1987).

Direct associations between breadmaking quality and the presence of certain HMW glutenin and gliadin subunits have been reported. A system was devised whereby values of relative importance were assigned to individual glutenin subunits. Depending on the Glu-1 bands present in a genotype a total Glu-1 scores can be calculated. Glu-1 scores proved to be positively correlated with baking performance and provide results that are as useful as rheological analysis (Payne, Seekings, Worland, Jarvis, & Holt, 1987). However Glu-1 scores accounted for only 25% of the variation in the breadmaking quality of South African wheat (P.G. Randall, personal communication). The importance of Glu1-loci in determining protein quality was assesed by Randall, Manley, McGill & Taylor (1993) and Schepers, *et al.* (1993). Allelic bands 1 or 2* on chromosome 1A, are equally desirable in contrast with the null allele (Moonen, Scheepstra & Graveland, 1982; Lukow, Payne & Tkachuk, 1989). Bands 7+8 as well as 7+9 (Lukow, 1991) and 13+16 (Lukow *et al.*, 1989) are desirable combinations on chromosome 1B. Dong, Sears, Cox, Hoseney, Lookhan & Shogren (1992) reported, however, that subunits 17+18 on chromosome 1B have the strongest positive association with loaf volume. Interaction of subunits 8+9 has a detrimental effect on the quality parameters and is associated with a reduced protein content (Khan, Tamminga, Lukow, 1989). Glu-D1 bands 5+10 are associated with superior in quality, whereas 2+12 are associated with low sedimentation volumes (Lukow, 1991). Selection for grain yield and baking quality may become more effective when early generations are screened for their HMW glutenin subunit composition (Schepers *et al.*, 1993). A variety may contain both the 5+10 and 2+12 bands, with intermediate sedimentation volumes.

HMW glutenin subunits appear to also have additive effects on dough quality, which enhance their value for predicting dough properties. Identification of proteins that confer good breadmaking quality of flour at an early stage will thus accelerate the process of developing new and better varieties (Gupta, Bekes, Wrigley, 1991).

2.1.3 Sodium dodecyl sulfate sedimentation

Rheological tests are expensive and labour intensive. Using the sodium dodecyl sulfate sedimentation test (SDSS) the wheat breadmaking quality on small samples can be assessed in a short time (Ayoub, Fregeau-Reid & Smith, 1993). SDSS volumes showed a significant correlation with dough development time and the width of the mixograph tail (Dhaliwal, Mares & Marshall, 1987). These authors also found in a second test found that SDSS was significantly correlated with mixograph height and dough strength parameters. A poor correlation has been observed between SDSS volumes and flour protein content. This shows that SDSS tests measured protein quality rather than the protein content. Schepers *et al.* (1993) found, however, that SDSS volumes and remix loaf volume were strongly affected by protein content. Lorenzo & Kronstad (1987) and Fowler & De la Roche, (1975b) reported that SDSS can be used to predict the breadmaking potential of hard wheats. Other also considered the SDSS a valuable parameter for assessing baking quality (Moonen *et al.*, 1982) and to select for strong dough and good loaf volume (De Villiers & Laubscher, 1995; Graybosch *et al.* 1996). SDSS combined with selection for favourable Glu1 combinations (SDS-PAGE), are good selection criteria in early generations (Lorenzo & Kronstad, 1989).

2.1.4 Hectolitre mass (test weight)

Hectolitre mass depends on the density of kernels and their packing efficiency. It is widely recognized as an important consideration for the grading of wheat grain (Ghaderi, & Everson, 1975), but may be influenced strongly by the environment (Jalaluddin & Harrison, 1989). Due to its economic importance Jalaluddin & Harrison (1989) stated that grain hectolitre mass must be used as a selection criterion. De la Roche & Fowler (1975) found that hectolitre mass, kernel weight and mixograph values

were positively correlated. Wheats with a higher hectolitre mass also tended to mill better (Gaines, Finney & Rubenthaler, 1996).

2.1.5 Flour extraction (flour yield)

In the first stage of utilisation, wheat grown for human consumption must be milled. The extraction percentage reflects the ease with which the endosperm is separated from the bran before conversion into flour. The roller-milling process consists of grinding and screening actions. The main objective is to achieve maximum flour yield with minimum bran and germ contamination. The more effective the extraction, the more flour is produced (Rubenthaler & King, 1987). The Bühler laboratory mill can be used to mill grain into a straight-grade flour and has been used in many studies (Dyck & Lukow, 1988; Drijepondt *et al.*, 1990; Ayoub *et al.*, 1993; Randall *et al.*, 1993; Gaines *et al.*, 1996).

2.1.6 Dough mixing properties

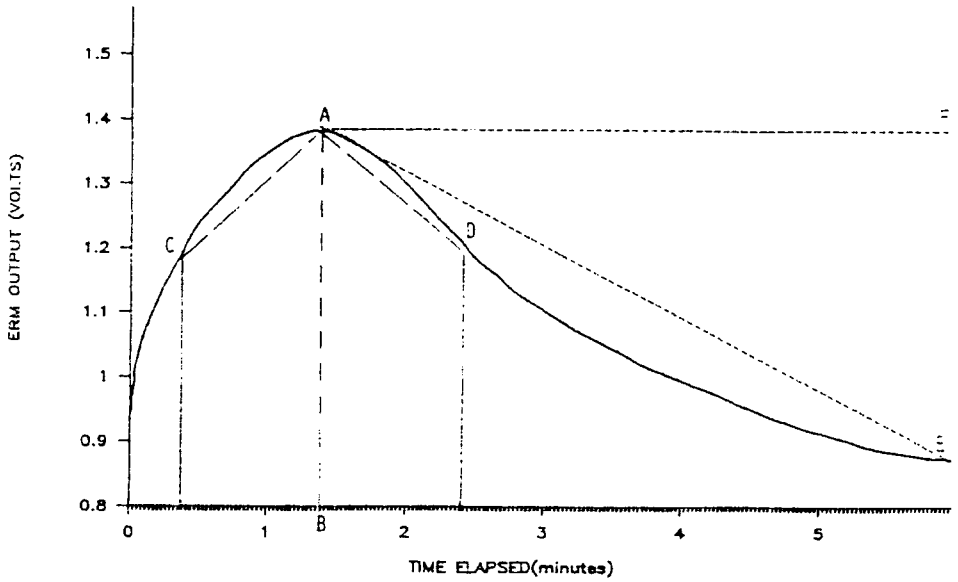
Wheat flour is an organic complex in which starch interacts with gluten and non-gluten protein, lipids and non-starch carbohydrates. Water mixed with wheat flour will result in hydration of the protein matrix to produce gluten and finally dough. Mixing is the last processing step in which the rheological properties of a dough can be significantly altered. It is only after a dough has been optimally developed that the full breadmaking potential of that dough can be realised. Many steps in the mixing process allow dough to reach this optimum state. Hydration of the flour particles is the first step. High shear rates in dough mixers help to speed up the hydration process. The gluten becomes hydrated and forms fibrils that are aligned into a matrix by repeated shearing action. During this process dough becomes increasingly resistant towards extension. At some point the dough ceases to increase the resistance to extension, and starts to break down. This is called the point of optimum mixing time (the dough is fully developed). Research has shown that in order to get the best loaf volume, the flour must be mixed to the peak of the mixing curve (Spies, 1990). Continued mixing beyond this point results in the break down of the dough (Faubion & Hoseney, 1990; Spies, 1990; Wikström & Bohlin, 1996). Mixing tolerance is the ability of dough to withstand overmixing and resist subsequent breakdown if the dough development time is

exceeded. Mixing time is measured as the time required to reach the peak of the curve (Peterson *et al.,* 1992; Walker & Hazelton, 1996).

The most commonly used instrument to measure mixing time, tolerance to mixing, and optimum water absorption, is the mixograph (Gras, Hibberd, Walker, 1990; Spies, 1990; Wikström & Bohlin, 1996). Five important characteristics (Figure 2.1) are measured with this method, namely 1) the degree of incline (developing slope); 2) the time to reach the peak; 3) the peak height; 4) the degree of decline (weakening slope); and 5) the angle made by the developing and weakening slope (Rubenthaler & King, 1987).

The y-axis of the graph (shown in Figure 2.1) is a measurement of resistance of the dough to extension. The length of the curve is related to the mixing time of the dough. The viscoelastic behavior of wheat dough results in a nonlinear ratio. The width of the curve is also related to the cohesiveness and elasticity of the dough. Mixograph properties have a significant correlation with flour protein content, SDSS, water absorption, dough development, dough resistance, and extensibility (Dhaliwal *et al.*, 1987; Peterson *et al.*, 1992). The flour protein content and quality, together with water absorption, determine the peak time and height (Walker & Hazelton, 1996). Dhaliwal *et al.* (1987) found that water absorption is significantly correlated with flour protein content. Water absorption is directly related to the amount of bread that can be produced with a given amount of flour. Rubenthaler & King (1987) and Lukow (1991) reported strong relationships between the peak height, curve width, weakening angle and loaf volume. Thus, mixograph characteristic may be used to predict important physical dough and breadmaking properties (Dhaliwal *et al.*, 1987).

The speed this test and the fact that only a small sample of wheat is needed, make the mixograph one of the most commonly used apparatus in wheat quality determination (Rubenthaler & King, 1987; Zounis & Quail, 1996), and allow for the selection of lines with desired mixing time requirements, water requirements, dough strength, and tolerance to overmixing (Gras *et al.*, 1990; Dong *et al.* 1992). These advantages make the mixograph a valuable selection criterion for wheat breeders to use when assessing breadmaking quality in early generation lines (Wikström & Bohlin, 1996)



Value	Definition
A	Peak height
B	Peak time
C	Value for 1 min. before peak
D	Value for 1 min. after peak
A-C	Developing slope
A-D	Weakening slope (minor)
A-E	Weakening slope (major)
Angle CAD	Angle of Tolerance

Figure.2.1. An example of a mixograph curve (Rubenthaler & King, 1987)

Another instrument used to predict baking quality is the alveograph which is designed to measure the resistance to biaxial extension of a thin sheet of flour-water-salt dough and the gluten fraction (Bettge, Rubenthaler & Pomeranz, 1989). A stiff dough is prepared with a mixer containing a sigmoidal blade. This process is similar to the effect of sheeting, rounding and moulding in the baking process.

Disks are cut from the sheet, allowed to relax for 20 minutes and then clamped above a valve mechanism (Walker & Hazelton, 1996). Air (↑) is blown at a constant rate, from below the disk, creating a bubble (Figure.2.2). The pressure inside the bubble, until it ruptures, is recorded. This method measures the resistance of the dough to deformation. The measurements (Figure. 2.3) include adjusted peak height (P), curve length (L) and work input (W). The P value is a predictor of the ability of the dough to retain gas. L is related to the extensibility and handling properties of the dough. W is

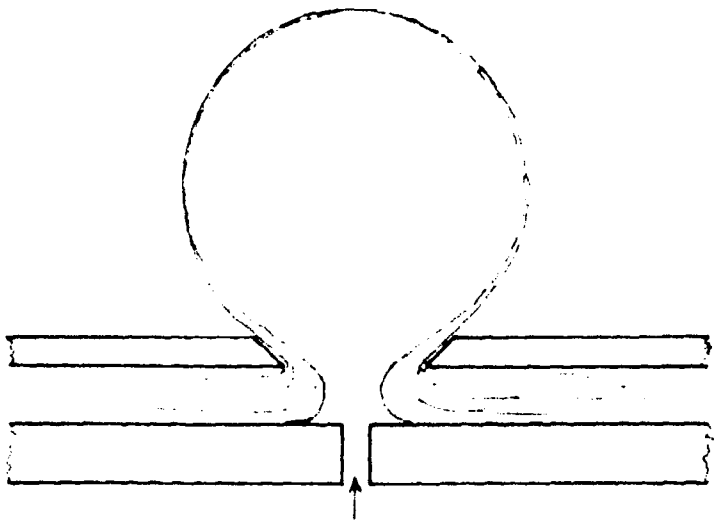
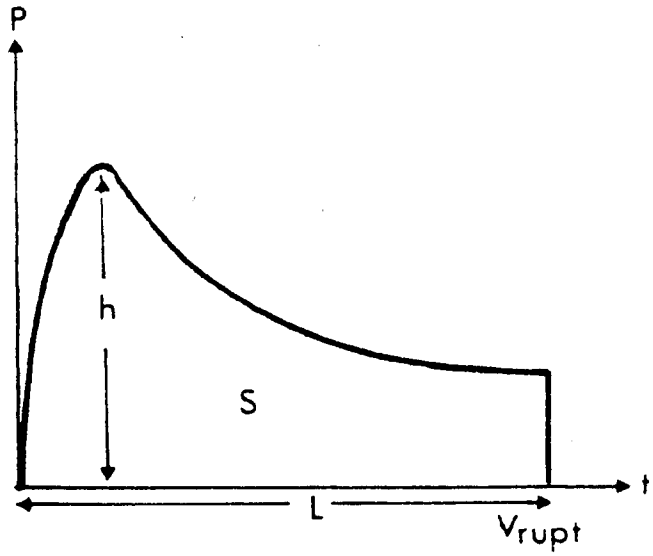


Figure.2.2 The operating principle of the alveograph (Walker & Hazelton, 1996)

the work input for deformation. This parameter is also related to the baking strength of the flour. Thus, high P and W values together with a short/medium L value suggest strong flours. The calculated P/L ratio in this method also serves as an index of protein quantity and quality (Walker & Hazelton, 1996). Bettge *et al.* (1989) found that the L value correlated with loaf volume.



P – overpressure, mm
L – abscissa at rupture, mm
G – swelling index, mL
V – volume of air, mL
W – deformation energy, 10^{-4} J

$P = h \times 1.1$

$G = \sqrt{V_{rupt}}$

$W = 1.32 \times \frac{V}{L} \times S$

Figure.2.3. Schematic representation of the alveogram and measurements (Rasper & Danihelkova, 1987).

The alveograph has some unique features, namely the mode of deforming its dough, which measures two primary dough properties, i.e. resistance to deformation and extensibility, the fact that it does not take the variable hydration of wheat flour into account, and the rate of extension. Other instruments stretch the dough at a constant rate, but the alveograph rate changes with the volume of the bubble (Rasper & Danihelkova, 1987). Randall *et al.* (1993) considered the alveograph a suitable tool for predicting breadmaking quality.

2.1.7 The baking test

Loaf volume is a major selection criterion in identifying cultivars with superior quality (McGuire & McNeal, 1974). Good gluten quality is needed to produce well-shaped loaf of bread with high volume and a good, fine and resilient crumb structure. Many components are important determinants of the texture of a slice of bread, for example the stickiness, springiness and most importantly, the firmness of the crumb (Spies, 1990). Schepers *et al.* (1993) reported a low correlation between loaf volume and grain yield.

2.2 YIELD COMPONENTS OF WHEAT

Yield remains an important factor in wheat production (Jalaluddin & Harrison, 1989). Since yield is influenced by the genotype and the environment, it is often difficult to predict (Fowler & De la Roche, 1975a). Yield of cereals is the product of three components, namely the number of spikes per unit area, the number of kernels per spike, and individual kernel weight (Bulman & Hunt, 1988). Usually the environment determines which component becomes the major contributor to yield. Spike number is of particular importance as it is the first yield component to be fixed and is often positively correlated with grain yield (Smid & Jenkinson, 1979; Darwinkel, 1983; Bulman & Hunt, 1988). Smid & Jenkinson (1979) also reported a highly significant correlation between kernels per spike and spikes per hectare.

Evidence exists that yield penalties are associated with certain *Lr* genes. Ortelli, Winzeler, Winzeler, Fried & Nosberger (1996) reported that under disease free conditions, grain yield of near-isogenic lines (NIL's) of wheat with *Lr9* was reduced by 12% in comparison with the recurrent parent, Arina. This reduction was explained by a reduced number of tillers per square meter and a reduced hectolitre mass. According to Seck, Roelfs & Teng (1988) the yield of Thatcher NIL's with *Lr9* or *Lr16* varied noticeably from the parents in a disease-free environment. The genotype Jupateco 73R, which contains the resistance gene *Lr34,* showed a reduction in yield of 2-6% in different planting arrangements (Singh & Huerto-Espino, 1997). The lower yield was due to a reduction in spike density, kernel weight and kernels per spike.

Thousand-kernel weight has also been identified as a reliable characteristic to estimate yield losses due to rust diseases (Pretorius, 1983). This characteristic has been correlated with flour protein concentration (Peterson, *et al.* 1992) but not hectolitre mass (Singh, Payne, Figuerosa & Valenzuela, 1991a).

2.3 RESISTANCE TO LEAF RUST OF WHEAT

2.3.1 Breeding for resistance

According to Knott (1989) several approaches can be used to breed wheat for resistance to leaf rust can be followed. The pedigree system has often been used to incorporate resistance in desirable genotypes. Crosses are made between two suitable parents and selection and testing conducted during ensuing generations. Eventually lines are tested in field nurseries for yield and rust resistance before the best selections are entered into national trials.

Bulk breeding has been used less frequently. Progenies, grown in bulk in rust nurseries, are selected on the basis of kernel plumpness that indirectly reflects resistance to rust diseases (Knott, 1989).

Backcross breeding is used mainly to incorporate individual resistance genes into existing disease-susceptible cultivars. Thus, the objective of this approach is to change one character in an already satisfactory cultivar. The resistance genes are usually dominant and easily detected in segregating progenies. The number of backcrosses depends on the objectives but at least five cycles are necessary if the phenotype of the recurrent parent is to be recovered (Knott, 1989).

Lr genes for wheat leaf rust resistance have often been used in backcrossing. McIntosh, Hart, Devos, Gale & Rogers (1998) have catalogued 46 *Lr* genes. Due to virulence in *P. recondita* f. sp. *tritici* for many of these genes (McIntosh, Wellings & Park, 1995), breeding attempts have often emphasised durability of resistance.

2.3.2 Durability of resistance

Johnson & Law, according to McIntosh (1992), defined durability in terms of resistance that remains effective after widespread deployment over a considerable period in an environment favourable for disease development. Durable resistance is usually 1) controlled by more than one gene; 2) more likely to be expressed only in the adult-plant than in both adult and seedling plants; and 3) most likely to be a non-hypersensitive

reaction (McIntosh, 1992). The durability and effectiveness of resistance can be enhanced by interaction between genes, even though this will not guarantee durability (German & Kolmer, 1992).

According to McIntosh *et al.* (1998) 24 *Lr* genes have been transferred from wild relatives to bread wheat. Although the availability of these genes accentuates the value of wild relatives as sources of diversity, it may be genetically linked to unknown deleterious characteritics (Knott & Dvorak, 1976; Hoogenboom, 1993; Cox, Bequette, Bowden & Sears, 1997).

2.3.3 Association of *Lr* genes with quality characteristics

Poor breadmaking quality has been associated with genes for rust resistance derived from rye (Law & Payne, 1983; Dhaliwal *et al.*, 1987). The short arm of the 1RS/1BL chromosome translocation contains several genes for disease resistance (Bartos, 1993). The genes *Lr26, Yr9*, *Pm8* and *Sr31*, conferring resistance to leaf rust, stripe rust, powdery mildew and stem rust of wheat, respectively, are located in this region. Although these genes are of value in wheat breeding programmes, the association of the rye segment with dough stickiness is undesirable (Martin & Stewart, 1986; Moreno-Sevilla, Baenzinger, Shelton, Graybosch & Peterson, 1995).

Cox *et al.* (1995) reported positive and negative influences on wheat quality associated with the *Lr41* gene (derived from *T.tauschii*). The hardness, flour yield and flour protein content were increased in lines containing *Lr41*, whereas mixing time and water absorption were reduced.

2.3.4 Description of *Lr29*, *Lr34*, *Lr35* and *Lr37* used in this study

The *Lr29* gene was derived from *Thinopyrum ponticum* and is situated on the short arm of chromosome 7D (Dyck & Lukow, 1988; McIntosh *et al.*, 1995). According to McIntosh *et al.* (1995) the low infection type varies from a 1N to 2+ reaction. Only three isolates with virulence to *Lr29,* one from Pakistan and two from Turkey, have been reported (McIntosh *et al.,* 1995). Despite its effectiveness (Dyck & Lukow, 1988;

Kochmadhavan, Tomar & Nambisan, 1988; Pretorius, 1990; Kloppers *et al.,* 1995), the exploitation of this gene in agriculture has been limited (McIntosh *et al.,* 1995).

Dyck & Lukow (1988) reported that lines containing *Lr29* showed a higher thousand-kernel weight than a susceptible control. They also reported a shorter mixograph development time, and higher grain and flour protein content in *Lr29* lines. Due to the increase in flour protein content, these lines showed higher farinograph absorption values. Furthermore, the shorter mixograph development time, indicating weaker dough mixing properties, suggested poorer protein quality. The presence of *Lr29* did not result in significant changes in flour yield or loaf volume (Dyck & Lukow, 1988). Kloppers *et al.* (1995), however, reported the absence of serious negative quality or yield responses in lines containing *Lr29.*

Lr34, situated on chromosome 7D (Dyck, 1991), was derived from common wheat and introduced into modern wheat breeding mainly through the South American cultivar, Frontana. *Lr34* is considered a widely effective and valuable source of adult-plant resistance to leaf rust (German & Kolmer, 1992; Sawhney, 1992; Singh, 1992a; Liu & Kolmer, 1997). The durability of leaf rust resistance in Frontana and its derivatives has led to extensive utilisation of *Lr34* in wheat breeding programmes (McIntosh *et al.*, 1995).

The origin of *Lr34* is not certain (Drijepondt *et al.,* 1990; McIntosh *et al.*, 1998; Nelson, Sorrells, Van Deynze, Lu-Yunhai, Atkinson, Bernard, Leroy, Faris & Anderson, 1995), but Dyck (1991) suggested that it might have originated from Chinese germplasm.

Lr34 is essentially a gene for adult-plant resistance, but can be detected in seedlings under certain conditions. The low seedling infection type conferred by *Lr34* has been described as a ; (fleck), 2, 3- and 3 (McIntosh *et al.*, 1995). In adult plants the *Lr34* resistance phenotype did not resemble hypersensitivity (Drijepondt & Pretorius, 1989; Rubiales & Niks, 1995). Although terminal leaf rust severity on lines with *Lr34* can be high under certain conditions, virulence has not been reported for this gene.

Genes that are closely linked to other genes have distinct advantages in wheat breeding and exploitation of resistance. Singh (1992a) provided evidence that *Lr34* is

closely linked to the *Yr18* gene for resistance to stripe rust. *Lr34* is also genetically associated with leaf tip necrosis (Singh, 1992b), which serves as a useful morphological marker in the field.

The value of *Lr34* is further emphasised by its ability to interact with other *Lr* genes, often resulting in improved levels of resistance (Dyck, 1987; German & Kolmer, 1992; Kloppers & Pretorius, 1997).

Drijepondt *et al.* (1990) found that flour yield, SDSS, mixograph mixing time, peak height and peak area, farinograph development time, stability, water absorption, and baking strength index (BSI) were reduced in RL6058, a Thatcher line with *Lr34*. An increase in flour protein content was attributed to the presence of *Lr34* (Drijepondt *et al.*, 1990). Drijepondt *et al.* (1990) furthermore, compared RL6058 with Thatcher in yield trials. RL6058 showed a reduction in thousand-kernel weight. This suggests that the presence of *Lr34* might be responsible for an alteration in thousand-kernel weight.

Lr35, located on wheat chromosome 2B, is an adult-plant resistance gene transferred from *Triticum speltoides* (Kerber & Dyck, 1990). The characteristic low flag leaf infection type of *Lr35* varies from ; to ;1^+ (McIntosh *et al.*, 1995). According to McIntosh *et al.* (1995) virulence has not been reported for *Lr35*, but the gene has not been widely tested or used in commercial cultivars. Kloppers *et al.* (1995) found that leaf rust severity on flag leaves of line RL6082 did not exceed 5MR-MS in the field.

Lr37, previously designated as *LrVPM*, is situated on the short arm of chromosome 2A and originated from *Aegilops ventricosa* (Bariana & McIntosh, 1993). Although expression of *Lr37* in primary leaves (infection types; 12-N to 3) is enhanced by lower temperatures (17°C) (Bariana & McIntosh, 1994; Kloppers & Pretorius, 1994), the gene is more clearly expressed in adult plants, specifically under field conditions (McIntosh *et al.*, 1995). Virulence for *Lr37* has been detected in Mexico (Z.A. Pretorius, personal communication).

Lr37 is closely linked with the stem rust resistance gene *Sr38* and stripe rust resistance gene *Yr17* (Bariana & McIntosh, 1993). In field experiments lines containing *Lr37* had higher grain and flour protein content (Dyck & Lukow, 1988). In other countries several

cultivars containing these rust resistance genes have been released, often inadvertently through selection for eyespot resistance which was also derived from the original VPM1 source (McIntosh *et al.*, 1995).

In South Africa investigation of yield and quality attributes of lines containing specific genes for rust resistance has been based on Thatcher near-isogenic lines (Drijepondt *et al.*, 1990; Kloppers *et al.*, 1995). The question thus remains if these leaf rust resistance genes, when incorporated in adapted South African germplasm, will have an effect on productivity and quality traits.

CHAPTER 3

MATERIALS AND METHODS

3.1 PLANT MATERIAL

Two bread wheat cultivars, namely Palmiet (spring type) and Karee (intermediate/winter type), were used by the Department of Plant Pathology, UOFS, as recurrent parents in a backcrossing (BC) programme aimed at improving wheat leaf rust resistance. The genes *Lr29*, *Lr34*, *Lr35* and *Lr37* were transferred from the donor sources to either Palmiet and/or Karee. A collection of BC6F3 lines developed in this programme was randomly selected and evaluated for yield and quality traits. Karee and Palmiet, the Thatcher NIL's used in the primary crosses, as well as Thatcher, were included as checks. The entry numbers, names and pedigrees are given in Table 3.1.

Following confirmation of the resistance genes in BC6F3 families, seed of selected entries were multiplied in a glasshouse. Harvested seed was treated with Vitavax® to prevent seedborne diseases. Three entries (P29-7, K29-3 and K34-5) were included in the trial but appeared to segregate. These entries were excluded from further analyses.

Table 3.1. Entry numbers, names and pedigrees of experimental material

Entry	Name	Pedigree	Resistance
1	Karee	Betta//Triumph/Agent	*Lr24*
2	Palmiet	SST3*3//Scout*5/Agent	*Lr24*
3	P29-1	Palmiet*6/RL6080	*Lr29*
4	P29-2	Palmiet*6/RL6080	*Lr29*
5	P29-3	Palmiet*6/RL6080	*Lr29*
6	P29-4	Palmiet*6/RL6080	*Lr29*
7	P29-5	Palmiet*6/RL6080	*Lr29*
8	P29-6	Palmiet*6/RL6080	*Lr29*
9	P29-7	Palmiet*6/RL6080 (rejected)	*Lr29*
10	P29-8	Palmiet*6/RL6080	*Lr29*
11	P29-9	Palmiet*6/RL6080	*Lr29*
12	P29-10	Palmiet*6/RL6080	*Lr29*
13	P34-1	Palmiet*6/RL6058	*Lr34*
14	P34-2	Palmiet*6/RL6058	*Lr34*
15	P34-3	Palmiet*6/RL6058	*Lr34*

Table 3.1 continued/....

Entry	Name	Pedigree	*Resistance*
16	P34-4	Palmiet*6/RL6058	*Lr34*
17	P34-5	Palmiet*6/RL6058	*Lr34*
18	P34-6	Palmiet*6/RL6058	*Lr34*
19	P34-7	Palmiet*6/RL6058	*Lr34*
20	P34-8	Palmiet*6/RL6058	*Lr34*
21	P34-9	Palmiet*6/RL6058	*Lr34*
22	P34-10	Palmiet*6/RL6058	*Lr34*
23	K29-1	Karee*6/RL6080	*Lr34*
24	K29-2	Karee*6/RL6080	*Lr29*
25	K29-3	Karee*6/RL6080 (rejected)	*Lr29*
26	K29-4	Karee*6/RL6080	*Lr29*
27	K29-5	Karee*6/RL6080	*Lr29*
28	K29-6	Karee*6/RL6080	*Lr29*
29	K29-7	Karee*6/RL6080	*Lr29*
30	K29-8	Karee*6/RL6080	*Lr29*
31	K29-9	Karee*6/RL6080	*Lr29*
32	K29-10	Karee*6/RL6080	*Lr29*
33	K34-1	Karee*6/RL6058	*Lr34*
34	K34-2	Karee*6/RL6058	*Lr34*
35	K34-3	Karee*6/RL6058	*Lr34*
36	K34-4	Karee*6/RL6058	*Lr34*
37	K34-5	Karee*6/RL6058 (rejected)	*Lr34*
38	K34-6	Karee*6/RL6058	*Lr34*
39	K34-7	Karee*6/RL6058	*Lr34*
40	K34-8	Karee*6/RL6058	*Lr34*
41	K34-9	Karee*6/RL6058	*Lr34*
42	K34-10	Karee*6/RL6058	*Lr34*
43	K35-2	Karee*6/RL6082	*Lr35*
44	K35-3	Karee*6/RL6082	*Lr35*
45	K35-4	Karee*6/RL6082	*Lr35*
46	K35-5	Karee*6/RL6082	*Lr35*
47	K35-6	Karee*6/RL6082	*Lr35*
48	K35-7	Karee*6/RL6082	*Lr35*
49	K35-8	Karee*6/RL6082	*Lr35*
50	K35-9	Karee*6/RL6082	*Lr35*
51	K35-10	Karee*6/RL6082	*Lr35*
52	K37-1	Karee*6/RL6081	*Lr37*
53	K37-2	Karee*6/RL6081	*Lr37*
54	K37-3	Karee*6/RL6081	*Lr37*
55	K37-4	Karee*6/RL6081	*Lr37*
56	K37-5	Karee*6/RL6081	*Lr37*

Table 3.1 continued/....

Entry	Name	Pedigree	*Resistance*
57	K37-6	Karee*6/RL6081	*Lr37*
58	K37-7	Karee*6/RL6081	*Lr37*
59	K37-8	Karee*6/RL6081	*Lr37*
60	K37-9	Karee*6/RL6081	*Lr37*
61	K37-10	Karee*6/RL6081	*Lr37*
62	Thatcher	Marquis/Iumillo//Marquis/Kanred	*Lr22b*
63	RL6080 (TC29)	Thatcher*6/CS 7D/Ag#11	*Lr29*
64	RL6058 (TC34)	Thatcher*6/PI58548	*Lr34*
65	RL6082 (TC35)	Thatcher*6/RL5711	*Lr35*
66	RL6081 (TC37)	Thatcher*8/VPM1	*Lr37*
67	PLMT1 (rep 1)	Karee OR Palmiet	*Lr24*
68	PLMT1 (rep 1)	Karee OR Palmiet	*Lr24*

[a] Original source of *Lr* genes

3.2 METHODS

3.2.1 Experimental layout

The trial entries were planted in the first week of June 1998 in the central Free State near Bloemfontein.

Before planting a 3:2:0 (25) N:P:K mixture was applied at 100 $kg.ha^{-1}$ according to the production potential of the region. Each plot consisted of two 5m rows spaced 48 cm apart, with 100 seeds sown per row. To ensure precision spacing, the experiment was planted by hand. The experiment was arranged in a randomised block design with three replicates.

Soil moisture was supplemented when necessary by overhead sprinkler irrigation. Three weeks after planting Kamikazi® (Carbaryl) was applied to control ants and after 12 weeks, plots were sprayed once with Chlorpyrifos at 600 $ml.ha^{-1}$ to control aphids. The rest of the season was disease and pest-free and no further chemical applications were necessary. Weeds were controlled by hand.

The entries were cut and threshed in November 1998. Each grain sample was cleaned individually before yield, thousand-kernel weight and hectolitre mass were determined. Quality analysis was done in the laboratories of the ARC-Small Grain Institute at Bethlehem. The recurrent parents Karee and Palmiet were used as checks in all procedures. Thatcher and the resistance carrying Thatcher NIL's (donor parents) were also included..

3.2.2 Characters measured

Yield components:

1. *Thousand-kernel weight (TKW)* - The mass of one thousand kernels was determined for each entry.
2. *Grain yield (T_HA)* - Plot yield was determined for each entry and adjusted to ton/ha.
3. *Heads per square meter (HSM)* - The number of heads per square meter for each entry was determined.
4. *Number of kernels per head (KPH)* - Fifteen heads per entry were randomly picked, threshed and the seed counted to determine the mean number of seeds per head.

Quality characteristics:

1. *High molecular weight glutenin subunits*:- SDS-PAGE was used to determine the HMW glutenin subunits of each entry. The SDS-PAGE method of Singh, Shepherd & Cornish (1991) was adapted and used. Firstly, the gliadins were removed with an ethanol extraction procedure. Then the endosperm of each entry was crushed and 1ml of 50% n-1-propanol added to each tube. Tubes were vortexed, incubated at 60°C for 30min., centrifuged at 10000rpm, and the supernatant removed. The process was then repeated twice. Residue was washed with 0.5 ml 50% n-1-propanol to remove all supernatant. Seventy-five µl of 50% n-1-propanol in 80mM Tris-HCl (pH 8.0), containing 1.25% 1,4 dithiothreitol, were added to the residue. Samples were vortexed and incubated at 60°C for 30min. The latter procedure was then repeated. An additional 75µl of 50% n-1-propanol in 80mM Tris-HCl buffer containing 16.8µl/ml 4-vinyl pyridine were added to these samples. Material was disjoined and incubated for

an hour at 60°C. The tubes were centrifuged and 110µl of the supernatant were transferred to new tubes containing 100µl sample buffer, consisting of 80mM Tris-HCl (pH 8.0), 40g glycerol, 2g SDS and 0.02g bromophenolblue. Samples were left for 15min. at 60°C and, following centrifugation, 20µl of each were loaded onto a gel. A separating gel of 10% was run at 66mA at 15°C for 3h. The gel was stained according to a staining procedure of Wrigley (1992). HMW glutenin subunits were determined visually.

2. *Flour protein content (FPC):-* The quantity of protein present in the flour was determined with a near infrared reflectance spectrophotometer (Bran Luebbe Infra Alyzer 360) calibrated against Kjeldahl data.
3. *SDS-sedimentation (SDSS):-* This value reflects the differences in the quantity and quality of wheat gluten, and hence is a rough measurement of baking strength. A modified version of AACC Method 56-60 was used. For each entry a 5g flour sample, suspended in 50ml distilled water in a 100ml-capacity cylinder, was shaken ten times. The cylinder was placed into a waterbath pre-heated to 30°C. At regular time intervals the cylinders were held horizontally and inverted left and right five times before replacement in the waterbath. Sedimentation volume was determined after 18min.
4. *Hectolitre mass (HLM):-* The "Dicky John" GAC 2000 Grain Analysis Computer was used for measurement of the kernel density.
5. *Breakflour Yield (BFY):-* The flour obtained from the break rolls, as a percentage of total flour regained, was determined. A Bühler pneumatic laboratory mill was used for this purpose (AACC Method 26-21A).
6. *Flour extraction (FLY):-* The amount of flour extracted, as a percentage of total mass regained, was also determined using the Bühler pneumatic laboratory mill (AACC Method 26-21A).
7. *Mixograph development time (MDT) and water absorption (WABS)):-* The mixing properties of flour were determined using a 35g mixograph method (AACC Method 54-40A). This instrument utilises of two pairs of planetary pins that revolve in a bowl containing flour and water. Mixing continues until the water is absorbed and the dough developed. The resistance of the pins passing through the dough is recorded on paper throughout the process.

8. *Alveograph (resistance to deformation (P/L))* - The resistance of dough to extension was determined (AACC Method 54-30A).
9. *Loaf volume (LF)* - The AACC Method 10-09 was used to bake a small loaf of bread. The volume and texture was used to score each entry.

3.2.3 Statistical analysis

The statistical programme SAS Institute Inc. "SAS/STAT" (Release 6.04 Edition, Cary, New York) was used to do analyses of variance. STATGRAPHICS (Version 4.0, STSC, Inc. USA) was used to compute the stepwise regression. AGROBASE '98 (Agronomix software Inc., Winnipeg, Canada) was used to determine coefficients of correlation among measured characteristics.

CHAPTER 4

RESULTS

4.1 HMW BANDING PATTERNS

The HMW glutenin subunit composition of all the entries are shown in Table 4.1

Table 4.1 HMW glutenin subunit banding patterns of entries

	Glu-A1		Glu-B1			Glu-D1	
ENTRY	1	0/2*	7+9	7+8	13+16	5+10	2+12
KAREE	*		*			*	
PALMIE		*			*		*
TC		*	*			*	
K29-1	*		*			*	
K29-2	*		*			*	
K29-4	*		*			*	
K29-5	*		*			*	
K29-6	*		*			*	
K29-7	*		*			*	
K29-8	*		*			*	
K29-9	*		*			*	
K29-10	*		*			*	
K34-1	*		*			*	
K34-2	*		*			*	
K34-3	*		*			*	
K34-4		*	*			*	
K34-6	*		*			*	
K34-7	*		*			*	
K34-8		*	*			*	
K34-9	*		*			*	
K34-10		*			*	*	
K35-2	*		*			*	
K35-3	*		*			*	
K35-4	*		*			*	
K35-5	*		*			*	
K35-6	*		*			*	
K35-7	*		*			*	
K35-8	*		*			*	
K35-9	*		*			*	

Table 4.1 continued/...

	Glu-A1		Glu-B1			Glu-D1	
ENTRY	1	0/2*	7+9	7+8	13+16	5+10	2+12
K35-10	*		*			*	
K37-1	*		*			*	
K37-2	*		*			*	
K37-3	*		*			*	
K37-4	*		*			*	
K37-5	*		*			*	
K37-6	*		*			*	
K37-7	*		*			*	
K37-8	*		*			*	
K37-9	*		*			*	
K37-10	*		*			*	
P29-1		*		*	*		*
P29-2		*		*	*		*
P29-3		*		*	*		*
P29-4		*		*	*		*
P29-5		*		*	*		*
P29-6		*		*	*		*
P29-8		*		*	*	*	*
P29-9		*		*	*	*	
P29-10		*		*	*		*
P34-1		*		*	*		*
P34-2		*		*	*		*
P34-3		*		*	*		*
P34-4		*		*	*		*
P34-5		*		*	*		*
P34-6		*		*	*		*
P34-7		*		*	*		*
P34-8		*		*	*	*	*
P34-9		*		*	*	*	*
P34-10		*		*	*		*
TC29		*	*			*	
TC34		*	*			*	
TC35		*	*			*	
TC37		*	*			*	

*present

For bands coded by the Glu-A1 locus, it was found that Karee and all its backcross lines had subunit 1. K34-4, K34-8 and K34-10 showed band 2*. The Palmiet NIL's all had 0 or 2* (the gels used could not distinguish between 2* and band 2 of 2+12 combination). Palmiet, Thatcher, TC29, TC34, TC35 and TC37 displayed a 0 or 2* at this locus.

For bands coded by the Glu-B1 locus, all the Karee NIL's, excluding K34-10, had the subunit pair 7+9. The Palmiet NIL's were more variable at the Glu-B1 locus, with all lines having both combinations 7+8 and 13+16.

For bands coded by genes at the Glu-D1 locus, Karee and all the Karee NIL's had the 5+10 bands. Palmiet and most of the Palmiet NIL's had the 2+12 band combination. Three of the lines had 5+10 and 2+12, which indicates segregation. P29-9 had only 5+10. This combination could have originated from the donor parent TC29.

4.2 ANALYSIS OF VARIANCE OF QUALITY COMPONENTS

To allow for specific comparisons of entries or groups of entries, data were analysed in different sets. The first analysis was conducted to compare all parents and NIL's. In this analysis all individual NIL's within a cross were pooled. In the second and third analyses, the effects of the different leaf rust resistance genes on, respectively, Palmiet and Karee were determined. The fourth to ninth analyses were done to investigate the performance of the individual NIL's in relation to their parents. Means were compared (p = 0.05) using the Tukey-Kramer method.

4.2.1 ANALYSES OF THE COMPLETE DATA SET, A SUBSET OF PALMIET DERIVATIVES AND A SUBSET OF KAREE DERIVATES

Table 4.2 Analysis of variance for quality characteristics (all entries[1])

Trait	MSE(entries)	MSE(error)	F-value	C.V.	Mean
FPC	12.541	1.476	8.495**	10.281	11.818
SDSS	495.819	15.565	31.854**	4.550	86.703
HLM	70.512	1.585	44.486**	1.581	79.636
BFY	21.522	2.432	8.850**	7.144	121.827
FLY	6.308	2.910	2.168*	2.276	74.934
MDT	1.478	0.111	13.302**	16.916	1.970
WABS	24.961	2.492	10.016**	2.623	60.192
PL	0.872	0.059	14.889**	28.134	0.860
LF	103945.611	4568.842	22.751**	7.938	851.533

** p = 0.01 & * p = 0.05

FPC = flour protein content (%)
SDSS = SDS-sedimentation (ml)
HLM = hectolitre mass (kg/hl)
BFY = breakflour yield (%)
FLY = flour extraction (%)
MDT = mixograph development time (min.)
WABS = water absorption (%)
PL = PL-ratio
LF = loaf volume (mm)

[1]Total degree of freedom (DF) = 194
Entries DF = 12
Error DF = 182

In the combined analysis (Table 4.2), the F-values indicated highly significant (p = 0.01) variation among lines for all measured characteristics except flour extraction (p = 0.05) (Table 4.2). Analysing the Palmiet and Karee derivatives as two separate data sets gave results comparable to the combined analysis. With the exception of flour yield (variation among the Palmiet lines was non-significant whereas the Karee set differed at p = 0.05), entries varied significantly for all quality attributes measured (Tables 4.3 and 4.4).

Table 4.3 Analysis of variance for quality characteristics (Palmiet NIL's and parents[2])

Trait	MSE(entries)	MSE(error)	F-value	C.V.	Mean
FPC	7.763	1.083	7.169**	8.804	11.831
SDSS	582.124	24.681	23.586**	5.982	83.042
HLM	6.075	1.601	3.795**	1.642	77.039
BFY	9.801	2.074	4.725**	6.896	20.887
FLY	4.841	3.507	1.380	2.512	74.563
MDT	0.544	0.094	5.789**	17.956	1.707
WABS	15.524	2.315	6.706**	2.524	60.281
PL	0.644	0.033	19.594**	27.312	0.664
LF	36808.925	4050.798	9.087**	6.812	934.366

**p = 0.01

Lines TC37, TC35, TC29 and TC34 had the highest flour protein content (13.13 to 15.7%). TC37 and TC35 each had a significantly higher protein content than Karee, Palmiet, and all their NIL's (Table 4.5). Considering the Karee and Palmiet NIL's, flour protein was highest in K29 (12.09%) and P29 (12.15%).

[2]Total DF = 70
Entries DF = 5
Error DF = 65

Table 4.4 Analysis of variance for quality characteristics (Karee NIL's and parents[3])

Trait	MSE(entries)	MSE(error)	F-value	C.V.	Mean
FPC	14.687	1.688	8.701**	10.910	11.909
SDSS	387.665	11.339	34.188**	3.833	87.842
HLM	14.055	1.575	8.921**	1.551	80.947
BFY	15.128	2.544	5.947**	7.135	22.355
FLY	5.253	2.641	1.989*	2.165	75.074
MDT	1.069	0.118	9.067**	16.471	2.085
WABS	30.326	2.626	11.551**	2.687	60.299
PL	0.432	0.075	5.791**	27.771	0.984
LF	32542.357	5132.880	6.340**	8.904	804.617

**p = 0.01 & *p = 0.05

SDSS values of Thatcher-related lines were generally lower (70.0 to 83.67 ml) than Karee-derived lines (86.3 to 91.43 ml). In the Palmiet background SDSS values ranged from 77.93 ml (P29) to 89.6 (Palmiet). Crosses involving *Lr29* lines had the lowest SDSS values in all three genetic backgrounds (Thatcher, Palmiet and Karee).

Entries with the highest hectolitre mass were Karee followed by K35 and K37, respectively. Karee (81.79 kg/hl) and the Karee NIL's (81.03 to 81.58 kg/hl) all had significantly higher hectolitre mass values than Thatcher (79.8 kg/hl), Palmiet (76.68 kg/hl) and their related NIL's.

Breakflour yield for the Karee NIL's varied between 21.27 and 23.39% and was statistically similar than that of Karee. Compared to the Karee data set breakflour yield values for the Palmiet NIL's were lower but did not differ significantly from Palmiet. In the Thatcher background breakflour yield ranged from 21.5% in TC29 to 25.5% in TC35.

In the analysis of the flour extraction percentages, no significant differences were observed among entries.

[3] Total DF = 132
Entries DF = 9
Error DF = 123

Table 4.5 Means[a] of quality characteristics for pooled data

CULTIVAR/ NIL	FPC (%)	SDSS (ml)	HLM (kg/hl)	BFY (%)	FLY (%)	MDT (min.)	WABS (%)	PL-ratio	LF (mm)
KAREE(7)[b]	10.57	91.86	81.79	22.86	75.06	2.24	58.26	1.35	793.57
PLMT(5)	11.60	89.60	76.68	21.43	76.47	1.94	60.16	0.42	913.00
TC(3)	12.60	82.33	79.80	20.55	74.48	1.60	61.53	1.52	810.00
K29(27)	12.09	86.33	81.21	21.27	74.63	1.76	60.55	1.11	820.74
K34(27)	11.64	89.52	81.03	23.39	75.68	2.07	60.10	0.80	837.04
K35(27)	11.33	89.07	81.58	21.76	75.38	2.16	59.38	0.92	717.00
K37(30)	11.59	91.43	81.24	22.42	75.35	2.45	59.78	0.95	826.33
P29(27)	12.15	77.93	76.93	20.76	74.66	1.50	60.58	0.64	959.26
P34(30)	11.15	89.07	76.75	20.52	74.30	1.89	59.37	0.59	952.33
TC29(3)	14.07	70.00	77.87	21.47	73.51	1.70	63.63	0.85	870.00
TC34(3)	13.13	71.67	77.87	24.61	74.26	1.47	62.27	1.04	755.00
TC35(3)	15.60	70.00	77.30	25.50	73.94	1.63	64.83	0.71	876.67
TC37(3)	15.70	83.67	79.33	23.88	73.31	2.10	66.00	0.95	898.33

[a] See Appendix A for tables of significant differences between entries.

[b] Values in brackets are the number of observations of each entry.

Based on the South African standard of 2.5 min., K37 followed by Karee and K35 had the longest and most ideal dough mixing times. In both Karee and Palmiet NIL's, crosses involving *Lr29* had the shortest mixing times (1.76 and 1.5 min., respectively). As a group, the mixing times of the Karee lines appeared longer than either the Palmiet or Thatcher groups.

The Thatcher NIL's had the highest water absorption (62.27 to 66.0%) of all entries. Water absorption values of Palmiet, K29, K34, K35, K37, P29 and P34 were close to South African standard of 60%. K29 had a significantly higher water absorption than its recurrent parent, Karee.

PL-ratios varied between 0.42 (Palmiet) and 1.52 (Thatcher). K34, followed by TC29 and TC35, respectively, were closest to the South African optimum of 0.8. In general, Karee lines exhibited a PL-ratio larger than 0.8 whereas the opposite was true for Palmiet and its NIL's. P29, P34 and Palmiet were the three best-ranking entries for loaf volume.

4.2.2. ANALYSIS OF NIL's CONTAINING THE *Lr29* GENE

4.2.2.1 Palmiet background

Table 4.6 Analysis of variance of quality characteristics for Palmiet NIL's with the *Lr29* gene and parents[4]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	2.717	1.150	2.362*	8.682	12.353	3.158
SDSS	143.535	16.389	8.758**	5.139	78.778	11.918
HLM	5.262	1.562	3.369**	1.619	77.200	3.679
BFY	5.254	1.192	4.409**	5.2371	20.845	3.214
FLY	6.273	2.461	2.549*	2.099	74.727	4.619
MDT	0.213	0.411	0.519**	12.896	1.572	0.597
WABS	6.191	2.089	2.964	2.371	60.945	4.255
PL	0.274	0.034	8.097**	25.784	0.713	0.541
LF	9711.111	4254.167	2.283*	6.955	937.778	192.020

**p = 0.01 & *p = 0.05

This analysis included Palmiet, nine sister Palmiet/*Lr29* NIL's, TC29 and Thatcher. With the exception of water absorption, F-values indicated significant variation (p = 0.01 or p = 0.05) among lines for all quality characteristics (Table 4.6). Entry means for each characteristic are given in Table 4.7. Within columns, values followed by different letters differ significantly at p = 0.05.

Analysis showed that the flour protein content of Palmiet and its NIL's were statistically similar (Table 4.7). Most entries had flour protein content above 12%, except P29-2 (10.63%), P29-4 (11.5%) and P29-8 (11.53%). TC29 had the highest flour protein content (14.07%), followed by P29-10 (13.77%) and P29-6 (12.9%). All the NIL's, except P29-2, were in the same flour protein content group as TC29, the donor parent.

[4] Total DF = 35
Entries DF = 11
Error DF = 24

Palmiet, followed by P29-2 and P29-9, were the three highest ranking entries for SDS-sedimentation. All the entries except P29-4 had values of 70 ml or above. P29-1, P29-2 and P29-9 were statistically similar to Palmiet.

Considering hectolitre mass, breakflour yield and flour extraction, and despite some variation among lines, all NIL's were statistically similar to as Palmiet. Thatcher had the highest hectolitre mass (79.8 kg/hl), but did not differ significantly from, in decreasing order, P29-8, P29-9, T29, P29-6, P29-10, P29-2, P29-3 and Palmiet. Breakflour yield of the NIL's ranged from 18.9% (P29-10) to 23.9% (P29-5), whereas flour extraction ranged from 72.4% (P29-10) to 77.2% (P29-4).

Palmiet (2.1 min.) had a mixograph development time similar to P29-9 (2.0 min.), P29-2 (1.7 min.) and P29-5 (1.6 min.). Palmiet and P29-9 were the only two entries with acceptable mixing time.

Water absorption values, PL-ratio and loaf volume indicated no significant variation among Palmiet and the Palmiet/*Lr29* NIL's. The PL-ratio for Thatcher (1.52) differed markedly from the other entries (range 0.35 to 0.85). P29-8 (0.81) had a PL-ratio closest to the optimum, followed by P29-1 (0.83) and P29-9 (0.84).

Table 4.7 Entry means and grouping of quality characteristics for Palmiet NIL's with the *Lr29* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
PALMIET[a]	12.200ab	91.667a	76.333ab	21.330abc	76.770ab	2.100a	60.932ab	0.460b	940.00a
THATCHER	12.600ab	82.333ab	79.800a	20.547bc	74.477ab	1.600abc	61.467ab	1.520a	810.00a
P29-1	12.067ab	81.000abc	75.500b	20.477bc	74.213ab	1.267c	60.767ab	0.830b	993.33a
P29-2	10.633b	86.000ab	77.033ab	21.243abc	74.900ab	1.667abc	58.900b	0.570b	885.00a
P29-3	12.333ab	77.333bcd	76.700ab	19.847bc	74.637ab	1.500bc	60.137ab	0.640b	991.67a
P29-4	11.500ab	66.000d	75.600b	22.150ab	77.207a	1.233c	59.033b	0.550b	970.00a
P29-5	12.000ab	79.333bc	75.600b	23.873a	75.477ab	1.567abc	60.667ab	0.350b	961.67a
P29-6	12.900ab	77.667bcd	77.667ab	19.380bc	72.660ab	1.433bc	61.900ab	0.570b	976.67a
P29-8	11.533ab	76.333bcd	78.467ab	20.090bc	75.167ab	1.367c	60.100ab	0.810b	933.33a
P29-9	12.633ab	83.333ab	78.233ab	20.807abc	75.320ab	2.000ab	60.607ab	0.840b	931.67a
P29-10	13.767ab	74.333bcd	77.600ab	18.930c	72.393b	1.433bc	63.133ab	0.580b	990.00a
TC29	14.067a	70.000cd	77.867ab	21.470abc	73.507ab	1.700abc	63.633a	0.850b	870.00a

[a]All the entries had 3 observations.

4.2.2.2 Karee background

Table 4.8 Analysis of variance of quality characteristics for Karee NIL's with the *Lr29* gene and parents[5]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	2.796	1.816	1.539	11.113	12.128	3.968
SDSS	88.755	12.667	7.007**	4.180	85.139	10.478
HLM	5.130	1.448	3.544**	1.487	80.933	3.542
BFY	0.821	0.721	1.138	3.987	21.298	2.500
FLY	2.166	2.229	0.972	2.002	74.570	4.396
MDT	0.052	0.030	1.731	9.865	1.764	0.512
WABS	5.920	3.303	1.792	2.995	60.689	5.351
PL	0.205	0.076	2.693*	22.739	1.213	0.812
LF	3609.785	5635.417	0.641	9.147	820.694	221.000

**p= 0.01 & *p= 0.05

This analysis included Karee, nine sister Karee/*Lr29* NIL's, TC29 and Thatcher. Analysis of variance revealed significant variation among entries for SDS-sedimentation, hectolitre mass and PL-ratio (Table 4.8). Entry means for each characteristic are given in Table 4.9. Within columns, values followed by different letters differ significantly at p = 0.05.

Despite the variation suggested by ANOVA, the mean separation test did not distinguish between lines for flour protein content, SDS-sedimentation, breakflour yield, flour extraction, PL-ratio and loaf volume (Table 4.9). Although lines did not respond similarly for hectolitre mass and water absorption, the NIL's did not differ from Karee. However, K29-7 had a dough mixing time significantly shorter and less desirable (1.53 min.) than Karee (2.07 min.).

[5] Total DF = 38
Entries DF = 12
Error DF = 26

Table 4.9 Entry means and grouping for quality characteristics for Karee NIL's with the *Lr29* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
KAREE[a]	10.100a	92.333a	82.633a	22.100a	75.163a	2.067a	58.233b	1.507a	781.67a
THATCHER	12.600a	82.333a	79.800ab	20.547a	74.477a	1.600ab	61.467ab	1.520a	810.00a
K29-1	12.733a	86.333a	80.767ab	21.827a	75.380a	1.833ab	61.667ab	0.940a	828.33a
K29-2	12.467a	86.333a	79.633ab	21.647a	75.670a	1.767ab	58.997ab	0.963a	811.67a
K29-4	11.733a	86.333a	81.400ab	20.993a	75.030a	1.733ab	60.367ab	1.443a	821.67a
K29-5	12.233a	88.667a	81.467a	21.530a	74.107a	1.767ab	60.967ab	1.043a	861.67a
K29-6	11.633a	85.333a	81.500a	21.067a	73.983a	1.767ab	60.167ab	1.023a	786.67a
K29-7	11.200a	82.667a	82.267a	21.577a	75.820a	1.533b	59.633ab	1.423a	805.00a
K29-8	12.733a	86.000a	81.300ab	20.590a	73.190a	1.833ab	61.667ab	1.083a	886.67a
K29-9	12.100a	88.000a	81.800a	20.603a	74.527a	1.833ab	60.900ab	1.190a	793.33a
K29-10	11.933a	87.333a	80.767ab	21.630a	73.983a	1.733ab	60.567ab	0.940a	791.67a
TC29	14.067a	70.000a	77.867b	21.470a	73.507a	1.700ab	63.633a	0.853a	870.00a

[a]All the entries had 3 observations.

4.2.3 ANALYSIS OF NIL's CONTAINING THE *Lr34* GENE

4.2.3.1 Palmiet background

Table 4.10 Analysis of variance of quality characteristics for Palmiet NIL's with the *Lr34* gene and parents[6]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	2.174	0.467	4.654**	5.946	11.495	2.028
SDSS	85.786	13.231	6.484**	4.161	87.410	10.793
HLM	4.511	0.627	7.192**	1.028	77.041	2.350
BFY	5.523	1.281	4.311**	5.4161	20.897	3.358
FLY	4.284	3.786	1.131	2.612	74.499	5.774
MDT	0.264	0.061	4.329**	13.325	1.854	0.733
WABS	4.896	1.296	3.779**	1.901	59.880	3.378
PL	0.264	0.041	6.403**	29.677	0.684	0.602
LF	15495.620	3832.692	4.043**	6.691	925.256	183.700

**p= 0.01 & *p= 0.05

This analysis included Palmiet, 10 sister Palmiet/*Lr34* NIL's, TC34 and Thatcher. With the exception of flour extraction, F-values indicated significant variation (p = 0.01) among lines for all quality characteristics (Table 4.10). Entry means for each characteristic are given in Table 4.11. Within columns, values followed by different letters differ significantly at p = 0.05

Apart from flour extraction, where entries responded similarly, significant differences were found for all other characteristics (Table 4.11). However, the Palmiet/*Lr34* NIL's were statistically equal to Palmiet in all comparisons.

[6] Total DF = 35
Entries DF = 11
Error DF = 24

Table 4.11 Entry means and grouping of quality characteristics for Palmiet NIL's with the *Lr34* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
PALMIET[a]	12.200abc	91.667a	76.333bcd	21.330ab	76.770a	2.100abc	60.933ab	0.460b	940.00ab
THATCHER	12.600abc	82.333ab	79.800a	20.547b	74.477a	1.600c	61.467ab	1.520a	810.00bc
P34-1	10.967bc	87.000a	76.633bcd	19.773b	73.463a	1.733abc	59.333ab	0.480b	958.33ab
P34-2	11.033bc	88.667a	77.367bc	20.763b	74.933a	1.633bc	58.433b	0.610b	980.00ab
P34-3	11.367abc	90.000a	75.000cd	20.943b	74.640a	1.767abc	59.833ab	0.480b	991.67ab
P34-4	12.633ab	87.000a	78.367ab	22.220ab	74.793a	1.567c	61.533ab	0.720b	966.67ab
P34-5	10.367c	87.667a	76.867bcd	21.213b	74.910a	1.633bc	58.533b	0.590b	943.33ab
P34-6	11.067bc	88.667a	77.633abc	20.430b	74.217a	2.333ab	59.467ab	0.720b	908.33abc
P34-7	11.067bc	89.667a	77.267bcd	20.657b	75.780a	1.867abc	58.477b	0.450b	878.33abc
P34-8	11.067bc	92.333a	75.833cd	19.780b	74.733a	2.400a	59.467ab	0.630b	958.33ab
P34-9	10.733bc	89.667a	76.200cd	20.180b	73.887a	1.933abc	59.033ab	0.540b	996.67a
P34-10	11.200abc	90.000a	76.367bcd	19.217b	71.630a	2.067abc	59.600ab	0.640b	941.67ab
TC34	13.133a	71.667b	77.867abc	24.610a	74.257a	1.467c	62.267a	1.040ab	755.00c

[a]All the entries had 3 observations.

4.2.3.2 Karee background

Table 4.12 Analysis of variance of quality characteristics for Karee NIL's with the *Lr34* gene and parents[7]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	1.804	1.401	1.288	10.103	11.717	3.485
SDSS	111.333	9.222	12.072**	3.464	87.667	8.940
HLM	6.302	0.574	10.982**	0.938	80.800	2.230
BFY	17.733	1.792	9.897**	5.783	23.145	3.941
FLY	8.589	2.486	3.455**	2.091	75.422	4.642
MDT	0.309	0.089	3.492**	15.009	1.983	0.876
WABS	3.658	2.339	1.564	2.540	60.241	4.502
PL	0.332	0.049	6.835**	23.430	0.941	0.649
LF	8409.091	5514.853	1.525	9.019	823.333	218.620

**p= 0.01 & *p= 0.05

This analysis included Karee, nine sister Karee/*Lr34* NIL's, TC34 and Thatcher. According to the ANOVA entries were similar for flour protein content, water absorption and loaf volume but differed significantly (p = 0.01) for the other attributes (Table 4.12). Entry means for each characteristic are given in Table 4.13. Within columns, values followed by different letters differ significantly at p = 0.05.

Like the ANOVA, the Tukey-Kramer test could not separate entries for flour protein content, water absorption and loaf volume. Variation among entries were evident for flour extraction and mixograph development time but the NIL's were similar to Karee.

For SDS-sedimentation K34-8 (85.0 ml) differed from Karee (92.3 ml). The hectolitre mass of K34-4 (79.7 kg/hl), K34-8 (79.8 kg/hl) and K34-10 (80 kg/hl) were significantly lower than that of Karee (82.6 kg/hl). Breakflour yield of K34-4 (27.6%) and K34-7 (18.8%) also differed from the recurrent parent, Karee (22.1%).

[7] Total DF = 35
Entries DF = 11
Error DF = 24

With regard to the PL-ratio, K34-4 (0.63), K34-6 (0.59), K34-8 (0.613), K34-9 (0.713) and K34-10 (0.6) had significantly lower values, but were closer to the optimum of 0.8, than Karee (1.507).

Table 4.13 Entry means and grouping of quality characteristics for Karee NIL's with the *Lr34* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
KAREE[a]	10.100a	92.333ab	82.633ab	22.100bcde	75.163ab	2.067ab	58.233a	1.507a	781.67a
THATCHER	12.600a	82.333c	79.800cd	20.547de	74.477b	1.600b	61.467a	1.520a	810.00a
K34-1	11.800a	90.667abc	80.767bc	22.570bcde	74.027b	2.267ab	60.400a	0.887ab	860.00a
K34-2	11.200a	91.000abc	81.333abc	22.833bcd	75.027ab	2.167ab	59.633a	1.007ab	836.67a
K34-3	11.167a	92.000ab	81.900abc	20.940cde	75.463ab	2.033ab	59.633a	1.043ab	840.00a
K34-4	11.333a	88.333abc	79.700cd	27.580a	76.943ab	2.00ab	58.790a	0.630b	810.00a
K34-6	12.267a	91.333ab	81.733abc	24.580abc	79.473a	1.800b	60.967a	0.590b	936.67a
K34-7	11.433a	86.667abc	81.067abc	18.763e	72.733b	1.867ab	59.933a	1.140ab	740.00a
K34-8	12.033a	85.000c	79.767cd	22.943bcd	75.813ab	1.800b	60.700a	0.613b	826.67a
K34-9	11.800a	86.667abc	83.000a	24.290abcd	75.290ab	2.033ab	60.433a	0.713b	871.67a
K34-10	11.733a	94.000a	80.033cd	25.717ab	76.393ab	2.700a	60.433a	0.600b	811.67a
TC34	13.133a	71.667d	77.867d	24.610abc	74.257b	1.467b	62.267a	1.040ab	755.00a

[a]All the entries had a n-value of 3.

4.2.4 ANALYSIS OF KAREE NIL's CONTAINING THE *Lr35* GENE

Table 4.14 Analysis of variance of quality characteristics for Karee NIL's with the *Lr35* gene and parents[8]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	6.789	1.100	6.174**	8.972	11.689	3.087
SDSS	142.694	7.333	19.458**	3.106	87.194	7.972
HLM	7.026	1.172	5.996**	1.334	81.161	3.187
BFY	5.067	1.493	3.394**	5.554	21.998	3.597
FLY	2.875	2.172	1.324	1.961	75.166	4.338
MDT	0.308	0.032	9.571**	8.709	2.061	0.529
WABS	9.997	1.569	6.374**	2.091	59.909	3.687
PL	0.279	0.042	6.637**	19.696	1.041	0.679
LF	6001.923	3931.410	1.527	7.580	827.179	182.860

**p= 0.01

This analysis included Karee, nine sister Karee/*Lr35* NIL's, TC35 and Thatcher. Entries differed ($p = 0.01$) for all characteristics except flour extraction and loaf volume (Table 4.14). Entry means for each characteristic are given in Table 4.15. Within columns, values followed by different letters differ significantly at $p = 0.05$.

The mean separation test did not reveal differences among entries for flour extraction, whereas for hectolitre mass, breakflour yield, mixograph development time, water absorption and loaf volume, the Karee/*Lr35* NIL's were similar to Karee.

The flour protein content of K35-5 (13.3%) was significantly higher than in Karee (10.1%) and the SDS-sedimentation value of K35-2 (78.7 ml) was significantly lower than the recurrent parent (92.3 ml). Several NIL's differed for PL-ratio with K35-3, K35-5, K35-6, K35-7 and K35-8 all displaying values considerably lower, but closer to the optimum, than Karee.

[8] Total DF = 35
Entries DF = 11
Error DF = 24

Table 4.15 Entry means and grouping of quality characteristics for Karee NIL's with the *Lr35* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
KAREE[a]	10.100c	92.333a	82.633ab	22.100ab	75.163a	2.067abc	58.230b	1.510a	781.67ab
THATCHER	12.600ab	82.333bc	79.800bc	20.547b	74.477a	1.600c	61.467ab	1.520a	810.00ab
K35-2	11.300bc	78.667c	81.800ab	20.900b	74.943a	1.700c	58.760b	1.170ab	778.00ab
K35-3	11.033bc	91.667a	81.567ab	20.687b	74.627a	2.400a	59.430b	0.810b	746.67ab
K35-4	11.167bc	91.333a	81.167ab	21.747b	74.127a	2.467a	59.630b	1.100ab	747.67ab
K35-5	13.267ab	89.000ab	81.933ab	22.450ab	74.977a	2.000abc	60.470b	0.810b	665.00b
K35-6	10.533bc	91.333a	83.133a	22.230ab	76.763a	1.833bc	58.800b	0.820b	662.67b
K35-7	10.933bc	91.000a	80.867ab	21.807b	75.330a	2.500a	59.330b	0.740b	697.67ab
K35-8	10.733bc	90.667a	80.433abc	21.370b	74.600a	2.333ab	58.010b	0.740b	699.33ab
K35-9	11.433bc	91.667a	82.233ab	22.700ab	77.040a	2.100abc	59.900b	0.900ab	711.67ab
K35-10	11.567bc	86.333abc	81.067ab	21.930ab	76.000a	2.100abc	60.100b	1.160ab	744.33ab
TC35	15.600a	70.000d	77.300c	25.503a	73.940a	1.633c	64.830a	0.710b	876.67a

[a]All the entries had 3 observations.

4.2.5 ANALYSIS OF KAREE NIL's CONTAINING THE *Lr37* GENE

Table 4.16 Analysis of variance of quality characteristics for Karee NIL's with the *Lr37* gene and parents[9]

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
FPC	6.250	2.278	2.744*	12.715	11.8692	4.478
SDSS	33.641	2.718	12.377**	1.828	90.205	4.892
HLM	3.350	1.149	2.916*	1.322	81.087	3.180
BFY	2.052	1.206	1.701	4.912	22.367	3.260
FLY	2.131	2.578	0.827	2.138	75.112	4.764
MDT	0.413	0.154	2.680*	16.842	2.331	1.165
WABS	12.516	3.446	3.632**	3.093	60.018	5.508
PL	0.279	0.042	6.637**	19.696	1.042	0.608
LF	6001.923	3931.410	1.527	7.580	827.179	186.050

**p= 0.01 & *p=0.05

This analysis included Karee, 10 sister Karee/*Lr37* NIL's, TC37 and Thatcher. ANOVA showed significant variation for SDS-sedimentation, water absorption and PL-ratio (p = 0.01), and flour protein content, hectolitre mass and mixograph development time (p = 0.05) (Table 4.16). Entry means for each characteristic are given in Table 4.17. Within columns, values followed by different letters differ significantly at p = 0.05.

All entries ranked equal for flour extraction and loaf volume (Table 4.17). For flour protein content, SDS-sedimentation, hectolitre mass, breakflour yield, mixograph development time and water absorption, some variation occurred but all NIL's clustered with Karee. The PL-ratio of K37-1, K37-4, K37-5, K37-6 and K37-7 were significantly lowered when compared with Karee. These entries were, though, better than Karee. K37-4 had the ideal PL-ratio of 0.8.

[9] Total DF = 38
Entries DF = 12
Error DF = 26

Table 4.17 Entry means and grouping of quality characteristics for Karee NIL's with the *Lr37* gene and parents

	FPC	SDSS	HLM	BFY	FLY	MDT	WABS	PL	LF
KAREE[a]	10.100b	92.333a	82.633a	22.1ab	75.163a	2.067ab	58.230b	1.510a	781.67a
THATCHER	12.600ab	82.333b	79.800ab	20.547b	74.477a	1.600b	61.530ab	1.520a	810.00a
K37-1	12.500ab	91.000a	81.333ab	22.063ab	74.340a	2.533ab	61.330ab	0.660b	880.00a
K37-2	11.833ab	92.333a	80.500ab	23.263b	75.400a	2.733ab	60.400b	0.970ab	843.33a
K37-3	11.733ab	92.000a	81.200ab	23.080ab	76.510a	2.200ab	59.530b	1.490ab	756.67a
K37-4	11.300ab	92.667a	80.733ab	22.910ab	75.730a	2.733ab	59.770b	0.800b	868.33a
K37-5	11.500ab	91.333a	80.400ab	22.460ab	75.573a	2.067ab	59.020b	0.700b	860.00a
K37-6	12.267ab	90.333a	80.800ab	22.027ab	74.750a	2.467ab	60.100b	0.870b	798.33a
K37-7	11.100b	93.000a	81.867ab	21.983ab	75.120a	2.533ab	59.500b	0.720b	848.33a
K37-8	12.767ab	90.667a	80.467ab	21.637ab	74.780a	2.967a	60.760ab	1.110ab	841.67a
K37-9	10.767b	89.667a	82.500ab	22.317ab	75.017a	2.067ab	59.100b	1.170ab	798.33a
K37-10	10.133b	91.333a	82.567a	22.497ab	76.287a	2.233ab	58.270b	1.050ab	768.33a
TC37	15.700a	83.667b	79.333ab	23.883a	73.307a	2.100ab	66.000a	0.970ab	898.33a

[a]All the entries had 3 observations.

4.3 ANALYSIS OF VARIANCE OF YIELD AND YIELD COMPONENTS

4.3.1 ANALYSIS OF POOLED, PALMIET AND KAREE DATA SETS

Similar to the analyses of quality data, data were analysed in different sets. Firstly, all parents and NIL's were compared. In this analysis data for all individual NIL's within a cross were pooled. Secondly, the effect of the presence of a resistance gene in the Palmiet and Karee genetic background respectively, was determined. Thirdly, the performance of the individual NIL's compared to their parents were studied. Means were compared (p = 0.05) using the Tukey-Kramer method.

Table 4.18 Analysis of variance of yield components (all entries)

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean
TKW	153.703	9.316	16.499**	8.470	36.035
T_HA	3.212	0.369	8.711**	18.10177	3.354
HSM	63469.000	4210.412	15.074**	18.416	352.33
KPH	720.197	33.188	21.700**	11.364	50.694

**p=0.01

TKW = thousand-kernel weight (g)
T_HA = yield (t/ha)
HSM = heads per square meter
KPH = kernel per head

Except for heads per square meter in the Karee analysis, ANOVA indicated highly significant (p = 0.01) F-values for all components (Tables 4.18, 4.19 and 4.20). The means for yield and its components, pooled for NIL's, are shown in Table 4.21.

Table 4.19 Analysis of variance of yield components (Palmiet NIL's and parents)

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean
TKW	211.827	13.550	15.634**	9.744	37.778
T_HA	1.816	0.341	5.326**	18.428	3.169
HSM	24561.450	3777.395	6.502**	22.050	278.73
KPH	779.966	59.649	13.076**	13.737	56.222

**p=0.01

Table 4.20 Analysis of variance of yield components (Karee NIL's and parents)

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean
TKW	95.807	6.623	14.465**	0.514	34.658
T_HA	3.841	0.375	10.239**	18.050	3.393
HSM	4472.066	4592.019	0.974	17.259	392.63
KPH	188.965	17.969	10.516**	9.0061	47.068

**p=0.01

Table 4.21 Means[a] of yield and yield components for pooled data

CULTIVAR/ NIL	TKW	T_HA	HSM	KPH
KAREE(7)[b]	35.53	4.08	376.29	46.28
PLMT(5)	44.17	3.99	286.80	61.01
TC(3)	35.16	2.96	370.00	41.36
K29(27)	35.18	3.35	385.56	43.81
K34(27)	36.07	3.18	383.04	50.95
K35(27)	34.84	3.92	406.00	47.80
K37(30)	35.70	3.59	398.60	49.70
P29(27)	37.59	3.24	291.78	53.06
P34(30)	39.39	3.17	239.07	62.92
TC29(3)	26.36	2.12	365.33	39.62
TC34(3)	26.76	2.32	366.67	41.18
TC35(3)	26.46	1.55	476.00	37.27
TC37(3)	27.29	2.43	412.00	40.93

[a]See Appendix B for significant differences.

[b]Values between brackets represent the number of observations.

The highest thousand-kernel weight was recorded for Palmiet (44.17 g) which differed significantly from P29 (37.59 g) but not from P34 (39.39 g). The thousand-kernel weight of P34 was significantly higher than that of K34 (36.07 g). Karee and the Karee NIL's were statistically similar. Thatcher (35.16 g) differed considerably from its NIL's (range: 26.36 – 27.29 g).

Karee yielded the best (4.08 t/ha). Except for K34 (3.18 t/ha), K29, K35 and K37 yielded similar to Karee. K35 (3.92 t/ha) was also significantly different from K34 and

K29 (3.35 t/ha). Palmiet (3.99 t/ha) yielded statistically similar to P29 (3.24 t/ha) and P34 (3.17 t/ha). K29 and P29, and K34 and P34, also gave similar yields.

Most heads per square meter were encountered for TC35 (476), followed by TC37 (412) and K35 (406). Palmiet, Karee and Thatcher all produced a statistically equal number of heads compared to their respective NIL's. However, K29 (386) and K34 (383) produced significantly more heads per square meter than P29 (292) and P34 (239), respectively. Also, significantly more heads were counted for P29 than P34.

P34 produced most kernels per head (62.9) and differed significantly from all entries except Palmiet (61). No significant differences were detected among the three recurrent parents and their respective NIL's. Furthermore, P29 (53) produced more kernels per head than K29 (43.8) and P34 more than K34 (51).

4.3.2 ANALYSIS OF NIL's CONTAINING THE *Lr29* GENE

4.3.2.1 Palmiet background

Table 4.22 Analysis of variance of yield components for Palmiet NIL's with the *Lr29* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
TKW	88.574	5.372	16.487**	6.265	36.996	6.824
T_HA	0.941	0.331	2.840*	17.977	3.203	1.695
HSM	8921.081	3852.778	2.315*	20.648	300.611	182.740
KPH	158.271	66.436	2.382*	15.689	51.952	23.996

**p=0.01 & *p=0.05

This analysis included Palmiet, nine sister Palmiet/*Lr29* NIL's, TC29 and Thatcher. The F-values indicated significant variation (p = 0.01 or p = 0.05) among entries for all yield parameters measured (Table 4.22). Entry means for each characteristic are given in Table 4.23. Within columns, values followed by different letters differ significantly at p = 0.05.

Table 4.23 Entry means and grouping of yield components for Palmiet NIL's with the *Lr29* gene

	TKW	T_HA	HSM	KPH
PALMIET	44.150a	4.150a	246.000a	64.910a
THATCHER	35.163cd	2.963ab	370.000a	41.357ab
P29-1	42.770ab	3.333ab	237.330a	56.133ab
P29-2	36.150bcd	3.847a	230.000a	56.287ab
P29-3	35.310cd	3.897a	304.000a	56.287ab
P29-4	35.267cd	3.170a	378.000a	52.290ab
P29-5	30.647de	2.803ab	322.670a	54.823ab
P29-6	37.737abc	2.763ab	271.330a	55.157ab
P29-8	41.377abc	2.993ab	289.330a	43.353ab
P29-9	34.797cd	3.280ab	342.670a	51.223ab
P29-10	44.230a	3.113ab	250.670a	51.977ab
TC29	26.360e	2.120b	365.330a	39.623b

The Tukey-Kramer test did not reveal differences among means for heads per square meter and although some variation occurred for yield and kernels per head, the Palmiet/*Lr29* lines were similar to Palmiet. Considering thousand-kernel weight, P29-2 (36.15 g), P29-3 (35.31 g), P29-4 (35.27), P29-5 (30.65 g) and P29-9 (34.8 g) differed significantly from Palmiet (44.15 g).

4.3.2.2 Karee background

Table 4.24 Analysis of variance of yield components for Karee NIL's with the *Lr29* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
TKW	22.629	1.624	13.932**	3.688	34.561	3.752
T_HA	0.812	0.340	2.387*	17.822	3.273	1.717
HSM	3614.899	5078.222	0.712	18.668	381.722	209.790
KPH	55.315	6.653	8.314**	5.895	43.756	7.594

**p=0.01 & *p=0.05

In this analysis Karee, nine sister Karee/*Lr29* NIL's, TC29 and Thatcher were included. With the exception of heads per square meter, F-values indicated significant variation ($p = 0.01$ or $p = 0.05$) among lines (Table 4.24). The mean separation test also did not detect differences among heads per square meter values. Entry means for each characteristic are given in Table 4.25. Within columns, values followed by different letters differ significantly at $p = 0.05$.

Table 4.25 Entry means and grouping of yield components for Karee NIL's with the *Lr29* gene

	TKW	T_HA	HSM	KPH
KAREE	36.543a	4.073a	375.33a	49.777a
THATCHER	35.163a	2.963ab	370.00a	41.357cd
K29-1	35.610a	3.160ab	458.00a	38.977cd
K29-2	32.793a	3.097ab	400.67a	35.130cd
K29-4	35.927a	3.050ab	354.33a	44.153abc
K29-5	34.633a	3.033ab	337.33a	45.113abc
K29-6	35.213a	3.110ab	345.33a	44.670abc
K29-7	35.403a	3.800ab	412.67a	44.800abc
K29-8	35.423a	3.847a	362.00a	48.270ab
K29-9	36.173a	3.420ab	416.00a	44.867abc
K29-10	35.483a	3.597ab	384.67a	48.333ab
TC29	26.360a	2.120b	365.33a	39.623cd

For thousand-kernel weight and yield all K29 lines were statistically the same as Karee. K29-1 (39) and K29-2 (35.1) produced less kernels than Karee (49.8).

4.3.3 ANALYSIS OF NIL's CONTAINING THE *Lr34* GENE

4.3.3.1 Palmiet background

Table 4.26 Analysis of variance of yield components for Palmiet NIL's with the *Lr34* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
TKW	64.681	3.320	19.482**	4.738	38.459	5.407
T_HA	0.804	0.280	2.868*	16.712	3.168	1.571
HSM	11402.256	2486.256	4.586**	19.216	259.487	147.950
KPH	305.481	21.086	14.487**	7.686	59.744	13.625

**p=0.01 & *p=0.05

In this analysis Palmiet, 10 sister Palmiet/*Lr34* NIL's, TC34 and Thatcher were included. All yield components varied significantly at either p = 0.01 or 0.05 according to the ANOVA (Table 4.26). Entry means for each component are given in Table 4.27. Within columns, values followed by different letters differ significantly at p = 0.05.

Table 4.27 Entry means and grouping of yield components for Palmiet NIL's with the *Lr34* gene

	TKW	T_HA	HSM	KPH
PALMIET	44.150a	4.150a	246.000abcd	64.910a
THATCHER	35.163d	2.963ab	370.000a	41.357c
P34-1	41.107abc	3.167ab	227.330abcd	64.043a
P34-2	41.163abc	3.263ab	234.000abcd	62.910a
P34-3	42.040ab	2.643ab	230.000abcd	61.553a
P34-4	36.38cd	3.100ab	348.670abc	46.757bc
P34-5	37.167bcd	3.630ab	254.670abcd	62.710a
P34-6	43.817a	3.413ab	250.670abcd	65.980a
P34-7	41.277abc	3.883ab	240.670abcd	58.933ab
P34-8	38.197bcd	3.123ab	202.000cd	68.400a
P34-9	36.190cd	2.550b	220.000bcd	65.910a
P34-10	36.560cd	2.973ab	182.670d	72.023a
TC34	26.760e	2.323b	366.670ab	41.18c

Regarding thousand-kernel weight, Palmiet (44.2 g) differed significantly from P34-4 (36.4 g), P34-5 (37.2 g), P34-8 (38.2 g), P34-9 (36.2 g) and P34-10 (36.6 g). For heads per square meter the P34 NIL's were similar to Palmiet. P34-4 produced significanlty less (46.8) kernels per head than Palmiet (64.9).

4.3.3.2 Karee background

Table 4.28 Analysis of variance of yield components for Karee NIL's with the *Lr34* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
TKW	56.806	8.649	6.568**	8.342	35.257	8.658
T_HA	1.293	0.353	3.665**	18.754	3.167	1.749
HSM	7057.081	5112.667	1.380	18.819	379.944	210.500
KPH	51.092	10.066	5.076**	6.443	49.240	9.340

**p=0.01

In this analysis Karee, nine sister Karee/*Lr34* NIL's, TC34 and Thatcher were included. According to the ANOVA, yield components, except heads per square meter, varied significantly at p = 0.01 (Table 4.28). Entry means for each component are given in Table 4.29. Within columns, values followed by different letters differ significantly at p = 0.05.

Table 4.29 Entry means and grouping of yield components for Karee NIL's with the *Lr34* gene

	TKW	T_HA	HSM	KPH
KAREE	36.543ab	4.073ab	375.33a	49.777a
THATCHER	35.163b	2.963abc	370.00a	41.357b
K34-1	33.960bc	3.230abc	422.00a	51.310a
K34-2	36.830ab	4.270a	335.33a	55.710a
K34-3	35.490bc	3.443abc	378.67a	51.287a
K34-4	39.387ab	2.727abc	342.67a	51.157a
K34-6	33.020bc	2.350bc	437.33a	51.087a
K34-7	33.237bc	2.467bc	348.67a	50.510ab
K34-8	35.023bc	3.530abc	485.33a	49.110ab
K34-9	32.573bc	2.893abc	388.00a	48.533ab
K34-10	45.097a	3.733abc	309.33a	49.867ab
TC34	26.760c	2.323c	366.67a	41.180b

The Tukey-Kramer procedure did not detect any significant differences between the NIL's and their recurrent parent Karee.

4.3.4 ANALYSIS OF KAREE NIL's CONTAINING THE *Lr35* GENE

Table 4.30 Analysis of variance of yield components for Karee NIL's with the *Lr35* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Mean	MSD
TKW	21.034	1.758	11.964**	3.864	34.313	3.904
T_HA	1.636	0.434	3.770**	18.025	3.655	1.940
HSM	5305.081	4913.889	1.080	17.254	406.278	206.370
KPH	52.856	17.614	3.001*	9.016	46.550	7.073

**p=0.01 & *p=0.05

In this analysis Karee, nine sister Karee/*Lr35* NIL's, TC35 and Thatcher were included. According to the ANOVA yield components, except heads per square meter, varied significantly at p = 0.01 or 0.05 (Table 4.30). Entry means for each component are given in Table 4.31. Within columns, values followed by different letters differ significantly at p = 0.05. Means for the NIL's and Karee could, however, not be separated (Table 4.31).

Table 4.31 Entry means and grouping of yield components for Karee NIL's with the *Lr35* gene

	TKW	T_HA	HSM	KPH
KAREE	36.543a	4.073a	375.33a	49.777a
THATCHER	35.163a	2.963a	370.00a	41.357ab
K35-2	35.217a	4.333a	396.00a	51.867a
K35-3	34.050a	4.013a	380.67a	49.777a
K35-4	33.817a	3.740a	426.00a	49.843a
K35-5	34.057a	3.700ab	488.00a	44.333ab
K35-6	36.690a	3.837a	405.33a	44.180ab
K35-7	34.837a	3.763a	368.00a	46.510ab
K35-8	34.430a	3.903a	420.67a	46.623ab
K35-9	35.887a	3.997a	354.00a	47.443ab
K35-10	34.617a	3.983a	415.33a	49.623ab
TC35	26.457b	1.553ab	476.00a	37.270b

4.3.5 ANALYSIS OF KAREE NIL's CONTAINING THE *Lr37* GENE

Table 4.32 Analysis of variance of yield components for Karee NIL's with the *Lr37* gene

TRAIT	MSE(entries)	MSE(error)	F-value	C.V.	Means	MSD
TKW	18.669	3.012	6.199**	4.947	35.080	5.149
T_HA	0.637	0.311	2.047	15.995	3.487	1.655
HSM	1300.581	5189.846	0.251	18.209	395.641	213.760
KPH	42.114	14.582	2.888*	7.891	48.391	11.331

**p=0.01 &*p=0.05

In this analysis Karee, 10 sister Karee/*Lr37* NIL's, TC37 and Thatcher were included. According to the ANOVA entries varied only for thousand-kernel weight (p = 0.01) and kernels per head (p = 0.05) (Table 4.32). Entry means for each component are given in Table 4.33. Within columns, values followed by different letters differ significantly at p = 0.05. The Tukey-Kramer test failed to detect any significant differences among means for the NIL's and Karee (Table 4.33).

Table 4.33 Entry means and grouping of yield components for Karee NIL's with the *Lr37* gene

	TKW	T_HA	HSM	KPH
KAREE	36.543a	4.073a	375.33a	49.777ab
THATCHER	35.163a	2.963a	370.00a	41.357ab
K37-1	34.903a	3.383a	389.33a	52.710a
K37-2	35.537a	3.277a	426.67a	51.643ab
K37-3	35.427a	3.610a	419.33a	47.710ab
K37-4	34.450a	3.327a	394.00a	51.153ab
K37-5	35.437a	3.803a	371.33a	50.757ab
K37-6	34.970a	4.000a	428.00a	48.487b
K37-7	36.353a	3.397a	396.00a	48.667b
K37-8	36.090a	3.307a	404.00a	51.423ab
K37-9	37.757a	3.867a	376.00a	49.047ab
K37-10	36.123a	3.897a	381.33a	45.423ab
TC37	27.287b	2.430a	412.00a	40.933ab

4.4 REGRESSION ANALYSIS AND CORRELATION MATRIX

4.4.1 STEPWISE REGRESSION

Loaf volume was used as the independent variable in the regression analysis as it is the end product of bread baking. To determine which variable explained most variation in loaf volume, all yield and quality characteristics were regressed against this important breadbaking characteristic.

The following variables were used to run entries:

1.	T_HA	2.	TKW
3.	HSM	4.	KPH
5.	FPC	6.	SDSS
7.	HLM	8.	BFY
9.	FLY	10.	MDT
11.	WABS	12.	PL-RATIO

Model fitting for loaf volume resulted in an adjusted R-Square of 0.5450 with 194 degrees of freedom.

Table 4.34 Fitting model with LF as independent variable.

Traits in Model	Accumulated R-Square	Traits not in Model
HLM	0.43692	HSM
WABS	0.47011	FPC
KPH	0.51213	SDSS
TKW	0.53179	BFY
T_HA	0.54497	FLY
		MDT
		PL-RATIO

Therefore, 54% of the variability in loaf volume was explained by five factors, which were hectolitre mass, water absorption, kernels per head, thousand-kernel weight and yield, with hectolitre mass making the largest overall contribution (Table 4.34). The other seven traits were not included in the model, because their contributions were very low.

4.4.2 CORRELATION MATRIX

Coefficients of correlation among the yield and quality factors measured are given in Table 4.35. Only significant correlations will be mentioned here. Loaf volume was correlated positively with flour protein content and water absorption, but negatively related to SDS-sedimentation, hectolitre mass, breakflour yield, mixing time and PL-ratio. Flour protein content correlated negatively with SDS-sedimentation and flour extraction, but positively with water absorption. SDS-sedimentation was positively correlated with hectolitre mass, mixograph mixing time and water absorption. Hectolitre mass correlated positively with breakflour yield, mixograph development time and the PL-ratio. Breakflour yield and flour extraction were also positively correlated. Flour extraction and water absorption, though, correlated negatively.

A positive relationship existed between yield and thousand-kernel weight, and between thousand-kernel weight and heads per square meter, and heads per square meter and kernels per head. Heads per square meter and kernels per head also correlated positively.

Thousand-kernel weight correlated positively with loaf volume, SDSS-sedimentation, but negatively with flour protein content, water absorption and the PL-ratio. Thousand-kernel weight and hectolitre mass correlated negatively, although the coefficient was low. Yield and SDS-sedimentation were positively correlated in contrast with yield and loaf volume, flour protein content and water absorption. Heads per square meter and hectolitre mass, breakflour yield and PL-ratio were correlated. Heads per square meter and loaf volume showed a negative relationship. A correlation was also observed between heads per square meter and flour protein content. Kernels per head were negatively correlated with flour protein content, hectolitre mass, breakflour yield, water

absorption and PL-ratio. However, a positive correlation existed between kernels per head and SDS-sedimentation, and between kernels per head and loaf volume.

Table 4.35 Correlation matrix of quality and yield components

	TKW	T_HA	HSM	KPH	LF	FPC	SDSS	HLM	BFY	FLY	MDT	WABS
T_HA	0.2918**											
HSM	-0.4667**	0.1775										
KPH	0.4389**	0.1286	-0.5446**									
LF	0.2411**	-0.2918**	-0.4605**	0.4303**								
FPC	-0.375**	-0.3864**	0.1861*	-0.2417**	0.2673**							
SDSS	0.2397**	0.2771**	-0.0182	0.2115*	-0.2058*	-0.3475**						
HLM	-0.1858*	0.2724**	0.497**	-0.479**	-0.6644**	-0.1803	0.3961**					
BFY	-0.2892**	-0.0992	0.3793**	-0.2657**	-0.1879*	0.0975	0.054	0.1954*				
FLY	0.0918	0.1086	0.1821	-0.0713	-0.0456	-0.2041*	0.169	0.1423	0.5364**			
MDT	-0.0542	0.1293	0.1413	0.0559	-0.2027*	-0.0808	0.6362**	0.3396**	0.181	0.0997		
WABS	-0.3386**	-0.4016**	0.146	-0.2404**	0.2859**	0.892**	-0.3152**	-0.1498	0.0842	-0.1906*	-0.0361	
PL	-0.242**	0.1806	0.3851**	-0.3994**	-0.4697**	-0.1244	0.064	0.5378**	-0.0408	-0.0972	0.0706	-0.1036

*p = 0.01 & **p = 0.001

CHAPTER 5

DISCUSSION

5.1 HMW GLUTENIN SUBUNITS

For bands coded by the *Glu-A1* locus, Thatcher, TC29, TC34, TC35 and TC37 had 2*. Karee and all but four of the Karee NIL's had subunit 1. K34-4, K34-5, K34-8 and K34-10 had band 2*, which was probably derived from the donor parent, TC34. The Palmiet NIL's had the same subunit as their recurrent parent and were all pure-breeding for this locus. According to Moonen *et al.* (1983) and Lukow *et al.* (1989) the presence of either subunit 1 or 2* is regarded as advantageous. All the entries had either of these subunits.

Except for K34-10, Karee, Thatcher and their NIL's produced bands 7+9 coded by the *Glu-B1* locus. Palmiet NIL's varied more for bands at this locus. However, most lines showed a hybrid combination, which indicates that segregation occurred in these lines. All the entries had one of the banding patterns 7+9, 7+8 or 13+16 which have been suggested to contribute to good quality (Lukow, 1991; Lukow *et al.*, 1989).

For bands coded by genes at the *Glu-D1* locus, Karee as well as the Karee NIL's had 5+10 and can be considered pure breeding for this locus. Palmiet had the 2+12 band combination and the Palmiet NIL's also had predominantly the 2+12 subunit. Three Palmiet NIL's, though, had both the 5+10 and 2+12 subunits, which indicates segregation. This variation was not unexpected as some segregation could be expected in BC6. However, one line, P29-9, had only the 5+10 subunits. This banding pattern may derive from the donor parent, TC29 which also had these subunits. It was interesting that the Palmiet NIL's segregated to a much larger extent than the Karee NIL's. It should also be emphasised that the Karee and Palmiet NIL's were developed primarily for leaf rust resistance and that no selection for HMW subunits was carried out.

According to Lukow (1991) *Glu-D1* bands are the most important in the assessment of breadmaking quality, with the 5+10 banding combination being the more desirable

subunit combination. Most of the Palmiet NIL's had the undesirable 2+12 combination. However, it should be kept in mind that Glu-1 banding patterns account for only 25% of the variation in quality in South African wheats (Randall, personal communication).

5.2 ANALYSIS OF VARIANCE OF POOLED DATA

Considering the charactersistics measured, no genotype could be singled out as being superior in all respects. The Thatcher NIL's had the best flour protein content, good breakflour yield, and many heads per square meter, but were inferior regarding the other analyses. Thatcher and its derivatives, which are of Canadian origin, were however not expected to perform well in the yield analysis as they are not adapted to South African conditions. Palmiet had the highest flour extraction and thousand-kernel weight, and also a good SDS-sedimentation value and loaf volume, satisfactory yield and high kernel number per head. Karee had the best SDS-sedimentation, hectolitre mass and yield but was the only entry with a protein content below 11%, which is undesirable for South African conditions (Koekemoer, 1997).

Dyck & Lukow (1988) found that lines containing *Lr29* or *Lr37* had higher flour protein content. In the present study all lines with *Lr29* had a higher flour protein content than their recurrent parents, but these differences were not significant. Neither TC37 nor K37 had a higher flour protein content than their parents. Working with RL6058, Drijepondt *et al.* (1990) found that the presence of *Lr34* enhanced the flour protein content of the line. Similar increases in flour protein content in K34 and TC34 could, however, not be confirmed. Likewise, flour protein content in P34 was lower than in Palmiet although this difference was not significant. From this study it can thus be concluded that neither *Lr29, Lr34* or *Lr37* had any effect on the flour protein content. Positive advances in flour protein content by using genes such as *Lr29* and *Lr37* (Dyck & Lukow, 1988) seem to be cultivar and/or environment specific. These results were probably biased because the Thatcher background were used, a cultivar which may be genetically inclined to have a higher flour protein content.

Karee and two of the Karee NIL's had the best SDS-sedimentation values of all the entries evaluated, which also suggested cultivar-specificity for this attribute. Drijepondt *et al.* (1990) found that SDS-sedimentation was reduced in a line containing *Lr34*.

Although TC34, K34 and P34 each had a lower SDS-sedimentation value, it was not significantly lower than that of their recurrent parents. Regarding *Lr29,* the SDS-sedimentation value for P29 was significantly lower than that of Palmiet. The fact that a reduction of similar magnitude was not observed in K29 suggested that the lower SDSS value in P29 could be ascribed to factors other than the *Lr29* gene.

Karee and the Karee NIL's had significantly higher hectolitre mass values than the Palmiet and Thatcher NIL's which may relate to differences shape and density.

Flour extraction in lines containing *Lr29* and *Lr34* was statistically equal to their recurrent parents. Similarly, Kloppers *et al.* (1995) found that *Lr29* did not have a negative effect on flour extraction. Drijepondt *et al.* (1990), though, found that flour extraction was reduced in RL6058 containing *Lr34.*

Mixograph development times of between 2 and 3 min. are required for South African cultivars. Karee and most of the Karee NIL's had a mixing time above 2 min., whereas all the Palmiet lines were below this mark. TC37 was the only Thatcher line with a mixing time above 2 min.

Dyck & Lukow (1988) reported a shorter mixing time for lines containing the *Lr29* gene. This was not found in the present study as K29 and P29 had mixograph development times similar to their recurrent parents. Drijepondt *et al.* (1990) found that the mixograph mixing time were reduced in RL6058, a line with *Lr34.* Although mixing times were shorter in the NIL's, no significant differences were observed comparing K34 and Karee or P34 and Palmiet. As in other quality measurements, e.g. SDSS and HLM, variation in mixing time appeared to be determined by the recurrent genotype rather than the different *Lr* genes.

A water absorption value approaching 60% is usually expected of South African cultivars. Therefore, Palmiet, Palmiet NIL's, Karee and Karee NIL's all had satisfactory water absorption. Water absorption in most of the Thatcher NIL's was higher. Drijepondt *et al.* (1990) found a reduction in water absorption in a line containing *Lr34.* No significant differences were observed in this study between the lines containing *Lr34* and their recurrent parents.

K34, K35 and K37 all had a significantly better PL-ratios than Karee. Similarly, the Thatcher NIL's, TC29 and TC34 also had significantly better PL-ratios. The PL-ratios of Palmiet and the Palmiet NIL's were very low. This indicated that the extensibility of the Palmiet lines was too high with a poor ability to retain gas. P29 and P34 produced the best loaf volumes of all the entries evaluated and could be statistically separated from Karee and its NIL's. No references could be found in the literature where the effect of *Lr* genes on PL-ratios or loaf volume was studied.

Dyck & Lukow (1988) reported a higher thousand-kernel weight in lines containing *Lr29* and Kloppers *et al.* (1995) did not find negative quality or yield responses in certain Thatcher NIL's. The present study contradicts these results as P29 and TC29 had a significantly lower thousand-kernel weight than their recurrent parents. The thousand-kernel weight of K29, though not significantly, was lower than that of Karee. Drijepondt *et al.* (1990) reported a reduction in thousand-kernel weight in a line containing *Lr34*. These results could only be confirmed in the Thatcher background. K34 and P34 did not differ significantly from their recurrent parents.

Seck *et al.* (1988) reported a reduction in yield in NIL's with the *Lr9* and *Lr16* gene. Ortelli *et al.* (1996) also reported a yield reduction in NIL's with *Lr9*. Singh & Huerto-Espino (1997) found a reduction in yield in a line with *Lr34*. In the present study K34 yielded significantly lower than Karee. However, significant differences were observed between NIL's with different leaf rust genes. For example, K35 had a significantly higher yield than K34. The reason for the reduced yield of K34 is not clear. It is possible that leaf tip necrosis, which is genetically associated with *Lr34*, reduced the photosynthetic flag leaf area of K34 lines. P34 also yielded less than Palmiet, although not significantly.

It was further observed that the incorporation of the leaf rust resistance genesinfluenced Palmiet and Karee differently. Palmiet is a high-yielding cultivar in spring wheat producing areas, but is known to have poor breadmaking quality. Karee is very well adapted to the area where the experiment was conducted and also yielded well. Karee has acceptable quality in general. Palmiet had higher thousand-kernel weight, yield, SDS-sedimentation, flour extraction, mixing time, and water absorption

than its NIL's. Karee had the highest SDS-sedimentation value, hectolitre mass and yield, and an acceptable mixing time and thousand-kernel weight.

P29 had good loaf volume and flour extraction, PL-ratio, thousand-kernel weight, yield and kernels per head. K29 on the other hand, did not perform weell in either quality or yield analyses.

In comparison with Palmiet, P34 had good SDS-sedimentation values, water absorption, loaf volume, thousand kernel weight, yield and a high number of kernels per head. K34 performed satisfactory for SDS-sedimentation, flour extraction, water absorption, PL-ratio, thousand-kernel weight and kernels per head.

Although comparisons for *Lr35* and *Lr37* were not possible in both backgrounds, K35 appeared acceptable for hectolitre mass, flour extraction, mixing time, water absorption, yield and heads per square meter. K37 was low yielding, but produced good SDS-sedimentation, hectolitre mass, flour extraction, mixing time and water absorption results.

Considering all measurements, none of the Karee or Palmiet NIL's performed worse overall than their recurrent parents.

5.3 ANALYSIS OF VARIANCE OF PALMIET NIL's CONTAINING THE *Lr29* GENE

Palmiet and some of the NIL's varied significantly for measured characteristics and certain sister NIL's can be used to replace Palmiet. P29-1 would be the best substitute. Regarding mixing time, however, P29-1 is inferior to Palmiet. In general, most of the NIL's performed very similar to their recurrent parent and differed for three characteristics only, i.e. thousand-kernel weight, SDS-sedimentation and mixing time.

5.4 ANALYSIS OF VARIANCE OF KAREE NIL's CONTAINING THE *Lr29* GENE

Most of Karee *Lr29* NIL's would be a good leaf rust-resistant substitute for Karee. K29-4, K29-5, K29-6, K29-8, K29-9 and K29-10 were similar to Karee for all the characteristics analysed. K29-1 and K29-2 produced significantly less kernels per head

than Karee did, and the mixing time of K29-7 was significantly shorter, thus excluding them as potential substitutes Karee.

5.5 ANALYSIS OF VARIANCE OF PALMIET NIL's CONTAINING THE *Lr34* GENE

No significant differences were observed between Palmiet and the P34 NIL's for any of the quality characteristics evaluated. P34-4, P34-5, P34-8, P34-9 and P34-10 had a lower thousand-kernel weight than Palmiet, P34-9 a lower yield, and P34-4 fewer kernels per head. P34-1, P34-2, P34-3, P34-6 and P34-7 did not differ significantly from Palmiet and can be used in cultivar development.

5.6 ANALYSIS OF VARIANCE OF KAREE NIL's CONTAINING THE *Lr34* GENE

No significant differences were observed between the Karee NIL's and Karee in any of the yield analyses. However, K34-4, K34-6, K34-7, K34-8, K34-9 and K34-10 differed from Karee for a number of the quality attributes. K34-1, K34-2 and K34-3 appeared to bethe most suitable substitutes for Karee.

The value of acceptable Palmiet and Karee lines with *Lr34* is enhanced by the linkage between *Lr34* and *Yr18*, an effective gene for adult-plant resistance to stripe rust of wheat (McIntosh *et al.,* 1995).

5.7 ANALYSIS OF VARIANCE OF KAREE NIL's CONTAINING THE *Lr35* GENE

The *Lr35* NIL's did not differ significantly from Karee for any of the yield components, and it could therefore be assumed that no yield penalties are associated with the *Lr35* gene. Taking the quality analyses into account, K35-2 was the only less desirable entry due to a lower SDS-sedimentation volume. Based on PL-ratio, K35-3, K35-5, K35-6, K35-7 and K35-8 were superior to Karee. Of these, K35-5 was the best line as it combined a significantly higher flour protein content with a more ideal PL-ratio.

5.8 ANALYSIS OF VARIANCE OF KAREE NIL's CONTAINING THE *Lr37* GENE

Analyses of yield components showed no significant differences between Karee and the Karee *Lr37* NIL's. As a result of a significantly lower hectolitre masses, K37-1 and K37-10 will not be good substitutes for Karee. Breeders wishing to utilise this source of resistance should consider K37-4, K37-5, K37-6 and K37-7 as the PL-ratios of these lines was closer to the optimum value of 0.8 value than that of Karee.

An added advantage to the use of the Karee and Palmiet NIL's with *Lr37* is the close linkage between *Lr37*, *Yr17* (Bariana & McIntosh, 1993) and *Sr38* (Dyck & Lukow, 1988).

5.8 REGRESSION ANALYSIS

Irrespective of the many traits addressed in wheat breeding, the end-product remains the most important factor in identifying superior quality (McGuire & McNeal, 1974). Although considerable efforts are being made to incorporate useful genes, e.g. *Lr* genes in new breeding lines, loaf volume and texture must be acceptable to the consumer. The stepwise regression analysis, conducted to determine which characteristics have the most important influence on the bread, showed that 54.5% of loaf volume differences (in this specific set of genotypes)could be explained by five characteristics. Hectolitre mass contributed 44%, water absorption 3%, kernel per head 4%, thousand-kernel weight 2% and yield 1,5% of the total variation. These characteristics reflect the density, moisture, amount and weight of kernels and emphasised their importance in selecting for factors that may improve the loaf volume of bread.

4.10 CORRELATION MATRIX

This study confirmed the negative relationship between protein content and yield (Schepers *et al.,* 1993) as well as the positive correlation between SDSS and mixograph development time (Dhaliwal *et al.*, 1987). The latter authors also reported a negative association between SDSS and flour protein content, which was confirmed in this study. Similar to the results of De la Roche & Fowler (1975), hectolitre mass and

mixograph values were positively correlated. Furthermore, the highly significant correlation found between water absorption and flour protein content supported previous findings (Dhaliwal *et al.*, 1987).

Dhaliwal *et al.* (1987) also reported significant correlations between mixograph properties and flour protein content, and mixograph properties and water absorption. This study could not confirm either of these correlations. In contrast with Walker & Hazelton (1996) no significant correlations between the PL-ratio and protein quantity were found in this study.

CHAPTER 6

CONCLUSIONS

Research on the possible pleiotropic effect of leaf rust resistance genes on baking quality has been limited. From the few reports available it is apparent that this study did not necessarily confirm the findings of others. The experiment was conducted under leaf rust-free conditions to exclude any influence the disease may have. The results obtained might have been different, had leaf rust occurred.

None of *Lr29*, *Lr34*, *Lr35* or *Lr37* significantly altered quality or yield components. It was found that a specific gene reacted differently in the different genetic backgrounds, which may explain why previous results could not always be repeated. In the present study *Lr34* appeared to give the best results Palmiet whereas *Lr35* and *Lr37* seemed to perform the best in Karee.

The HMW subunit banding patterns have shown that the sixth backcross is not necessarily homogeneous. Some cultivars also appeared more inclined to segregate in BC6 than other cultivars.

It is generally believed that the incorporation of alien genes for disease resistance will result in a reduction of yield. This premise could not be confirmed. Furthermore, the fact that certain sister NIL's with the same leaf rust resistance gene performed significantly better than others, strongly emphasised the importance of selection within a specific cross.

CHAPTER 7

SUMMARY

Keywords: Wheat, leaf rust resistance, *Lr29, Lr34, Lr35, Lr37*, quality, yield.

1. The aim of this study was to determine if the leaf rust resistance genes *Lr29, Lr34, Lr35* and *Lr37* have an effect on the quality and yield characteristics of a cultivar it is incorporated into.
2. Near-isogenic lines (NIL's) of Palmiet/*Lr29* and Palmiet/*Lr34*, as well as of Karee/*Lr29*, Karee/*Lr34*, Karee/*Lr35* and Karee/*Lr37* as well as all relevant parents, were evaluated for four yield and nine quality characteristics in a field experiment in the central Free State. The experiment was conducted in a randomised block design.
3. Results and conclusions:
   - The HMW glutenin subunits indicated segregation in BC6, especially in the Palmiet lines.
   - Thatcher and Palmiet lines with *Lr29* had significantly lower thousand-kernel weight values compared to their recurrent parents.
   - Palmiet NIL's with *Lr29* had significantly shorter mixograph mixing time compared to Palmiet.
   - Karee NIL's with the genes *Lr34, Lr35* and *Lr37* had significantly better PL-ratio's compared to Karee.
   - None of the leaf rust resistance genes used in this study had an influence on all the quality characteristics and yield components.
   - The results suggested that the introduction of foreign genes will not necessarily result in a yield reduction. The only reduction in yield was observed in Karee NIL's containing *Lr34*.
   - The two genetic backgrounds responded differently following to incorporation of the same *Lr* gene.
   - Some sister NIL's performed better than others, which emphasises the importance of sampling.

OPSOMMING

Sleutelwoorde: Koring, blaarroesweerstand, *Lr29, Lr34, Lr35, Lr37*, kwaliteit, opbrengs.

1. Die doel van hierdie studie was om te bepaal of die blaarroes- weerstandsgene *Lr29, L34, Lr35* en *Lr37* 'n effek het op die kwaliteit- en opbrengseienskappe van 'n kultivar waarin dit geïnkorporeer word.
2. Naby-isogeniese lyne (NIL) van Palmiet/*Lr29* en Palmiet/*Lr34*, sowel as Karee/*Lr29*, Karee/*Lr34*, Karee/*Lr35* en Karee/*Lr37* en die relevante ouers, is geëvalueer ten opsigte van vier opbrengs- en nege kwaliteitseienskappe in 'n veldeksperiment in die sentrale Vrystaat. Die ekperiment is uitgevoer in 'n gerandomiseerde blokontwerp en het alle relevante ouers ingesluit.
3. Resultate en gevolgtrekkings:
   - HMG glutenien-subeenhede het nog 'n sekere mate van segregasie getoon na die sesde terugkruising.
   - Thatcher en Palmiet lyne met *Lr29* het 'n betekenisvolle laer duisendkorrelmassa gehad as hul herhalende ouers.
   - Palmiet NIL met *Lr29* het 'n betekenisvolle verlaging in mixogram mengtyd getoon.
   - Die Karee NIL met die gene *Lr34, Lr35* en *Lr37* het almal 'n betekenisvolle verbetering in die PL-verhouding getoon.
   - Nie een van die blaarroesweerstandsgene wat in die studie gebruik is het 'n invloed op al die kwaliteitseienskappe of opbrengskomponente gehad nie.
   - Die resultate toon dat opbrengs nie noodwendig verlaag word indien gene vanaf verwante spesies in broodkoringkultivars oorgedra sou word, kon nie bevestig word nie. Slegs Karee derivate met die *Lr34* geen het 'n laer opbrengs as Karee self gehad.
   - Die twee genetiese agtergronde het verskillend gereageer ten opsigte van die inkorporering van dieselfde *Lr* geen.
   - Sommige suster NIL het beter gevaar as ander vir sekere eienskappe en het dus is die belang van monstering beklemtoon.

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APPENDIX A

A1. Table of significance for FPC of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--												
PLMT		--											
TC			--										
K29				--									
K34					--								
K35						--							
K37							--						
P29								--					
P34									--				
TC29	*					*	*		*	--			
TC34											--		
TC35	*	*		*	*	*	*	*	*			--	
TC37	*	*		*	*	*	*	*	*				--

* p=0.05

The table of significance explains which entries did significant better than others. For example TC29 has a significant higher protein content than Karee (KRE).

A2. Table of significance for SDSS of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--		*					*		*	*	*	
PLMT		--						*		*	*	*	
TC			--							*		*	
K29				--				*		*	*	*	
K34					--			*		*	*	*	
K35						--		*		*	*	*	
K37			*	*			--	*		*	*	*	
P29								--					
P34								*	--	*	*	*	
TC29										--			
TC34											--		
TC35												--	
TC37										*	*	*	--

A3. Table of significance for HLM of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	—	*						*	*	*	*	*	
PLMT		—											
TC		*	—					*	*				
K29		*		—				*	*	*	*	*	
K34		*			—			*	*	*	*	*	
K35		*				—		*	*	*	*	*	
K37		*					—	*	*	*	*	*	
P29								—					
P34									—				
TC29										—			
TC34											—		
TC35												—	
TC37									*				--

A4. Table of significance for BFY of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--								*				
PLMT		—											
TC			--										
K29				—									
K34				*	--	*		*	*				
K35						--							
K37							—	*	*				
P29								--					
P34									--				
TC29										—			
TC34				*				*	*		--		
TC35		*	*	*		*		*	*			--	
TC37									*				--

A5. Table of significance for FLY of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--												
PLMT		--											
TC			--										
K29				—									
K34					--								
K35						—							
K37							--						
P29								--					
P34									—				
TC29										—			
TC34											—		
TC35												—	
TC37													--

A6. Table of significance for MDT of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	—							*			*		
PLMT		--											
TC			—										
K29				—									
K34					--			*					
K35				*		—		*			*		
K37			*	*	*		—	*	*	*	*	*	
P29								—					
P34								*	—				
TC29										—			
TC34											--		
TC35												—	
TC37													--

A7. Table of significance for WABS of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--												
PLMT		--											
TC			--										
K29	*			--									
K34					--								
K35						--							
K37							--						
P29	*							--					
P34									--				
TC29	*				*	*	*		*	--			
TC34	*										--		
TC35	*	*		*	*	*	*	*	*			--	
TC37	*	*	*	*	*	*	*	*	*				--

A8. Table of significance for PL of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--	*			*	*	*	*	*			*	
PLMT		--											
TC		*	--		*	*	*	*	*	*		*	
K29		*		--	*	*		*	*				
K34					--				*				
K35		*				--		*	*				
K37		*					--	*	*				
P29								--					
P34									--				
TC29										--			
TC34		*									--		
TC35												--	
TC37													--

A9. Table of significance for LF of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--												
PLMT		--				*							
TC			--										
K29				--		*							
K34					--	*							
K35						--							
K37						*	--						
P29	*		*	*	*	*	*			--	*		
P34	*		*	*	*	*	*		--		*		
TC29													
TC34											--		
TC35						*						--	
TC37						*							--

A10. Table of significance FPC for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC		--				
P29			--	*		
P34				--		
TC29	*		*	*	--	
TC34				*		--

A11. Table of significance SDSS for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--		*		*	*
TC		--			*	
P29			--			
P34			*	--	*	*
TC29					--	
TC34						--

A12. Table of significance HLM for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC	*	--	*	*		
P29			--			
P34				--		
TC29					--	
TC34						--

A13. Table of significance BFY for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC		--				
P29			--			
P34				--		
TC29					--	
TC34	*	*	*	*		--

A14. Table of significance FLY for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC		--				
P29			--			
P34				--		
TC29					--	
TC34						--

A15. Table of significance MDT for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--		*			
TC		--				
P29			--			
P34			*	--		
TC29					--	
TC34						--

A16. Table of significance WABS for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC		--				
P29			--	*		
P34				--		
TC29	*		*	*	--	
TC34				*		--

A17. Table of significance PL for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC	*	--	*	*	*	*
P29			--			
P34				--		
TC29	*				--	
TC34	*		*	*		--

A18. Table of significance LF for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					*
TC		--				
P29		*	--			*
P34		*		--		*
TC29					--	
TC34						--

A19. Table of significance FPC for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--							
K34				--						
K35					--					
K37						--				
TC29	*				*		--			
TC34								--		
TC35	*		*	*	*	*			--	
TC37	*		*	*	*	*				--

A20. Table of significance SDSS for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--	*	*				*	*	*	*
TC		--					*	*	*	
K29			--				*	*	*	
K34		*		--			*	*	*	
K35		*			--		*	*	*	
K37		*	*			--	*	*	*	*
TC29							--			
TC34								--		
TC35									--	
TC37							*	*	*	--

A21. Table of significance HLM for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--						*	*	*	
TC		--								
K29			--				*	*	*	
K34				--			*	*	*	
K35					--		*	*	*	
K37						--	*	*	*	
TC29							--			
TC34								--		
TC35									--	
TC37										--

A22. Table of significance BFY for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--							
K34			*	--	*					
K35					--					
K37						--				
TC29							--			
TC34			*					--		
TC35		*	*		*	*			--	
TC37										--

A23. Table of significance FLY for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--							
K34				--						
K35					--					
K37						--				
TC29							--			
TC34								--		
TC35									--	
TC37										--

A24. Table of significance MDT for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--							*		
TC		--								
K29			--							
K34				--						
K35			*					*		
K37		*	*	*			*	*	*	
TC29							--			
TC34								--		
TC35									--	
TC37										--

A25. Table of significance WABS for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29	*		--							
K34				--						
K35					--					
K37						--				
TC29	*			*	*	*	--			
TC34	*							--		
TC35	*		*	*	*	*			--	
TC37	*	*	*	*	*	*				--

A26. Table of significance PL for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--			*	*	*			*	
TC		--		*	*	*			*	
K29			--	*	*					
K34				--						
K35					--					
K37						--				
TC29							--			
TC34								--		
TC35									--	
TC37										--

A27. Table of significance LF for NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--		*					
K34				--	*					
K35					--					
K37					*	--				
TC29					*		--			
TC34								--		
TC35					*				--	
TC37					*					--

APPENDIX B

B1. Table of significance for TKW of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--									*	*	*	*
PLMT	*	--	*	*	*	*	*	*		*	*	*	*
TC			--							*	*	*	
K29				--						*	*	*	*
K34					--					*	*	*	*
K35						--				*	*	*	*
K37							--			*	*	*	*
P29								--		*	*	*	*
P34				*	*	*	*		--	*	*	*	*
TC29										--			
TC34											--		
TC35												--	
TC37													--

B2. Table for significance of T HA for POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--				*				*	*	*	*	*
PLMT		--								*	*	*	*
TC			--										
K29				--								*	
K34					--							*	
K35				*	*	--		*	*	*	*	*	*
K37							--			*	*	*	
P29								--				*	
P34									--			*	
TC29										--			
TC34											--		
TC35												--	
TC37													--

B3. Table of significance for HSM of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--								*				
PLMT		--											
TC			--										
K29				--				*	*				
K34					--			*	*				
K35		*				--		*	*				
K37		*					--	*	*				
P29								--					
P34									--				
TC29										--			
TC34											--		
TC35		*						*	*			--	
TC37									*				--

B4. Table of significance for KPH of POOLED DATA:

	KRE	PLMT	TC	K29	K34	K35	K37	P29	P34	TC29	TC34	TC35	TC37
KRE	--												
PLMT	*	--	*	*	*	*	*			*	*	*	*
TC			--										
K29				--									
K34				*	--							*	
K35						--							
K37				*			--					*	
P29				*				--		*	*	*	*
P34	*		*	*	*	*	*	*	--	*	*	*	*
TC29										--			
TC34											--		
TC35												--	
TC37													--

B5. Table of significance for TKW of NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--	*	*		*	*
TC		--				
P29			--		*	*
P34				--	*	*
TC29					--	
TC34						--

B6. Table of significance for T HA of NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--				*	*
TC		--				
P29			--		*	
P34				--	*	
TC29					--	
TC34						--

B7. Table of significance for HSM for NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--					
TC		--		*		
P29			--	*		
P34				--		
TC29				*	--	
TC34				*		--

A8. Table of significance for KPH of NIL in PALMIET background:

	PLMT	TC	P29	P34	TC29	TC34
PLMT	--	*			*	*
TC		--				
P29			--			
P34		*	*	--	*	*
TC29					--	
TC34						--

A9. Table of significance for TKW of NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--						*	*	*	*
TC		--					*	*	*	*
K29			--				*	*	*	*
K34				--			*	*	*	*
K35					--		*	*	*	*
K37						--	*	*	*	*
TC29							--			
TC34								--		
TC35									--	
TC37										--

A10. Table of significance for T HA of NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--			*			*	*	*	*
TC		--								
K29			--						*	
K34				--					*	
K35			*	*	--		*	*	*	*
K37						--	*	*	*	
TC29							--			
TC34								--		
TC35									--	
TC37										--

A11. Table of significance for HSM of NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--							
K34				--						
K35					--					
K37						--				
TC29							--			
TC34								--		
TC35									--	
TC37										--

A12. Table of significance for KPH of NIL in KAREE background:

	KRE	TC	K29	K34	K35	K37	TC29	TC34	TC35	TC37
KRE	--									
TC		--								
K29			--							
K34		*	*	--			*	*	*	*
K35			*		--		*		*	
K37			*			--	*	*	*	*
TC29							--			
TC34								--		
TC35									--	
TC37										--

APPENDIX C

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
1	1	1	5	P29-3	12.2	72	75.60	18.89	74.46	1.5	60.90	0.65	1030+
2	1	1	53	K37-2	12.9	92	79.60	24.56	76.14	3.0	61.80	0.94	885
3	1	1	45	K35-4	12.2	90	80.60	23.41	75.51	2.7	60.90	1.02	850
4	1	1	11	P29-9	13.0	84	77.40	20.63	75.13	1.8	62.10	0.79	940
5	1	2	65	TC35	15.2	66	76.60	26.96	75.10	1.7	65.20	0.83	925
6	1	2	39	K34-7	12.1	89	79.80	20.10	73.76	2.0	60.80	1.17	735
7	1	2	46	K35-5	11.9	90	82.40	22.52	76.16	2.0	60.60	0.92	820
8	1	2	41	K34-9	12.4	85	83.50	24.53	75.60	1.6	61.20	0.90	790
9	1	3	15	P34-3	12.0	85	75.60	20.46	75.01	1.3	60.60	0.44	1030+
10	1	3	52	K37-1	12.0	90	79.60	23.55	76.01	2.5	60.60	0.77	890
11	1	3	48	K35-7	12.6	92	77.50	23.63	76.24	2.7	61.50	0.62	935
12	1	3	59	K37-8	13.0	92	79.30	22.94	75.58	3.0	62.00	0.93	875
13	1	4	21	P34-9	11.4	88	76.00	20.68	73.58	1.8	59.90	0.46	1000
14	1	4	31	K29-9	11.4	85	81.50	18.13	72.93	1.5	59.80	1.62	790
15	1	4	38	K34-6	12.9	90	82.00	24.26	79.00	1.7	61.80	0.57	885
16	1	4	8	P29-6	12.5	75	76.50	20.93	73.74	1.3	61.30	0.48	1005
17	1	5	66	TC37	14.3	83	80.00	24.05	73.55	1.5	63.90	1.06	865
18	1	5	62	THATCHER	12.5	85	79.50	21.61	76.84	1.7	61.40	1.92	850
19	1	5	26	K29-4	11.8	85	81.60	20.60	73.87	1.7	60.40	1.34	825
20	1	5	56	K37-5	10.8	90	81.90	22.58	75.94	2.1	59.10	1.01	800
21	1	6	19	P34-7	10.3	91	77.00	20.41	75.45	2.2	58.50	0.49	795
22	1	6	49	K35-8	10.2	92	80.00	23.26	76.57	2.4	58.40	0.79	815
23	1	6	55	K37-4	10.4	94	80.60	23.06	76.23	3.0	58.60	0.92	890
24	1	6	32	K29-10	11.4	85	80.60	21.45	74.40	1.6	59.90	1.53	785
25	1	7	12	P29-10	13.8	70	76.60	20.40	74.18	1.5	63.20	0.59	1025
26	1	7	6	P29-4	12.4	60	75.60	22.03	76.87	1.2	61.20	0.62	975
27	1	7	44	K35-3	10.7	89	81.60	20.81	74.93	2.0	59.00	0.67	970
28	1	7	3	P29-1	12.4	75	75.80	20.00	73.98	1.2	61.20	0.83	960
29	1	8	16	P34-4	12.3	86	79.60	22.68	75.72	1.5	61.10	0.93	910

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
30	1	8	20	P34-8	10.9	92	76.00	19.13	74.22	2.0	59.20	0.71	940
31	1	8	64	TC34	13.3	65	79.20	25.05	73.76	1.2	62.50	0.93	675
32	1	8	27	K29-5	12.2	84	83.20	21.91	73.28	1.5	60.90	0.99	790
33	1	9	43	K35-2	10.2	78	82.50	20.78	74.03	1.5	58.30	1.29	800
34	1	9	50	K35-9	11.0	90	82.70	23.08	77.26	2.1	59.30	1.01	820
35	1	9	33	K34-1	11.6	90	80.70	22.91	75.35	2.3	60.10	0.98	825
36	1	9	1	KAREE	10.7	93	82.70	22.01	74.81	2.0	58.90	1.46	775
37	1	10	9	P29-7	12.3	80	77.10	20.95	74.09	1.3	61.10	0.85	935
38	1	10	17	P34-5	10.6	85	77.10	21.27	75.51	1.4	58.80	0.69	910
39	1	10	30	K29-8	11.5	85	81.30	20.79	74.37	2.0	60.00	1.18	845
40	1	10	25	K29-3	11.3	82	81.10	21.17	75.85	2.0	59.70	1.10	800
41	1	11	37	K34-5	11.4	88	82.60	23.40	74.40	2.1	59.80	0.54	750
42	1	11	60	K37-9	10.1	87	82.00	23.30	75.75	2.0	58.20	1.08	745
43	1	11	63	TC29	14.0	65	78.20	22.04	74.43	1.5	63.50	0.75	835
44	1	11	14	P34-2	11.7	90	77.60	21.30	76.95	1.7	60.30	0.60	960
45	1	12	22	P34-10	10.9	87	76.80	20.10	74.10	2.0	59.20	0.72	930
46	1	12	42	K34-10	10.1	94	79.80	26.34	77.15	2.2	58.20	0.68	760
47	1	12	23	K29-1	11.2	86	80.70	22.21	76.28	1.8	59.60	1.09	695
48	1	12	40	K34-8	10.7	85	79.70	24.05	74.71	1.6	58.90	0.65	750
49	1	13	28	K29-6	11.3	85	82.10	20.86	74.43	1.5	59.70	1.06	685
50	1	13	18	P34-6	11.3	87	77.70	22.09	77.01	2.0	59.70	0.98	885
51	1	13	35	K34-3	11.8	90	81.90	19.37	77.67	1.8	60.40	1.13	885
52	1	13	51	K35-10	10.1	83	80.70	22.20	77.32	2.0	58.20	1.41	775
53	1	14	13	P34-1	10.8	90	76.60	21.88	76.29	1.7	59.10	0.54	1005
54	1	14	47	K35-6	10.0	90	83.40	24.39	77.90	1.7	58.10	0.86	765
55	1	14	4	P29-2	11.1	82	76.00	20.74	75.19	1.5	59.50	0.48	930
56	1	14	61	K37-10	9.9	90	83.20	22.96	76.27	2.0	58.00	1.09	700
57	1	15	29	K29-7	10.3	80	83.00	21.11	76.03	1.5	58.50	1.57	725
58	1	15	54	K37-3	10.0	92	81.60	24.60	77.76	2.0	58.20	1.43	670
59	1	15	10	P29-8	11.2	76	78.30	21.67	75.92	1.3	59.70	0.80	895

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
60	1	15	7	P29-5	11.1	75	75.60	24.40	76.94	1.5	59.50	0.32	920
61	1	16	36	K34-4	10.7	87	80.10	25.21	76.74	2.0	59.00	0.58	785
62	1	16	57	K37-6	9.8	90	81.50	22.10	75.53	2.2	57.80	1.07	730
63	1	16	34	K34-2	11.2	90	80.40	24.40	75.97	2.0	59.60	0.85	800
64	1	16	2	PALMIET	11.9	88	74.50	21.15	76.90	1.8	60.50	0.48	990
65	1	17	24	K29-2	11.2	85	80.00	21.51	76.03	1.8	59.70	0.87	775
66	1	17	58	K37-7	11.0	92	81.90	22.28	73.72	2.0	59.30	0.73	770
67	1	17	67	PLMT1	10.6	88	77.00	21.54	76.43	1.6	58.80	0.39	875
68	1	17	68	PLMT2	10.8	85	77.40	21.64	75.61	1.8	59.20	0.35	870
69	2	1	26	K29-4	10.0	84	82.30	21.42	76.23	1.7	58.10	1.68	740
70	2	1	11	P29-9	10.5	84	79.70	21.43	76.67	2.5	58.70	0.80	875
71	2	1	42	K34-10	10.1	94	80.30	25.38	75.43	2.5	58.20	0.74	765
72	2	1	3	P29-1	11.4	80	75.10	21.50	74.85	1.2	59.90	0.89	995
73	2	2	64	TC34	11.9	70	76.80	24.91	74.86	1.5	60.50	1.16	765
74	2	2	61	K37-10	9.7	91	83.30	22.35	75.95	2.5	57.70	1.28	760
75	2	2	15	P34-3	10.0	92	74.40	21.52	73.86	2.0	58.10	0.67	960
76	2	2	58	K37-7	9.4	94	81.70	22.19	76.34	2.5	57.30	0.82	900
77	2	3	4	P29-2	9.8	86	77.60	22.67	74.30	1.8	57.90	0.69	795
78	2	3	31	K29-9	9.8	86	82.50	21.41	74.79	2.0	57.90	1.29	720
79	2	3	17	P34-5	9.5	89	76.80	22.02	75.24	1.7	57.40	0.62	895
80	2	3	39	K34-7	11.1	84	81.70	18.48	71.18	1.6	59.50	0.90	675
81	2	4	10	P29-8	11.5	76	79.70	19.14	74.46	1.3	60.00	0.94	875
82	2	4	54	K37-3	9.7	92	82.00	22.62	78.25	2.2	57.70	1.68	775
83	2	4	63	TC29	12.3	72	78.80	21.01	71.53	1.6	61.10	0.95	785
84	2	4	29	K29-7	10.7	79	82.30	21.73	75.92	1.5	58.90	1.41	795
85	2	5	34	K34-2	11.7	90	81.20	21.63	73.20	2.5	60.30	1.29	780
86	2	5	65	TC35	15.8	75	77.90	24.21	74.02	1.7	66.20	0.81	845
87	2	5	18	P34-6	10.7	88	77.80	18.93	71.52	2.4	59.00	0.67	820
88	2	5	12	P29-10	12.8	76	78.50	17.32	69.18	1.3	61.80	0.55	915
89	2	6	62	THATCHER	12.7	82	81.10	19.63	71.24	1.6	61.60	1.76	760

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
90	2	6	52	K37-1	12.5	92	82.90	20.06	72.19	2.6	61.40	0.76	825
91	2	6	13	P34-1	10.4	90	76.70	18.46	70.66	1.8	58.60	0.55	900
92	2	6	48	K35-7	9.6	92	82.30	19.87	73.06	2.3	57.60	0.84	790
93	2	7	45	K35-4	9.9	93	81.60	20.05	73.08	2.2	58.00	1.31	760
94	2	7	8	P29-6	12.9	75	78.80	18.21	69.97	1.5	61.90	0.68	895
95	2	7	53	K37-2	11.4	92	80.20	21.47	72.94	2.5	59.80	1.13	795
96	2	7	22	P34-10	11.4	90	75.70	16.61	67.04	2.0	59.80	0.74	910
97	2	8	9	P29-7	12.7	81	77.90	18.17	69.48	1.2	61.60	1.11	925
98	2	8	30	K29-8	13.6	85	83.30	20.39	71.55	1.8	62.90	1.12	885
99	2	8	59	K37-8	10.8	90	80.60	19.44	73.28	3.3	59.10	1.28	770
100	2	8	1	KAREE	9.6	90	82.60	22.59	75.19	2.1	57.70	1.66	725
101	2	9	49	K35-8	10.2	90	80.60	19.87	73.68	2.5	58.30	0.90	765
102	2	9	36	K34-4	10.6	89	80.00	31.44	77.54	2.3	58.80	0.83	800
103	2	9	33	K34-1	11.2	91	80.20	21.89	72.98	2.3	59.60	0.93	835
104	2	9	28	K29-6	12.3	81	80.90	21.10	72.00	1.9	61.10	1.33	855
105	2	10	23	K29-1	13.3	87	81.80	20.92	73.40	2.0	62.40	1.08	865
106	2	10	60	K37-9	10.1	89	83.60	20.80	72.84	2.1	58.30	1.53	755
107	2	10	21	P34-9	10.4	89	76.40	19.13	72.57	2.0	58.60	0.61	970
108	2	10	47	K35-6	11.0	91	82.90	22.16	76.00	1.8	59.40	0.84	825
109	2	11	14	P34-2	10.4	91	77.10	20.28	72.82	1.7	58.70	0.72	950
110	2	11	44	K35-3	11.7	92	80.80	19.92	73.11	2.7	60.30	0.91	845
111	2	11	38	K34-6	12.0	90	81.40	25.97	82.03	2.0	60.60	0.58	895
112	2	11	66	TC37	16.2	82	78.80	24.50	73.11	1.5	66.80	1.02	880
113	2	12	7	P29-5	13.3	80	73.30	23.82	74.36	1.5	62.40	0.41	975
114	2	12	37	K34-5	13.4	90	81.40	23.50	72.38	2.0	62.60	0.42	945
115	2	12	55	K37-4	11.7	91	81.60	23.13	76.53	2.4	60.30	0.96	825
116	2	12	2	PALMIET	11.7	93	77.60	21.09	76.63	2.0	60.20	0.53	870
117	2	13	50	K35-9	11.6	92	81.80	22.44	76.66	2.2	60.10	0.93	845
118	2	13	20	P34-8	10.7	92	75.30	20.69	75.41	2.6	59.00	0.64	905
119	2	13	6	P29-4	11.5	69	76.20	22.04	77.58	1.2	60.00	0.50	930

Data of quality characteristics

PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
120	2	13	27	K29-5	13.3	90	79.60	20.85	73.07	1.8	62.40	1.14	875
121	2	14	40	K34-8	12.2	81	79.20	21.64	78.09	1.9	60.90	0.68	830
122	2	14	32	K29-10	11.9	85	80.10	21.61	74.00	1.7	60.50	1.74	775
123	2	14	41	K34-9	10.9	87	83.30	24.13	74.61	2.0	59.30	0.59	795
124	2	14	35	K34-3	12.2	91	81.70	21.96	73.54	1.9	61.00	1.00	825
125	2	15	51	K35-10	11.8	86	80.10	21.74	74.66	2.2	60.40	1.23	815
126	2	15	25	K29-3	11.9	89	80.60	20.99	73.59	1.7	60.50	1.31	740
127	2	15	16	P34-4	13.0	85	78.30	22.91	74.78	1.6	62.10	0.64	960
128	2	15	57	K37-6	12.0	90	79.90	21.96	73.89	2.2	57.61	0.98	785
129	2	16	43	K35-2	12.8	74	81.10	21.10	74.69	1.7	58.77	1.18	820
130	2	16	5	P29-3	13.8	80	76.40	18.59	74.20	1.5	60.11	0.77	1030+
131	2	16	19	P34-7	11.2	86	77.30	20.41	75.44	1.5	56.63	0.52	950
132	2	16	56	K37-5	11.8	91	78.40	23.05	74.87	2.0	57.36	0.50	850
133	2	17	46	K35-5	12.4	89	82.30	22.88	75.22	2.0	58.19	0.96	790
134	2	17	24	K29-2	13.8	85	77.60	20.73	74.87	1.8	60.14	1.23	795
135	2	17	67	KRE1	12.4	90	77.90	24.17	73.93	2.5	58.20	1.43	845
136	2	17	68	KRE2	12.0	90	80.50	23.50	74.68	2.0	59.62	0.83	805
137	3	1	9	P29-7	15.1	83	76.70	19.36	73.68	1.5	62.13	0.61	1030+
138	3	1	59	K37-8	14.5	90	81.50	22.53	75.48	2.6	61.17	1.13	880
139	3	1	14	P34-2	11.0	85	77.40	20.71	75.03	1.5	56.30	0.50	985
140	3	1	6	P29-4	10.6	69	75.00	22.38	77.17	1.3	55.90	0.52	1005
141	3	2	65	TC35	15.8	69	77.40	25.34	72.70	1.5	63.10	0.50	860
142	3	2	11	P29-9	14.4	82	77.60	20.36	74.16	1.7	61.02	0.92	980
143	3	2	49	K35-8	11.8	90	80.70	20.98	73.55	2.1	57.34	0.53	845
144	3	2	36	K34-4	12.7	89	79.00	26.09	76.55	1.7	58.57	0.48	875
145	3	3	46	K35-5	15.5	88	81.10	21.95	73.55	2.0	62.61	0.54	835
146	3	3	54	K37-3	15.5	92	80.00	22.02	73.52	2.4	62.68	1.35	825
147	3	3	24	K29-2	12.4	89	81.30	22.70	76.11	1.7	57.15	0.79	865
148	3	3	58	K37-7	12.9	93	82.00	21.48	75.30	3.1	61.90	0.62	875
149	3	4	55	K37-4	11.8	93	80.00	22.54	74.43	2.8	60.40	0.52	890

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
150	3	4	45	K35-4	11.4	91	81.30	21.78	73.79	2.5	59.80	0.96	820
151	3	4	32	K29-10	12.5	92	81.60	21.83	73.55	1.9	61.30	1.43	815
152	3	4	17	P34-5	11.0	89	76.70	20.35	73.98	1.8	59.40	0.45	1020
153	3	5	57	K37-6	15.0	91	81.00	22.02	74.83	3.0	64.90	0.57	880
154	3	5	52	K37-1	13.0	91	81.50	22.58	74.82	2.5	62.00	0.45	925
155	3	5	18	P34-6	11.2	91	77.40	20.27	74.12	2.6	59.70	0.52	890
156	3	5	42	K34-10	15.0	94	80.00	25.43	76.60	3.4	64.90	0.38	910
157	3	6	16	P34-4	12.6	90	77.20	21.07	73.88	1.6	61.40	0.58	1025
158	3	6	60	K37-9	12.1	93	81.90	22.85	76.46	2.1	60.80	0.91	895
159	3	6	41	K34-9	12.1	88	82.20	24.21	75.66	2.5	60.80	0.65	1030
160	3	6	30	K29-8	13.1	88	79.30	20.59	73.65	1.7	62.10	0.95	930
161	3	7	13	P34-1	11.7	81	76.60	18.98	73.44	1.7	60.30	0.36	1030+
162	3	7	8	P29-6	13.3	83	77.70	19.00	74.27	1.5	62.50	0.54	1030+
163	3	7	12	P29-10	14.7	77	77.70	19.07	73.82	1.5	64.40	0.61	1030+
164	3	7	47	K35-6	10.6	93	83.10	20.14	76.39	2.0	58.90	0.76	820
165	3	8	3	P29-1	12.4	88	75.60	19.93	73.81	1.4	61.20	0.78	1025
166	3	8	64	TC34	14.2	80	77.60	23.87	74.15	1.7	63.80	1.03	825
167	3	8	33	K34-1	12.6	91	81.40	22.91	73.75	2.2	61.50	0.75	930
168	3	8	40	K34-8	13.2	89	80.40	23.14	74.64	1.9	62.30	0.51	900
169	3	9	37	K34-5	12.8	94	80.50	23.84	74.56	2.1	61.70	0.54	1030+
170	3	9	27	K29-5	11.2	92	81.60	21.83	75.97	2.0	59.60	1.00	920
171	3	9	61	K37-10	10.8	93	81.20	22.18	76.64	2.2	59.10	0.79	845
172	3	9	48	K35-7	10.6	89	82.80	21.92	76.69	2.5	58.90	0.77	820
173	3	10	66	TC37	16.6	86	79.20	23.10	73.26	3.3	67.30	0.84	950
174	3	10	63	TC29	15.9	73	76.60	21.36	74.56	2.0	66.30	0.86	990
175	3	10	43	K35-2	10.9	84	81.80	20.82	76.11	1.9	59.20	1.03	865
176	3	10	20	P34-8	11.6	93	76.20	19.52	74.57	2.6	60.20	0.55	1030+
177	3	11	29	K29-7	12.6	89	81.50	21.89	75.51	1.6	61.50	1.29	895
178	3	11	23	K29-1	13.7	86	79.80	22.35	76.46	1.7	63.00	0.65	925
179	3	11	34	K34-2	10.7	93	82.40	22.47	75.91	2.0	59.00	0.88	810

Data of quality characteristics													
PLOT	Rep	Block	Entry	NAME	FPC (12%mb)	SDSS (ml)	*HLM (kg/ha)	BFY (%)	FLY (%)	MDT (min)	WABS (ml)	PL-RATIO	LF (mm)
180	3	11	2	PALMIET	13.0	94	76.90	21.75	76.78	2.5	62.10	0.36	960
181	3	12	10	P29-8	11.9	77	77.40	19.46	75.12	1.5	60.60	0.69	1030+
182	3	12	53	K37-2	11.2	93	81.70	23.76	77.12	2.7	59.60	0.83	850
183	3	12	31	K29-9	15.1	93	81.40	22.27	75.86	2.0	65.00	0.66	870
184	3	12	19	P34-7	11.7	92	77.50	21.15	76.45	1.9	60.30	0.35	1030+
185	3	13	50	K35-9	11.7	93	82.20	22.58	77.20	2.0	60.30	0.77	885
186	3	13	62	THATCHER	12.6	80	78.80	20.40	75.35	1.5	61.40	0.88	820
187	3	13	5	P29-3	11.0	80	78.10	22.06	75.25	1.5	59.40	0.49	915
188	3	13	22	P34-10	11.3	93	76.60	20.94	73.75	2.2	59.80	0.47	985
189	3	14	4	P29-2	11.0	90	77.50	20.32	75.21	1.7	59.30	0.53	930
190	3	14	7	P29-5	11.6	83	77.90	23.40	75.13	1.7	60.10	0.31	990
191	3	14	51	K35-10	12.8	90	82.40	21.85	76.02	2.1	61.70	0.84	865
192	3	14	25	K29-3	12.8	88	81.70	21.72	74.65	1.7	61.80	0.88	795
193	3	15	15	P34-3	12.1	93	75.00	20.85	75.05	2.0	60.80	0.34	1030+
194	3	15	39	K34-7	11.1	87	81.70	17.71	73.26	2.0	59.50	1.35	810
195	3	15	44	K35-3	10.7	94	82.30	21.33	75.84	2.5	59.00	0.85	835
196	3	15	35	K34-3	9.5	95	82.10	21.49	75.18	2.4	57.50	0.76	845
197	3	16	21	P34-9	10.4	92	76.20	20.73	75.51	2.0	58.60	0.55	960
198	3	16	28	K29-6	11.3	90	81.50	21.24	75.52	1.9	59.70	0.68	820
199	3	16	1	KAREE	10.0	94	82.60	21.70	75.49	2.1	58.10	1.40	845
200	3	16	26	K29-4	13.4	90	80.30	20.96	74.99	1.8	62.60	1.31	900
201	3	17	56	K37-5	11.9	93	80.90	21.75	75.91	2.1	60.60	0.58	930
202	3	17	38	K34-6	11.9	94	81.80	24.32	77.39	1.7	60.50	0.62	920
203	3	17	67	KRE1	9.2	94	83.10	23.09	76.56	2.5	57.10	1.26	790
204	3	17	68	KRE2	10.1	92	83.10	22.97	74.77	2.5	58.20	1.43	770

APPENDIX D

Data of the yield components								
PLOT	Rep	Block	Entry	NAME	TKW (g)	Yield (t/ha)	HSM	KPH
1	1	1	5	P29-3	33.99	4.02	372	35.60
2	1	1	53	K37-2	33.29	3.04	498	54.07
3	1	1	45	K35-4	32.43	3.30	470	58.47
4	1	1	11	P29-9	35.12	3.16	406	55.47
5	1	2	65	TC35	25.25	1.74	608	35.47
6	1	2	39	K34-7	24.27	3.11	472	51.13
7	1	2	46	K35-5	34.82	3.70	462	44.13
8	1	2	41	K34-9	33.25	2.84	398	49.27
9	1	3	15	P34-3	43.59	2.61	254	57.60
10	1	3	52	K37-1	33.29	3.10	400	56.13
11	1	3	48	K35-7	32.07	3.10	442	47.13
12	1	3	59	K37-8	34.97	3.36	480	47.00
13	1	4	21	P34-9	35.23	3.21	246	67.93
14	1	4	31	K29-9	34.41	3.63	414	47.20
15	1	4	38	K34-6	32.94	2.46	402	57.00
16	1	4	8	P29-6	36.73	2.76	294	49.60
17	1	5	66	TC37	30.13	2.62	366	39.07
18	1	5	62	THATCHER	34.49	2.53	482	41.20
19	1	5	26	K29-4	35.63	3.51	414	47.00
20	1	5	56	K37-5	34.73	3.92	420	51.07
21	1	6	19	P34-7	40.27	4.04	270	60.80
22	1	6	49	K35-8	34.75	3.83	426	49.80
23	1	6	55	K37-4	33.79	3.11	414	50.73
24	1	6	32	K29-10	36.12	4.04	480	50.33
25	1	7	12	P29-10	45.71	3.23	264	42.20
26	1	7	6	P29-4	35.85	3.21	348	53.67
27	1	7	44	K35-3	35.62	4.69	436	52.33
28	1	7	3	P29-1	41.85	4.19	288	51.20
29	1	8	16	P34-4	37.49	3.30	310	50.47
30	1	8	20	P34-8	41.81	3.31	202	61.00
31	1	8	64	TC34	26.87	2.74	404	39.67
32	1	8	27	K29-5	34.89	3.69	362	44.47
33	1	9	43	K35-2	36.97	4.67	426	48.80
34	1	9	50	K35-9	35.23	3.47	328	40.20
35	1	9	33	K34-1	34.95	3.47	422	51.07
36	1	9	1	KAREE	37.57	3.06	396	45.07
37	1	10	9	P29-7	45.99	3.17	326	48.07
38	1	10	17	P34-5	40.34	3.86	252	64.67
39	1	10	30	K29-8	36.51	3.49	388	48.27
40	1	10	25	K29-3	36.01	3.96	424	46.73
41	1	11	37	K34-5	37.25	3.43	378	57.27
42	1	11	60	K37-9	35.39	3.61	314	48.07

Data of the yield components								
PLOT	Rep	Block	Entry	NAME	TKW (g)	Yield (t/ha)	HSM	KPH
43	1	11	63	TC29	26.81	2.17	314	39.80
44	1	11	14	P34-2	40.97	3.03	264	53.40
45	1	12	22	P34-10	36.45	3.95	238	68.33
46	1	12	42	K34-10	46.22	4.09	298	48.67
47	1	12	23	K29-1	37.19	3.36	568	41.53
48	1	12	40	K34-8	36.95	3.90	560	50.80
49	1	13	28	K29-6	36.57	4.33	428	45.87
50	1	13	18	P34-6	44.59	3.76	294	63.80
51	1	13	35	K34-3	36.55	3.61	386	54.13
52	1	13	51	K35-10	36.13	4.89	390	49.87
53	1	14	13	P34-1	41.04	3.12	260	58.93
54	1	14	47	K35-6	37.15	3.99	458	41.07
55	1	14	4	P29-2	34.79	4.17	232	57.33
56	1	14	61	K37-10	36.57	5.04	450	47.47
57	1	15	29	K29-7	36.97	4.04	420	43.40
58	1	15	54	K37-3	35.02	3.68	364	43.47
59	1	15	10	P29-8	45.85	3.30	316	44.53
60	1	15	7	P29-5	33.84	2.95	318	53.33
61	1	16	36	K34-4	44.92	3.16	424	50.40
62	1	16	57	K37-6	36.57	4.34	426	44.20
63	1	16	34	K34-2	37.87	3.95	364	55.27
64	1	16	2	PALMIET	46.97	4.15	318	61.47
65	1	17	24	K29-2	35.70	3.74	352	34.73
66	1	17	58	K37-7	37.70	3.48	370	48.73
67	1	17	67	PLMT	42.42	3.82	350	56.33
68	1	17	68	PLMT	45.99	3.67	346	54.00
69	2	1	26	K29-4	36.45	2.87	304	41.33
70	2	1	11	P29-9	35.14	3.60	310	46.53
71	2	1	42	K34-10	44.24	3.32	276	48.40
72	2	1	3	P29-1	45.64	3.69	234	55.33
73	2	2	64	TC34	25.59	1.93	334	43.80
74	2	2	61	K37-10	36.09	3.81	422	46.33
75	2	2	15	P34-3	40.44	2.57	218	59.53
76	2	2	58	K37-7	36.95	3.60	456	43.80
77	2	3	4	P29-2	36.43	4.20	272	68.40
78	2	3	31	K29-9	37.12	3.22	380	44.60
79	2	3	17	P34-5	35.45	3.34	260	59.93
80	2	3	39	K34-7	37.89	2.20	322	48.67
81	2	4	10	P29-8	36.99	3.19	334	42.80
82	2	4	54	K37-3	36.39	4.12	454	52.13
83	2	4	63	TC29	26.27	2.21	460	40.80
84	2	4	29	K29-7	34.05	3.43	376	44.00

Data of the yield components								
PLOT	Rep	Block	Entry	NAME	TKW (g)	Yield (t/ha)	HSM	KPH
85	2	5	34	K34-2	35.95	5.12	354	59.13
86	2	5	65	TC35	26.83	0.93	436	41.27
87	2	5	18	P34-6	45.47	3.78	264	66.47
88	2	5	12	P29-10	44.49	3.64	228	50.40
89	2	6	62	THATCHER	35.61	3.47	382	39.27
90	2	6	52	K37-1	36.73	3.58	360	46.07
91	2	6	13	P34-1	40.23	3.29	186	67.47
92	2	6	48	K35-7	36.43	4.77	394	45.20
93	2	7	45	K35-4	35.73	4.93	470	45.53
94	2	7	8	P29-6	35.83	2.38	238	47.47
95	2	7	53	K37-2	37.43	3.30	430	50.13
96	2	7	22	P34-10	36.94	2.45	176	71.47
97	2	8	9	P29-7	42.93	2.78	290	44.80
98	2	8	30	K29-8	35.09	3.79	352	48.67
99	2	8	59	K37-8	37.15	2.76	358	51.67
100	2	8	1	KAREE	35.27	4.36	300	54.53
101	2	9	49	K35-8	35.45	4.20	388	45.47
102	2	9	36	K34-4	35.41	2.39	268	52.27
103	2	9	33	K34-1	33.49	3.01	370	51.93
104	2	9	28	K29-6	33.85	3.06	340	46.27
105	2	10	23	K29-1	34.45	2.84	418	39.07
106	2	10	60	K37-9	35.69	4.52	428	49.80
107	2	10	21	P34-9	36.15	2.37	236	58.93
108	2	10	47	K35-6	36.13	4.06	400	43.27
109	2	11	14	P34-2	41.63	3.84	240	68.40
110	2	11	44	K35-3	33.54	4.31	388	53.27
111	2	11	38	K34-6	31.87	3.26	496	52.73
112	2	11	66	TC37	26.59	2.38	488	45.20
113	2	12	7	P29-5	25.67	3.47	360	56.07
114	2	12	37	K34-5	32.63	3.33	528	52.80
115	2	12	55	K37-4	35.62	4.16	440	50.80
116	2	12	2	PALMIET	42.79	4.94	232	67.33
117	2	13	50	K35-9	35.82	4.18	394	52.40
118	2	13	20	P34-8	37.59	3.39	200	75.27
119	2	13	6	P29-4	35.11	3.15	338	51.53
120	2	13	27	K29-5	33.52	2.33	370	46.87
121	2	14	40	K34-8	34.23	3.31	540	47.13
122	2	14	32	K29-10	35.54	3.59	386	50.40
123	2	14	41	K34-9	31.40	2.82	386	46.13
124	2	14	35	K34-3	32.27	4.21	412	47.13
125	2	15	51	K35-10	32.95	3.23	448	51.13
126	2	15	25	K29-3	34.01	2.85	340	35.60

Data of the yield components								
PLOT	Rep	Block	Entry	NAME	TKW (g)	Yield (t/ha)	HSM	KPH
127	2	15	16	P34-4	33.71	3.39	402	45.67
128	2	15	57	K37-6	34.05	3.76	402	53.93
129	2	16	43	K35-2	34.05	3.94	398	57.33
130	2	16	5	P29-3	35.57	4.34	286	67.33
131	2	16	19	P34-7	40.57	3.11	232	55.00
132	2	16	56	K37-5	35.23	3.87	244	54.80
133	2	17	46	K35-5	33.61	3.76	548	44.20
134	2	17	24	K29-2	30.79	2.48	442	32.73
135	2	17	67	KRE1	33.05	4.82	444	51.27
136	2	17	68	KRE2	35.05	4.56	436	48.87
137	3	1	9	P29-7	35.43	3.77	298	57.73
138	3	1	59	K37-8	36.15	3.80	374	55.60
139	3	1	14	P34-2	40.89	2.92	198	66.93
140	3	1	6	P29-4	34.84	3.15	448	51.67
141	3	2	65	TC35	27.29	1.99	384	35.07
142	3	2	11	P29-9	34.13	3.08	312	51.67
143	3	2	49	K35-8	33.09	3.68	448	44.60
144	3	2	36	K34-4	37.83	2.63	336	50.80
145	3	3	46	K35-5	33.74	3.64	454	44.67
146	3	3	54	K37-3	34.87	3.03	440	47.53
147	3	3	24	K29-2	31.89	3.07	408	37.93
148	3	3	58	K37-7	34.41	3.11	362	53.47
149	3	4	55	K37-4	33.94	2.71	328	51.93
150	3	4	45	K35-4	33.29	2.99	338	45.53
151	3	4	32	K29-10	34.79	3.16	288	44.27
152	3	4	17	P34-5	35.71	3.69	252	63.53
153	3	5	57	K37-6	34.29	3.90	456	47.33
154	3	5	52	K37-1	34.69	3.47	408	55.93
155	3	5	18	P34-6	41.39	2.70	194	67.67
156	3	5	42	K34-10	44.83	3.79	354	52.53
157	3	6	16	P34-4	37.94	2.61	334	44.13
158	3	6	60	K37-9	42.19	3.47	386	49.27
159	3	6	41	K34-9	33.07	3.02	380	50.20
160	3	6	30	K29-8	34.67	4.26	346	47.87
161	3	7	13	P34-1	42.05	3.09	236	65.73
162	3	7	8	P29-6	40.65	3.15	282	68.40
163	3	7	12	P29-10	42.49	2.47	260	63.33
164	3	7	47	K35-6	36.79	3.46	358	48.20
165	3	8	3	P29-1	40.82	2.12	190	61.87
166	3	8	64	TC34	27.82	2.30	362	40.07
167	3	8	33	K34-1	33.44	3.21	474	50.93
168	3	8	40	K34-8	33.89	3.38	356	49.40

Data of the yield components								
PLOT	Rep	Block	Entry	NAME	TKW (g)	Yield (t/ha)	HSM	KPH
169	3	9	37	K34-5	33.94	3.14	440	57.13
170	3	9	27	K29-5	35.49	3.08	280	44.00
171	3	9	61	K37-10	35.71	2.84	272	42.47
172	3	9	48	K35-7	36.01	3.42	268	47.20
173	3	10	66	TC37	25.14	2.29	382	38.53
174	3	10	63	TC29	26.00	1.98	322	38.27
175	3	10	43	K35-2	34.63	4.39	364	49.47
176	3	10	20	P34-8	35.19	2.67	204	68.93
177	3	11	29	K29-7	35.19	3.93	442	47.00
178	3	11	23	K29-1	35.19	3.28	388	36.33
179	3	11	34	K34-2	36.67	3.74	288	52.73
180	3	11	2	PALMIET	42.69	3.36	188	65.93
181	3	12	10	P29-8	41.29	2.49	218	42.73
182	3	12	53	K37-2	35.89	3.49	352	50.73
183	3	12	31	K29-9	36.99	3.41	454	42.80
184	3	12	19	P34-7	42.99	4.50	220	61.00
185	3	13	50	K35-9	36.61	4.34	340	49.73
186	3	13	62	THATCHER	35.39	2.89	246	43.60
187	3	13	5	P29-3	36.37	3.33	254	65.93
188	3	13	22	P34-10	36.29	2.52	134	76.27
189	3	14	4	P29-2	37.23	3.17	186	43.13
190	3	14	7	P29-5	32.43	1.99	290	55.07
191	3	14	51	K35-10	34.77	3.83	408	47.87
192	3	14	25	K29-3	35.12	3.53	418	46.80
193	3	15	15	P34-3	42.09	2.75	218	67.53
194	3	15	39	K34-7	37.55	2.09	252	51.73
195	3	15	44	K35-3	32.99	3.04	318	43.73
196	3	15	35	K34-3	37.65	2.51	338	52.60
197	3	16	21	P34-9	37.19	2.07	178	70.87
198	3	16	28	K29-6	35.22	1.94	268	41.87
199	3	16	1	KAREE	36.79	4.80	430	49.73
200	3	16	26	K29-4	35.70	2.77	342	44.13
201	3	17	56	K37-5	36.35	3.62	450	46.40
202	3	17	38	K34-6	34.25	1.33	414	43.53
203	3	17	67	KRE1	35.21	3.91	320	35.40
204	3	17	68	KRE2	35.80	3.02	308	39.07