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**Genetics of resistance to *Stenocarpella maydis*  
ear rot of maize**

**By**

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## ABSTRACT

The objective of this study was to determine if germplasm available in South Africa and elsewhere, have sufficient variation in resistance to be used for the improvement of resistance to *Stenocarpella maydis*, and to assess the viability of using recurrent selection as a breeding method under conditions of artificial infection with the pathogen. The study attempted to provide a better understanding of effective methods to screen for resistance without sacrificing other favorable agronomic traits. The inheritance and combining ability of resistance, as well as genetic and phenotypic correlation of resistance parameters with other characteristics, were investigated.

The study comprised of three experiments. The first experiment was a complete diallel cross containing 10 commercial and experimental inbred lines, ranging from resistant to susceptible. Five South African developed inbreds, four USA developed and one Brazilian inbred were used. The diallel was evaluated during the 1999/2000 season at three environments across the South African maize growing area. Plants were artificially inoculated twice, two weeks prior to anthesis. Different *S. maydis* related and agronomic characteristics were measured. The second experiment was a trial containing both South African developed hybrids and hybrids derived from crosses between South African developed germplasm and those of exotic and temperate origin. The trial was evaluated at one environment in the South African maize growing area. Again, plants were artificially inoculated twice, two weeks prior to anthesis. Flowering data were taken along with *S. maydis* incidence and grain moisture at harvest. The third experiment involved the evaluation of a recurrent selection program, using three previously identified resistant inbreds as donor parents for the development of new genotypes with superior resistance to *S. maydis*. Selection was done on an ear-to-row basis over three years, using the segregating progenies derived from crosses between the three inbreds.

Highly significant differences were obtained between genotypes for all characteristics measured, indicating variation for resistance in germplasm used in local breeding programs. Across all three environments, the general combining ability (GCA) and specific combining ability (SCA) effects were significant. Inbreds DO620Y, MON1

and F2834T had the greatest negative GCA effects for *S. maydis* related characteristics that contributed towards resistance, with MON1 being heterotically unique, combining to all the other inbreds. F1 combinations with inbred B37 had the greatest negative SCA effects of all genotype combinations evaluated. GCA:SCA ratio's indicated that resistance is controlled by additive gene effects, with low dominance and interaction effects. Genetic correlations existed between the *S. maydis* related characteristics, with very high heritability and high correlated response between them. Due to it's simplicity, percentage rotted ears was the best method to measure resistance. Upright ears were found to result from *S. maydis* infection, rather than to predispose ears to the disease.

Significant differences were found between maturity classification and *S. maydis* incidence for South African developed germplasm crossed to temperate and tropical germplasm. Later flowering hybrids showed less *S. maydis* infection compared to earlier hybrids. Using resistant parents in breeding populations, superior genotypes could be selected by applying artificial inoculation and recurrent selection on an ear-to-row basis.

**Keywords:** Disease measurement, ear rot, inheritance, maturity, *Stenocarpella maydis*, *Zea mays*

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## CHAPTER I

### INTRODUCTION

Maize (*Zea mays* L.) breeding has been effective in developing improved varieties and hybrids over the past 100 years to meet the rapidly changing cultural conditions and the demand of an increasing world population. Maize is an important crop in the world economy and an ingredient in manufactured items that affects a large proportion of the world's population, especially in third world countries, where it serves as staple food for millions of people. For breeders to meet the ever increasing need and divergent use of maize, breeding methods must be modified and information obtained to increase the effectiveness and efficiency of selection for many traits.

Maize is the most important crop in the United States and second most important in Brazil and Argentina. In South Africa, it is the most prominent crop, used mainly for human consumption and animal feed. In Asia, the area planted to maize is increasing, and is expected to become one of the most important maize producing countries in the near future.

*Stenocarpella maydis* (Berk.) Sutton, is an important ear rot pathogen of maize in South Africa. *S. maydis* caused an annual loss of R400 million to the Maize Board during the epidemic seasons of 1985/86 and 1986/87. These losses were due to loss in yield and downgrading of grain. If the same epidemic should occur, losses would at present amount to approximately R1 400 million (B.C. Flett, ARC - Grain Crops Institute, personal communication).

*S. maydis* epidemics, recorded during the 1997/98 season, were limited to the northern Free State, northern Northwest Province, isolated areas in KwaZulu-Natal and Mpumalanga regions of South Africa. During the last five seasons, losses varied from R1,5 million to R40 million per annum (B.C. Flett, ARC - Grain Crops Institute, personal communication). There was a close climatic resemblance between the 1985/1986 and 1999/2000 seasons for *S. maydis* incidence and intensity, and similar

infestation levels were to be expected. The prediction was that fifty percent of the maize produced in 1999/2000 would be downgraded, which eventually proved to be true.

In the past, resistance to tassel smut and northern maize leaf blight were bred into commercial maize hybrids whereas, the other diseases were ignored. A phenotypically balanced hybrid with a high grain yield potential and grain yield stability became the primary objective of breeders (Gevers, 1989). Maize ear rot, subsequently, became problematic as a result of *S. maydis* inoculum build-up and climatic conditions favorable to disease development. Other factors that also contributed to the ear rot epidemic was the planting of highly susceptible maize hybrids on a large scale, the increased use of reduced tillage and a change in virulence or aggressiveness of the fungus.

The ear rot epidemic of the 1980's exposed the genetic vulnerability of the breeding material used in South African maize hybrids of that time and resulted in considerable research in the field of phytopathology. Research is still needed on the genetics of plant resistance, sources of which were found in studies during the early 1990's (Van Rensburg & Ferreira, 1997). Maize breeders have experienced difficulties in improving resistance to *S. maydis* without loss of yield and stability, and therefore did not incorporate resistance breeding successfully into commercial breeding programs. In South Africa *S. maydis* is problematic to commercial production because of the use of monoculture practices, reduced tillage practices and stressful environmental conditions. A complicating factor is the use of early maturing, temperate germplasm in breeding programs, which contributes to susceptibility.

Another country that also has a great problem with *S. maydis* is Brazil, where 90 % of the maize is produced under no-tillage practices, causing inoculum build-up in the soil. As a consequence, epidemic years resulted under environmental conditions favorable to disease development (F. Ide, Monsanto - Brazil, personal communication).

In the USA, ear rot caused by *S. maydis* is usually only experienced in a band across southern Ohio, Illinois, Indiana and Missouri. During the 1940's and 1950's ear rots

were a significant cause of yield loss and breeders started to select against the disease in order to increase levels of resistance. This resulted in germplasm with improved levels of resistance released during the 1960's and 1970's. A decline in occurrence of *S. maydis* was observed during this period (Hooker & White, 1976). Germplasm introduction from the USA to South Africa and Brazil in that period originated from late temperate or more tropical sources in the USA. These germplasm sources were not developed in the areas where *S. maydis* was problematic and therefore no selection was done to increase the levels of resistance to ear rot. Fall tillage with crop rotation was used in the USA until the mid-1980's and helped to reduce the pathogen. Since then conservation tillage with crop rotation was mostly used, causing an increase in the disease (Latterell & Rossi, 1983; J. Perkins, Monsanto - USA, personal communication).

The objective of this study was therefore to determine if germplasm available in South Africa and elsewhere have sufficient variation in resistance to be used for the improvement of levels of resistance to *S. maydis*, and to assess the viability of using recurrent selection as a breeding method under conditions of artificial infection with the pathogen. The study attempted to provide a better understanding of effective methods to screen for resistance without sacrificing other favorable agronomic traits. The inheritance and combining ability of resistance as well as genetic and phenotypic correlation of resistance parameters with other characteristics were investigated.

The study comprised of three experiments. The first was a ten parent complete diallel cross using Griffing's Method I, between five South African developed inbreds, four USA inbreds and one Brazilian inbred. F1's, reciprocals and parents were evaluated across three environments in South Africa, using artificial inoculation with the pathogen. The second experiment was an evaluation of the effects of maturity classification and genetic diversity of hybrids on *S. maydis* incidence. The trial was evaluated at one location and artificially inoculated with the pathogen. The third experiment involved the evaluation of a recurrent selection program, using three previously identified resistant inbreds as donor parents for the development of new genotypes with superior resistance to the disease. Selection was done on an ear-to-

row basis over three years, using the segregating progenies derived from crosses between the three inbreds.

## CHAPTER II

### REVIEW OF LITERATURE

#### 2.1 The pathogen

*Stenocarpella maydis* (Berk.) Sutton (syn. *Diplodia maydis* (Berk.) Sacc.) is the most prevalent ear rot pathogen of South African maize (*Zea mays* L.), causing reduction in yield, grain quality (De Wet, 1989; Rheeder, Marasas, Van Wyk, Du Toit, Pretorius & Van Schalkwyk, 1990) and diplodiosis in sheep and cattle (Marasas, 1977).

Diplodiosis is a well-known endemic neuromycotoxicosis of domestic ruminants grazing on maize stubble in winter and is caused by the ingestion of maize infected by the ear rot fungus. Diplodiosis is not only of historical interest, it is also one of the most common nervous disorders of livestock in Southern Africa. The disease is characterized by ataxia, paresis and paralysis. Although mortality may be high, the prognosis is good if stock is removed from the toxic land as soon as the first signs appear. Usually, recovery is complete, without significant long-term deleterious effects. However, one experiment showed that an animal became permanently paralyzed and another developed an irreversible change in gait after being dosed with cultures of the fungus (Kellerman, Rabie, Van der Westhuizen, Kriek & Prozesky, 1985).

##### 2.1.1 Taxonomy

The *Stenocarpella* (*Diplodia*) diseases of maize are widespread throughout the world. The principle pathogens involved are *S. maydis* (Berk.) Sutton, which was described by Berkeley as *Spaeria maydis* from an Ohio specimen in 1847, and as *S. macrospora* (Earle) Sutton, described 50 years later in Alabama by Earle (Latterell & Rossi, 1983).

### 2.1.2 *Symptoms*

Symptoms of *S. maydis* are expressed in different ways. Initially symptoms are yellowing and drying of infected leaves on the green maize plant. A white fungal mycelium starts at the base of the ear and may cover the entire ear with pycnidia at the kernel base. Another symptom is discolored kernel embryos that can only be seen if the ear is broken, termed "hidden Diplodia" in South Africa (Flett, 1999). This symptom expression makes it difficult to determine the real state of Diplodia infection without opening the ear. Farmers only see the effect of Diplodia at harvest when the prominent symptom is discolored kernel embryos. When harvesting with a combine harvester the kernels are usually removed by the blower, resulting in yield loss. For hybrids of which the initial infection occurred relatively late and the rate of mycelium ramification was less due to limitation in kernel moisture, kernels may be retained during harvesting, to be observed in the harvested sample, with a consequent downgrading of the crop delivered to the silo. "Hidden Diplodia" is sometimes ignored by breeders during screening of breeding material for levels of resistance. An ear with "hidden Diplodia" may look healthy on the outside but when broken the discolored kernel embryos can be seen.

### 2.1.3 *Isolate differences*

Several reports of variability in *S. maydis* were published in recent years. Differences were found in pathogenicity of *S. maydis* stalk rot and mycelial growth temperature requirements. Isolates are more virulent at the locality of origin (Young, Wilcoxson, Whitehead, Devay, Grogan & Zuber, 1959). Aversions, inhibition of growth at the edge of different cultures, was discovered among *S. maydis* isolates on culture media (Hoppe, 1936). Variation was also observed in aggressiveness between isolates, colour phenotype and pycnidiospore production of the fungus. Pycnidiospore production is, however, not a stable phenotype to base genetic studies on, due to the influence of environment (Kappelman, Thompson & Nelson, 1965; Maxwell & Thompson, 1974; Dorrance, Miller & Warren, 1999). Significant differences occurred for stalk rot severity between combinations of maize inbreds and testers inoculated

with high or weak virulent isolates (Maxwell & Thompson, 1974). A collection of *S. maydis* isolates from the USA and South Africa were assayed for isozyme polymorphisms variability using ten enzymes that resulted in no significant isozyme polymorphisms (Dorrance *et al.*, 1999). Rating of genotype resistance levels is highly dependent on environmental conditions favorable to a particular isolate, and isolate differences in aggressiveness may result in differences in efficacy of infection (Van Rensburg & Ferreira, 1997).

In contrast with this, no differences were found in the incidence of ear rot caused by five isolates collected from various maize production areas in the United States (Ullstrup, 1949).

Pathologists and breeders should keep isolate differences in mind when using artificial inoculation in screening for resistance. For proper discrimination between genotypes for resistance to benefit a breeding program, one must keep the importance of a balance between genotype resistance and isolate aggressiveness in mind (Maxwell & Thompson, 1974).

#### 2.1.4 *Environmental effects*

Resistant reactions of hybrids over locations and seasons vary due to the overshadowing effect of environment over genetic effects, which include climatic conditions and inoculum potential (Flett & McLaren, 1994). A complex relationship also exists in which the crop phenotype and the pathogen are independently and differentially affected by environmental conditions favorable to a particular isolate of the pathogen. The most consistent infection levels were recorded in seasons with extreme droughts and high summer temperatures, whereas the lowest average infection rates occurred in years with cool and humid conditions (Van Rensburg & Ferreira, 1997).

Breeders should consider screening for the pathogen in the natural environment of the disease to ensure that the genotype x environmental interaction is expressed correctly.

### 2.1.5 Control

#### Crop rotation

Crop rotation has been used to control plant diseases effectively, primarily by reducing the amount of pathogen inoculum. The success of crop rotation depends on the ability of the pathogen to infect an alternative host, or the time needed for inoculum reduction, which in turn is related to reduced survival of the pathogen in the field (Curl, 1963). *S. maydis* inoculum builds up and over-winters on maize stalk stubble retained on the soil surface (Flett, 1991). Maize is the only crop host for the fungus and therefore any other crop can be used in rotation with maize to reduce inoculum build-up in the soil. The only other host reported for *S. maydis* is an *Arundinaria* sp. (Sutton & Waterston, 1966 ; Sutton, 1980).

#### Tillage practices

The utilization of cultural practices such as no-till will result in an increase in inoculum (Latterell & Rossi, 1983) due to more stubble being left on the soil surface for the pathogen to over-winter. Changes to minimum or no-till practices should go along with increased host resistance towards *S. maydis*.

Significantly less *S. maydis* ear rot was observed in fields where the infected stubble was ploughed under, in comparison with minimum and no-tillage practices. A linear relationship was also found between severity of *S. maydis* ear rot and surface stubble mass (Flett & Wehner, 1991). For long term cultural control of *S. maydis*, mouldboard ploughing was recommended (Flett, 1999).

#### Fungicides

*S. maydis* can be successfully controlled with applications of benomyl, mancozeb or a mixture of benomyl and carbendazim fungicides (Warren & Von Qualen, 1984; Beukes

& Flett, 1992). However, chemical control is often not economically justified under South African conditions, due to low yields per hectare in most areas and the relatively low producer prices of maize. Chemical control is therefore regarded as the last option.

### Resistant hybrids

*S. maydis* can be managed effectively through the use of resistant hybrids (Hooker & White, 1976). Resistant hybrids in combination with sanitation practices can play a pronounced role in controlling *S. maydis* (Flett, 1999). Hybrid resistance is the only long term solution to manage the incidence of *S. maydis* with the most cost effective outcome. Variation in resistance in commercial hybrids was observed, but not even the hybrids that are considered resistant can prevent losses due to *S. maydis* under conditions of severe infection. Although some hybrids are considered to be more resistant than others, the development of total horizontal resistance to *S. maydis* remains the main focus in breeding programs.

## **2.2 Artificial inoculation with the pathogen**

Time of artificial inoculation, aggressiveness of the isolate and environmental conditions are the most important factors that breeders should keep in mind when screening breeding material for levels of resistance to *S. maydis*. Breeders should also keep the growing season requirements of genotypes in mind when inoculating material of different maturity and should attempt to inoculate all entries at the same growth stage.

### **2.2.1 Methods of artificial inoculation**

The success and usefulness of a method for inoculating maize ears with *S. maydis* depend on several criteria. Clear differentiation must be obtained between resistant and susceptible host material with the selected screening method. Results must be

reproducible from year to year. Environmental effects on the relative disease reaction of the host plant should also be minimal. Inoculation techniques must be simple and free from complicated and laborious procedures. The method must simulate the phenomena attending the natural mode of infection by the parasite (Ullstrup, 1949).

Screening for resistant lines requires a reliable method of inoculation that will distinguish between resistant and susceptible genotypes, provide consistent results between years and within lines, and simulate the natural mode of infection as much as possible. This method must also have practical application in a breeding program such as allowing large numbers of plants to be screened in a limited period of time (Klapproth and Hawk, 1991). Progress is made by using artificial inoculation in breeding for resistance to ear rot. Various ways of artificial inoculation with *S. maydis* have been developed until now and all of these methods have been used to select for resistance to ear rot. These methods differ in their effectiveness in creating high disease incidence and severity, and until now researchers tried to improve the inoculation methods to show greater differences in resistance levels in breeding material.

The first report of *S. maydis* as a parasite of maize as well as the first inoculation with the pathogen, was done in 1909. Dry ear rot developed after inoculation was done by puncturing the husk at pollination, and pycnidia matured two to three weeks after infection (Heald, Wilcox & Pool, 1909). Different inoculation techniques were experimented with, such as inserting spores under the outer husk at the base of the ear, spraying of a spore suspension on to the ear, inserting spores into the shank and placing spores into the silk channel. The most successful methods were placing spores in the silk and under the outer husk at the base of the ear (Burril & Barret, 1909).

It was earlier believed that *S. maydis* entered the ear through the silk and that moisture was the most important factor determining the degree of reaction of the fungus. Rain occurring during the pollination period increased the disease severity (Durrel, 1923). Inoculation ten days after silking caused increased infection (Koehler, 1930). Ears sprayed with a conidial and mycelial fragment suspension had to be covered to prevent

rapid desiccation of the suspension. This technique resulted in the successful differentiation of ear rot resistance between genotypes (Ullstrup, 1949).

Several methods of direct introduction of *S. maydis* into the ear have been successful in causing infection. These included inserting infected toothpicks into the middle of the ear (Villena, 1969; Chambers, 1988; Drepper & Renfro, 1990), inserted into the butt of the ear (Villena, 1969), drilling holes in the ear followed by insertion of infected grain or spores (Kang, Pappelis, Mumford, Murphy & Bemiller, 1974) and injecting a conidial suspension with a hypodermic syringe into the middle, tip, or butt, or both the tip and butt of the ear (Laterall & Rossi, 1983; Villena, 1969). Other techniques used in the past include brushing the ear or silk with an agar-spore slurry and dropping a spore suspension among the silks with a medicine dropper (Villena, 1969).

The most commonly used method of artificial inoculation is the placement of conidial suspension in the whorl of the plant approximately ten days before tasseling. The whorl method has the advantage that the inoculum is easy to apply and does not injure the plant (Klapproth & Hawk, 1991). This method was modified over the past few years to improve its efficiency (Bensch, 1995). Successful whorl inoculations are dependent on adequate inoculum pressure and overhead irrigation or sufficient rainfall following inoculation to promote disease development (Klapproth & Hawk, 1991).

Performance of inbred lines were related to the method by which the plants were inoculated. This interaction of genotype and inoculation methods should be considered when choosing an inoculation method and when comparing results from different studies (Klapproth & Hawk, 1991).

In South Africa different methods of ear rot inoculation were developed in recent years, such as the toothpick method, spraying the ears with a conidial suspension, application of conidial suspension either in the leaf whorl or behind the ear, and the placement of ground-infected kernels in the leaf whorl. These techniques have been tested under local conditions in South Africa and it appeared that the techniques in which conidial suspension were placed behind the ear and where ground-infected kernels were applied in the leaf whorl at the three leaf stage were the most consistent

in inducing ear rot. The toothpick method was also dispensed with because it overcame the mechanism of resistance by injuring the plant and creating an infection position (Bensch, 1995).

The whorl inoculation technique was more refined by using inoculum of milled *S. maydis* rotted ears in the whorl of the plant under South African conditions (Nowell, 1992).

A revised technique was later used where ground infected kernels were placed in the whorl of each plant two weeks prior to tasseling (Flett & McLaren, 1994). Different techniques were also compared, but infected ground kernels in the whorl of the plant was found to be the most successful (Bensch, 1995).

Acceptable disease potentials can vary from  $\pm 0.6\%$  to  $\pm 50.6\%$  to determine differences between resistant and susceptible genotypes, with differentiation optimum between 17 and 20%. This can be achieved with artificial inoculation on a wide range of experimental sites (Flett, 1999).

### **2.2.2 Time of artificial inoculation**

Time of inoculation is an important factor for efficient disease development (Ullstrup, 1949; Kerr, 1965; Fajemisin, Durojaiy, Efron & Kim, 1987). *S. maydis* grows well on maize ears above 21.5% grain moisture, indicating that the time of artificial inoculation is important for successful differentiation between genotypes (Koehler, 1938). Maize ears were most susceptible 10 to 20 days after mid-silk but resistant when kernel moisture dropped below 22% (Koehler, 1959). In another report ears were most susceptible for infection 21 to 28 days after silking (Smith & White, 1988).

Ear rot decreases sharply with later inoculation date after mid-silk. Percentage ear rot decreased non-linearly with increase in time of inoculation and correlated significantly with grain mass per plant (Chambers, 1988).

Time of inoculation is most critical in a breeding program for screening of germplasm and it was suggested that inoculations should be done before 20 days after mid-silk, before the kernel moisture decreases too much (Chambers, 1988). Inoculations done at silking resulted in the highest disease incidence (Latterell & Rossi, 1983; Bensch, Van Staden & Rijkenberg, 1992). Inoculations up to 15 days after silking provided less disease incidence. This shows that the pathogen has a critical period for colonization and symptom development before the plant reaches physiological maturity ( $\pm$  50 days after silking) (Bensch *et al.*, 1992).

### 2.2.3 Disease measurement

Breeders should consider the most accurate, practical and efficient method of ear rot assessment for maximum gain in *S. maydis* resistance.

Percentage rotted ears and percentage rotted kernels in a representative 200 to 300 g sample of shelled maize are two methods previously used in a study to determine the amount of ear rot in strains of maize. The ear separation method gave inaccurate results (Hoppe & Holbert, 1936).

Three different methods to determine the incidence of rotted ears were compared, viz. percentage rotted ears, percentage rotted kernels (by mass) in a representative 250 g sample of shelled maize and the use of a disease index. These three methods provided results which were closely correlated and percentage rotted ears was considered the simplest method (Ullstrup, 1949).

Four methods were evaluated for ear rot assessment, viz. a non-linear scale method, percentage rotted ears, percentage rotted kernels in a representative sample and a separate fungi method in which infected ears were categorized according to their casual organism (*Stenocarpella*, *Fusarium*, *Gibberella*, Stalkborer and other). The percentage rotted ears method was the most practical, yet still accurate, method for ear

rot assessment. For “hidden Diplodia” ear rot assessment, the grain should be removed from the base and tip of the ear to observe the symptoms (Nowell, 1997).

Both percentage rotted ears and disease severity were assessed in a diallel analyses. Only percentage rotted ears was used for data analysis because disease severity parameters which indicated the colonization of the ears by *S. maydis* were limited by grain moisture and not by host resistance (Dorrance, Hinkelmann & Warren, 1998).

### 2.3 Diallel analysis

More than 140 years ago Lious de Vilmorin found that the only way to know the value of an individual plant is to study its progeny. This came to be known as Vilmorin’s isolation principle or progeny test. Today the diallel cross is a sophisticated application of this principle (Christie & Shattuck, 1992).

The first written report of diallel crossing in plant breeding is that of Jinks and Hayman (1953), in which all possible crosses among a group of parents, including the parents themselves were used. With  $n$  parents there will be  $n^2$  families, also known as a complete diallel cross (Jinks & Hayman, 1953, Crumpacker & Allard, 1962). Morley-Jones (1965) defined a diallel cross where the F1 and reciprocal crosses are combined, as a half diallel. A modified diallel is one in which the parents are not included, as proposed by Griffing (1956a). A partial diallel includes less than  $[n(n-1)/2]$  crosses, which still can be used to generate valid statistical analysis and interpretation (Kempthorne & Curnow, 1961).

Diallel analysis can be grouped into four basic methods (Christie & Shattuck, 1992):

- 1) Griffing’s analysis of general combining ability (GCA) and specific combining ability (SCA) (Griffing, 1956b).
- 2) Jinks and Hayman analysis of array variance and covariance (Jinks & Hayman, 1953).

- 3) Gardner and Eberhart's analysis of additive and dominance effects (Gardner & Eberhart, 1966; Eberhart & Gardner, 1966).
- 4) Partial diallels (Kempthorne & Curnow, 1961).

For the purpose of this study Griffing's analysis was used.

### 2.3.1 *Griffing's analysis*

Griffing (1956b) proposed a diallel technique for determining the combining ability of lines and the nature and extent of gene actions. The method is widely used by plant breeders. Fixed (Model 1) and random (Model 2) effects can be tested for, using Griffing's analysis.

Griffing (1956b) proposed four methods of diallel crossings:

- 1) Method 1 (complete diallel): This includes parents, F1's and reciprocal F1's ( $n^2 =$  total number of entries, where  $n =$  number of parents).
- 2) Method 2 (half diallel): This includes parents and F1's without reciprocals ( $n(n+1)/2 =$  total number of entries, where  $n =$  number of parents).
- 3) Method 3: This includes F1's and reciprocal F1's without parents ( $n^2-p =$  total number of entries, where  $p =$  number of parents).
- 4) Method 4: This only include F1's without parents and reciprocals ( $n(n-1)/2 =$  total number of entries). This method allows the option to test for fixed (Model 1) or random (Model 2) effects.

Combining ability of inbreds is the most important factor that determines the use of an inbred in hybrid combination with another. The general concept of combining ability is to classify an inbred in hybrid cross performance (Hallauer & Miranda, 1988). As soon as the combining ability of the parental lines is identified, the best lines can be crossed in hybrid combination to obtain optimal combinations, or hybridized to select promising genotypes within the segregating generation. Inbred parents with high

combining ability can be crossed with one another in a recurrent selection program to accumulate desirable alleles in the base population (Christie & Shattuck, 1992).

Two new concepts were introduced by Sprague and Tatum (1942) which had an impact on inbred evaluation and population improvement. These were general combining ability (GCA) and specific combining ability (SCA). GCA is the average performance of an inbred in hybrid combination and SCA helps to determine the specific hybrid combinations where the combination can be better or poorer than would be expected on the average performance of the parent, inbreds included. It should be kept in mind that the estimates of GCA and SCA are related to, and depend on, the set of inbreds used for the hybrids in evaluation. GCA was important for unselected inbreds and SCA for previously selected inbreds for influencing yield and stalk lodging. It was also interpreted that GCA is an indication of genes having additive effects and SCA an indication of genes having dominance and epistatic effects.

For the purpose of this study Method 1 (complete diallel) was used.

### **2.3.2 *General combining ability***

General combining ability is defined as the average performance of a line in hybrid combination (Sprague & Tatum, 1942).

### **2.3.3 *Specific combining ability***

Specific combining ability is defined as those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved (Sprague & Tatum, 1942).

#### 2.3.4 *Reciprocal effects*

When the trait measured is influenced by maternal effects or cytoplasmic inheritance, Method 1 or Method 3 with modification can be used, but when reciprocal effects are absent the F1's and reciprocal crosses can be combined for analysis (Borges, 1987).

#### 2.3.5 *GCA:SCA ratio*

If the GCA:SCA ratio is relatively high, the additive gene effects are important, whereas a low ratio suggests the presence of dominance and/or epistatic effects (Griffing, 1956a; Bhullar, Gill & Khehra, 1979). If the SCA effect is small relative to the GCA effect, the performance of the single cross progeny can be predicted on the basis of the GCA of the parents. If inbred parents are used in a diallel study; the closer the following equations are to unity, the greater the predictability will be based on GCA (Baker, 1978).

$$\text{Model 1: } 2g_i^2/(2g_i^2+s_{ij}^2)$$

$$\text{Model 2: } 2\sigma_g^2/(2\sigma_g^2+\sigma_s^2)$$

where,

$g_i^2, \sigma_g^2$  = GCA mean square and variance, respectively;

$s_{ij}^2, \sigma_s^2$  = SCA mean square and variance, respectively.

#### 2.4 **Genetic correlation**

Genetic correlation can arise from pleiotropy, linkage or induction of genes involved into a population. In pleiotropy the same genes affect different traits in a complimentary way, whereas in epistasis different genes affect the same trait. If pleiotropy exists for quantitative traits, it can be possible to use a secondary trait for selection with a greater heritability than the primary trait. Linkage refers to genes which show a tendency to be transmitted together within a population. Genetic correlation is of interest to determine the degree of association between traits in order

to enhance selection. Genetic correlation is useful if indirect selection gives greater response when selecting a certain trait, than direct selection for the same trait (Hallauer & Miranda, 1988).

## **2.5 Inheritance**

Heritability in the broad sense is the ratio of total genetic variance to phenotypic variance and in the narrow sense the ratio of additive genetic variance to phenotypic variance. Phenotypic variance is the total variance among phenotypes when grown over a range of environments of interest to the breeder. Total genetic variance is the part of phenotypic variance which can be attributed to genetic differences among the phenotypes. The total genetic variance can also be divided into additive genetic variance, dominance genetic variance and epistatic genetic variance (Dudley & Moll, 1969).

## **2.6 Correlated response**

Correlated response is the correlation, measured by a correlation coefficient, which indicates the degree of association, genetic and non-genetic, between two or more characters. If genetic association exists, selection for one trait will cause changes in other traits (Hallauer & Miranda, 1988).

## **2.7 Resistance to the pathogen**

### ***2.7.1 Variation for resistance***

Maximizing the use of USA germplasm in South African breeding efforts can only be successful if disease susceptibility to the most important diseases in South Africa like *S. maydis*, are kept in mind and genetic material are used according to what is known about them (Coetzee, 2000). It is important that breeders continue looking for new

sources of ear rot resistant germplasm (usually in tropical germplasm) that can be adapted for local conditions and/or incorporated into locally adapted germplasm (Van der Plank, 1984). Koehler (1959) identified superior germplasm with ear rot resistance but it did not have the required yield characteristics, nor did it display complete resistance to ear rot.

The rate of progress in developing resistance to the ear rot complex, and the heritability of the resistance, is influenced by the base level of resistance of the germplasm and the intensity of the selection pressure (both inoculum pressure and quantitative or qualitative selection). Once the level of resistance has reached the desired level, it is important that screening pressure is maintained, since quantitative resistance can easily be lost to stabilizing selection in the absence of ear rot selection pressure (Van der Plank, 1984).

Koehler (1953), working with yellow maize inbreds for ear rot resistance, found that ear rot development in maize fields depended on a number of factors such as physiological resistance to the host, husk protection, declination of the ears and environmental conditions appropriate for fungal development. It was indicated that under natural infection, disease development is governed by environmental conditions to which different hybrids may respond differently. Variation occurred for resistance to *S. maydis* and for resistance between years (Hooker, 1956; Thompson, Villena & Maxwell, 1971).

Maize inbred lines were evaluated for resistance to *S. maydis* ear rot by means of artificial inoculation. The inbreds varied widely in their levels of resistance and susceptibility to the pathogen (Wiser, Kramer & Ullstrup, 1960; Thompson *et al.*, 1971). Some inbreds transmitted a high degree of resistance to their progeny while others transmitted susceptibility. A study of six inbred lines, their possible F1 and F2 generations, and their respective back crosses, indicated that the distribution of the infections showed few ears in the intermediate infection classes. These results were interpreted as the ability of the resistant lines to resist initial infection rather than differences in the development of the fungus at a specific stage (Wiser *et al.*, 1960).

High lysine maize in the USA was shown to be particularly susceptible to *S. maydis*, expressed in both inbreds and hybrids. However, it depended on the background that the Opaque-2 gene was introduced into (Ullstrup, 1971). In contrast, high lysine maize inbreds and hybrids were developed in South Africa that have significant levels of resistance to *S. maydis* (Gevers, 1989).

Significant differences between the response of hybrids to *S. maydis* ear rot infection and development, has been demonstrated in South Africa. Most studies have shown that white-grained hybrids were more resistant to ear rot than yellow-grained hybrids (Rheeder, 1988; Gevers, 1989; Nowell, 1992; Ferreira, 1994; Flett & McLaren, 1994; McLaren & Flett, 1994). For yellow-grained inbreds the heterotic groups F (F2834T) and M (M37) produced significantly more resistant inbreds than the other groups, with the main resistance in the F group. Genotypes of Reid derivation and I137TN inbreds were responsible for the susceptibility in South African germplasm, along with the direct introduction of USA germplasm in hybrids that were not selected and screened for *S. maydis* resistance. Opaque-2 genotypes provided the most inbreds with resistance (Gevers, 1989; Gevers, Lake & McNab, 1992).

Selection for yield in the presence of disease (both northern leaf blight and *S. maydis* ear rot) will improve both grain yield and disease resistance simultaneously (Carson & Wicks, 1993).

Hybrids react non-linearly to different disease potentials and at a disease potential above 50.6 % *S. maydis* is not significantly controlled by resistance (Flett & McLaren, 1994). Inconsistent results were obtained in different localities and seasons with both natural and inoculated infections (B.C. Flett, ARC - Grain Crops Institute, personal communication). This variation has prevented reliable identification of resistance and susceptibility over a long period of time, and made it difficult to determine if severity of *S. maydis* ear rot is genetically controlled or, rather, the result of climatic conditions or inoculum potential at a specific time.

Genetic effects of the phenotype are overshadowed by environmental effects, including climatic conditions and inoculum potential (Flett & McLaren, 1994). Hybrid response to *S. maydis* was not consistent over locations and/or seasons, and resistant hybrids showed severe ear rot symptoms from time to time (Nowell, 1997; Van Rensburg & Ferreira, 1997).

### 2.7.2 *General combining ability*

For *S. maydis*, GCA effects were significant in a diallel study over two consecutive years of the F1's. Both the inbreds, B37 and H111, had negative GCA values for resistance, indicating lower infection of *S. maydis*, while B73 had a positive GCA value (Dorrance *et al.*, 1998).

In a recurrent selection breeding approach, parents with high GCA (in the case of disease parameters, high negative) can be crossed with one another in an attempt to accumulate desirable alleles within a base population (Christie & Shattuck, 1992).

### 2.7.3 *Specific combining ability*

With ear rot, SCA effects were only significantly different for one of two years in a diallel study of F1's. This indicated that susceptibility may be dominant over resistance (Dorrance *et al.*, 1998). SCA was more important than GCA when open pollinated maize varieties were studied in a diallel cross (Das, Chattopadhyay & Basak, 1984).

### 2.7.4 *Reciprocal effects*

No reciprocal differences were found by Dorrance *et al.* (1998), indicating that maternal effects were not important for resistance to *S. maydis*. Only in seed production areas, where *S. maydis* is a problem, should the resistant inbred parent be used as the female to reduce losses due to *S. maydis*.

### 2.7.5 *GCA:CSA ratio*

Ear rot resistance was found to be additively inherited (Koehler, 1953). Many types of inheritance mechanisms have been reported, which included additive resistance, dominance, modifier genes, epistasis and recessive resistance. The heritability of ear rot resistance seems to be complex (Hooker, 1956; Wiser *et al.*, 1960; Gevers *et al.*, 1992).

### 2.7.6 *Genetic and phenotypic correlation*

A correlation exists between early maturity and the amount of *S. maydis* infected ears in sweet corn (Smith & Trost, 1934). Material known to be more susceptible to ear rots in the field had a delayed and less effective closing of the *hilar orifice* after fertilisation of the kernel (Johann, 1935).

Tight husk cover is a factor for reduced susceptibility to *S. maydis* (Boewe, 1936). A relationship was found between ear declination and ear rot (Koehler, 1959). Hanging ears had less ear rot than those erect in relation to the plant stalk. Closely associated with the effect of ear declination on ear rot, was the protection of the ear by the husks. Ears with loose husks and/or those that were open at the tips had significantly more ear rot than the well covered ears, especially in association with the upright ears. Ears of which husks were opened by hand had more ear rot than the closed ones and even more if it were opened earlier. It was also found that ears of lodging plants that touched the ground had significantly more ear rot. Koehler (1959) concluded that not all hybrids respond as indicated above.

A relationship exists between pith parenchyma cell death and infection of maize ears by *S. maydis*. A hybrid with a slow death rate of the parenchyma cells will reduce the infection of *S. maydis* (Pappelis, Mayama, Mayama, BeMiller, Murphy, Mumford, Pappelis & Kang, 1973).

In South Africa, a recent study indicated that ear declination and prolificacy (number of ears per plant) were correlated to ear rot resistance under South African conditions. No correlation was found between shank length and *S. maydis* infection (Ferreira, 1994).

Sugar content increased with time of inoculation and was non-significantly correlated with ear rot. Starch accumulation was found to correlate significantly with percentage ear rot. Kernel moisture, like ear rot, decreased with time of inoculation and resulted in a significant correlation with percentage ear rot (Chambers, 1988).

Resistance to *S. maydis* was found to be inherited independently from resistance to other ear rot pathogens (Hooker, 1956). No correlation was found between inheritance of *S. maydis* ear rot and *S. maydis* stalk rot (Hooker, 1956; Thompson *et al.*, 1971).

### 2.7.7 *Inheritance*

Ear rot resistance is inherited quantitatively, but partial dominance plays a role (Wiser *et al.*, 1960).

Resistance was reported to be dominant from studies of crosses between resistant and susceptible parents under natural infection (Koehler & Holbert, 1930). Crosses with susceptible inbred parents usually contributed susceptibility to the F1, depending on the year evaluated. In contrast with this, in crosses with resistant inbred parents, F1's will be closer to the susceptible parents in one year and closer to the resistant parents in another (Ullstrup, 1949). Genes for resistance may be additive and GxE have a large influence on the expression of resistance (Koehler, 1953).

Susceptibility was reported to be dominant (Wiser *et al.*, 1960). Additive effects were important for resistance to *S. maydis* except in one of six populations evaluated, where dominant gene effects were significant (Villena, 1969).

Epistasis in ear rot resistance was present in a number of inbreds and D940Y exhibited a high specific combining ability for ear rot resistance. This indicates that both recurrent selection and back crossing could be used to improve resistance of susceptible inbreds, depending upon the resistant source (McLennan, 1991).

#### 2.7.8 *Correlated response*

No correlated response between grain yield and selection for disease resistance was found (Miles, Dudley, White & Lambert, 1981).

## CHAPTER III

### MATERIAL AND METHODS

The study involved three experiments. The first comprised of a full diallel study at three locations, conducted in the 1999/2000 season. The second experiment involved two trials at one location during the same season, to investigate different germplasm backgrounds for correlation of disease severity and relative maturity. The third experiment comprised of a recurrent selection program for *S. maydis* resistance, commencing in the 1997/1998 season.

#### 3.1 Experiment 1 - Diallel study

This experiment consisted of ten parental inbred lines, crossed in a complete diallel (parents, F1's and reciprocal crosses). Three field trials were conducted, one at each of the locations, Petit, Hillcrest and Lichtenburg during the 1999/2000 season, using three replications per trial. All genotypes were artificially inoculated with *S. maydis*. Different variables were measured to quantify *S. maydis* severity.

##### 3.1.1 *Experimental material*

Ten yellow inbred lines that varied from susceptible to highly resistant were used as parents. Resistant inbred lines DO620Y, E739, B37 and H111 were included, based on a previous evaluation on a number of isolates of the causal organism for aggressiveness (Van Rensburg & Ferreira, 1997). Locally developed susceptible inbred lines were I137TN, F2834T and ARC1. Susceptible inbred lines of USA origin were B73 and Mo17. One resistant Brazilian inbred, MON1 was also included (Table 3.1 and Table 3.2.).

### I137TN

I137TN is a subtropical, South African public inbred line with intermediate levels of resistance, late maturity and combines well in hybrid combinations with all other heterotic groups (Figure 3.1). I137TN was used extensively in commercial hybrids and was involved in 30% of the hybrids sold by private seed companies during 1993 (Cowie, 1998).

### B73

B73 was developed from the fifth cycle of general-combining-ability recurrent selection, using Stiff Stalk Synthetic (SSS) with double cross hybrid, Iowa 13, as tester at the Iowa State University, and released in 1972. Dark green color, upright leaves and large ear size made it unique, with outstanding yield potential. The inbred *per se* is a yellow dent with 18 to 20 kernel rows on the ear (Figure 3.2). The first single cross hybrid B73/Mo17 was first grown commercially in 1973 and is still used in breeding programs throughout the world (Troyer, 1999). B73 was found to be highly susceptible to *S. maydis* in USA environments (Dorrance *et al.*, 1998). B73 contributed to susceptibility in South African hybrids (Caulfield, 1988; Gevers, 1989; Klapproth & Hawk, 1991; Gevers *et al.*, 1992; Van Rensburg & Ferreira, 1997).

### B37

B37 was developed from the first cycle of recurrent selection of SSS with double cross hybrid Iowa 13 as tester at the Iowa State University, and released in 1958. It was first identified in the 1940's test cross program with above average yield potential, good stalks and root development, and good seed quality but had a problem with silk delay and pollen shed (Troyer, 1999). B37 was classified as resistant (Figure 3.3) (Caulfield, 1988; Van Rensburg & Ferreira, 1997; Dorrance *et al.*, 1998).

### F2834T

F2834T was developed from the Kroonstad Robyn variety in South Africa and was included as a susceptible parent (Figure 3.4). The inbred *per se* has a white cob, flint kernels and needs 82 to 83 days to mid pollen. The inbred line was released to the public sector of South Africa in 1975 (J. du Plessis, ARC - Grain Crops Institute, personal communication).

### MON1

MON1 is the code name for a Brazilian inbred from Monsanto South Africa, with orange flint grain and high levels of resistance to *S. maydis*. It is genetically different from all other inbreds used and combines excellently in any hybrid combination with other heterotic groups (Figure 3.5). It is of late maturity, subtropical, with good resistance to most foliar diseases such as grey leaf spot (GLS) (M.J. Alberts, Monsanto - South Africa, personal communication).

### DO620Y

DO620Y was included in this study due to its high level of resistance to *S. maydis* (Van Rensburg & Ferreira, 1997). It is a DO940Y-1 type, with a characteristic modified orange-yellow opaque-2 kernel and belongs to the M heterotic group. It was developed in KwaZulu-Natal, South Africa (Figure 3.6).

### E739

E739 was first indicated as resistant by Van Rensburg and Ferreira (1997) (Figure 3.7). This inbred line has a red cob and needs 69 to 72 days to mid pollen. It was released to the public sector in the 1950's (J. du Plessis, ARC - Grain Crops Institute, personal communication).

### H111

H111 is considered a resistant standard in the USA (Warren, 1982; Dorrance *et al.*, 1998). H111 is a yellow dent inbred developed from the cross B37/PI209135 selection Mb.2. It was backcrossed to B37 to add stalk and root quality. After each generation of selfing it was selected for disease resistance and agronomic acceptability. It is morphologically similar to B37 but matures about four days earlier with improved resistance to foliar and stalk diseases (Warren, 1982).

### Mo17

Mo17 was released in 1964 from the University of Missouri. The selection objectives for Mo17 were higher yield from both parents, more leaf and stalk disease resistance from the parent line C103 and better roots, better seed quality and faster dry down from parent inbred 187-2 (Troyer, 1999). Mo17 is intermediately susceptible to *S. maydis* (Figure 3.8) (Caulfield, 1988). It combines notably well with inbred line B73.

### ARC1

ARC1 is an experimental inbred line from the ARC - Grain Crops Institute, included as a susceptible parent. It was derived from USA Corn Belt germplasm and is related to both B73 and Mo17 (J.B.J. van Rensburg, ARC - Grain Crops Institute, personal communication).

**Table 3.1 Derivation of maize inbred lines used in the diallel study**

	<b><u>Inbred</u></b>	<b><u>Pedigree</u></b>	<b><u>Origin</u></b>
1	I137TN	Natal Yellow Horsetooth x Teko Yellow	South Africa
2	B73	Iowa Stiff Stalk Synthetic	Iowa, USA
3	B37	Iowa Stiff Stalk Synthetic	Iowa, USA
4	F2834T	Teko Yellow	South Africa
5	MON1(experimental)	Experimental, Brazil	Brazil
6	DO620Y	M37W derivative (DO940Y isolate)	South Africa
7	E739	Kroonstad Robyn	South Africa
8	H111	(Mayorbella x B37)B37	Indiana, USA
9	Mo17	187-2 x C103	Missouri, USA
10	ARC1(experimental)	Experimental, Corn Belt	South Africa

**Table 3.2 Resistance classification to *S. maydis* of the maize inbred lines used in the diallel study**

	<u>Inbred</u>	<u>Reaction to <i>S. maydis</i></u>
1	B37	Resistant
2	MON1	Resistant
3	DO620Y	Resistant
4	E739	Resistant
5	I137TN	Intermediate
6	H111	Intermediate
7	Mo17	Intermediate
8	B73	Susceptible
9	F2834T	Susceptible
10	ARC1	Susceptible

### 3.1.2 *Trials*

Nine inbred lines (B73, I137TN, B37, DO620Y, H111, E739, F2834T, ARC1 and Mo17) were obtained from the germplasm bank at the ARC - Grain Crops Institute, Potchefstroom. One inbred line (MON1) was obtained from Monsanto, South Africa. Single crosses and reciprocals in all combinations were produced, using a diallel crossing system. This was done at the ARC - Grain Crops Institute, Potchefstroom (26°42'S, 27°05'E) during the 1997/1998 season, Burgershall Research Station, Hazyview (25°07'S, 31°05'E) during the winter of 1998, Monsanto Research Station, Petit (26°05'S, 28°22'E) during the 1998/1999 season and at Monsanto Research Station, Malelane (25°29'S, 31°31'E) during the winter of 1999. The material from the crosses were hand-harvested at the end of each season and consisted of ten parent inbreds, 45 single crosses (F1's) and 45 reciprocal crosses (F1's).

The diallel was planted in the 1999/2000 season at three locations, Petit, on 30 November 2000, Hillcrest (29°46'S, 30°45'E) on 3 December 2000 and at Lichtenburg (26°08'S, 26°09'E) on 7 December 2000, using three replications at each location. Petit is a typical eastern environment with above average rainfall throughout the season. Hillcrest typically has high humidity with higher rainfall than Petit. Lichtenburg is a typical western environment with dry weather and high temperatures. The trial layouts was randomized block designs, with parents and crosses assigned randomly. An inbred line, not part of the study, was used as guard rows to reduce interplot competition between inbreds and hybrid entries in adjacent plots. The inbred guard rows were placed as single rows on either side of each plot (Hohls & Clark, 1996). This inbred was smaller than those used in the study, in order to minimize competition between adjacent plots.

Parents and crosses were planted in two-row plots, 5 m long and 0.91 m apart. The trials were planted by hand with two kernels per hill and thinned by hand after emergence to a uniform stand of 22 plants per 5 m. Fertilization, insect and weed control were routinely applied as required.

### 3.1.3 *Preparation of inoculum*

The inoculum for artificial infection of plants was prepared according to the technique described by Flett & McLaren (1994) and Bensch (1995). The Viljoenskroon isolate from the ARC - Grain Crops Institute, Potchefstroom culture collection, was used for inoculating both crosses and parents. Jars (500 ml) were filled with maize kernels (400 ml), and tap water was added to fill the jars. Kernels were soaked for 24 hr, after which the water was decanted and 30 ml of modified Fries Bosal (Chambers, 1987) medium was added. Jars were autoclaved for 30 min at 120°C on two consecutive days. Each jar was inoculated with a 1cm<sup>2</sup> block of actively growing mycelium of *S. maydis* cultures on potato-dextrose agar. Jars containing inoculated kernels were incubated at 28°C for 60 days. Colonized kernels were removed from the jars, air-dried for five days, and milled to a fine meal, which was stored in a cool room ( $\pm 6^\circ\text{C}$ ) prior to use.

### 3.1.4 *Artificial inoculation*

The whorl inoculation method was used, as described by Flett & McLaren (1994) and Bensch (1995). All parents and crosses were inoculated twice. Plants were inoculated with *S. maydis* by placing 5 g of inoculum into the apical whorl of each plant, approximately two weeks prior to anthesis, and again at anthesis. Irrigation of 25 mm was applied directly after each inoculation at all three locations.

### 3.1.5 *Variables measured*

Variables that could possibly be linked with *S. maydis* infection and expression, were measured. Agronomic characteristics previously indicated possibly to be correlated with disease severity (shank length, ear declination and husk cover and tightness) were measured (Koehler, 1959; Ferreira, 1994). Four different disease screening methods were used. These were percentage rotted ears, percentage rotted kernels (by mass), percentage rotted kernels (by numbers) and infection severity index (Hoppe & Holbert,

1936; Ullstrip, 1949). Yield potential components were measured to determine the effect of *S. maydis* on genotypes, both alone and in different combinations.

#### 3.1.5.1 Shank length (SH)

The length of the ear shank (distance between the stalk and the ear base) was determined from six plants in each plot and the average calculated. Measurements were only taken at Petit (1999/2000).

#### 3.1.5.2 Ear declination (DC)

An average rating on a scale of one to nine was used to rate each plot for the declination of the ear relative to the stalk, where one equals erect up the stalk and nine equals declined down against the stalk (Figure 3.9).

#### 3.1.5.3 Husk cover and tightness (HC)

Husk cover over the tip of the ear and husk tightness around the ear were rated on an average for each plot. A scale of one to nine was used, where one equals tight husks with total cover of the ear and nine equals loose husks with the tip of the ear showing (Figure 3.10).

#### 3.1.5.4 Stalk lodging (SL)

Stalk lodged plants were counted in each plot and expressed as a percentage of the stand at harvest, using:

$$SL = [\text{stalk lodge plants/stand at harvest}] \times 100.$$

#### 3.1.5.5 Root lodging (RL)

Root lodged plants were counted in each plot and expressed as a percentage of the stand at harvest, using:

$$RL = [\text{root lodge plants}/\text{stand at harvest}] \times 100.$$

#### 3.1.5.6 Total lodging (TL)

Total lodged plants were expressed as a percentage of the stand at harvest, using:

$$TL = [(\text{root lodge plants} + \text{stalk lodge plants})/\text{stand at harvest}] \times 100.$$

#### 3.1.5.7 Percentage rotted ears (RE)

Husk leaves were removed from the ears at a grain moisture of approximately 18 %. The number of *S. maydis* infected ears per plot was visually determined. Infected ears were expressed as a percentage of the total number of ears harvested in both rows of each plot (Figure 3.11).

#### 3.1.5.8 Percentage rotted kernel mass (RM)

All ears in each plot were threshed. Mass of *S. maydis* rotted kernels were determined from a 200 g sample of grain collected from each plot and expressed as a percentage of the sample mass.

#### 3.1.5.9 Percentage rotted kernels (RK)

*S. maydis* rotted kernels were counted in a 200 g sample of grain collected from each plot and expressed as a percentage of the total number of kernels per sample.

#### 3.1.5.10 Infection severity index (RS)

A rating on a scale of one to nine was used to determine the level and severity of infection of diseased ears (Figure 3.12), where one equals no visual symptoms (this did not include symptoms within the ear on the endosperm) and nine equals totally rotted ears without any healthy kernels. An average was calculated for each plot.

#### 3.1.5.11 Yield potential (YL)

Plots were harvested separately and the grain mass determined per plot. Grain yield potential was calculated in  $\text{tha}^{-1}$  at a standard grain moisture of 12.5 %, corrected to a uniform plant population of 48 000 plants per hectare at all three locations.

#### 3.1.5.12 Grain moisture (MS)

Grain moisture content was determined in percentage using a Dickey John moisture tester.

#### 3.1.5.13 Yield:moisture ratio (YM)

The yield to moisture ratio for each entry, was determined as follows:

$$\text{YM} = \text{Yield/moisture} \times 100,$$

where a higher ratio indicates a high yielding genotype with faster dry-down (earlier maturity).

### 3.1.6 *Statistical analyses*

All data were analyzed using Agrobase 98 and Genstat.

#### 3.1.6.1 Analyses of variance (ANOVA)

Anova's were performed for randomized complete block design. Simple as well as combined analyses were performed.

##### 3.1.6.1.1 Simple analyses of variance

All three diallel experiments were analyzed separately to determine the response of each genotype at each location for *S. maydis* related characteristics. The analyses provided means, mean squares, F-values, probability levels of significance, least significant differences (LSD) and coefficient of variance (CV).

##### 3.1.6.1.2 Combined analyses of variance

Combined analyses of the Petit, Hillcrest and Lichtenburg (1999/2000) locations were performed to provide an estimate performance of genotype across locations and to determine genotype by location interaction for *S. maydis* related characteristics. The analyses provided means, mean squares, F-values, probability levels of significance, LSD and CV.

##### 3.1.6.2 Mean performance of genotypes

Mean performances for each of Petit, Hillcrest and Lichtenburg and the combined response for all three locations (1999/2000) were determined for all genotypes, parents, F1's and reciprocals.

LSD-values at  $P=0.05$  were calculated to determine significant differences between genotypes, both parents and F1's, and to rank them for the different *S. maydis* related characteristics. Repeatability was also determined for each characteristic measured. Microsoft Excell'95 was used to draw the frequency histograms, based on the means of the genotypes.

### 3.1.6.3 Diallel analyses

Diallel analyses were done for each of the three diallel experiments conducted at Petit, Hillcrest and Lichtenburg (1999/2000). Griffing's Method I was used that included parents, single crosses and reciprocal crosses.

#### 3.1.6.3.1 Combining ability

Griffing's analyses (Griffing, 1956b) provided information on general combining ability, specific combining ability, and maternal effects. This diallel crossing system provided for  $p^2$  genotypes, therefore in a randomized block analyses  $\alpha = p^2$ . The mathematical model for combining ability used with Method I was (Table 3.3):

$$Y = m + g_i + g_j + s_{ij} + r_{ij} + 1/bc \sum \sum e_{ijkl}$$

$m$  = population mean

$g_i$  = GCA effect of the  $i$ th parents

$g_j$  = GCA effect of the  $j$ th parents

$s_{ij}$  = SCA effect for the cross between the  $i$ th and  $j$ th parents such that  $s_{ij} = s_{ji}$

$r_{ij}$  = reciprocal effect for the reciprocal crosses between the  $i$ th and  $j$ th parents such that  $r_{ij} = r_{ji}$

$b$  = number of replications

$c$  = number of observations per genotype

$e_{ijkl}$  = environmental effect associated with the  $ijkl$ th observation (Griffing, 1956b).

**Table 3.3 Analyses of variance for Method I giving the mean square for Model I (Griffing, 1956b)**

Source	df	Sum of squares*	Mean squares	Expectation of mean squares
GCA	$p-1$	$S_g$	$M_g$	$\sigma^2 + 2p(1/p-1)\Sigma g_i^2$
SCA	$p(p-1)/2$	$S_s$	$M_s$	$\sigma^2 + 2/p(p-1)\Sigma\Sigma s_{ij}^2$
Reciprocal effects	$p(p-1)/2$	$S_r$	$M_r$	$\sigma^2 + 2(2/p(p-1))\Sigma_{i>j}\Sigma r_{ij}^2$
Error	$m$	$S_e$	$M_e$	$\sigma^2$

Where:

$$S_g = \frac{1}{2p}\Sigma_i(X_i + X_{.i})^2 - \frac{2}{p^2}X_{..}^2$$

$$S_s = \frac{1}{2}\Sigma_i\Sigma_j x_{ij}(x_{ij} + x_{ji}) - \frac{1}{2p}\Sigma_i(X_i + X_{.i})^2 + \frac{1}{p^2}X_{..}^2$$

$$S_r = \frac{1}{2}\Sigma_{i<j}\Sigma(x_{ij} - x_{ji})^2$$

$$M_e = M_e/bc$$

$$\sigma^2(\text{error}) = \sigma^2/bc$$

Mean square is used to test for significant differences between GCA, SCA and reciprocal effects (Table 3.4).

**Table 3.4 Formulae for testing overall differences among the various classes of effects (Griffing, 1956b)**

Source	Formulae
GCA	$F_{[(p-1),m]} = M_g/M_e$
SCA	$F_{[p(p-1)/2,m]} = M_s/M_e$
Reciprocal	$F_{[p(p-1)/2,m]} = M_r/M_e$

### 3.1.6.3.1.1 General combining ability (GCA)

GCA is an indication of genes having largely additive genetic effects (Sprague & Tatum, 1942).

GCA effects were calculated from the formula:

$$G_i = [1/(n + 2)][\Sigma(Y_i + Y_{ii}) - (2/n)Y_{..}]$$

LSD for testing differences between effects was calculated using the formula:

$$LSD = q\alpha; t, f. \sqrt{S^2_E/r} \quad (t = 0,5)$$

$q\alpha; t, f$  =  $\alpha$  value at  $t$  treatment's degree of freedom and error's degree of freedom (Singh & Chaudhry, 1979).

### 3.1.6.3.1.2 Specific combining ability (SCA)

SCA is an indication of genes having dominance and epistatic effects (Sprague & Tatum, 1942).

SCA effects were calculated from the formula:

$$S_{ij} = Y_{ij} - [1/(n + 2)](Y_i + Y_{ii} + Y_j + Y_{jj}) + [2/(n + 1)(n + 2)]Y_{..}$$

LSD for testing differences between effects was calculated using the formula:

$$LSD = q\alpha; t, f. \sqrt{S^2_E/r} \quad (t = 0,5)$$

$q\alpha; t, f$  =  $\alpha$  value at  $t$  treatment degree of freedom and error degree of freedom (Singh & Chaudhry, 1979).

### 3.1.6.3.1.3 GCA:SCA Ratio

The ratios were calculated by using the mean square of GCA and SCA. The ratio determines if the characters are controlled by additive or non-additive (dominant) gene action and which factor plays a more important role in genetic control (Sing, Paroda & Behl, 1986).

### 3.1.6.4 Correlation coefficient

#### 3.1.6.4.1 Phenotypic correlation

A phenotypic correlation matrix was calculated for all characteristics measured. The formula for phenotypic correlation between two characteristics,  $X$  and  $Y$  are (Falconer & Mackay, 1996):

$$r_P = \text{COV}_P / \sigma_{PX} \sigma_{PY}$$

Where:  $r_P$  = phenotypic correlation between characters  $X$  and  $Y$   
 $\text{COV}_P$  = phenotypic covariance ( $\text{COV}_P = \text{COV}_A + \text{COV}_E$ )  
 $\sigma_{PX}$  or  $\sigma_{PY}$  = phenotypic variance of character  $X$  or  $Y$

If both characters have low heritability, the phenotypic correlation is mostly determined by the environmental correlation and if they have high heritability, the genetic correlation is more important (Falconer & Mackay, 1996).

### 3.1.6.4.2 Genetic correlation

Genetic correlations were determined for all characteristics measured using the formula (Falconer & Mackay, 1996):

$$r_A = \text{cov}_{XY} / \sqrt{(\text{var}_X \text{var}_Y)}$$

Where:  $r_A$  = additive genetic correlation  
 $\text{cov}_{XY}$  = covariance of the characters X and Y  
 $\text{var}_X$  or  $\text{var}_Y$  = variance of characters X or Y, respectively  
var and cov = refer to the components of variance and covariance

### 3.1.6.5 Heritability

Broad sense heritability is the extent to which individual phenotypes are determined by the genotypes (Falconer & Mackay, 1996):

$$h^2_b = V_G / V_P$$

Where:  $V_G$  = total genetic variance = 2GCA + SCA  
 $V_P$  = phenotypic variance = 2GCA + SCA + Residual

Narrow sense heritability is the extent to which phenotypes are determined by the genes transmitted from the parents (Falconer & Mackay, 1996):

$$h^2_n = V_A / V_P$$

Where:  $V_A$  = additive genetic variance = 2GCA  
 $V_P$  = phenotypic variance = 2GCA + SCA + Residual

### 3.1.6.6 Correlated response (CR)

If selection was applied to character X, the correlated response of character Y, can be calculated by using the formula described by Falconer and Mackay (1996).

$$CR_Y = ih_X h_X r_A \sigma_{PY}$$

where  $CR_Y$  = correlated response of character Y from selection on character X  
 $i$  = intensity of selection  
 $r_A$  = genetic correlation between X and Y  
 $h_X$  = heritability (narrow sense) of character X  
 $h_Y$  = heritability (narrow sense) of character Y  
 $\sigma_{PY}$  = square root of phenotypic variance of character Y

## 3.2 Experiment 2 - Evaluation of the effect of maturity classification and genetic diversity in hybrids on *S. maydis* incidence

This study was conducted during the 1999/2000 season at one location, Hillcrest, using one replication. It comprised of South African derived, tropical and temperate germplasm in different hybrid combinations. All genotypes were artificially inoculated and comparisons between percentage rotted ears and maturity classifications (grain moisture and days to 50 % flower) were made.

### 3.2.1 Trials

Two trials were planted at Hillcrest (29°46'S, 30°45'E) during mid October of the 1999/2000 season. Both trials included a total of 98 hybrids of which 66 were derived from South African germplasm and 32 hybrids of South African derived germplasm crossed to exotic and temperate germplasm. The trial layout was a 7 x 7 lattice design, with hybrids assigned randomly. Entries were planted in two-row plots, 5 m long and

0.91 m apart. The trails were planted by hand using two kernels per hill and thinned by hand after emergence to a uniform stand of 22 plants per 5 m row. Fertilization, insect and weed control were routinely applied as required.

### 3.2.2 *Artificial inoculation*

All plants were artificial inoculated by placing 5 g of inoculum in the whorls during the mid-whorl stage and again prior to tasselling. Inoculum was prepared from *S. maydis* rotted ears collected the previous season, dried, milled and stored at 6°C.

### 3.2.3 *Variables measured*

All ears were hand harvested from each plot and *S. maydis* infected ears were expressed as a percentage of the total ears in each plot. Days to 50 % flowering were determined for each entry. The grain moisture at harvest of a representative sample of each plot, was determined after harvesting, using a Dickey John device.

### 3.2.4 *Statistical analyses*

Genstat was used to analyse the data and Microsoft Excel to draw regression graphs for each trial, plotting percentage rotted ears against both grain moisture content and days to 50 % flowering.

## 3.3 **Experiment 3 - Recurrent selection for *S. maydis* resistance in an inbred development program**

The study comprised four cycles of recurrent selection with artificial inoculation during each generation of selection, commencing in the 1997 season. Population means were compared between different cycles of recurrent selection, to determine genetic gain for resistance to *S. maydis*.

### 3.3.1 *Experimental material and nursery fields*

The inbred lines B37, DO620Y and E739 as sources of *S. maydis* resistance were crossed in all combinations in the greenhouse. The F1 progeny was selfed, from which 200 plants of the segregating F2 population were evaluated for resistance to *S. maydis* in the field during 1997/1998. Plants were artificially infested twice. Fifty uninfected ears from each of the three populations were selected at harvest and planted ear-to-row at Burgershall Research Station, Hazyview (25°07'S, 31°05'E) during the winter of 1998. These were artificially infected. A number of plants in each row was selfed. The best twenty percent on row basis were selected from each population (percentage infected ears less than ten percent), and planted ear-to-row at both Potchefstroom (26°42'S, 27°05'E) and Cedara (29°32'S, 30°15'E) during the 1998/1999 season. All trials were artificially inoculated.

Further more, the populations A2P31 (D940Y/B37 derivation) and A2P22 (ARC1/Va35 derivation), both in combination with each other and when crossed to a moderately resistant source (B2), were used. These populations progressed from the F2 to F3 generation during 1997/1998 and to F4 during 1998/1999, using artificial inoculation during each generation. The twenty percent most resistant ear row selections for *S. maydis* were planted at Hazyview (25°07'S, 31°05'E) during the winter of 1998 and crossed in all possible combinations for evaluation at Potchefstroom (26°42'S, 27°05'E) during the 1998/1999 season. Four other families from the conventional program, (VHC/B73, VHC/I137TN, P65/B73 and VHC/P28), that were known to be susceptible to *S. maydis*, were also evaluated.

### 3.3.2 *Preparation of inoculum*

The inoculum for artificial infection of plants was prepared according to the technique described by Flett & McLaren (1994) and Bensch (1995). The Viljoenskroon isolate (centrally located in the maize production area) from the ARC - Grain Crops Institute,

Potchefstroom culture collection was used for inoculating the crosses and parents. Jars (500 ml) were filled with maize kernels (400 ml), and tap water was added to fill the jars. Kernels were soaked for 24 hr, after which the water was decanted and 30 ml of modified Fries Bosal (Chambers, 1987) medium was added. Jars were autoclaved for 30 min at 120°C on two consecutive days. Each jar was inoculated with 1cm<sup>2</sup> block of actively growing mycelium of *S. maydis* cultures on potato-dextrose agar. Jars containing inoculated kernels were incubated at 28°C for 60 days. Colonized kernels were removed from the jars, air-dried for five days, and milled to a fine meal, which was stored in a cool room ( $\pm 6^\circ\text{C}$ ) prior to use.

### 3.3.3 *Artificial inoculation*

The whorl inoculation method was used, as described by Flett & McLaren (1994) and Bensch (1995). All parents and crosses were inoculated twice. Plants were inoculated with *S. maydis* by placing 5 g of inoculum into the apical whorl approximately two weeks prior to anthesis and again at anthesis. Irrigation of 25 mm was applied directly after each inoculation.

### 3.3.4 *Statistical analyses*

Genstat was used to analyse the data and Microsoft Excel to draw graphs of frequency histograms.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### 4.1 Experiment 1 - Diallel study

##### 4.1.1 *Genotype response over locations*

The mean squares for various sources of variation are provided in Table 4.1 for Petit (1999/2000), 4.2 for Hillcrest (1999/2000), 4.3 for Lichtenburg (1999/2000) and 4.4 for the combined analysis over locations. At both Petit and Hillcrest the statistical analyses succeeded to separate significant variation for replications. Highly significant differences between genotypes were obtained for all characteristics measured at all locations. The location by genotype interaction was highly significant for all characteristics measured. This indicates that sufficient variability exists within local germplasm used in commercial breeding programs to improve *S. maydis* resistance in local hybrids by selection and breeding, using the most resistant inbreds as donor parents. Based on mean square values, the *S. maydis* related characteristics evaluated (percentage rotted ears, percentage rotted kernel mass and percentage rotted kernels) seemed to provide an effective method to distinguish between genotypes at any of the locations used.

##### 4.1.1.1 Percentage rotted ears, kernel mass and kernels

The mean percentage rotted ears (RE), percentage rotted kernel mass (RM) and percentage rotted kernels (RK), for both parental inbreds and F1 combinations evaluated at Petit, are provided in Tables 4.5a (entries 1 - 50) and 4.5b (entries 51 - 100). Mean values for each of the ten inbreds used are illustrated in Figure 4.1. The corresponding results for Hillcrest are provided in Tables 4.6a and 4.6b and the means of inbreds illustrated in Figure 4.1. The Lichtenburg results are provided in Tables 4.7a and 4.7b with illustrated mean values for the inbreds provided in Figure 4.1. The combined mean values for Petit, Hillcrest and Lichtenburg are provided in Tables 4.8a and 4.8b with illustrated values of the inbreds provided in Figure 4.2.

The mean *S. maydis* incidence based on percentage rotted ears for the different locations were; Petit: 21.56 % with a repeatability of 51.60 %, Hillcrest: 25.40 % with a repeatability of 77.80 % and Lichtenburg: 3.40 % with a repeatability of 47.00 %. The corresponding means for the combined analysis over locations (environments) was 16.94 % with a repeatability of 87.20 %. The mean incidence of *S. maydis* per plot ranged from 0.90 % to 79.73 % at Petit, from 2.21 % to 83.19 % at Hillcrest and from 0.00 % to 30.18 % at Lichtenburg.

This indicates that Hillcrest was the best location to screen for *S. maydis* with the highest repeatability across replications. It should be kept in mind not to screen outside the main maize production area in order to get representative and trustworthy data. At Lichtenburg, environmental conditions were not optimal for *S. maydis* development and the location seems to be unfavorable for future screening of resistant material. Genotype combinations and inbred performance varied in accordance with prevailing environmental conditions and infection levels. This result is in accordance with those of Koehler (1953), Thompson *et al.* (1971) and Flett & McLaren (1994). Different infection levels and different environments played a significant role in the inconsistency of the data, which should be kept in mind when interpreting the analyses. Based on the *S. maydis* incidence and repeatability recorded at the Petit location, (located centrally in the maize production area) this should be the most suitable location to screen for *S. maydis* resistance under conditions of artificial inoculation. However, if resources were available it will be best to screen across different environments to minimize the GxE effects. The significant GxE interaction is of importance to maize breeders, who should consider to screen for *S. maydis* resistance in the dominant environment where the bulk of the end product (commercial hybrids) will be grown.

At all three locations, the inbred DO620Y had the lowest mean values for *S. maydis* related characteristics. Inbred MON1 had the second lowest value across all three locations, with no significant differences recorded between the two inbreds. Across all three locations the inbred B73 had the highest incidence of all the *S. maydis* related

characteristics, followed by inbreds B37 and ARC1. The only exception was at Hillcrest where inbred ARC1 had the highest values followed by inbred B73.

At all three locations, F1 combinations with inbreds DO620Y and MON1 consistently had low *S. maydis* values, whereas combinations with inbreds B73 and ARC1 had high values. F1 combinations MON1/DO620Y, F2834T/MON1, Mo17/DO620Y and I137TN/DO620Y had low values across all three locations indicating superior levels of resistance to *S. maydis* in hybrid combination, with stability across environments. At both Petit and Lichtenburg, DO620Y/F2834T had low values. F1 combinations H111/MON1, DO620Y/B37 and MON1/B73 performed well at Hillcrest.

All three *S. maydis* related characteristics, (percentage rotted ears, percentage rotted kernel mass and percentage rotted kernel) can be used as reliable indicators of *S. maydis* incidence. All three methods are highly accurate, with percentage rotted ears being the least labor intensive, most practical and simplest method to screen large numbers of entries. The result is in accordance with findings of Ullstrup (1949) and Nowell (1997), who indicated that the methods evaluated were closely correlated, and that percentage rotted ears was considered the simplest. Note that only recording the incidence of rotted ears, without using some measurement of kernel infection, can inevitably result that "hidden Diplodia" goes undetected.

Improved resistance will be obtained by using inbreds MON1, DO620Y and F2834T as donor parents in a breeding program, while B73 and ARC1 will contribute towards susceptibility. Inbreds I137TN, B37, E739, H111 and Mo17 can be regarded as having intermediate levels of resistance. Previous studies indicated inbred F2834T to be relatively susceptible, while inbreds B37, E739 and H111 were resistant to *S. maydis* (Warren, 1982; Caulfield, 1988; Van Rensburg & Ferreira, 1997; Dorrance *et al.*, 1998).

#### 4.1.1.2 Infection severity index

The mean infection severity index (RS), for both parent inbreds and F1 combinations, evaluated at Petit are provided in Tables 4.5a (entries 1 - 50) and 4.5b (entries 51 - 100). Mean values for each of the ten inbreds used are illustrated in Figure 4.3. The corresponding results for Hillcrest are provided in Tables 4.6a and 4.6b and the inbred means illustrated in Figure 4.3. Whereas the Lichtenburg results are provided in Tables 4.7a and 4.7b with illustrated mean values for the inbreds provided in Figure 4.3. The mean values from combined analysis over locations are provided in Tables 4.8a and 4.8b, with inbred means illustrated in Figure 4.4.

Inbreds DO620Y and MON1 had the lowest values across all three locations for infection severity index, while inbreds B73 and B37 scored the highest on the index.

At all three locations, F1 combinations F2834T/MON1, MON1/DO620Y and MON1/I137TN had the lowest mean values for infection severity index. The highest mean values were observed for F1 combinations B73/ARC1, Mo17/ARC1 and ARC1/Mo17.

These results indicate that some of the germplasm evaluated can be used to increase resistance to infection by the host. Inbreds DO620Y and MON1 could be used to suppress the infection severity with less yield potential loss to the pathogen, while inbreds B73, B37, ARC1 and Mo17 should be used with care. F1 combinations with inbreds MON1, DO620Y and F2834T consistently scored the lowest on the index across all the environments evaluated.

#### 4.1.1.3 Ear declination and husk cover and tightness

The mean values for ear declination (DC) and husk cover and tightness (HC) for both parent inbreds and F1 combinations evaluated at Petit are provided in Tables 4.5a (entries 1 - 50) and 4.5b (entries 51 - 100). Mean values for each of the ten inbreds used are illustrated in Figure 4.5. The corresponding results for Hillcrest are provided

in Tables 4.6a and 4.6b and the inbred means illustrated in Figure 4.5. Those for Lichtenburg are provided in Tables 4.7a and 4.7b with inbred means illustrated in Figure 4.5. The mean values obtained from analysis over locations are provided in Tables 4.8a and 4.8b with inbred means illustrated in Figure 4.6.

At all three locations the most erect ears and tightest husk cover were recorded with inbreds I137TN, F2834T and MON1. Inbreds E739, H111 and Mo17 had the most declined ears and the loosest husk cover.

Analysis across the three locations indicated that F1 combinations with inbreds MON1, I137TN and F2834T had the most erect ears with combination MON1/F2834T having the most erect ears of all. F1 combinations with inbred E739 had the most declined ears and the loosest husk cover. The F1 combinations with the tightest husk cover were those employing inbreds I137TN, F2834T and MON1, as well as F2834T/MON1.

Inbred E739 contributed towards declined ears and loose husks in hybrid combinations, whereas inbreds MON1 and F2834T provided more erect ears and tighter husk cover. Since both erect and declined ears are recorded with inbreds observed to provide low levels of *S. maydis* incidence, e.g. MON1 and E739 (see 4.1.1.1), ear declination seemed not to contribute to *S. maydis* susceptibility. The same applies to husk cover and tightness. These results are further discussed in 4.1.2.2.3.

#### 4.1.2 *Combining ability over locations*

Mean squares for combining ability are provided in Tables 4.9 for Petit (1999/2000), 4.10 for Hillcrest (1999/2000) and 4.11 for Lichtenburg (1999/2000). Highly significant differences for GCA effects were obtained for all characteristics measured at all locations. Similarly, highly significant differences for SCA effects were obtained for all characteristics measured at all locations, except for root lodging at Hillcrest. Highly significant differences for reciprocal effects were obtained for all characteristics

measured at all locations, except for percentage rotted ears, kernel mass, kernels and shank length at Petit and for root lodging and total lodging at Hillcrest.

Results indicate that sufficient GCA, SCA and reciprocal effects exist in the germplasm evaluated in this study, to improve levels of resistance as well as other agronomic traits in a commercial breeding program. Inbreds with general combining ability for resistance was identified to serve as donor parents in a breeding effort, along with inbreds with specific combining abilities. There also were sufficient differences to indicate if additive gene action or dominance and interaction effects is important in the expression of these characteristics.

#### 4.1.2.1 General combining ability (GCA)

GCA effects for various *S. maydis* and agronomic characteristics evaluated at Petit, Hillcrest and Lichtenburg, are provided in Table 4.12.

##### 4.1.2.1.1 Percentage rotted ears, kernel mass and kernels

In accordance with 4.1.1.1, inbreds DO620Y, MON1 and F2834T had the best negative GCA effects for all *S. maydis* related characteristics, across environments, and inbreds B73 and ARC1 had the greatest positive GCA effects for these characteristics, indicating these inbreds to contribute towards *S. maydis* susceptibility. Inbreds I137TN, B37, E739, H111 and Mo17 showed average GCA effects, to be used with care in breeding programs where *S. maydis* is a factor of consideration. However, H111 is regarded to be resistant in the USA (Dorrance *et al.*, 1998), whereas both B37 and E739 were shown to be resistant under local conditions (Van Rensburg & Ferreira, 1997). The latter two inbreds have been successfully used in combinations with DO620Y to obtain new sources with superior resistance.

#### 4.1.2.1.2 Infection severity index

In accordance with 4.1.1.2, inbreds F2834T, MON1 and DO620Y had the best negative GCA effects for infection severity index (RS) across environments. Inbreds B73 and ARC1 had the greatest positive GCA effects for infection severity index. Inbreds F2834T, MON1 and DO620Y can be used in a recurrent breeding program to suppress the infection severity with less yield potential loss to *S. maydis*.

#### 4.1.2.1.3 Ear declination and husk cover and tightness

Inbreds E739 and B37 had the greatest positive GCA for ear declination (DC) while E739 also had the greatest positive GCA for husk cover and tightness (HC) across environments. Inbreds F2834T and MON1 had the best negative GCA for ear declination while F2834T also had the best negative GCA for husk cover and tightness across environments.

E739 had the most declined ears with loose husks and tips of the ears showing, while F2834T had the most erect ears with tight husks and good cover of the eartips. These two inbreds can therefore be used in a breeding program to incorporate the specific agronomic characteristics required. However, as indicated earlier, this would not necessarily contribute towards resistance to *S. maydis*.

#### 4.1.2.1.4 Yield potential, grain moisture and yield:moisture ratio

Inbreds MON1 and I137TN had the greatest positive GCA for yield potential (YL) across all environments evaluated, while inbreds B37, F2834T and Mo17 had the greatest negative GCA for yield potential. For grain moisture content (MS), inbreds I137TN, MON1 and DO620Y had the greatest positive GCA and inbreds B37, H111 and Mo17 had the greatest negative GCA. Inbreds MON1, E739 and DO620Y had the greatest positive GCA for yield:moisture ratio, with inbreds B37 and F2834T having the greatest negative GCA.

If yield potential needs to be considered in all the environments evaluated and under *S. maydis* pressure, inbreds MON1 and I137TN can be used in a recurrent breeding program. MON1 is classified as heterotically unrelated to the other inbreds and can therefore be used both in new breeding efforts, using related breeding material as recurrent parents, or in hybrid combinations with unrelated inbreds. For the Petit environment, inbreds I137TN and MON1 will have the best general combining ability for yield potential. Similarly, inbreds MON1 and DO620Y will have the best general combining ability for the Hillcrest environment and inbreds ARC1 and I137TN for Lichtenburg. It is noteworthy that in accordance with 4.1.1.1 inbred ARC1 performed better under low *S. maydis* incidence due to its susceptibility to *S. maydis*. The significant GxE interaction for yield potential is of importance to determine which inbreds to use to capture yield potential, as a tester for segregating material, in hybrid combinations with inbreds from different heterotic backgrounds and in new breeding efforts with inbreds that are genetically closely related. In crosses, inbreds I137TN, MON1 and DO620Y will contribute towards medium to late maturity hybrids while inbreds B37, H111 and Mo17 will increase drydown in hybrid combinations. In accordance with 4.1.2.1.1, MON1 and DO620Y also had the best GCA for *S. maydis* resistance, while B37, H111 and Mo17 showed average GCA for resistance. This indicates that more resistance can be found in the later maturity range and less in the earlier temperate germplasm. MON1, E739 and DO620Y will capture higher yields and contribute towards faster drydown, and can therefore be used with success in commercial breeding programs.

#### 4.1.2.1.5 Stalk lodging, root lodging and total lodging

Across environments, inbreds DO620Y, MON1 and I137TN had the greatest negative GCA for stalk lodging (SL), root lodging (RL) and total lodging (TL). Inbreds B73 and B37 had the greatest positive GCA for these characteristics across the environments evaluated.

Results indicated that inbreds DO620Y, MON1 and I137TN can be used to improve lodging due to their positive GCA values under environments with lodging problems.

The other inbreds evaluated must be used with care. It should be noted that if ears of lodged plants touch the ground, more rotted ears occur. However, stalk lodging caused by *S. maydis* is not physiologically related to ear rot caused by the same pathogen (Koehler, 1959) and improvement of standability by means of conventional breeding methods, would not necessarily contribute to ear rot resistance (Thompson *et al.*, 1971). The resistance to ear rot identified in DO620Y and MON1, therefore, seems to be unrelated to their positive contribution to standability.

#### 4.1.2.1.6 Shank length

Analysis at Petit indicated that inbred MON1 had the greatest positive GCA for shank length (SH) while inbred B37 contributed most towards shorter shanks.

Inbred MON1 will be the best donor to increase shank length in hybrids and breeding starts. Hybrids with longer shanks have more declined ears but this will not necessarily contribute to *S. maydis* resistance (see 4.1.2.2.3).

#### 4.1.2.2 Specific combining ability (SCA)

SCA effects for various *S. maydis* related and agronomic characteristics evaluated at Petit are provided in Table 4.13 for Hillcrest in Table 4.14 and for Lichtenburg in Table 4.15.

##### 4.1.2.2.1 Percentage rotted ears, kernel mass and kernels

Analysis across environments indicated that F1 combinations I137TN/Mo17, B73/F2834T, B37/F2834T and B37/DO620Y had the greatest negative SCA for all *S. maydis* related characteristics. F1 combinations B73/ARC1, Mo17/ARC1, B73/Mo17, I137TN/E739, F2834T/E739 and B37/Mo17 had the greatest positive SCA for the different environments evaluated.

Combinations with B37, on average, had better negative SCA for the characteristics measured while combinations with inbreds B73 and ARC1 had less resistance. Inbreds MON1, DO620Y and F2834T had excellent GCA for the *S. maydis* related characteristics (see 4.1.2.1.1) while inbred B37 will add value in combination with other inbreds, in both breeding efforts and hybrid combinations. Large variation existed between the three environments for the best F1 combinations, indicating that the GxE was large for these characteristics.

#### 4.1.2.2.2 Infection severity index

Analysis across environments indicated that F1 combinations B37/F2834T, I137TN/Mo17, B37/H111, B37/DO620Y and F2834T/H111 had the best negative SCA for infection severity index (RS). F1 combinations I137TN/H111, MON1/H111, F2834T/E739, F2834T/Mo17, I137TN/F2834T and DO620Y/H111 had the greatest positive SCA across the locations evaluated.

In accordance with 4.1.2.2.1, B37 had the lowest infection severity in F1 combinations, while inbreds F2834T, MON1 and DO620Y had the best GCA for low infection severity (see 4.1.2.1.2).

#### 4.1.2.2.3 Ear declination and husk cover and tightness

Analysis across environments indicated that F1 combinations B37/F2834T, B37/H111, I137TN/Mo17, F2834T/H111 and B37/DO620Y had the best negative SCA for ear declination (DC) and husk cover and tightness (HC). These combinations are characterized by erect ears, tight husks and good husk cover. Combinations B73/H111, DO620Y/H111, I137TN/F2834T, F2834T/E739, F2834T/DO620Y and I137TN/B37 had the greatest positive SCA, contributing towards declined ears, loose husks and open tips.

Note that the F1 combination, B37/F2834T, had highly negative SCA effects for *S. maydis* related characteristics (see 4.1.2.2.1), infection severity index (see 4.1.2.2.2),

ear declination, husk cover and tightness and shank length (see 4.1.2.2.6). This F1 combination therefore showed the lowest *S. maydis* incidence with the most erect ears, tightest husk cover and shortest shanks, indicating that genotypes with erect ears are not necessarily more prone to infection, but that the high incidence of erect ears often noticed in diseased plantings, is possibly a result of infected ears having less mass, with less pressure on the shank to bend down.

#### 4.1.2.2.4 Yield potential, grain moisture and yield:moisture ratio

Analysis across environments indicated that F1 combinations with the greatest positive SCA for yield potential (YL) were B37/Mo17, H111/ARC1, H111/Mo17, MON1/H111, F2834T/ARC1, F2834T/Mo17, F2834T/MON1, I137TN/H111 and I137TN/F2834T.

F1 combinations I137TN/H111, H111/Mo17, H111/ARC1, MON1/H111, F2834T/Mo17, F2834T/MON1, F2834T/ARC1, B37/MON1 and B37/Mo17 had the greatest positive SCA for yield:moisture ratio (YM) across all environments. These F1 combinations are therefore high yielding with relative quick drydown.

F1 combinations B37/Mo17, F2834T/DO620Y, F2834T/MON1, I137TN/MON1, I137TN/F2834T, H111/ARC1 and E739/H111 had the greatest positive SCA for grain moisture content (MS) across all environments. These combinations had the highest grain moisture at harvest and can be used in the later maturity group of hybrids. F1 combinations with the best negative SCA for grain moisture were MON1/Mo17, B37/F2834T, I137TN/Mo17, F2834T/H111 and B37/DO620Y across all three environments. These combinations had the lowest grain moisture at harvest and can be used in the earlier maturity category of hybrids. Grain moisture content can give an indication in which maturity group more resistance can be found. In accordance with 4.1.2.2.1, F1 combinations with good SCA for *S. maydis* resistance are found in the medium to late maturity range. The earlier maturity range of F1 combinations were more susceptible to *S. maydis*.

#### 4.1.2.2.5 Stalk lodging, root lodging and total lodging

Analysis across environments indicated that F1 combinations B73/DO620Y, B73/MON1, B73/F2834T, B73/ARC1, I137TN/H111, DO620Y/ARC1, F2834T/H111, B37/DO620Y and B37/F2834T had the best negative SCA. These combinations had the lowest lodging of all combinations evaluated. F1 combinations B73/B37, B73/H111 and B73/Mo17 should be used with care because of their great positive SCA, indicating increasing incidence of lodging in the environments evaluated.

Results indicated that the use of South African developed inbreds improved lodging in F1 combinations whereas USA developed inbreds contributed to lodging. Less lodging with less ears touching the ground may indirectly lead to reduced incidence of *S. maydis* (Koehler, 1959), but as discussed in 4.1.2.1.5 the use of genotypes which contribute to improved standability will not necessarily contribute genetically to resistance.

#### 4.1.2.2.6 Shank length

Analysis at Petit indicated that F1 combinations B37/F2834T, B37/H111 and MON1/ARC1 had the best negative SCA for shank length (SH). Combinations B73/MON1, I137TN/B37 and B73/E739 had the greatest positive SCA. Results were discussed in 4.1.2.2.3.

#### 4.1.2.3 GCA:SCA ratio

GCA:SCA ratio's for various *S. maydis* related and agronomic characteristics evaluated at Petit, Hillcrest and Lichtenburg are provided in Table 4.16.

At Petit the GCA:SCA ratio for shank length (SH) was extremely high which indicated that shank length is largely controlled by additive gene effects. The GCA:SCA ratio's for percentage rotted ears (RE), percentage rotted kernel mass (RM), percentage rotted kernels (RK), ear declination (DC), husk cover and tightness (HC), stalk

lodging (SL), root lodging (RL), total lodging (TL) and grain moisture content (MS) were above the 4:1 ratio. This indicated that additive gene action is more important in the expression of these characteristics than either dominance or interaction effects in the Petit environment. For the characteristics, infection severity index (RS), yield potential (YL) and yield:moisture ratio (YM), the additive effects was just as important as the dominance and interaction effects.

For percentage rotted kernel mass, percentage rotted kernels, ear declination, husk cover and tightness and grain moisture at Hillcrest the GCA:SCA ratio's differed from Petit and were below the 4:1 ratio. Additive effects were just as important as the dominance and interaction effects for these characteristics. At Lichtenburg additive gene action was more important in the expression of husk cover and tightness than dominance and interaction effects while for the rest of the characteristics additive gene actions were just as important as the dominance and interaction effects.

The GCA:SCA ratio's varied from location to location. Petit had the highest ratio followed by Hillcrest and Lichtenburg. This was probably caused by variance in environmental effects such as soil moisture and temperature. Results indicated that *S. maydis* related characteristics are controlled by additive gene effects with low dominance and interaction effects. Resistance to *S. maydis* therefore seems to be additively inherited, confirming results by Koehler (1953). In lodging, additive gene effects also played a role while for infection severity index, additive gene effects were just as important as dominance and interaction effects.

#### 4.1.3 *Correlation coefficients over locations*

##### 4.1.3.1 Phenotypic correlation

Linear correlation analyses pertaining to the three locations are provided in Tables 4.17 (Petit), 4.18 (Hillcrest) and 4.19 (Lichtenburg).

Analysis across environments indicated highly significant to significant phenotypic correlations for all agronomic characteristics. Very high positive correlation values were found between the *S. maydis* related characteristics, percentage rotted ears (RE), kernel mass (RM) and kernels (RK). See 4.1.3.2 for discussion.

#### 4.1.3.2 Genetic correlation

Linear correlation analyses pertaining to the three locations are provided in Tables 4.20 (Petit), 4.21 (Hillcrest) and 4.22 (Lichtenburg).

Analysis across environments indicated a highly significant, positive genetic correlation between percentage rotted ears (RE), percentage rotted kernel mass (RM) and percentage rotted kernels (RK). All three *S. maydis* related characteristics can therefore be used with success to discriminate between genotypes for *S. maydis* resistance, confirming the results discussed in 4.1.1.1.

Note that no significant genetic correlations were found between any of the *S. maydis* related characteristics and either ear declination (DC) or husk cover and tightness (HC) across all three environments, confirming the results discussed in 4.1.2.2.3.

Although significant positive genetic correlations were found between infection severity index (RS) and the *S. maydis* related characteristics, these were less pronounced than between the last three characteristics themselves. This was due to lack of expression of discolored kernels ("hidden" Diplodia) on some genotypes, which can only be effectively evaluated when the ear is broken. In screening for this symptom, the other three characteristics (relating to external ear rot incidence) will not be that effective and selections of infected kernels may be favored. This indicates that infection severity index can not be used as a *S. maydis* parameter without the use of one of the others. As expected, highly significant positive genetic correlations were found between total lodging, root lodging and stalk lodging. The same applied to the correlation between yield potential and yield:moisture ratio and between yield:moisture ratio and grain moisture content.

At Lichtenburg a highly positive genetic correlation existed between yield potential and grain moisture, indicating that hybrids of later maturity classification had a higher yield than earlier hybrids due to the drought escape.

Although not significant, a negative genetic correlation was found at both Petit and Hillcrest between infection severity index and grain moisture. This could be due to colonization of ears by the pathogen being limited by high grain moisture levels rather than by host resistance, as reported by Dorrance *et al.* (1998).

#### 4.1.4 *Heritability over locations*

Broad sense ( $h^2_b$ ) and narrow sense ( $h^2_n$ ) heritability were calculated for each characteristic measured and provided in Table 4.23 for all three locations.

Estimates of broad and narrow sense heritability were high for all the characteristics measured across all three environments. Heritability was extremely high for the disease related characteristics, indicating a high level of efficacy when selecting for these characteristics. The relatively high narrow sense heritability for all the characteristics can probably be explained by the relatively small contribution of environmental variance.

#### 4.1.5 *Correlated response (CR) over locations*

Correlated response values for the three locations are provided in Tables 4.24 (Petit), 4.25 (Hillcrest) and 4.26 (Lichtenburg).

#### 4.1.5.1 Percentage rotted ears, kernel mass and kernels

High ( $CR > 0.4$ ) to extremely high ( $CR > 0.8$ ) positively correlated responses were found between percentage rotted ears (RE), percentage rotted kernel mass (RM) and percentage rotted kernels (RK) across all three environments.

If selection was applied at any of Petit, Hillcrest or Lichtenburg, favorable responses would be obtained for all *S. maydis* related characteristics. Selection for lower percentage rotted ears, percentage rotted kernel mass or percentage rotted kernels will automatically decrease the other two characteristics. Extremely high response will be obtained for selection at Petit for any one of these three characteristics. Practically, percentage rotted ears would be the best method to screen large numbers of entries when time and resources available were limited (Klapproth & Hawk, 1991). No effective correlated responses were found between any of these characteristics and other agronomic traits that could be used as simple phenotypic traits to select for resistance.

#### 4.1.5.2 Infection severity index

Relatively high positive correlated responses were found between infection severity index (RS) and percentage rotted ears (RE), kernel mass (RM) and kernels (RK).

Correlated response between infection severity and the *S. maydis* related characteristics was not as high as between the *S. maydis* related characteristics themselves (see 4.1.5.1). This indicated that infection severity will not be sufficient enough on its own to select for resistance.

#### 4.1.5.3 Ear declination and husk cover and tightness

Ear declination (DC) showed relatively high positive correlated responses with both infection severity index and husk cover/tightness (HC) across all three environments.

Selecting for better and tighter husk cover will respond in more erect ears. The positively correlated response between infection severity index and ear declination is discussed in 4.1.2.2.3.

#### 4.1.5.4 Yield potential, grain moisture and yield:moisture ratio

A relatively high positively correlated response was found between yield potential (YL) and the yield:moisture ratio (YM) across all three environments.

Non-significant negatively correlated responses were found between yield potential and *S. maydis* related characteristics for both Petit and Hillcrest. At Lichtenburg a non-significant positive correlated response was found due to low infection levels (see 4.1.1.1). Selection for *S. maydis* resistance will therefore not have a significant effect on yield potential.

#### 4.1.5.5 Stalk lodging, root lodging and total lodging

Only at Hillcrest, where lodging was a severe problem, high positively correlated responses were found between *S. maydis* related characteristics and stalk lodging (SL), root lodging (RL) and total lodging (TL). Also, a relatively high correlated response was found across all three locations for stalk, root and total lodging.

Selection for reduced lodging will therefore contribute towards a reduction in the incidence of rotted ears in environments where lodging is a problem.

## 4.2 Experiment 2 - Evaluation of the effects of maturity classification and genetic diversity in hybrids on *S. maydis* incidence

### 4.2.1 *South African developed hybrids*

Data on the incidence of percentage rotted ears, grain moisture content and days to flowering (50 % pollen shed) for South African developed experimental hybrids are provided in Table 4.27. Mean values are illustrated in Figure 4.7.

No significant differences ( $P>0.05$ ) were observed between the different hybrids developed from South African germplasm, based on any of the characteristics measured. This was possibly due to a combination of routine selection in local breeding programs for adaptation to South African environmental conditions as well as continued selection against genotypes with extreme susceptibility to the pathogen at normal disease levels.

### 4.2.2 *Hybrids derived from crosses between South African developed germplasm and those of exotic and temperate origin*

Data on percentage rotted ears, grain moisture content and days to flowering (50 % pollen shed) for exotic and temperate hybrids are provided in Table 4.28. Mean values are illustrated in Figure 4.8.

No significant differences ( $P>0.05$ ) were observed between the different exotic and temperate hybrids in terms of grain moisture content (percentage) at harvest. Significant differences ( $P<0.05$ ) were observed based on days to flowering. The linear regression shows that later flowering hybrids had less *S. maydis* infected ears.

The later hybrids have Argentine germplasm in common and possibly showed better resistance due to selection during development in the place of origin against *S. maydis* as well as good grain quality. The earlier hybrids (temperate) were more susceptible.

These are mostly B73 (SSS) crossed to Mo17 (C103), and selected in the USA under no selection pressure from *S. maydis*. Inferior grain quality (dent types as opposed to flint) and soft endosperm may have contributed to susceptibility, but needs further investigation.

#### **4.3 Experiment 3 - Recurrent selection breeding for *S. maydis* resistance in an inbred development program**

Frequency histograms of ear rows in various classes of percentage infection are shown for each cycle of selection in Figure 4.9 (B37/DO620Y/E739 complex), Figure 4.10 (B2/A2P22/A2P31 complex) and Figure 4.11 (other groups). For purposes of illustration, data were pooled over families. Note that the 1999/2000 evaluation at Cedara was lost to water logging due to prolonged and excessive rainfall.

The results from the 1999/2000 evaluation showed increased resistance in both the B37/DO620Y/E739 and B2/A2P31/A2P22 complexes (Figure 4.9 and Figure 4.10 respectively), with average infection rates decidedly in the resistant range. The elite crosses (B73/DO620Y/E739 complex) had progressed after three cycles of selection to a level of resistance where approximately 50 % of the selections showed less than 10 % infected ears. The distribution of the resistance was decidedly skew towards low levels of infection, with a total of 52 selections showing no infection. Similarly the B2/A2P31/A2P22 complex, in which resistant sources were deployed, provided 32 selections without disease. However, resistance in the other families (Figure 4.11) from the conventional program were found to be inadequate, with average levels of resistance approximating those of the susceptible standards. No selections without *S. maydis* infected ears were observed in any of the four populations.

Inbreds at the F5 level, with high levels of *S. maydis* resistance, were obtained during the 1999/2000 season from both the B37/DO620Y/E739 and B2/A2P31/A2P22 complexes. The results indicate that the use of parent inbreds with good levels of resistance (in this case the elite inbreds DO620Y, B37 and E739) will lead to quicker genetic gain for resistance under sufficient selection pressure from the pathogen, in

accordance with the principle formulated by Van der Plank (1984). After three to four generations of selection on an ear-to-row basis with efficient disease pressure, superior resistant genotypes can be obtained.

Experiment 1 showed that better GCA and SCA for resistance existed in local breeding programs utilizing inbreds like MON1, DO620Y and F2834T. These inbreds (MON1, DO620Y and F2834T) can be used in breeding efforts as a base level of resistance in a recurrent breeding program for inbred development. Inbreds are also available with good SCA for both yield and *S. maydis* resistance. These can be used directly in hybrid combinations with inbreds from different heterotic backgrounds. Inbred MON1 is a unique, unrelated inbred. By choosing the correct parental inbreds for the breeding population, applying disease pressure and using an efficient disease evaluation method, rapid genetic gain can be made for *S. maydis* resistance. The possibility of obtaining inbred lines with both high levels of resistance to *S. maydis* and combining ability for yield potential from the conventional program is less certain and may require a further cycle of recombination.

## CHAPTER V

### SUMMARY AND CONCLUSION

The objective of this study was to determine if germplasm available in South Africa and elsewhere have sufficient variation in resistance to be used for the improvement of levels of resistance to *S. maydis*, and to assess the viability of using recurrent selection as a breeding method under conditions of artificial infection with the pathogen.

The study comprised of three experiments. The first was a ten parent full diallel cross using Griffing's Method I. The parents and progeny were evaluated across three environments in South Africa: Petit, Hillcrest and Lichtenburg. The second experiment was an evaluation of the effects of maturity classification and genetic diversity of hybrids on *S. maydis* incidence. This trial was evaluated at one location. The third experiment involved the evaluation of a recurrent selection program to develop new genotypes with superior resistance to the disease. Selections were performed on an ear-to-row basis over three years. All three experiments were artificially inoculated with *S. maydis*.

Highly significant differences between genotypes were obtained for all characteristics measured at all locations. The location by genotype interaction was highly significant for all characteristics measured. Sufficient variability exists within local germplasm used in commercial breeding programs to improve *S. maydis* resistance in hybrids. Across all three environments, inbreds DO620Y and MON1 had the lowest and B73 and ARC1 the highest mean values for *S. maydis* related characteristics. The same applied for F1 combinations involving the above mentioned inbreds. F1 combinations MON1/DO620Y, F2834T/MON1, Mo17/DO620Y and I137TN/DO620Y had low values across all three environments indicating superior levels of resistance to *S. maydis*.

Based on the *S. maydis* incidence and repeatability recorded at the Petit location, (located centrally in the maize production area) this should be the most suitable

location to screen for *S. maydis* resistance under conditions of artificial inoculation. At Lichtenburg environmental conditions were not optimal for *S. maydis* development and the location seems to be unfavorable for future screening of resistant material.

All three *S. maydis* related characteristics, (percentage rotted ears, percentage rotted kernel mass and percentage rotted kernels) can be used and will be highly accurate, with percentage rotted ears being the least labor intensive, most practical and simplest method to screen large numbers of entries for *S. maydis* resistance.

Highly significant differences for GCA and SCA effects were obtained for all characteristics measured across all environments. Inbreds MON1, DO620Y and F2834T had the best negative GCA for all the *S. maydis* related characteristics measured, while inbreds MON1 and I137TN had the greatest positive GCA for yield potential. F1 combinations I137TN/Mo17, B73/F2834T, B37/F2834T and B37/DO620Y had the greatest negative SCA for all *S. maydis* related characteristics. F1 combinations with the greatest positive SCA for yield potential were B37/Mo17, H111/ARC1, H111/Mo17, MON1/H111, F2834T/ARC1, F2834T/Mo17, F2834T/MON1, I137TN/H111 and I137TN/F2834T. The GCA:SCA ratio indicated that *S. maydis* related characteristics are controlled by additive gene effects with low dominance and interaction effects.

Positive genetic correlations were found between the *S. maydis* related characteristics with no significant correlations between them and ear declination and husk cover and tightness. This indicates that upright ears is the result of *S. maydis* infection, rather than to predispose ears to the disease.

The heritability for the *S. maydis* related characteristics was extremely high with extremely high correlated responses between them.

Earlier maturity germplasm containing mostly B73 (SSS) and Mo17 (C103) in their background was more susceptible to *S. maydis* than the later flowering South African developed germplasm.

Selection in segregating progenies derived from crosses between the inbreds B37, DO620Y and E739 provided high levels of resistance within three generations, confirming previous indications of resistance present in these lines. Results also confirmed that these inbreds may serve as donor parents in a recurrent selection program for improvement of susceptible germplasm.

It is concluded that the use of a resistant source and sufficient *S. maydis* pressure in a breeding program are essential to ensure stability of resistance across environments. Earlier maturity germplasm must be used with care because of the susceptibility inherent to especially the B73 (SSS) background. A recurrent breeding program on an ear-to-row basis, with sufficient yield testing of the families, is advised. A selection index can be used to screen for *S. maydis* and other agronomic characteristics of importance according to their economic value and heritability.

## CHAPTER VI

### OPSOMMING EN GEVOLGTREKKING

Die doel van die studie was om vas te stel of genoeg variasie in plaaslike en oorsese kiemplasma bestaan om die weerstandsvlakke teen *S. maydis* te verbeter. Die studie het ook ten doel gehad om die lewensvatbaarheid van herhalende seleksie as 'n weerstandsteeltgniek vir *S. maydis* te bepaal onder kunsmatige inokulasies.

Die studie het bestaan uit drie eksperimente. Die eerste was 'n tien ouer dialleel kruisingsblok volgens Griffing se Metode I. Die ouers en nageslag is geplant op drie lokaliteite in Suid Afrika naamlik: Petit, Hillcrest en Lichtenburg. Die tweede eksperiment was 'n evaluering van die invloed van groeilenkte klassifikasie en genetiese diversiteit van kiemplasma op die insidensie van *S. maydis*. Eksperiment twee is uitgevoer op een lokaliteit. Die derde eksperiment het ten doel gehad om vas te stel of herhalende seleksie met sukses gebruik kan word om verbeterde weerstand vir die siekte te kry. Seleksies is gedoen op 'n kop-tot-ry basis oor drie opeenvolgende jare. Al drie eksperimente is kunsmatig geïnkuleer met *S. maydis*.

Genotipes het hoog betekenisvol verskil vir al die eienskappe gemeet. Hoogs betekenisvolle verskille is ook gevind vir die lokaliteit-genotipe interaksie. Genoeg variasie is gevind in plaaslike kiemplasma, wat in kommersiële teelprogramme gebruik word, om *S. maydis* weerstand te verkry. Ingeteelde lyne DO620Y en MON1 het die laagste gemiddeldes vir *S. maydis* verwante eienskappe getoon terwyl B73 en ARC1 die hoogste waardes getoon het. Dieselfde geld vir F1 kombinasies met bogenoemde ingeteelde lyne. F1 kombinasies MON1/DO620Y, F2834T/MON1, Mo17/DO620Y en I137TN/DO620Y het die laagste waardes gehad oor al drie lokaliteite vir die *S. maydis* verwante eienskappe wat gedui het op verbeterde weerstand.

Gebaseer op die voorkoms en herhaalbaarheid van *S. maydis*, sal Petit (sentraal geleë in die mielie produserende area), die beste lokaliteit wees om deur gebruik van kunsmatige inokulasies vir weerstand teen die patogeen te evalueer. Omgewings-

toestande was nie optimaal by Lichtenburg vir *S. maydis* ontwikkeling nie en die lokaliteit moet verkieslik nie gebruik word vir weerstands evaluering nie.

Al drie *S. maydis* verwante eienskappe nl. persentasie vrot koppe, persentasie vrot pitmassa en persentasie vrot pitte kan met hoë doeltreffendheid gebruik word vir die evaluering van weerstand. Persentasie vrot koppe sal egter die beste metode wees as gevolg daarvan dat dit die minste arbeidsintensief is, asook die mees praktiese en eenvoudige metode om groot getalle inskrywings vir *S. maydis* te evalueer.

Hoogs betekenisvolle verskille is gevind vir beide algemene kombineer vermoë (AKV) en spesifieke kombineer vermoë (SKV) vir al die eienskappe gemeet by al die lokaliteite. Ingeteelde lyne MON1, DO620Y en F2834T het die beste negatiewe SKV gehad vir die *S. maydis* verwante eienskappe terwyl MON1 en I137TN ook die hoogste positiewe SKV gehad het vir opbrengspotensiaal. F1 kombinasies I137TN/Mo17, B73/F2834T, B37/F2834T en B37/DO620Y het die grootste negatiewe SKV vir die *S. maydis* verwante eienskappe terwyl B37/Mo17, H111/ARC1, H111/Mo17, MON1/H111, F2834T/ARC1, F2834T/Mo17, F2834T/MON1, I137TN/H111 en I137TN/F2834T die hoogste positiewe SKV het. Die AKV:SKV verhouding het getoon dat die *S. maydis* weerstand hoofsaaklik beheer word deur additiewe gene effekte met lae dominansie en interaksie effekte.

Die *S. maydis* verwante eienskappe was geneties positief gekorreleer met mekaar, maar nie gekorreleer met kopdeklinasie of met kopblaarbedekking en digtheid nie. Dit het daarop gedui dat regop koppe die gevolg was van *S. maydis* infeksie, en nie soos vroeër geglo, die rede was vir *S. maydis* infeksie nie.

Uitsonderlike hoë oorerflikhede is gevind vir die *S. maydis* verwante eienskappe met 'n hoë gekorreleerde responsie tussen die eienskappe.

Materiaal met kort groeiseisoenbehoefte wat meestal B73 (SSS) en Mo17 (C103) in hulle genetiese agtergrond het, was meer vatbaar vir *S. maydis* as die later materiaal van Suid Afrikaanse oorsprong.

Deur te selekteer in die segregerende nageslag van die kruisings tussen B37, DO620Y en E739 is hoë vlakke van weerstand verkry na net drie generasies van seleksie onder kunsmatige inokulasie. Dit het ook vroeëre bevindings bevestig dat weerstand teenwoordig is in die bogenoemde ingeteelde lyne.

Die aanbevelings uit hierdie studie is dat die keuse en gebruik van 'n weerstandsbron asook 'n doeltreffende *S. maydis* druk baie belangrik is om stabiliteit vir weerstand oor omgewings te verseker. Korter groeilengte kiemplasma, veral B73 en Mo17 heterotiese tipes moet met versigtigheid gebruik word in plaaslike teelprogramme as gevolg van die lyne se hoë vatbaarheid. 'n Herhalende seleksie teelprogram op 'n kop-tot-ry basis met doeltreffende opbrengs toetsing binne families is aantebevele om suksesvolle genetiese vordering te maak vir weerstand in kommersiële programme. Gebruik van 'n seleksie-indeks word ook sterk aanbeveel om vir beide *S. maydis* en ander agronomiese eienskappe terselfdertyd te selekteer op grond van hulle ekonomiese waardes en oorerflikheid.

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**Table 4.1 Mean squares for *S. maydis* related characteristics for Petk (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC
Replication	2	1471.70**	504.31**	831.70**	0.34	7.94**	4.69*
Genotype	98	768.64**	375.51**	619.75**	8.25**	13.19**	11.11**
Residual	196	183.08	82.96	137.61	2.40	1.21	1.483

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

**Table 4.2 Mean squares for *S. maydis* related characteristics for Hillcrest (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC
Replication	2	4130.01**	1000.65**	1009.68**	17.24**	0.60	20.31**
Genotype	94	724.34**	238.47**	258.61**	6.59**	9.83**	7.75**
Residual	188	62.76	35.48	45.45	1.45	1	1.72

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

**Table 4.3 Mean squares for *S. maydis* related characteristics for Lichtenburg (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC
Replication	2	20.90	1.70	17.55	4.54	0.42	3.49
Genotype	92	52.73**	28.89**	35.59**	8.73**	12.62**	14.01**
Residual	184	14.39	10.93	10.55	4.40	2.05	2.19

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

**Table 4.4 Mean squares for *S. maydis* related characteristics for Petit, Hillcrest and Lichtenburg (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC
Location	2	39289.23**	8634.66**	11653.76**	365.71**	38.32**	77.89**
Rep in loc	6	1883.58**	537.11**	639.79**	7.62*	2.71	9.77**
Genotype	92	868.06**	343.59**	480.43**	12.04**	29.66**	26.78**
Loc by genotype	184	359.65**	160.83**	234.84**	5.49**	2.93**	3.19**
Residual	552	87.64	43.76	66.39	2.76	1.51	1.80

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.5a Means for various *S. maydis* related characteristics for Pettit (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
1	1x2	I137TN/B73	96	2.53	99	0.00	99	0.00	94	2.00	91	3.33	84	3.67
2	1x3	I137TN/B37	27	28.94	68	3.67	20	21.36	25	6.33	60	7.00	27	7.33
3	1x4	I137TN/F2834T	45	20.00	43	9.00	55	7.55	41	5.67	71	5.67	60	5.00
4	1x5	I137TN/MON1	82	7.01	65	4.33	66	5.62	72	4.00	93	3.33	82	4.00
5	1x6	I137TN/DO620Y	87	5.00	87	1.00	86	1.34	69	4.00	83	4.67	86	3.67
6	1x7	I137TN/E739	53	17.72	52	7.00	40	11.78	60	4.33	6	9.00	17	8.33
7	1x8	I137TN/H111	86	5.84	85	1.67	83	2.29	65	4.00	76	5.00	64	5.00
8	1x9	I137TN/Mo17	19	33.61	9	21.33	28	19.35	29	6.00	48	8.00	87	3.67
9	1x10	I137TN/ARC1	56	17.21	34	11.67	30	18.08	78	3.67	89	3.67	47	5.67
10	2x1	B73/I137TN	49	18.41	42	9.00	36	13.42	26	6.00	58	7.00	43	5.67
11	2x3	B73/B37	9	41.23	19	17.33	19	21.50	31	6.00	11	9.00	77	4.33
12	2x4	B73/F2834T	43	20.86	37	10.00	64	5.83	93	2.33	64	6.33	65	4.67
13	2x5	B73/MON1	50	18.39	22	16.67	27	19.36	21	6.33	67	6.00	78	4.00
14	2x6	B73/DO620Y	68	12.33	60	5.67	51	8.20	74	4.00	14	9.00	50	5.33
15	2x7	B73/E739	28	28.61	46	8.00	58	7.34	52	4.67	15	9.00	34	7.00
16	2x8	B73/H111	13	38.66	13	19.33	26	19.75	37	5.67	16	9.00	52	5.33
17	2x9	B73/Mo17	5	54.39	5	33.33	7	37.36	9	7.00	57	7.00	85	3.67
18	2x10	B73/ARC1	1	79.73	1	62.00	1	77.14	2	8.67	77	5.00	89	3.33
19	3x1	B37/I137TN	16	36.41	11	20.67	12	26.09	47	5.33	19	9.00	40	6.00
20	3x2	B37/B73	25	31.62	23	16.33	29	19.26	44	5.33	20	9.00	44	5.67
22	3x5	B37/MON1	63	15.56	64	4.67	63	6.17	57	4.33	43	8.67	24	8.00
23	3x6	B37/DO620Y	73	9.60	81	2.00	74	3.62	58	4.33	23	9.00	48	5.67
24	3x7	B37/E739	17	35.54	21	17.00	25	20.28	38	5.67	24	9.00	5	9.00
25	3x8	B37/H111	70	11.23	55	6.84	61	7.26	86	3.06	99	3.00	8	9.00
26	3x9	B37/Mo17	29	27.81	24	16.33	24	20.58	33	6.00	13	9.00	59	5.00
27	3x10	B37/ARC1	10	40.03	8	25.00	5	37.73	4	7.67	46	8.33	28	7.33
28	4x1	F2834T/I137TN	94	2.86	91	0.67	88	1.20	98	1.67	90	3.67	99	3.00
29	4x2	F2834T/B73	64	15.34	59	5.67	52	7.98	51	5.00	59	7.00	75	4.33
30	4x3	F2834T/B37	58	16.65	96	0.00	96	0.00	88	3.00	17	9.00	15	8.33
31	4x5	F2834T/MON1	99	0.90	98	0.00	98	0.00	99	1.00	94	3.00	91	3.33
32	4x6	F2834T/DO620Y	91	3.33	95	0.33	94	0.55	91	2.67	66	6.00	69	4.67
33	4x7	F2834T/E739	59	16.63	57	5.67	70	4.64	84	3.33	8	9.00	9	9.00
34	4x8	F2834T/H111	60	16.55	83	1.67	85	1.72	68	4.00	47	8.33	92	3.33
35	4x9	F2834T/Mo17	51	18.32	28	14.00	35	14.27	48	5.00	28	9.00	81	4.00
36	4x10	F2834T/ARC1	92	3.26	97	0.00	97	0.00	97	1.67	36	9.00	67	4.67
37	5x1	MON1/I137TN	81	7.31	72	3.00	72	4.35	70	4.00	88	4.00	41	5.67
38	5x2	MON1/B73	12	39.33	20	17.00	22	20.95	15	6.67	84	4.33	90	3.33
39	5x3	MON1/B37	31	25.82	32	12.00	38	12.65	11	7.00	49	8.00	25	7.67
40	5x4	MON1/F2834T	84	6.37	53	7.00	46	9.72	39	5.67	96	3.00	94	3.00
41	5x6	MON1/DO620Y	98	1.15	93	0.67	89	1.19	83	3.33	92	3.33	31	7.00
42	5x7	MON1/E739	54	17.66	45	8.33	37	13.04	61	4.33	56	7.00	4	9.00
43	5x8	MON1/H111	42	20.90	49	8.00	43	10.75	63	4.33	69	6.00	68	4.67
44	5x9	MON1/Mo17	30	26.87	35	11.09	33	15.64	34	6.00	55	7.33	63	5.00
45	5x10	MON1/ARC1	44	20.79	33	11.67	32	16.57	46	5.33	85	4.33	23	8.00
46	6x1	DO620Y/I137TN	77	7.94	67	3.67	77	3.35	80	3.67	87	4.33	72	4.33
47	6x2	DO620Y/B73	18	34.27	29	13.33	14	24.20	24	6.33	22	9.00	74	4.33
48	6x3	DO620Y/B37	75	9.06	80	2.00	80	2.90	36	5.67	35	9.00	42	5.67
49	6x4	DO620Y/F2834T	80	7.44	84	1.67	84	2.18	79	3.67	81	4.67	66	4.67
50	6x5	DO620Y/MON1	93	3.18	89	0.67	90	1.19	71	4.00	78	5.00	21	8.00
		<b>Mean</b>		21.56		10.52		13.47		4.95		7.10		5.84
		<b>LSD (0.05)</b>		18.26		12.29		15.83		2.09		1.49		1.64
		<b>Repeatability</b>		51.60		54.00		53.90		44.80		76.70		68.40

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.5b Means for various *S. maydis* related characteristics for Petit (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
51	6x7	DO620Y/E739	90	3.42	94	0.33	95	0.51	89	3.00	45	8.33	35	6.67
52	6x8	DO620Y/H111	83	6.82	92	0.67	87	1.31	92	2.33	1	9.00	39	6.33
53	6x9	DO620Y/Mo17	85	6.29	77	2.33	78	3.17	13	7.00	2	9.00	73	4.33
54	6x10	DO620Y/ARC1	23	32.28	25	15.67	18	22.02	23	6.33	54	7.67	22	8.00
55	7x1	E739/I137TN	20	33.48	27	15.33	21	21.27	16	6.67	4	9.00	10	8.67
56	7x2	E739/B73	32	25.04	44	8.67	41	11.50	42	5.67	5	9.00	33	7.00
57	7x3	E739/B37	34	24.05	48	8.00	62	6.66	45	5.33	25	9.00	6	9.00
58	7x4	E739/F2834T	61	15.66	71	3.00	75	3.56	59	4.33	7	9.00	7	9.00
59	7x5	E739/MON1	88	4.89	86	1.00	93	0.72	90	2.67	42	8.67	1	9.00
60	7x6	E739/DO620Y	79	7.67	78	2.33	76	3.47	85	3.33	9	9.00	18	8.00
61	7x8	E739/H111	74	9.43	74	2.67	67	5.52	54	4.67	10	9.00	14	8.33
62	7x9	E739/Mo17	37	22.58	39	10.00	39	12.13	49	5.00	39	9.00	13	8.67
63	7x10	E739/ARC1	55	17.33	62	5.33	49	8.71	62	4.33	12	9.00	16	8.33
64	8x1	H111/I137TN	36	22.93	40	9.33	42	10.87	19	6.33	79	5.00	62	5.00
65	8x2	H111/B73	8	41.85	47	8.00	71	4.64	77	3.67	37	9.00	71	4.33
66	8x3	H111/B37	14	37.26	12	20.00	9	28.39	55	4.67	50	8.00	32	7.00
67	8x4	H111/F2834T	76	8.31	75	2.34	73	3.93	96	1.94	80	5.00	20	8.00
68	8x5	H111/MON1	33	25.00	54	7.00	59	7.29	30	6.00	51	7.67	36	6.67
69	8x6	H111/DO620Y	72	9.70	70	3.33	69	4.68	35	5.67	44	8.33	57	5.00
70	8x7	H111/E739	67	12.65	82	1.67	81	2.42	75	4.00	31	9.00	11	8.67
71	8x9	H111/Mo17	46	19.45	31	12.00	17	22.36	5	7.67	33	9.00	79	4.00
72	8x10	H111/ARC1	57	16.74	51	7.67	48	9.23	50	5.00	53	7.67	29	7.33
73	9x1	Mo17/I137TN	62	15.60	36	11.00	34	14.59	18	6.33	63	6.67	76	4.33
74	9x2	Mo17/B73	6	47.72	6	31.33	6	37.61	14	7.00	32	9.00	55	5.00
75	9x3	Mo17/B37	26	30.80	16	19.00	15	23.38	12	7.00	40	9.00	58	5.00
76	9x4	Mo17/F2834T	89	4.56	79	2.00	82	2.33	66	4.00	18	9.00	46	5.67
77	9x5	Mo17/MON1	66	14.11	30	12.67	16	22.81	20	6.33	26	9.00	45	5.67
78	9x6	Mo17/DO620Y	95	2.61	88	1.00	92	1.08	95	2.00	27	9.00	70	4.33
79	9x7	Mo17/E739	41	20.95	41	9.33	45	10.17	32	6.00	3	9.00	3	9.00
80	9x8	Mo17/H111	22	32.62	18	18.08	44	10.43	7	7.47	29	9.00	56	5.00
81	9x10	Mo17/ARC1	15	36.83	17	18.67	11	27.95	6	7.67	73	5.33	95	3.00
82	10x1	ARC1/I137TN	52	17.75	58	5.67	60	7.26	56	4.33	82	4.67	37	6.67
83	10x2	ARC1/B73	7	45.06	7	29.33	8	37.02	17	6.33	65	6.33	96	3.00
84	10x3	ARC1/B37	11	39.81	10	21.00	13	25.51	22	6.33	34	9.00	30	7.00
85	10x4	ARC1/F2834T	38	22.11	38	10.00	56	7.39	87	3.00	68	6.00	51	5.33
86	10x5	ARC1/MON1	21	32.68	14	19.33	10	27.97	43	5.33	74	5.33	12	8.67
87	10x6	ARC1/DO620Y	65	15.07	56	6.00	54	7.83	8	7.33	61	7.00	80	4.00
88	10x7	ARC1/E739	47	19.35	63	5.00	50	8.31	28	6.00	30	9.00	2	9.00
89	10x8	ARC1/H111	35	23.93	50	7.67	47	9.34	40	5.67	86	4.33	53	5.33
90	10x9	ARC1/Mo17	4	62.07	4	37.00	4	52.64	1	8.67	75	5.33	93	3.00
91	1	I137TN	24	32.16	15	19.09	23	20.67	81	3.50	98	3.00	83	3.67
92	2	B73	3	67.73	3	43.00	3	56.27	10	7.00	52	7.67	88	3.67
93	3	B37	2	76.27	2	56.33	2	73.12	3	7.67	72	5.67	54	5.00
94	4	F2834T	40	21.06	61	5.33	65	5.77	73	4.00	97	3.00	97	3.00
95	5	MON1	71	10.09	69	3.33	68	4.98	27	6.00	95	3.00	38	6.33
96	6	DO620Y	97	1.97	90	0.67	91	1.13	67	4.00	62	6.67	49	5.67
97	7	E739	48	18.61	76	2.33	79	3.08	76	3.67	21	9.00	19	8.00
98	8	H111	69	11.34	73	2.84	57	7.39	64	4.06	38	9.00	98	3.00
99	9	Mo17	39	21.08	26	15.33	31	17.65	53	4.67	41	9.00	26	7.67
100	10	ARC1	78	7.70	66	4.08	53	7.96	82	3.47	70	6.00	61	5.00
		Mean		21.56		10.52		13.47		4.95		7.10		5.84
		LSD (0.05)		18.26		12.29		15.83		2.09		1.49		1.64
		Repeatability		51.60		54.00		53.90		44.80		76.70		68.40

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.6a Means for various *S. maydis* related characteristics for Hillcrest (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
1	1x2	I137TN/B73	35	29.96	33	11.74	44	10.62	29	6.00	79	5.67	83	4.00
2	1x3	I137TN/B37	25	35.33	31	12.44	43	10.69	68	4.67	2	9.00	59	5.00
3	1x4	I137TN/F2834T	20	36.21	52	8.57	53	9.07	46	5.33	60	8.33	68	4.67
4	1x5	I137TN/MON1	88	6.42	69	6.56	41	10.86	84	3.67	94	3.00	3	8.67
5	1x6	I137TN/DO620Y	94	3.01	85	4.25	92	4.39	74	4.33	5	9.00	91	3.33
6	1x7	I137TN/E739	18	36.90	26	13.62	27	13.88	71	4.67	6	9.00	2	9.00
7	1x8	I137TN/H111	62	17.38	68	6.74	64	7.77	40	5.67	82	5.00	42	5.67
8	1x9	I137TN/Mo17	42	25.71	51	8.71	68	7.14	76	4.33	8	9.00	81	4.00
9	1x10	I137TN/ARC1	29	31.85	39	10.33	52	9.16	19	6.67	76	6.33	70	4.67
10	2x1	B73/I137TN	31	31.06	32	12.38	38	12.18	47	5.33	10	9.00	84	4.00
11	2x3	B73/B37	41	25.82	65	7.34	69	7.13	73	4.67	11	9.00	61	5.00
13	2x5	B73/MON1	68	13.72	82	4.82	76	6.04	79	4.00	55	8.33	75	4.33
14	2x6	B73/DO620Y	79	9.48	76	5.89	86	5.01	43	5.67	14	9.00	57	5.00
15	2x7	B73/E739	52	23.12	79	5.30	85	5.04	56	5.00	15	9.00	34	6.67
16	2x8	B73/H111	69	13.42	87	4.02	79	5.72	32	6.00	16	9.00	47	5.33
17	2x9	B73/Mo17	34	30.02	62	7.49	61	8.02	53	5.00	17	9.00	74	4.33
18	2x10	B73/ARC1	11	44.50	12	19.83	13	20.54	28	6.33	63	7.67	62	4.67
19	3x1	B37/I137TN	21	36.01	24	14.23	25	14.30	63	5.00	19	9.00	76	4.33
20	3x2	B37/B73	59	20.62	57	8.13	60	8.06	69	4.67	20	9.00	48	5.33
22	3x5	B37/MON1	75	10.78	86	4.10	93	4.12	90	3.33	22	9.00	30	6.67
23	3x6	B37/DO620Y	82	8.14	81	4.90	77	6.03	1	9.33	23	9.00	45	5.67
24	3x7	B37/E739	26	34.31	16	16.56	14	20.44	33	6.00	24	9.00	9	8.33
25	3x8	B37/H111	57	21.62	47	9.21	57	8.25	25	6.33	25	9.00	38	5.67
26	3x9	B37/Mo17	72	12.25	58	8.04	51	9.38	45	5.33	26	9.00	55	5.00
27	3x10	B37/ARC1	27	34.06	40	10.24	32	12.83	52	5.00	59	8.33	10	8.00
28	4x1	F2834T/I137TN	65	16.13	59	7.95	70	7.06	77	4.33	83	5.00	69	4.67
29	4x2	F2834T/B73	4	51.37	6	28.02	6	28.50	7	7.67	74	7.00	87	4.00
30	4x3	F2834T/B37	24	35.38	10	20.79	16	20.02	39	5.67	30	9.00	82	4.00
31	4x5	F2834T/MON1	87	6.67	78	5.50	62	7.95	88	3.33	87	4.33	90	3.33
32	4x6	F2834T/DO620Y	80	9.42	74	6.12	82	5.48	48	5.33	70	7.00	67	4.67
33	4x7	F2834T/E739	3	56.35	4	31.96	5	31.46	20	6.67	58	8.33	14	8.00
34	4x8	F2834T/H111	48	24.08	46	9.32	39	11.22	60	5.00	57	8.33	73	4.33
35	4x9	F2834T/Mo17	33	30.16	17	16.51	31	12.91	14	7.00	93	3.00	92	3.33
36	4x10	F2834T/ARC1	45	24.86	30	12.63	22	15.89	22	6.67	36	9.00	36	6.00
37	5x1	MON1/I137TN	85	7.30	48	9.01	49	9.50	94	2.33	88	4.33	50	5.33
38	5x2	MON1/B73	93	3.60	95	2.87	54	8.96	57	5.00	13	9.00	95	2.67
39	5x3	MON1/B37	56	22.12	19	16.29	17	18.24	83	3.67	54	8.33	54	5.00
40	5x4	MON1/F2834T	86	7.12	83	4.54	88	4.86	78	4.33	91	3.00	89	3.67
41	5x6	MON1/DO620Y	92	4.60	77	5.50	78	5.80	95	1.67	89	4.33	37	6.00
42	5x7	MON1/E739	50	23.61	37	10.96	34	12.43	75	4.33	77	6.33	11	8.00
43	5x8	MON1/H111	47	24.11	42	10.11	24	14.72	91	3.00	53	8.33	71	4.67
45	5x10	MON1/ARC1	38	29.03	25	13.88	33	12.65	30	6.00	80	5.67	58	5.00
46	6x1	DO620Y/I137TN	76	10.35	38	10.47	36	12.38	82	3.67	21	9.00	85	4.00
47	6x2	DO620Y/B73	70	12.74	84	4.48	87	4.94	44	5.33	44	9.00	56	5.00
48	6x3	DO620Y/B37	91	4.66	94	3.20	90	4.82	85	3.67	35	9.00	51	5.33
49	6x4	DO620Y/F2834T	73	11.67	45	9.49	56	8.64	50	5.33	73	7.00	60	5.00
50	6x5	DO620Y/MON1	81	8.49	50	8.73	42	10.81	86	3.67	81	5.00	12	8.00
		<b>Mean</b>		25.40		11.74		12.65		5.43		7.76		5.74
		<b>LSD (0.05)</b>		10.69		8.04		9.10		1.62		1.52		1.77
		<b>Repeatability</b>		77.80		65.60		61.00		54.20		69.30		53.80

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.6b Means for various *S. maydis* related characteristics for Hillcrest (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
51	6x7	D0620Y/E739	22	35.95	66	7.20	75	6.09	65	4.67	38	9.00	8	8.33
52	6x8	DO620Y/H111	66	15.64	72	6.43	50	9.49	54	5.00	1	9.00	49	5.33
53	6x9	DO620Y/Mo17	89	6.38	80	4.93	80	5.60	89	3.33	46	9.00	39	5.67
54	6x10	D0620Y/ARC1	32	31.06	36	11.15	26	14.16	24	6.33	3	9.00	31	6.67
55	7x1	E739/I137TN	5	50.83	8	25.37	7	27.59	61	5.00	4	9.00	17	7.67
56	7x2	E739/B73	51	23.44	67	6.92	71	6.89	66	4.67	18	9.00	21	7.33
57	7x3	E739/B37	19	36.71	35	11.22	59	8.10	34	5.67	31	9.00	6	8.33
58	7x4	E739/F2834T	9	49.20	7	27.06	8	26.54	6	8.00	7	9.00	4	8.67
59	7x5	E739/MON1	46	24.31	60	7.83	58	8.22	81	4.00	34	9.00	1	9.00
60	7x6	E739/DO620Y	55	22.71	70	6.51	73	6.86	72	4.67	9	9.00	5	8.33
61	7x8	E739/H111	64	17.03	44	9.63	63	7.88	67	4.67	47	9.00	24	7.00
62	7x9	E739/Mo17	23	35.90	22	14.51	28	13.68	31	6.00	51	9.00	19	7.33
63	7x10	E739/ARC1	36	29.78	64	7.35	55	8.83	37	5.67	12	9.00	25	7.00
64	8x1	H111/I137TN	40	26.77	23	14.26	21	16.37	36	5.67	64	7.67	72	4.33
65	8x2	H111/B73	71	12.28	73	6.31	72	6.88	27	6.33	40	9.00	80	4.00
66	8x3	H111/B37	43	25.70	54	8.41	45	10.50	41	5.67	41	9.00	41	5.67
68	8x5	H111/MON1	83	8.08	90	3.71	94	3.64	92	3.00	75	6.33	77	4.33
69	8x6	H111/DO620Y	77	10.27	75	6.00	74	6.81	58	5.00	52	8.33	93	3.33
70	8x7	H111/E739	61	18.95	43	9.73	37	12.25	70	4.67	45	9.00	29	7.00
71	8x9	H111/Mo17	78	9.59	93	3.21	84	5.13	49	5.33	39	9.00	64	4.67
72	8x10	H111/ARC1	60	19.40	34	11.48	46	10.31	17	6.67	67	7.67	33	6.67
74	9x2	Mo17/B73	54	22.78	56	8.17	65	7.68	64	5.00	42	9.00	52	5.33
75	9x3	Mo17/B37	63	17.05	71	6.46	81	5.50	62	5.00	43	9.00	88	4.00
76	9x4	Mo17/F2834T	44	25.45	63	7.41	48	9.75	42	5.67	48	9.00	26	7.00
77	9x5	Mo17/MON1	84	7.73	88	3.91	91	4.51	80	4.00	68	7.67	32	6.67
78	9x6	Mo17/DO620Y	90	5.32	89	3.86	83	5.16	93	2.33	27	9.00	40	5.67
79	9x7	Mo17/E739	30	31.70	53	8.49	47	10.03	21	6.67	28	9.00	16	7.67
80	9x8	Mo17/H111	74	11.21	91	3.59	89	4.85	59	5.00	29	9.00	63	4.67
81	9x10	Mo17/ARC1	16	37.84	20	16.16	19	17.25	15	7.00	72	7.00	65	4.67
82	10x1	ARC1/I137TN	6	50.67	27	13.27	23	15.53	23	6.33	84	5.00	18	7.33
83	10x2	ARC1/B73	7	49.82	15	17.58	12	21.86	12	7.00	32	9.00	78	4.33
84	10x3	ARC1/B37	17	37.17	49	8.76	66	7.56	51	5.33	33	9.00	35	6.33
85	10x4	ARC1/F2834T	10	48.40	14	17.88	15	20.07	16	7.00	85	5.00	79	4.33
86	10x5	ARC1/MON1	14	38.15	11	20.54	18	17.93	26	6.33	69	7.00	7	8.33
87	10x6	ARC1/DO620Y	39	28.60	41	10.14	40	10.93	18	6.67	71	7.00	23	7.00
88	10x7	ARC1/E739	13	42.75	29	12.91	30	13.44	55	5.00	37	9.00	27	7.00
89	10x8	ARC1/H111	15	37.96	21	15.10	20	16.43	38	5.67	65	7.67	13	8.00
90	10x9	ARC1/Mo17	28	33.17	28	13.26	29	13.50	13	7.00	56	8.33	86	4.00
91	1	I137TN	12	42.88	5	30.48	4	36.47	4	8.33	90	4.33	66	4.67
92	2	B73	2	72.18	3	39.22	2	42.50	2	9.00	61	8.00	43	5.67
93	3	B37	8	49.50	2	40.37	3	42.00	11	7.33	62	8.00	44	5.67
94	4	F2834T	49	23.69	9	21.67	9	24.75	8	7.33	92	3.00	94	3.00
95	5	MON1	67	14.98	61	7.54	67	7.55	87	3.33	95	3.00	28	7.00
96	6	DO620Y	95	2.21	92	3.32	95	3.28	35	5.67	78	6.33	53	5.00
97	7	E739	53	22.94	55	8.35	35	12.39	9	7.33	50	9.00	20	7.33
98	8	H111	58	20.71	18	16.38	11	21.94	5	8.00	66	7.67	22	7.00
99	9	Mo17	37	29.63	13	19.09	10	22.83	10	7.33	49	9.00	46	5.33
100	10	ARC1	1	83.19	1	58.35	1	58.74	3	8.67	86	5.00	15	8.00
		Mean		25.40		11.74		12.65		5.43		7.76		5.74
		LSD (0.05)		10.69		8.04		9.10		1.62		1.52		1.77
		Repeatability		77.80		65.60		61.00		54.20		69.30		53.80

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.7a Means for various *S. maydis* related characteristics for Lichtenburg (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
1	1x2	I137TN/B73	35	3.16	40	1.00	41	1.48	60	2.33	73	5.67	53	4.00
2	1x3	I137TN/B37	19	5.21	4	7.67	17	3.35	15	5.00	32	8.67	14	7.67
3	1x4	I137TN/F2834T	47	2.59	5	7.00	15	3.50	41	3.33	40	8.33	89	1.67
4	1x5	I137TN/MON1	62	1.15	53	0.67	56	0.88	74	1.67	64	6.67	47	4.33
5	1x6	I137TN/DO620Y	51	2.30	20	2.00	23	2.63	56	2.33	35	8.67	85	2.33
6	1x7	I137TN/E739	46	2.71	41	1.00	42	1.39	31	4.00	6	9.00	22	7.00
7	1x8	I137TN/H111	36	3.14	33	1.17	36	1.75	11	5.33	87	3.67	80	2.67
8	1x9	I137TN/Mo17	43	2.90	29	1.50	28	2.01	52	3.00	78	5.00	74	3.00
9	1x10	I137TN/ARC1	28	4.10	56	0.50	58	0.86	22	4.67	86	3.67	35	5.67
10	2x1	B73/I137TN	22	5.06	16	2.83	8	4.69	14	5.00	53	8.00	91	1.67
11	2x3	B73/B37	34	3.19	26	1.50	33	1.86	33	4.00	33	8.67	48	4.33
13	2x5	B73/MON1	66	1.01	83	0.00	80	0.12	64	2.00	39	8.33	30	6.00
14	2x6	B73/DO620Y	90	0.00	90	0.00	90	0.00	90	1.00	46	8.33	84	2.33
15	2x7	B73/E739	38	3.03	51	0.67	53	1.05	53	2.67	2	9.00	36	5.33
16	2x8	B73/H111	6	9.65	9	3.83	4	5.26	21	4.67	16	9.00	68	3.33
17	2x9	B73/Mo17	4	11.01	13	3.00	20	2.77	39	3.67	34	8.67	59	3.67
18	2x10	B73/ARC1	8	8.55	6	4.67	6	4.82	4	6.33	70	5.67	60	3.67
19	3x1	B37/I137TN	33	3.34	55	0.67	48	1.18	62	2.33	19	9.00	19	7.00
20	3x2	B37/B73	14	6.49	32	1.17	24	2.62	16	5.00	13	9.00	38	5.33
22	3x5	B37/MON1	57	1.42	85	0.00	85	0.00	73	1.67	30	8.67	20	7.00
24	3x7	B37/E739	53	1.96	30	1.50	39	1.54	49	3.00	21	9.00	1	9.00
25	3x8	B37/H111	15	5.61	18	2.33	11	4.36	2	7.00	65	6.33	11	8.00
26	3x9	B37/Mo17	39	3.01	84	0.00	73	0.39	65	2.00	29	8.67	79	3.00
27	3x10	B37/ARC1	27	4.18	37	1.17	51	1.09	13	5.33	60	7.00	31	6.00
28	4x1	F2834T/I137TN	18	5.21	64	0.33	61	0.75	55	2.67	79	4.67	75	3.00
29	4x2	F2834T/B73	59	1.31	67	0.17	75	0.26	6	6.00	22	9.00	77	3.00
30	4x3	F2834T/B37	79	0.13	74	0.02	76	0.21	81	1.00	48	8.33	66	3.33
31	4x5	F2834T/MON1	82	0.00	82	0.00	83	0.11	82	1.00	68	6.33	93	1.00
32	4x6	F2834T/DO620Y	83	0.00	93	0.00	93	0.00	83	1.00	66	6.33	49	4.33
33	4x7	F2834T/E739	42	2.94	68	0.17	64	0.68	45	3.00	23	9.00	18	7.67
34	4x8	F2834T/H111	74	0.64	59	0.50	52	1.07	44	3.33	43	8.33	87	1.67
36	4x10	F2834T/ARC1	31	3.46	58	0.50	38	1.54	63	2.33	63	6.67	63	3.67
37	5x1	MON1/I137TN	61	1.15	66	0.17	72	0.42	77	1.00	84	4.00	71	3.00
38	5x2	MON1/B73	89	0.00	89	0.00	78	0.17	89	1.00	76	5.33	86	2.00
39	5x3	MON1/B37	58	1.39	61	0.33	63	0.73	72	1.67	28	8.67	54	4.00
40	5x4	MON1/F2834T	88	0.00	88	0.00	88	0.00	88	1.00	83	4.00	90	1.67
41	5x6	MON1/DO620Y	87	0.00	80	0.00	87	0.00	87	1.00	88	3.33	82	2.33
42	5x7	MON1/E739	86	0.00	86	0.00	86	0.00	86	1.00	42	8.33	9	8.33
43	5x8	MON1/H111	91	0.00	91	0.00	82	0.11	91	1.00	67	6.33	78	3.00
45	5x10	MON1/ARC1	68	0.85	48	0.83	57	0.87	70	1.67	75	5.33	10	8.33
46	6x1	DO620Y/I137TN	63	1.11	47	0.83	19	2.79	43	3.33	14	9.00	32	6.00
47	6x2	DO620Y/B73	73	0.65	72	0.17	77	0.19	69	2.00	15	9.00	70	3.33
48	6x3	DO620Y/B37	71	0.68	77	0.00	92	0.00	67	2.00	20	9.00	44	4.67
49	6x4	DO620Y/F2834T	92	0.00	92	0.00	81	0.12	92	1.00	49	8.33	45	4.67
50	6x5	DO620Y/MON1	77	0.58	76	0.00	84	0.10	38	3.67	85	3.67	21	7.00
		<b>Mean</b>		3.40		1.62		2.06		3.22		7.25		4.91
		<b>LSD (0.05)</b>		5.12		4.46		4.38		2.83		1.93		2.00
		<b>Repeatability</b>		47.00		35.40		44.20		24.70		63.20		64.20

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity Index, DC = ear declination, HC = husk cover and tightness

Table 4.7b Means for various *S. maydis* related characteristics for Lichtenburg (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
51	6x7	DO620Y/E739	80	0.00	54	0.67	44	1.26	79	1.00	1	9.00	3	8.67
52	6x8	DO620Y/H111	69	0.83	27	1.50	34	1.83	37	3.67	50	8.33	43	5.00
53	6x9	DO620Y/Mo17	85	0.00	78	0.00	68	0.48	85	1.00	58	7.33	40	5.00
54	6x10	DO620Y/ARC1	64	1.09	50	0.67	47	1.19	68	2.00	61	6.67	33	6.00
55	7x1	E739/I137TN	70	0.76	62	0.33	55	0.88	7	6.00	4	9.00	6	8.33
56	7x2	E739/B73	16	5.55	28	1.50	29	2.00	40	3.67	5	9.00	37	5.33
57	7x3	E739/B37	49	2.36	23	1.67	16	3.42	54	2.67	25	9.00	7	8.33
58	7x4	E739/F2834T	67	0.93	35	1.17	45	1.24	57	2.33	7	9.00	4	8.67
59	7x5	E739/MON1	84	0.00	71	0.17	71	0.47	84	1.00	8	9.00	2	8.67
60	7x6	E739/DO620Y	72	0.67	57	0.50	50	1.11	75	1.67	9	9.00	24	6.67
61	7x8	E739/H111	13	6.54	45	0.83	43	1.31	24	4.33	10	9.00	15	7.67
62	7x9	E739/Mo17	65	1.01	43	1.00	32	1.88	76	1.67	11	9.00	8	8.33
63	7x10	E739/ARC1	29	3.82	87	0.00	79	0.12	50	3.00	36	8.67	12	8.00
64	8x1	H111/I137TN	78	0.54	75	0.00	89	0.00	80	1.00	82	4.33	73	3.00
65	8x2	H111/B73	10	8.14	10	3.33	9	4.58	12	5.33	55	7.67	72	3.00
66	8x3	H111/B37	40	2.99	36	1.17	40	1.49	23	4.33	31	8.67	41	5.00
68	8x5	H111/MON1	81	0.00	81	0.00	91	0.00	78	1.00	71	5.67	65	3.67
69	8x6	H111/DO620Y	55	1.53	34	1.17	22	2.74	9	5.67	18	9.00	76	3.00
70	8x7	H111/E739	60	1.26	63	0.33	65	0.59	59	2.33	27	9.00	25	6.67
71	8x9	H111/Mo17	54	1.84	49	0.83	62	0.75	71	1.67	26	9.00	67	3.33
72	8x10	H111/ARC1	30	3.57	46	0.83	54	0.99	8	5.67	72	5.67	39	5.33
74	9x2	Mo17/B73	24	4.40	65	0.17	74	0.33	48	3.00	41	8.33	58	4.00
75	9x3	Mo17/B37	41	2.95	25	1.67	26	2.40	51	3.00	24	9.00	46	4.67
76	9x4	Mo17/F2834T	48	2.36	44	0.83	30	1.94	46	3.00	12	9.00	26	6.33
77	9x5	Mo17/MON1	76	0.62	70	0.17	70	0.47	58	2.33	57	7.67	52	4.00
78	9x6	Mo17/DO620Y	20	5.18	73	0.05	69	0.47	42	3.33	69	6.00	62	3.67
79	9x7	Mo17/E739	45	2.74	24	1.67	21	2.75	32	4.00	3	9.00	13	8.00
80	9x8	Mo17/H111	75	0.63	60	0.33	59	0.85	61	2.33	17	9.00	50	4.00
81	9x10	Mo17/ARC1	12	7.04	22	1.83	35	1.79	3	6.67	59	7.00	61	3.67
82	10x1	ARC1/I137TN	17	5.34	42	1.00	60	0.84	19	5.00	89	3.33	23	6.67
83	10x2	ARC1/B73	5	10.75	11	3.17	12	4.13	5	6.00	38	8.67	83	2.33
84	10x3	ARC1/B37	23	4.90	8	4.17	5	5.00	34	4.00	52	8.00	34	5.67
85	10x4	ARC1/F2834T	25	4.36	15	2.83	7	4.75	25	4.33	80	4.67	42	5.00
86	10x5	ARC1/MON1	37	3.05	31	1.33	31	1.90	66	2.00	77	5.33	5	8.33
87	10x6	ARC1/DO620Y	44	2.77	19	2.17	18	3.34	35	4.00	74	5.67	28	6.33
88	10x7	ARC1/E739	21	5.10	17	2.67	25	2.60	18	5.00	37	8.67	16	7.67
89	10x8	ARC1/H111	32	3.38	52	0.67	46	1.24	47	3.00	45	8.33	55	4.00
90	10x9	ARC1/Mo17	52	2.05	21	1.83	27	2.19	27	4.00	56	7.67	64	3.67
91	1	I137TN	3	12.14	2	10.83	2	11.98	10	5.67	92	1.67	92	1.00
92	2	B73	1	30.18	1	25.17	1	29.10	1	8.00	62	6.67	69	3.33
93	3	B37	26	4.24	7	4.33	10	4.50	17	5.00	51	8.00	51	4.00
94	4	F2834T	2	16.00	3	7.83	3	9.53	30	4.00	93	1.00	88	1.67
95	5	MON1	56	1.48	79	0.00	66	0.53	36	4.00	91	2.33	81	2.67
96	6	DO620Y	93	0.00	69	0.17	67	0.49	93	1.00	81	4.33	56	4.00
97	7	E739	50	2.32	38	1.00	37	1.68	26	4.33	54	8.00	17	7.67
98	8	H111	9	8.32	39	1.00	49	1.13	28	4.00	47	8.33	29	6.00
99	9	Mo17	11	7.15	12	3.17	14	3.65	29	4.00	44	8.33	27	6.33
100	10	ARC1	7	8.74	14	3.00	13	3.72	20	4.67	90	3.33	57	4.00
		Mean		3.40		1.62		2.06		3.22		7.25		4.91
		LSD (0.05)		5.12		4.46		4.38		2.83		1.93		2.00
		Repeatability		47.00		35.40		44.20		24.70		63.20		64.20

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.8a Means for various *S. maydis* related characteristics for Petit, Hillcrest and Lichtenburg (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
1	1x2	I137TN/B73	62	11.89	64	4.25	77	4.03	77	3.44	79	4.89	76	3.89
2	1x3	I137TN/B37	21	23.16	36	7.92	23	11.80	22	5.33	44	8.22	26	6.67
3	1x4	I137TN/F2834T	34	19.60	33	8.19	55	6.71	43	4.78	56	7.44	78	3.78
4	1x5	I137TN/MON1	83	4.86	69	3.85	61	5.78	84	3.11	87	4.33	37	5.67
5	1x6	I137TN/DO620Y	90	3.43	87	2.42	86	2.79	72	3.56	55	7.44	88	3.11
6	1x7	I137TN/E739	37	19.11	41	7.21	43	9.01	55	4.33	6	9.00	10	8.11
7	1x8	I137TN/H111	74	8.79	78	3.19	78	3.94	33	5.00	82	4.56	66	4.44
8	1x9	I137TN/Mo17	30	20.74	21	10.51	37	9.50	50	4.44	59	7.33	84	3.56
9	1x10	I137TN/ARC1	42	17.72	39	7.50	39	9.37	31	5.00	84	4.56	45	5.33
10	2x1	B73/I137TN	40	18.18	35	8.07	32	10.09	18	5.44	50	8.00	82	3.78
11	2x3	B73/B37	20	23.41	30	8.72	29	10.16	40	4.89	24	8.89	64	4.56
13	2x5	B73/MON1	63	11.04	42	7.16	46	8.51	64	4.11	54	7.56	57	4.78
14	2x6	B73/DO620Y	78	7.27	70	3.85	73	4.40	74	3.56	30	8.78	70	4.22
15	2x7	B73/E739	39	18.25	61	4.65	72	4.48	63	4.11	2	9.00	32	6.33
16	2x8	B73/H111	31	20.58	27	9.06	28	10.24	16	5.44	16	9.00	59	4.67
17	2x9	B73/Mo17	7	31.81	8	14.61	10	16.05	24	5.22	45	8.22	74	3.89
18	2x10	B73/ARC1	2	44.26	3	28.83	3	34.16	2	7.11	73	6.11	75	3.89
19	3x1	B37/I137TN	14	25.25	16	11.86	16	13.86	57	4.22	19	9.00	34	5.78
20	3x2	B37/B73	35	19.58	31	8.54	35	9.98	29	5.00	13	9.00	42	5.44
22	3x5	B37/MON1	72	9.25	83	2.92	82	3.43	83	3.11	33	8.78	21	7.22
24	3x7	B37/E739	19	23.94	17	11.69	15	14.09	39	4.89	14	9.00	2	8.78
25	3x8	B37/H111	61	12.82	52	6.13	56	6.62	15	5.46	72	6.11	19	7.56
26	3x9	B37/Mo17	55	14.36	34	8.13	31	10.11	51	4.44	23	8.89	67	4.33
27	3x10	B37/ARC1	12	26.09	15	12.14	8	17.22	9	6.00	51	7.89	22	7.11
28	4x1	F2834T/I137TN	75	8.07	82	2.98	85	3.00	86	2.89	85	4.44	85	3.56
29	4x2	F2834T/B73	22	22.67	20	11.29	22	12.24	7	6.22	53	7.67	79	3.78
30	4x3	F2834T/B37	43	17.39	44	6.94	54	6.74	81	3.22	31	8.78	47	5.22
31	4x5	F2834T/MON1	91	2.52	90	1.83	87	2.69	93	1.78	83	4.56	93	2.56
32	4x6	F2834T/DO620Y	87	4.25	88	2.15	92	2.01	85	3.00	69	6.44	62	4.56
33	4x7	F2834T/E739	13	25.31	12	12.60	21	12.26	54	4.33	29	8.78	9	8.22
34	4x8	F2834T/H111	57	13.76	72	3.83	71	4.67	62	4.11	43	8.33	87	3.11
36	4x10	F2834T/ARC1	68	10.53	63	4.38	60	5.81	76	3.56	46	8.22	55	4.78
37	5x1	MON1/I137TN	82	5.25	66	4.06	68	4.76	91	2.44	88	4.11	60	4.67
38	5x2	MON1/B73	54	14.44	49	6.62	34	10.03	61	4.22	71	6.22	91	2.67
39	5x3	MON1/B37	48	16.44	25	9.54	25	10.54	65	4.11	41	8.33	39	5.56
40	5x4	MON1/F2834T	85	4.50	71	3.85	67	4.86	69	3.67	90	3.33	90	2.78
41	5x6	MON1/DO620Y	92	1.92	89	2.06	90	2.33	92	2.00	89	3.67	48	5.11
42	5x7	MON1/E739	56	13.76	51	6.43	47	8.49	82	3.22	61	7.22	5	8.44
43	5x8	MON1/H111	51	15.00	54	6.04	45	8.53	88	2.78	64	6.89	71	4.11
45	5x10	MON1/ARC1	46	16.89	29	8.79	33	10.03	56	4.33	78	5.11	23	7.11
46	6x1	DO620Y/I137TN	80	6.47	60	4.99	57	6.17	73	3.56	57	7.44	56	4.78
47	6x2	DO620Y/B73	49	15.89	55	5.99	36	9.77	46	4.56	8	9.00	68	4.22
48	6x3	DO620Y/B37	84	4.80	91	1.73	89	2.57	67	3.78	17	9.00	46	5.22
49	6x4	DO620Y/F2834T	81	6.37	73	3.72	80	3.65	78	3.33	66	6.67	58	4.78
50	6x5	DO620Y/MON1	89	4.08	79	3.13	76	4.03	68	3.78	81	4.56	18	7.67
		<b>Mean</b>		16.94		8.01		9.50		4.53		7.38		5.51
		<b>LSD (0.05)</b>		7.27		5.14		6.33		1.29		0.95		1.04
		<b>Repeatability</b>		87.20		79.00		74.20		37.00		20.90		59.60

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

Table 4.8b Means for various *S. maydis* related characteristics for Petit, Hillcrest and Lichtenburg (1999/2000)\*

Entry	Combinations	Pedigree	Rank	RE	Rank	RM	Rank	RK	Rank	RS	Rank	DC	Rank	HC
51	6x7	D0620Y/E739	60	13.12	85	2.73	88	2.62	87	2.89	34	8.78	12	7.89
52	6x8	DO620Y/H111	76	7.76	84	2.87	75	4.21	71	3.67	27	8.78	40	5.56
53	6x9	DO620Y/Mo17	88	4.22	86	2.42	84	3.08	66	3.78	40	8.44	49	5.00
54	6x10	DO620Y/ARC1	27	21.48	26	9.16	20	12.46	37	4.89	52	7.78	25	6.89
55	7x1	E739/I137TN	9	28.36	10	13.68	9	16.58	10	5.89	4	9.00	7	8.22
56	7x2	E739/B73	41	18.01	57	5.70	53	6.80	44	4.67	5	9.00	27	6.56
57	7x3	E739/B37	28	21.04	43	6.96	58	6.06	45	4.56	18	9.00	4	8.56
58	7x4	E739/F2834T	25	21.93	22	10.41	26	10.45	38	4.89	7	9.00	3	8.78
59	7x5	E739/MON1	71	9.74	81	3.00	83	3.14	89	2.56	22	8.89	1	8.89
60	7x6	E739/DO620Y	69	10.35	80	3.11	79	3.81	80	3.22	9	9.00	15	7.67
61	7x8	E739/H111	65	11.00	62	4.38	66	4.90	47	4.56	10	9.00	17	7.67
62	7x9	E739/Mo17	33	19.83	32	8.50	41	9.23	59	4.22	11	9.00	11	8.11
63	7x10	E739/ARC1	44	16.98	65	4.23	59	5.89	52	4.33	25	8.89	14	7.78
64	8x1	H111/I137TN	47	16.75	37	7.86	42	9.08	53	4.33	76	5.67	72	4.11
65	8x2	H111/B73	29	20.76	56	5.88	64	5.37	28	5.11	37	8.56	80	3.78
66	8x3	H111/B37	24	21.99	24	9.86	17	13.46	36	4.89	38	8.56	33	5.89
68	8x5	H111/MON1	64	11.03	75	3.57	81	3.64	79	3.33	67	6.56	53	4.89
69	8x6	H111/DO620Y	79	7.17	76	3.50	69	4.75	17	5.44	39	8.56	81	3.78
70	8x7	H111/E739	66	10.96	67	3.91	65	5.09	70	3.67	20	9.00	20	7.44
71	8x9	H111/Mo17	70	10.29	59	5.35	38	9.41	35	4.89	1	9.00	73	4.00
72	8x10	H111/ARC1	59	13.24	47	6.66	52	6.85	12	5.78	63	7.00	28	6.44
74	9x2	Mo17/B73	15	24.96	11	13.22	13	15.21	32	5.00	28	8.78	54	4.78
75	9x3	Mo17/B37	45	16.93	28	9.04	27	10.42	30	5.00	21	9.00	65	4.56
76	9x4	Mo17/F2834T	67	10.79	77	3.41	70	4.68	60	4.22	12	9.00	31	6.33
77	9x5	Mo17/MON1	77	7.49	58	5.58	40	9.26	58	4.22	47	8.11	41	5.44
78	9x6	Mo17/DO620Y	86	4.37	92	1.64	91	2.24	90	2.56	48	8.00	61	4.56
79	9x7	Mo17/E739	38	18.46	50	6.50	50	7.65	14	5.56	3	9.00	8	8.22
80	9x8	Mo17/H111	52	14.82	40	7.33	63	5.38	34	4.94	15	9.00	63	4.56
81	9x10	Mo17/ARC1	11	27.24	14	12.22	12	15.66	3	7.11	70	6.44	77	3.78
82	10x1	ARC1/I137TN	18	24.58	48	6.64	49	7.88	23	5.22	86	4.33	24	6.89
83	10x2	ARC1/B73	4	35.21	7	16.69	7	21.00	6	6.44	49	8.00	86	3.22
84	10x3	ARC1/B37	10	27.29	19	11.31	19	12.69	25	5.22	35	8.67	30	6.33
85	10x4	ARC1/F2834T	16	24.96	23	10.24	24	10.74	41	4.78	77	5.22	52	4.89
86	10x5	ARC1/MON1	17	24.62	9	13.74	11	15.93	48	4.56	74	5.89	6	8.44
87	10x6	ARC1/DO620Y	50	15.48	53	6.10	51	7.36	8	6.00	68	6.56	36	5.78
88	10x7	ARC1/E739	23	22.40	45	6.86	48	8.12	20	5.33	26	8.89	13	7.89
89	10x8	ARC1/H111	26	21.76	38	7.81	44	9.00	42	4.78	65	6.78	35	5.78
90	10x9	ARC1/Mo17	6	32.43	6	17.36	6	22.78	5	6.56	62	7.11	83	3.56
91	1	I137TN	8	29.06	5	20.13	5	23.04	11	5.83	91	3.00	89	3.11
92	2	B73	1	56.70	1	35.80	1	42.62	1	8.00	58	7.44	69	4.22
93	3	B37	3	43.34	2	33.68	2	39.87	4	6.67	60	7.22	50	4.89
94	4	F2834T	32	20.25	18	11.61	18	13.35	27	5.11	93	2.33	92	2.56
95	5	MON1	73	8.85	74	3.62	74	4.35	49	4.44	92	2.78	43	5.33
96	6	DO620Y	93	1.39	93	1.38	93	1.63	75	3.56	75	5.78	51	4.89
97	7	E739	53	14.62	68	3.89	62	5.72	26	5.11	36	8.67	16	7.67
98	8	H111	58	13.46	46	6.74	30	10.15	19	5.35	42	8.33	44	5.33
99	9	Mo17	36	19.28	13	12.53	14	14.71	21	5.33	32	8.78	29	6.44
100	10	ARC1	5	33.21	4	21.81	4	23.47	13	5.60	80	4.78	38	5.67
		Mean		16.94		8.01		9.50		4.53		7.38		5.51
		LSD (0.05)		7.27		5.14		6.33		1.29		0.95		1.04
		Repeatability		87.20		79.00		74.20		37.00		20.90		59.60

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness

**Table 4.9 Mean square for combining ability for different *S. maydis* and agronomic characteristics using Griffings, Model I (parents, F1's and reciprocals) for Petit (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS	SH
GCA	9	1551.74**	696.73**	1135.82**	21.68**	36.99**	36.82**	21.06**	200.40**	452.92**	1161.06**	1226.92**	117.50**	7802.22**
SCA	45	201.04**	110.82**	184.06**	7.25**	8.65**	7.17**	7.23**	106.83**	99.45**	143.16**	252.12**	21.10**	556.19**
Reciprocal	45	96.16	42.28	69.51	6.01**	8.95**	6.01**	3.65**	25.25**	30.14**	221.66**	269.18**	19.55**	248.86
Residual	198	68.07	30.6	49.02	2.17	2.17	2.19	1.19	9.95	16.82	83.59	99.65	5.47	184.69

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture, SH = shank length

**Table 4.10 Mean square for combining ability for different *S. maydis* and agronomic characteristics using Griffings, Model I (parents, F1's and reciprocals) for Hillcrest (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS
GCA	9	1574.92**	254.85**	250.90**	21.25**	39.29**	39.03**	8.74**	92.53**	113.93**	129.56**	396.70**	57.70**
SCA	45	204.89**	124.54**	139.59**	12.18**	11.74**	11.71**	9.74**	84.36**	23.38**	29.00	60.84**	46.37**
Reciprocal	45	130.45**	45.25**	50.11**	13.11**	21.11**	13.38**	14.92**	88.11**	14.88**	19.32	35.52	67.25**
Residual	198	21.22	11.95	15.32	1.23	1.49	1.09	0.85	7.39	7.00	22.26	34.82	3.35

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

**Table 4.11 Mean square for combining ability for different *S. maydis* and agronomic characteristics using Griffings, Model I (parents, F1's and reciprocals) for Lichtenburg (1999/2000)\*\*\***

Source	df	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS
GCA	9	84.23**	32.92**	39.67**	32.48**	44.83**	62.71**	30.37**	493.57**	10.80**	83.52**	107.84**	50.33**
SCA	45	32.17**	21.90**	26.53**	9.86**	16.31**	12.58**	13.43**	243.18**	9.54**	30.53**	40.08**	34.43**
Reciprocal	45	9.66**	8.15**	8.19**	11.82**	22.22**	13.32**	18.26**	238.62**	12.56**	21.15**	29.07**	42.88**
Residual	198	4.79	3.57	3.48	1.66	1.23	1.03	0.77	18.36	2.71	11.58	14.34	1.47

\*,\*\* = significantly different at P=0.05 or P=0.01 level of probability, respectively

\*\*\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.12 GCA effects for different *S. maydis* and agronomic characteristics using Griffings, Model I (parents, F1's and reciprocals) for Petit, Hillcrest and Lichtenburg (1999/2000)\*

Genotypes	Locations	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS	SH
I137TN	Petit	-3.63	-1.94	-2.13	-0.23	-1.39	-0.47	0.89	1.39	-5.09	1.95	-3.24	3.41	-16.40
	Hillcrest	2.84	1.39	1.60	-0.13	-0.82	-0.43	0.43	-0.35	-1.82	-1.29	-3.11	2.50	#
	Lichtenburg	0.80	1.25	1.00	0.72	-0.75	-0.35	1.08	3.91	-0.14	0.00	-0.39	1.62	#
B73	Petit	16.16	10.11	11.67	1.25	0.99	-0.62	0.15	0.25	6.47	-1.74	4.35	0.14	-4.69
	Hillcrest	3.89	0.70	0.65	0.22	0.41	-0.98	-0.28	0.25	1.05	1.76	2.95	-1.45	#
	Lichtenburg	4.21	2.61	3.06	1.24	1.08	-0.83	0.24	0.95	0.43	0.54	0.73	0.31	#
B37	Petit	9.20	5.51	7.89	0.18	0.38	0.11	-1.64	-6.47	5.33	0.09	5.79	-2.49	-25.3
	Hillcrest	1.27	1.12	0.71	-0.33	0.71	-0.28	-0.78	-2.44	0.32	0.39	0.86	-1.39	#
	Lichtenburg	-0.60	-0.18	-0.35	-0.16	0.40	0.10	-1.30	-5.77	1.08	1.88	3.32	-1.36	#
F2834T	Petit	-9.41	-6.43	-9.32	-1.90	-1.42	-1.41	0.47	0.38	-4.65	20.63	16.34	2.36	-6.19
	Hillcrest	-0.83	1.01	0.78	-0.69	-2.55	-2.05	-0.89	-3.83	-1.87	-3.29	-4.42	-0.11	#
	Lichtenburg	-1.62	-1.31	-1.42	-2.09	-2.89	-2.90	-2.02	-8.88	-1.37	-3.22	-3.33	-2.15	#
MON1	Petit	-5.64	-2.53	-2.77	0.30	-1.21	0.74	1.16	3.32	-0.53	-1.59	-2.37	2.41	34.00
	Hillcrest	-10.42	-3.59	-3.49	-1.74	-1.92	0.07	0.80	1.52	-2.16	-2.27	-4.28	2.04	#
	Lichtenburg	-2.20	-1.08	-1.30	-1.06	-0.89	0.10	0.71	2.09	-0.12	-1.04	-1.40	1.08	#
DO620Y	Petit	-11.33	-6.54	-7.86	-0.05	0.79	0.38	0.73	2.23	-3.33	-3.10	-6.81	1.45	13.06
	Hillcrest	-12.09	-4.89	-5.05	-0.41	0.45	0.13	0.69	2.35	-1.24	-1.89	-3.29	0.91	#
	Lichtenburg	-2.28	-0.92	-0.87	-0.86	0.06	-0.05	0.33	0.89	-0.53	-2.40	-3.02	0.53	#
E739	Petit	-1.89	-3.58	-4.70	0.15	2.41	3.19	0.29	2.33	0.09	-1.27	-1.57	-0.89	18.31
	Hillcrest	8.50	1.99	1.90	1.09	2.21	2.98	0.60	2.44	1.92	-0.25	1.07	0.25	#
	Lichtenburg	-0.15	0.08	0.16	0.76	2.83	3.83	1.01	4.66	0.84	1.60	1.55	1.16	#
H111	Petit	-4.62	-4.74	-6.18	-1.58	-1.34	-1.67	-1.94	-4.86	7.47	-3.90	4.53	-4.30	-18.87
	Hillcrest	-6.17	-2.45	-1.66	0.34	0.71	0.00	0.19	2.20	-0.29	-0.58	-1.02	-1.26	#
	Lichtenburg	0.44	-0.22	-0.11	0.74	0.75	-0.08	0.11	0.81	0.02	3.65	3.43	0.02	#
Mo17	Petit	4.23	4.99	5.76	1.17	1.28	-0.47	-0.06	1.02	-3.95	-5.62	-9.65	-1.17	18.93
	Hillcrest	-4.29	-2.75	-2.93	-0.41	0.08	-0.95	-0.86	-1.08	-1.49	2.03	0.84	-2.74	#
	Lichtenburg	-0.94	-1.26	-1.29	-1.21	-0.75	-1.37	-1.87	-5.05	-0.67	-0.75	-0.61	-2.83	#
ARC1	Petit	6.93	5.16	7.64	0.72	-0.49	0.23	-0.05	0.41	-1.82	-5.46	-7.36	-1.11	-12.85
	Hillcrest	17.30	7.46	7.50	2.06	0.71	1.52	0.11	-1.06	5.57	5.41	10.39	1.24	#
	Lichtenburg	2.34	1.03	1.12	1.92	0.16	1.55	1.51	6.39	0.68	-0.26	-0.27	1.64	#
LSD(0.05)	Petit	9.34	6.26	7.92	1.67	1.67	1.67	1.23	3.57	4.64	10.35	11.30	2.65	15.38
	Hillcrest	5.21	3.91	4.43	1.26	1.38	1.18	1.04	3.08	2.99	5.34	6.68	2.07	#
	Lichtenburg	2.48	2.14	2.11	1.46	1.26	1.15	0.99	4.85	1.86	3.85	4.29	1.37	#

# = trait not measured at location

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness  
YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture, SH = shank length

Table 4.13 SCA effects for different characteristics measured at Petit (1999/2000)\*

Genotypes	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS	SH
I137TN/B73	-22.44	-13.41	-15.44	-1.40	-0.88	0.57	1.17	3.79	-6.62	7.79	1.26	1.91	-5.10
I137TN/B37	6.73	-1.14	5.36	1.50	2.57	1.84	1.22	6.32	-3.35	2.88	-1.13	-0.37	23.85
I137TN/F2834T	4.10	3.46	3.22	1.42	1.04	0.69	0.78	2.97	4.06	-3.08	0.33	-0.35	9.74
I137TN/MON1	-3.95	-1.61	-2.73	-0.45	-0.18	-0.63	0.60	-0.64	-0.05	2.05	1.93	1.75	-2.95
I137TN/DO620Y	1.05	1.08	-0.28	-0.27	-1.34	-1.09	-0.26	-4.84	2.74	23.15	25.98	2.38	0.49
I137TN/E739	10.74	6.94	10.75	1.20	1.54	0.59	-0.19	1.36	-0.25	-7.01	-7.17	-2.33	-8.10
I137TN/H111	2.25	2.44	2.28	2.60	1.29	1.96	2.11	8.88	-3.48	-6.80	-11.55	1.43	12.42
I137TN/Mo17	3.63	3.38	0.73	0.85	1.01	-0.24	1.39	6.05	3.77	-7.05	-3.49	0.41	0.45
I137TN/ARC1	-6.19	-4.29	-5.45	-0.87	-0.39	1.22	0.86	1.41	1.68	8.07	9.54	2.39	-1.93
B73/B37	-9.31	-8.52	-11.79	-0.15	1.19	0.32	0.58	1.22	25.84	-5.02	20.47	1.13	-4.53
B73/F2834T	-9.03	-5.59	-8.05	-0.07	0.66	1.34	1.33	4.57	-0.46	15.96	15.14	1.65	-10.31
B73/MON1	-2.05	-0.49	-1.36	0.57	-1.06	-1.64	-0.12	3.04	-9.21	-3.26	-12.23	-2.23	33.67
B73/DO620Y	-1.91	-3.81	-0.22	-0.42	0.77	-0.11	0.41	7.12	-5.46	-7.74	-12.81	-2.52	-8.73
B73/E739	-7.83	-7.94	-10.16	-0.62	-0.84	-0.76	-0.54	-1.76	5.39	5.59	11.36	-0.63	21.02
B73/H111	8.33	-1.44	-5.90	0.62	2.91	1.94	0.52	-2.22	19.57	3.13	21.74	2.56	-0.96
B73/Mo17	10.29	7.49	7.44	0.20	-0.71	0.24	-0.29	0.70	-6.64	-5.43	-11.98	-1.17	7.07
B73/ARC1	18.93	20.66	25.16	1.15	-1.28	-1.63	-0.36	-0.86	-7.17	-4.77	-11.85	-0.31	15.52
B37/F2834T	-16.34	-13.32	-15.67	-5.67	-5.39	-4.23	-4.92	-10.77	-8.22	0.95	-3.88	-10.57	-30.86
B37/MON1	-3.25	-4.39	-8.32	0.80	2.72	1.79	1.62	8.23	1.62	9.13	10.24	1.13	10.12
B37/DO620Y	-8.92	-6.71	-9.38	0.48	1.39	-0.01	1.27	7.17	-3.23	-6.80	-10.39	0.41	6.89
B37/E739	2.10	0.83	-2.33	0.78	-0.23	0.51	0.23	-2.02	-5.97	5.48	-0.85	2.03	-8.36
B37/H111	-7.43	-2.34	-1.81	-3.15	-3.98	-1.63	-2.52	-11.13	10.36	-7.55	4.09	-2.71	-17.51
B37/Mo17	-4.50	-2.57	-4.28	0.77	0.91	0.17	0.71	-0.48	1.89	13.90	15.13	3.07	-0.65
B37/ARC1	3.41	2.59	3.49	1.72	2.34	1.64	0.88	1.96	-2.60	-0.28	-3.54	2.43	4.14
F2834T/MON1	-1.70	2.71	4.34	0.55	-0.81	-1.36	1.27	1.91	0.87	-0.52	-0.16	2.43	11.00
F2834T/DO620Y	5.74	4.23	5.94	0.73	-0.48	0.51	0.92	0.36	2.29	12.53	14.47	2.71	10.27
F2834T/E739	7.06	4.59	5.52	1.20	1.57	2.02	1.43	6.42	-0.70	2.14	1.09	0.78	9.19
F2834T/H111	-0.36	-0.74	0.89	-1.57	-1.68	-2.11	-1.92	-4.51	-8.49	-2.49	-9.69	-3.99	-13.30
F2834T/Mo17	-3.76	-0.31	-0.75	0.85	2.71	1.52	2.11	8.05	4.55	9.83	13.72	1.84	5.24
F2834T/ARC1	-5.21	-3.47	-7.23	-0.87	2.97	0.99	1.43	4.48	2.46	-5.62	-3.82	1.55	5.35
MON1/DO620Y	-1.25	-0.01	-0.80	-0.97	-1.86	1.19	0.17	-1.35	1.54	-3.79	-2.01	1.46	12.59
MON1/E739	-1.58	1.03	1.74	-1.33	0.19	-0.13	-0.20	0.83	4.94	2.65	7.83	-1.12	10.67
MON1/H111	12.82	5.03	5.36	2.07	2.94	1.41	2.04	8.00	2.20	1.40	2.49	2.44	7.85
MON1/Mo17	-5.08	-4.04	-0.92	-2.18	-1.01	-2.46	-1.83	-1.89	-2.30	-6.47	-7.34	-5.13	-4.78
MON1/ARC1	5.07	3.13	4.78	-0.07	0.09	2.17	0.37	0.01	-0.75	7.46	6.65	2.00	-16.50
DO620Y/E739	-1.62	1.71	1.94	-1.32	-0.98	-1.43	-0.25	1.06	-1.62	-1.33	-2.56	-1.38	6.60
DO620Y/H111	3.82	3.54	4.43	1.25	2.77	1.77	1.29	4.24	0.95	-1.49	-1.50	1.87	-2.05
DO620Y/Mo17	-8.83	-6.52	-8.39	-1.00	0.49	-0.76	0.74	7.06	1.59	-0.71	0.98	-1.12	-1.51
DO620Y/ARC1	7.69	2.48	2.54	1.78	0.59	0.21	-0.40	-1.25	0.23	-4.90	-4.59	-0.27	-1.40
E739/H111	-2.84	0.74	2.24	1.38	1.49	1.79	1.52	3.63	-0.01	7.54	6.56	3.49	11.04
E739/Mo17	-0.96	-1.49	-2.52	-0.20	-1.13	0.92	-0.18	-0.47	-0.96	-5.24	-6.12	-0.03	8.24
E739/ARC1	-7.08	-6.16	-7.04	-0.08	0.64	0.06	0.16	2.25	-0.17	-2.49	-2.57	0.18	0.02
H111/Mo17	-0.93	0.51	0.88	0.87	-0.38	-0.88	-0.14	-0.16	-5.48	5.13	-0.11	0.17	13.92
H111/ARC1	-2.36	-2.49	-4.78	1.82	1.40	2.59	2.38	9.13	1.74	8.91	9.39	3.83	13.87
Mo17/ARC1	17.91	7.94	14.29	1.90	-1.89	-1.94	-0.16	-1.77	0.52	-0.88	-0.57	1.08	3.57
LSD (0.05)	9.34	6.26	7.92	1.67	1.67	1.67	1.23	3.57	4.64	10.35	11.3	2.65	15.38

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture, SH = shank length

Table 4.14 SCA effects for different characteristics measured at Hillcrest (1999/2000)\*

Genotypes	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS
I137TN/B73	0.31	-0.54	-2.17	1.13	1.12	0.63	1.78	4.46	-0.10	-0.65	-1.50	3.46
I137TN/B37	8.09	0.32	-1.13	0.84	2.49	0.60	1.56	3.84	2.01	1.31	2.57	3.29
I137TN/F2834T	0.68	-4.63	-5.63	1.21	3.42	2.37	2.22	6.81	0.92	2.92	2.48	2.98
I137TN/MON1	-9.03	-0.52	0.75	0.43	-0.21	2.58	1.83	2.82	1.20	2.70	3.16	4.68
I137TN/DO620Y	-8.74	-1.66	-1.50	-2.07	-0.25	-2.82	-1.55	-4.25	-0.75	0.51	0.81	-3.24
I137TN/E739	9.05	5.61	5.91	-0.57	0.99	1.00	0.15	2.08	-0.23	-1.01	-1.24	-1.43
I137TN/H111	1.93	1.06	0.82	1.01	-0.18	0.65	1.82	7.62	-0.21	-0.77	-1.42	0.71
I137TN/Mo17	-13.67	-9.28	-10.92	-6.24	-5.88	-5.90	-5.01	-11.31	-2.34	-5.78	-4.52	-11.48
I137TN/ARC1	-2.36	-7.55	-8.07	0.13	-0.85	0.13	0.15	0.80	-2.32	-0.94	-3.26	-0.05
B73/B37	-5.41	-4.59	-5.08	0.33	1.25	1.65	1.00	0.98	7.05	5.93	12.08	3.29
B73/F2834T	-5.35	-2.70	-3.00	-4.64	-5.48	-4.25	-3.89	-8.28	-4.52	-6.49	-8.00	-9.53
B73/MON1	-11.22	-7.12	-6.34	-3.09	-2.45	-4.20	-2.78	-3.54	-4.23	-5.13	-7.26	-8.60
B73/DO620Y	-4.16	-1.13	-1.95	1.24	1.52	1.07	1.96	6.83	-0.33	-0.26	-1.19	2.21
B73/E739	-12.58	-7.08	-7.90	-0.92	-0.25	0.22	0.17	0.58	2.24	4.37	6.46	0.45
B73/H111	-8.34	-3.59	-4.00	1.16	1.25	0.87	0.70	1.75	1.54	2.09	3.04	1.73
B73/Mo17	3.33	-0.62	-1.18	0.74	1.89	1.98	2.14	6.63	3.02	8.58	10.56	3.69
B73/ARC1	2.50	0.04	1.73	-0.06	0.59	-0.82	0.53	2.91	-3.46	-4.01	-7.62	-0.10
B37/F2834T	-10.72	-6.73	-7.29	-5.09	-4.78	-4.95	-3.78	-7.08	-4.38	-5.12	-6.49	-9.68
B37/MON1	2.14	2.16	2.64	1.13	3.25	1.27	1.65	5.27	2.30	-0.65	0.75	2.45
B37/DO620Y	-12.75	-7.50	-6.79	-3.37	-4.78	-4.13	-2.94	-3.90	-4.35	-2.13	-4.08	-8.55
B37/E739	2.27	0.28	0.34	0.63	-0.55	0.85	0.03	-0.60	-3.03	-2.47	-5.65	0.63
B37/H111	5.10	-0.37	-0.99	1.54	0.95	1.17	-0.23	-3.57	1.03	3.42	3.85	1.76
B37/Mo17	-5.79	-1.62	-1.66	1.46	1.59	0.95	2.23	7.22	1.30	4.26	4.51	3.38
B37/ARC1	-6.42	-9.58	-9.33	-1.01	0.62	1.15	0.34	0.87	-0.26	-0.27	-0.68	0.69
F2834T/MON1	-5.32	-2.90	-2.20	1.83	1.52	0.70	3.20	8.58	2.88	3.09	4.47	5.02
F2834T/DO620Y	0.00	1.19	0.01	1.99	2.49	1.97	2.15	4.52	1.86	4.45	5.11	4.69
F2834T/E739	21.63	16.01	15.00	2.49	2.39	2.62	1.80	4.22	-0.60	0.46	-0.89	3.74
F2834T/H111	-8.93	-8.90	-9.32	-6.09	-5.11	-5.07	-4.63	-10.05	-3.34	-1.90	-1.94	-10.89
F2834T/Mo17	9.46	3.21	2.17	2.99	1.85	3.38	1.91	4.46	4.15	0.63	3.13	3.97
F2834T/ARC1	-3.31	-3.71	-1.61	1.03	2.22	0.92	1.89	5.03	-3.28	-2.22	-6.25	3.76
MON1/DO620Y	5.59	5.09	5.52	0.38	-0.48	2.02	1.05	0.03	1.35	1.52	2.26	4.13
MON1/E739	2.41	0.49	0.59	0.38	0.75	0.67	0.66	2.81	-1.59	0.92	-0.82	0.26
MON1/H111	9.22	2.45	3.02	-0.04	1.92	-0.35	1.68	5.05	0.42	0.56	0.39	2.37
MON1/Mo17	-9.39	-6.70	-7.14	-4.79	-5.45	-5.07	-4.98	-9.76	-3.64	-6.82	-7.01	-12.35
MON1/ARC1	3.24	2.84	-0.04	1.41	0.92	0.30	0.07	-0.30	-1.19	0.93	-0.41	1.06
DO620Y/E739	9.45	-0.75	-1.70	-0.46	-0.28	0.43	-0.02	1.52	-2.54	-0.93	-3.32	-1.14
DO620Y/H111	7.75	3.05	3.54	0.63	0.89	-0.58	0.96	3.75	0.13	-1.04	-1.21	1.03
DO620Y/Mo17	-1.23	1.54	2.04	-0.79	1.85	1.70	1.73	6.10	1.79	3.30	4.34	2.16
DO620Y/ARC1	1.15	-2.43	-1.23	0.41	0.22	0.40	-0.06	1.67	-4.43	-5.69	-9.97	-1.69
E739/H111	-7.81	-0.36	-1.49	-1.21	-0.55	-0.77	0.14	1.97	0.14	-2.20	-1.90	-0.37
E739/Mo17	6.12	1.76	1.56	1.21	0.09	0.68	-0.20	-3.05	-2.66	-0.09	-3.05	1.44
E739/ARC1	-13.01	-9.83	-9.58	-2.26	-0.55	-2.28	-0.75	-1.10	10.28	-4.16	6.72	-2.08
H111/Mo17	-2.60	-1.90	-1.73	0.79	1.59	0.83	2.17	9.01	-0.50	-2.54	-3.79	2.68
H111/ARC1	-5.92	-2.22	-3.78	-0.67	-0.38	1.03	0.22	1.68	-1.94	1.82	0.04	-0.14
Mo17/ARC1	-0.98	-0.50	-0.51	0.91	0.25	-1.02	0.67	1.33	-3.23	6.04	2.51	1.69
LSD (0.05)	5.21	3.91	4.43	1.26	1.38	1.18	1.04	3.08	2.99	5.34	6.68	2.07

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.15 SCA effects for different characteristics measured at Lichtenburg (1999/2000)\*

Genotypes	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS
I137TN/B73	-3.35	-2.76	-2.19	-0.59	0.50	0.17	0.34	-2.62	-1.01	-0.87	-2.08	2.66
I137TN/B37	1.62	2.28	0.39	0.81	3.19	3.73	2.15	11.65	0.55	2.47	2.21	1.29
I137TN/F2834T	2.26	2.91	1.33	2.08	4.14	1.73	2.39	6.89	2.44	2.81	3.54	5.15
I137TN/MON1	0.09	-0.57	-0.27	-0.62	0.97	0.07	0.93	2.99	-0.46	6.35	5.68	0.92
I137TN/DO620Y	0.73	0.27	1.36	0.68	3.52	0.72	1.04	4.60	0.40	-0.59	-0.55	0.74
I137TN/E739	-1.36	-1.48	-1.25	1.23	0.92	0.33	-0.10	2.96	2.05	-0.85	1.44	-1.62
I137TN/H111	-1.85	-1.26	-1.23	-0.59	-2.00	-0.58	0.94	6.69	-0.60	-3.11	-3.92	-0.15
I137TN/Mo17	-5.36	-4.56	-4.42	-4.81	-6.50	-5.13	-5.03	-15.04	-4.41	-6.02	-7.19	-8.84
I137TN/ARC1	-0.87	-2.34	-2.48	-0.11	-1.91	1.12	1.72	10.09	1.47	-0.50	1.21	-0.24
B73/B37	-1.23	-1.91	-1.69	1.13	1.35	1.72	1.05	2.64	5.15	6.85	11.18	2.00
B73/F2834T	-8.90	-6.54	-7.23	-2.94	-4.20	-3.12	-3.36	-7.22	-3.84	-4.36	-5.41	-7.56
B73/MON1	-3.96	-2.34	-2.83	-0.97	0.64	0.88	0.94	6.60	0.66	-1.99	-1.54	0.13
B73/DO620Y	-4.06	-2.43	-3.31	-1.17	1.52	-0.13	1.97	11.07	0.67	-0.73	-0.42	1.05
B73/E739	-2.22	-2.42	-2.91	-1.12	-0.91	-1.52	-0.59	-2.35	-0.64	1.99	1.59	-0.70
B73/H111	1.79	0.38	0.75	0.73	0.50	0.23	0.67	4.00	0.63	-0.26	0.15	0.51
B73/Mo17	1.98	-0.59	-1.44	1.01	2.17	2.18	2.03	6.70	0.88	2.06	1.68	3.37
B73/ARC1	0.65	-0.54	-0.92	0.71	-0.08	-1.57	0.13	3.41	-0.92	-1.35	-2.03	-0.80
B37/F2834T	-6.24	-5.33	-5.43	-5.71	-6.68	-5.88	-5.59	-15.62	-5.27	-5.79	-7.37	-10.30
B37/MON1	1.74	0.62	0.79	0.59	3.15	1.45	2.02	9.94	1.88	-0.89	0.18	1.99
B37/DO620Y	-3.74	-4.22	-4.50	-4.77	-6.46	-6.07	-5.73	-18.07	-5.04	-6.25	-7.76	-9.44
B37/E739	0.46	0.87	1.45	-0.06	-0.23	0.88	0.81	2.44	-0.64	1.05	0.05	1.28
B37/H111	2.00	1.34	2.16	2.79	0.35	2.63	-0.11	-6.88	0.94	11.14	11.27	2.57
B37/Mo17	2.07	1.46	1.81	1.58	3.19	1.25	3.68	13.95	3.67	-1.47	0.35	5.09
B37/ARC1	0.34	1.01	1.05	0.61	0.94	0.33	0.82	4.10	1.64	-1.33	-0.04	0.85
F2834T/MON1	1.36	1.57	1.55	1.86	2.94	0.28	3.24	10.25	1.64	2.20	2.13	5.08
F2834T/DO620Y	1.44	1.41	1.13	1.66	4.15	3.60	3.38	9.95	1.55	3.98	3.67	5.69
F2834T/E739	1.25	1.08	0.99	1.71	3.05	3.38	2.37	7.48	0.81	0.05	-0.40	3.52
F2834T/H111	-5.46	-3.54	-3.66	-3.77	-4.20	-4.53	-3.54	-7.57	-3.48	-7.54	-8.23	-7.70
F2834T/Mo17	-3.21	-2.34	-2.04	-1.99	-2.36	-0.92	-2.54	-5.41	0.84	-0.77	1.81	-5.40
F2834T/ARC1	0.74	1.13	2.23	1.21	2.39	1.83	3.44	13.91	0.79	2.88	2.41	3.69
MON1/DO620Y	2.31	1.18	1.00	1.96	-1.68	0.77	0.64	-0.40	0.62	1.93	2.19	2.09
MON1/E739	-0.11	0.27	0.15	-0.99	0.72	0.72	-0.04	2.23	-0.79	1.02	0.47	-0.99
MON1/H111	-0.70	0.49	0.25	-0.97	0.14	-0.53	1.00	5.95	-0.13	-4.75	-5.09	0.52
MON1/Mo17	-3.51	-2.89	-2.89	-3.36	-5.03	-5.08	-4.72	-12.79	-3.58	-2.95	-3.29	-8.58
MON1/ARC1	-0.65	0.32	0.35	-1.32	0.05	2.83	0.14	1.30	0.65	-0.01	0.88	-0.10
DO620Y/E739	0.31	0.61	0.67	-0.86	0.10	0.03	0.19	2.08	0.38	-0.80	-0.33	-0.37
DO620Y/H111	0.56	1.66	2.05	2.49	1.85	0.28	1.33	9.14	0.64	-1.43	-1.15	0.44
DO620Y/Mo17	0.94	-0.14	-0.20	-0.06	-1.15	-0.27	0.82	6.26	-0.50	-1.35	-1.75	-0.16
DO620Y/ARC1	-0.58	0.49	0.80	-0.36	-0.06	0.82	0.09	1.29	0.93	3.43	4.45	-0.20
E739/H111	1.16	-0.09	-0.32	-0.46	-0.58	-0.43	-0.38	-3.14	0.20	-3.21	-2.77	0.02
E739/Mo17	0.52	1.70	2.23	0.99	0.92	1.85	0.83	-0.14	0.92	5.12	5.24	2.54
E739/ARC1	-0.18	-0.59	-1.14	-0.97	-0.33	-1.40	-0.70	1.78	-1.10	-1.64	-2.05	-2.01
H111/Mo17	-0.72	1.25	0.99	0.17	3.00	1.27	3.57	16.48	2.26	-1.06	-0.07	3.81
H111/ARC1	-1.76	-0.87	-1.11	-0.62	0.09	-0.65	-0.38	-0.68	-0.66	-0.75	-1.17	-0.61
Mo17/ARC1	0.70	1.25	0.95	2.33	1.92	-0.37	0.70	0.33	-0.72	1.75	0.21	2.24
LSD (0.05)	2.48	2.14	2.11	1.46	1.26	1.15	0.99	4.85	1.86	3.85	4.29	1.37

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.16 GCA:SCA ratio's for Petit, Hillcrest and Lichtenburg (1999/2000)\*

Characteristics	Petit (1999/2000)	Hillcrest (1999/2000)	Lichtenburg (1999/2000)
RE	7.72	7.69	2.62
RM	6.29	2.05	1.50
RK	6.17	1.80	1.50
RS	2.99	1.74	3.29
DC	4.28	3.35	2.75
HC	5.14	3.33	4.98
YL	2.91	0.90	2.26
YM	1.88	1.10	2.03
SL	4.55	4.87	1.13
RL	8.11	4.47	2.74
TL	4.87	6.52	2.69
MS	5.57	1.24	1.46
SH	14.03	#	#

# = trait not measured at location

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture, SH = shank length

Table 4.17 Phenotypic correlation values for Petit (1999/2000)\*\*\*

	SL	RL	TL	DC	HC	RE	RM	RK	RS	YL	YM	MS
RL	0.0131											
TL	0.4794**	0.8808**										
DC	0.3343**	0.1680**	0.2490**									
HC	0.2440**	0.1749**	0.2118**	0.7820**								
RE	0.1968**	-0.1219*	-0.0366	0.2745**	0.1871**							
RM	0.1171*	-0.1518**	-0.1006	0.2263**	0.1316*	0.8921**						
RK	0.0850	-0.1572**	-0.1190*	0.1911**	0.1169*	0.8725**	0.9483**					
RS	0.2146**	0.0158	0.0558	0.7072**	0.6330**	0.5714**	0.5528**	0.5393**				
YL	0.0602	0.3289**	0.2552**	0.6658**	0.6988**	0.0529	0.0673	0.0429	0.6337**			
YM	-0.0441	0.1772**	0.0849	0.5825**	0.5666**	-0.0561	-0.0431	-0.0538	0.4970**	0.8946**		
MS	0.0637	0.4368**	0.3574**	0.5133**	0.6049**	0.1016	0.1139*	0.0790	0.5586**	0.8566**	0.5729**	
SH	-0.0450	0.0486	-0.0174	0.4352**	0.4529**	-0.0072	0.0086	-0.0002	0.4073**	0.5755**	0.5994**	0.4105**

\*,\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

Table 4.18 Phenotypic correlation values for Hillcrest (1999/2000)\*\*\*

	SL	RL	TL	DC	HC	RE	RM	RK	RS	YL	YM
RL	0.4943**										
TL	0.7850**	0.9100**									
DC	0.4506**	0.3489**	0.3232**								
HC	0.4478**	0.3102**	0.2965**	0.8278**							
RE	0.4326**	0.2570**	0.3268**	0.4250**	0.4977**						
RM	0.3795**	0.1894**	0.2506**	0.3700**	0.4577**	0.8121**					
RK	0.3530**	0.1653**	0.2209**	0.3678**	0.4432**	0.7759**	0.9717**				
RS	0.4711**	0.3530**	0.3373**	0.8176**	0.8105**	0.6215**	0.6213**	0.6116**			
YL	0.3345**	0.2847**	0.2141**	0.8328**	0.7987**	0.2838**	0.2826**	0.2757**	0.7484**		
YM	0.2270**	0.2328**	0.1480*	0.7634**	0.6579**	0.1029	0.0690	0.0640	0.5677**	0.9277**	
MS	0.3782**	0.2891**	0.2391**	0.7572**	0.8068**	0.4282**	0.4595**	0.4505**	0.8155**	0.9082**	0.6919**

\*,\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

Table 4.19 Phenotypic correlation values for Lichtenburg (1999/2000)\*\*\*

	SL	RL	TL	DC	HC	RE	RM	RK	RS	YL	YM
RL	0.3897**										
TL	0.6292**	0.9376**									
DC	0.6554**	0.4611**	0.4704**								
HC	0.6382**	0.4843**	0.4953**	0.8106**							
RE	0.3664**	0.3207**	0.3027**	0.4136**	0.4096**						
RM	0.3913**	0.2562**	0.2486**	0.4557**	0.4434**	0.8538**					
RK	0.3842**	0.2634**	0.2534**	0.4472**	0.4347**	0.8714**	0.9594**				
RS	0.5552**	0.4276**	0.4130**	0.7054**	0.6802**	0.6964**	0.6547**	0.6864**			
YL	0.6181**	0.3701**	0.3639**	0.8284**	0.7744**	0.3786**	0.4464**	0.4258**	0.7110**		
YM	0.4942**	0.2640**	0.2605**	0.7172**	0.6470**	0.2164**	0.2931**	0.2690**	0.5649**	0.9377**	
MS	0.6701**	0.4386**	0.4315**	0.8308**	0.8016**	0.5160**	0.5532**	0.5404**	0.7725**	0.9070**	0.7079**

\*,\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

Table 4.20 Genetic correlation values for Petit (1999/2000)\*\*\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.9731**										
RK	0.9639**	0.9945**									
RS	0.6834	0.7660*	0.7801*								
DC	0.3656	0.3239	0.3086	0.5931							
HC	-0.0120	-0.0660	-0.0321	0.3906	0.6447						
YL	-0.3356	-0.2268	-0.2370	0.2203	0.0055	0.3188					
YM	-0.3306	-0.2341	-0.2482	0.2858	0.1630	0.4247	0.9438**				
SL	0.5107	0.3673	0.3599	0.0309	0.1064	-0.1187	-0.7195*	-0.6764			
RL	-0.3733	-0.4008	-0.4474	-0.6526	-0.3927	-0.2935	0.2082	0.0249	-0.3141		
TL	-0.0609	-0.1787	-0.2287	-0.6554	-0.3481	-0.3925	-0.2774	-0.4305	0.3236	0.7955*	
MS	-0.3992	-0.2978	-0.3083	-0.0158	-0.2525	0.0793	0.9105**	0.7337*	-0.6969	0.4617	-0.0047

\*,\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

Table 4.21 Genetic correlation values for Hillcrest (1999/2000)\*\*\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.9708**										
RK	0.9668**	0.9958**									
RS	0.8299*	0.7545*	0.7746*								
DC	0.3870	0.2187	0.2251	0.6912							
HC	0.4451	0.3411	0.3549	0.6126	0.7106*						
YL	-0.1343	-0.1705	-0.1311	0.0640	0.1808	0.6096					
YM	-0.2950	-0.4235	-0.3796	0.0808	0.4674	0.5749	0.8290*				
SL	0.8357**	0.7916*	0.7966*	0.9032**	0.6121	0.6263	0.0550	0.0186			
RL	0.6854	0.6075	0.6085	0.7314*	0.5306	0.3313	-0.1927	-0.1043	0.8152*		
TL	0.7961*	0.7371*	0.7376*	0.8343*	0.5611	0.4406	-0.1383	-0.1054	0.9366**	0.9632**	
MS	0.0772	0.1710	0.1870	-0.0343	-0.3061	0.3014	0.7262*	0.2217	-0.0016	-0.2699	-0.1825

\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

Table 4.22 Genetic correlation values for Lichtenburg (1999/2000)\*\*\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.9342**										
RK	0.9510**	0.9927**									
RS	0.8246*	0.8310*	0.8298*								
DC	0.4037	0.442	0.4809	0.6743							
HC	0.1535	0.2307	0.2323	0.5997	0.8278*						
YL	0.3782	0.5263	0.5063	0.7243*	0.5165	0.695					
YM	0.4101	0.5235	0.5113	0.7556*	0.5716	0.7297*	0.9883**				
SL	0.5045	0.5573	0.5443	0.7497*	0.7535*	0.7006	0.471	0.4805			
RL	0.4129	0.3637	0.3682	0.6232	0.6965	0.4774	0.2429	0.2897	0.703		
TL	0.4041	0.3464	0.3471	0.5663	0.6526	0.4214	0.1051	0.1477	0.7536*	0.9748**	
MS	0.3287	0.5217	0.4912	0.667	0.4464	0.6407	0.9782**	0.9362**	0.451	0.197	0.0691

\*,\*\* = significantly difference at P=0.05 or P=0.01 levels of probability, respectively

\*\*\* SL = stalk lodging, RL = root lodging, TL = total lodging, DC = ear declination, HC = husk cover and tightness, RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, YL = yield potential, YM = yield:moisture ratio, MS = grain moisture

**Table 4.23 Broad and narrow sense heritability for Petit, Hillcrest and Lichtenburg (1999/2000)\***

Location	Heritability	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL	MS	SH
<b>Petit</b>	h2b	0.9798	0.9801	0.9804	0.9589	0.9744	0.9736	0.9765	0.9808	0.9835	0.9672	0.9645	0.9791	0.9887
	h2n	0.9202	0.9079	0.9069	0.8215	0.8724	0.8872	0.8334	0.7744	0.8862	0.9110	0.8746	0.8984	0.9547
<b>Hillcrest</b>	h2b	0.9937	0.9815	0.9767	0.9780	0.9838	0.9880	0.9697	0.9733	0.9729	0.9283	0.9608	0.9797	
	h2n	0.9330	0.7888	0.7641	0.7602	0.8559	0.8591	0.6227	0.6685	0.8824	0.8348	0.8924	0.6989	
<b>Lichtenburg</b>	h2b	0.9767	0.9609	0.9682	0.9783	0.9885	0.9926	0.9897	0.9853	0.9199	0.9446	0.9469	0.9892	
	h2n	0.8201	0.7211	0.7256	0.8494	0.8364	0.9021	0.8105	0.7905	0.6381	0.7987	0.7985	0.7371	

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture, SH = shank length

Table 4.24 Correlated response values for Petit (1999/2000)\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.8129										
RK	0.8044	0.8189									
RS	0.5166	0.5713	0.5812								
DC	0.2935	0.2565	0.2442	0.4251							
HC	-0.0098	-0.0532	-0.0258	0.2847	0.4990						
YL	-0.2574	-0.1716	-0.1791	0.1508	0.0040	0.2357					
YM	-0.2356	-0.1646	-0.1743	0.1818	0.1101	0.2918	0.6091				
SL	0.4165	0.2955	0.2893	0.0225	0.0823	-0.0933	-0.5314	-0.4642			
RL	-0.3130	-0.3315	-0.3697	-0.4884	-0.3121	-0.2372	0.1581	0.0176	-0.2536		
TL	-0.0490	-0.1419	-0.1814	-0.4709	-0.2656	-0.3046	-0.2022	-0.2916	0.2508	-0.0666	
MS	-0.3300	-0.2429	-0.2512	-0.0117	-0.1979	0.0632	0.6817	0.5105	-0.5549	-0.2580	-0.0037

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.25 Correlated response values for Hillcrest (1999/2000)\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.7144										
RK	0.6892	0.6002									
RS	0.5886	0.5351	0.2407								
DC	0.3090	0.1746	0.0412	0.4497							
HC	0.3568	0.2734	0.0745	0.4001	0.5225						
YL	-0.0780	-0.0991	0.0059	0.0303	0.0964	0.3261					
YM	-0.1840	-0.2642	0.0371	0.0411	0.2674	0.3302	0.3451				
SL	0.6880	0.6517	0.3426	0.6058	0.4623	0.4748	0.0302	0.0110			
RL	0.5339	0.4732	0.1930	0.4642	0.3791	0.2376	-0.1002	-0.0582	0.6005		
TL	0.6628	0.6137	0.3108	0.5660	0.4286	0.3378	-0.0769	-0.0629	0.7375	0.7176	
MS	0.0503	0.1115	0.0043	-0.0182	-0.1831	0.1810	0.3160	0.1036	-0.0010	-0.1575	-0.1138

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.26 Correlated response values for Lichtenburg (1999/2000)\*

	RE	RM	RK	RS	DC	HC	YL	YM	SL	RL	TL
RM	0.5524										
RK	0.5659	0.5194									
RS	0.5744	0.5090	0.5114								
DC	0.2769	0.2666	0.2918	0.4790							
HC	0.1136	0.1501	0.1521	0.4595	0.6246						
YL	0.2514	0.3076	0.2978	0.4986	0.3501	0.5082					
YM	0.2659	0.2984	0.2933	0.5074	0.3779	0.5204	0.6332				
SL	0.2640	0.2564	0.2520	0.4063	0.4022	0.4033	0.2436	0.2424			
RL	0.2704	0.2095	0.2134	0.4228	0.4653	0.3440	0.1572	0.1829	0.3583		
TL	0.2646	0.1995	0.2011	0.3841	0.4359	0.3036	0.0680	0.0932	0.3840	0.6217	
MS	0.1987	0.2773	0.2627	0.4176	0.2752	0.4260	0.5844	0.5455	0.2121	0.1160	0.0407

\* RE = percentage rotted ears, RM = percentage rotted kernel mass, RK = percentage rotted kernels, RS = infection severity index, DC = ear declination, HC = husk cover and tightness, YL = yield potential, YM = yield:moisture ratio, SL = stalk lodging, RL = root lodging, TL = total lodging, MS = grain moisture

Table 4.27 Values for *S. maydis* related characteristics for South African developed hybrids\*

Entry	Hybrid	RE	MS	DTF	TH
1	Yellow com.1	16.07	12.90	76	SA
2	Yellow exp.7	28.30	14.10	76	SA
3	Yellow exp.8	1.72	14.00	78	SA
4	Yellow exp.9	21.82	16.70	79	SA
5	Yellow exp.10	18.03	13.30	76	SA
6	Yellow exp.11	7.84	13.80	78	SA
7	Yellow exp.12	24.44	15.00	75	SA
8	Yellow exp.13	58.70	15.30	76	SA
9	Yellow exp.19	31.82	14.30	78	SA
10	Yellow exp.22	7.46	13.80	78	SA
11	Yellow exp.23	20.31	13.50	81	SA
12	Yellow exp.24	54.24	13.00	78	SA
13	Yellow exp.25	22.92	13.40	78	SA
14	Yellow exp.27	41.86	13.80	78	SA
15	Yellow com.2	25.49	13.70	82	SA
16	Yellow com.3	17.46	12.80	78	SA
17	Yellow com.4	18.03	12.90	76	SA
18	Yellow com.5	48.78	15.30	75	SA
19	Yellow com.6	18.75	13.10	79	SA
20	Yellow exp.28	20.37	13.70	77	SA
21	Yellow exp.29	2.70	17.30	75	SA
22	Yellow exp.31	23.88	13.40	76	SA
23	Yellow exp.37	9.43	15.60	79	SA
24	Yellow com.9	3.64	13.90	78	SA
25	White exp.1	23.91	19.80	79	SA
26	White com.2	37.78	15.70	82	SA
27	White com.3	13.64	13.80	78	SA
28	White com.4	21.88	13.70	82	SA
29	White exp.2	25.64	14.70	78	SA
30	White exp.5	37.21	14.50	78	SA
31	White exp.7	29.17	19.90	78	SA
32	White exp.8	11.90	13.20	81	SA
33	White exp.10	53.49	12.90	77	SA
34	White exp.11	2.17	16.60	79	SA
35	White exp.12	8.89	14.30	82	SA
36	White exp.13	11.63	17.10	78	SA
37	White exp.15	16.28	15.90	78	SA
38	White exp.16	13.95	18.30	79	SA
39	White exp.17	16.67	17.40	82	SA
40	White exp.18	30.95	18.60	81	SA
41	White exp.19	51.79	14.40	78	SA
42	White exp.20	52.73	13.90	76	SA
43	White exp.21	34.04	14.20	79	SA
44	White exp.22	22.73	14.10	75	SA
45	White exp.23	27.91	13.90	77	SA
46	White exp.24	39.53	17.70	81	SA
47	White exp.25	46.15	13.90	78	SA
48	White exp.26	45.00	14.10	77	SA
49	White exp.27	38.46	12.90	77	SA
50	White exp.28	30.23	13.50	75	SA
51	White exp.29	22.92	13.40	76	SA
52	White exp.30	30.77	13.90	78	SA
53	White exp.31	32.69	14.70	79	SA
54	White exp.32	16.28	14.30	81	SA
55	White exp.33	23.91	14.00	81	SA
56	White exp.34	40.00	17.20	78	SA
57	White exp.35	42.86	17.30	79	SA
58	White exp.36	20.00	13.80	81	SA
59	White exp.37	54.10	14.80	81	SA
60	White exp.38	40.00	13.50	81	SA
61	White exp.39	30.77	13.60	79	SA
62	White exp.40	19.51	13.80	75	SA
63	White exp.42	34.62	15.00	79	SA
64	White exp.43	27.91	15.40	79	SA
65	White exp.44	20.37	15.80	76	SA
66	White exp.45	25.58	13.40	75	SA

\* RE = percentage rotted ears, MS = grain moisture, DTF = days to flower, TH = type of hybrid

Table 4.28 Values for *S. maydis* related characteristics for crosses between South African developed germplasm and those of exotic and temperate origin\*

Entry	Hybrid	RE	MS	DTF	TH
1	Yellow exp.1	20.00	12.80	79	SAXTEMP
2	Yellow exp.2	40.00	12.70	75	SAXTEMP
3	Yellow exp.3	42.86	12.50	75	SAXTEMP
4	Yellow exp.4	69.77	12.60	75	SAXTEMP
5	Yellow exp.5	30.23	12.70	75	SAXTEMP
6	Yellow exp.6	64.29	13.30	75	SAXTEMP
7	Yellow exp.14	53.49	13.50	75	SAXTEMP
8	Yellow exp.15	29.55	16.20	77	SAXTEMP
9	Yellow exp.16	37.25	15.70	78	SAXTEMP
10	Yellow exp.17	64.29	16.30	76	SAXTEMP
11	Yellow exp.18	39.02	13.80	75	SAXTEMP
12	Yellow exp.26	16.28	12.90	77	SAXTEMP
13	Yellow exp.30	33.33	12.90	79	SAXTEMP
14	Yellow exp.32	13.95	12.70	77	SAXTEMP
15	Yellow exp.33	11.86	13.10	81	SAXTEMP
16	Yellow exp.34	21.21	13.60	77	SAXTEMP
17	Yellow exp.36	18.37	13.40	78	SAXTEMP
18	Yellow exp.38	52.08	13.00	76	SAXTEMP
19	Yellow exp.39	31.82	12.80	75	SAXTEMP
20	Yellow exp.40	54.35	13.00	75	SAXTEMP
21	White exp.3	19.05	13.60	77	SAXTEMP
22	White exp.6	26.09	15.10	78	SAXTEMP
23	White exp.9	25.00	14.80	81	SAXTEMP
24	White exp.14	17.78	22.10	79	SAXTEMP
25	White exp.41	64.81	13.30	79	SAXTEMP
26	Yellow exp.20	11.48	13.50	76	SAXTROP
27	Yellow exp.21	33.33	13.60	76	SAXTROP
28	Yellow exp.35	30.43	14.10	77	SAXTROP
29	White exp.4	30.23	13.50	81	SAXTROP
30	Yellow com.7	52.38	12.70	75	USA
31	Yellow com.8	20.45	12.60	77	USA
32	White com.1	62.79	13.10	77	USA

\* RE = percentage rotted ears, MS = grain moisture, DTF = days to flower, TH = type of hybrid



Figure 3.1 Inbred I137TN



Figure 3.2 Inbred B73



Figure 3.3 Inbred B37



Figure 3.4 Inbred F2834T



Figure 3.5 Inbred MON1



Figure 3.6 Inbred D0620Y



Figure 3.7 Inbred E739



Figure 3.8 Inbred Mo17

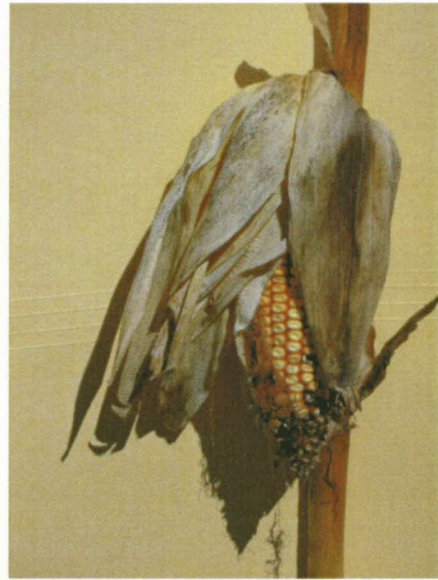


Figure 3.9 Scale for ear declination (1 = left, 9 = right)

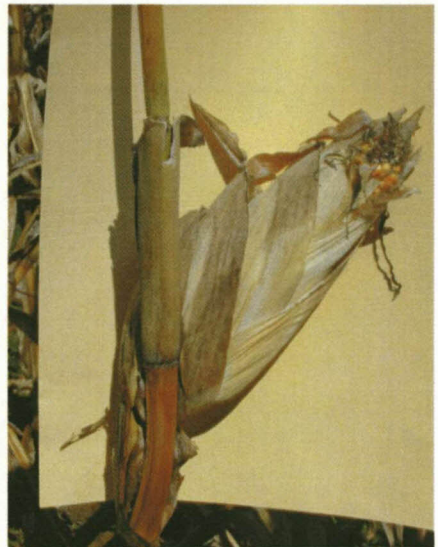


Figure 3.10 Scale for husk cover and tightness (1 = left, 9 = right)



Figure 3.11 Visual differences between non-infected and infected *S. maydis* ears



Figure 3.12 Index scale for infection severity index (1 = left, 9 = right)

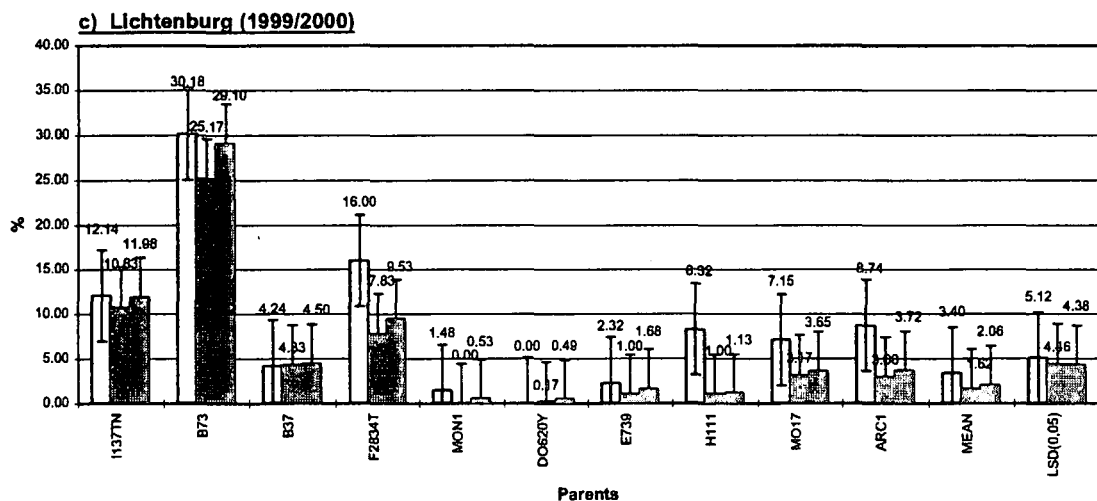
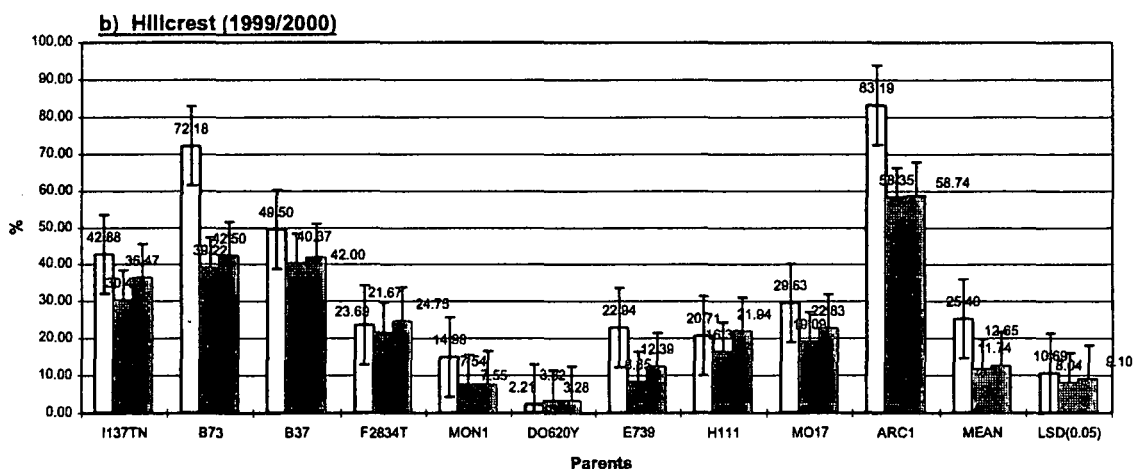
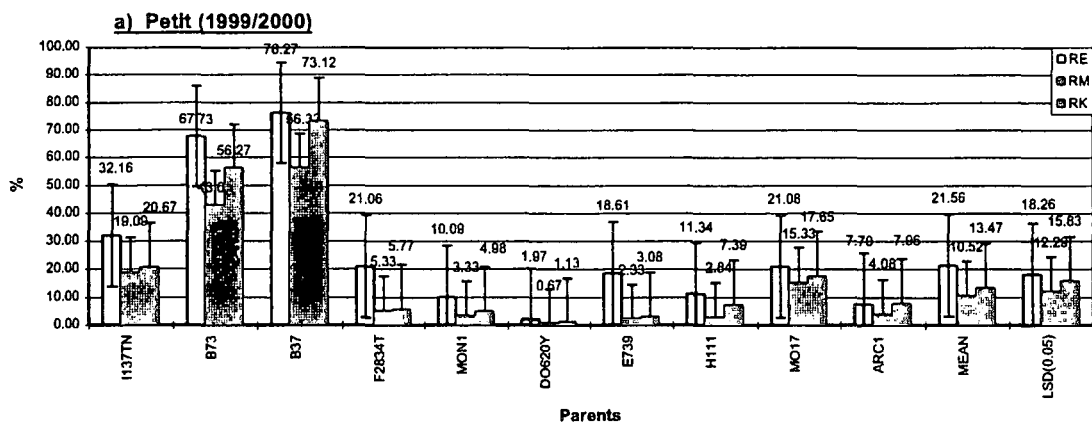


Figure 4.1 Average percentage rotted ears (RE), kernel mass (RM) and kernels (RK) with LSD values for the inbreds at Petit, Hillcrest and Lichtenburg (1999/2000)

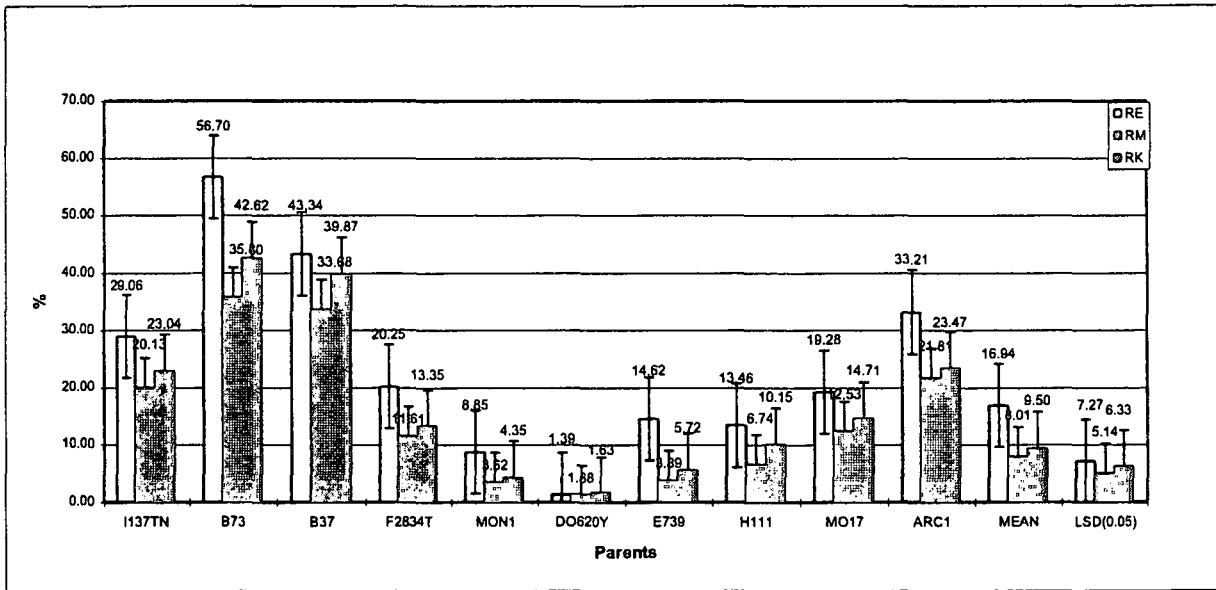


Figure 4.2 Combined values for percentage rotted ears (RE), mass (RM) and kernels (RK) with LSD values for the Inbreds at Petit, Hillcrest and Lichtenburg (1999/2000)

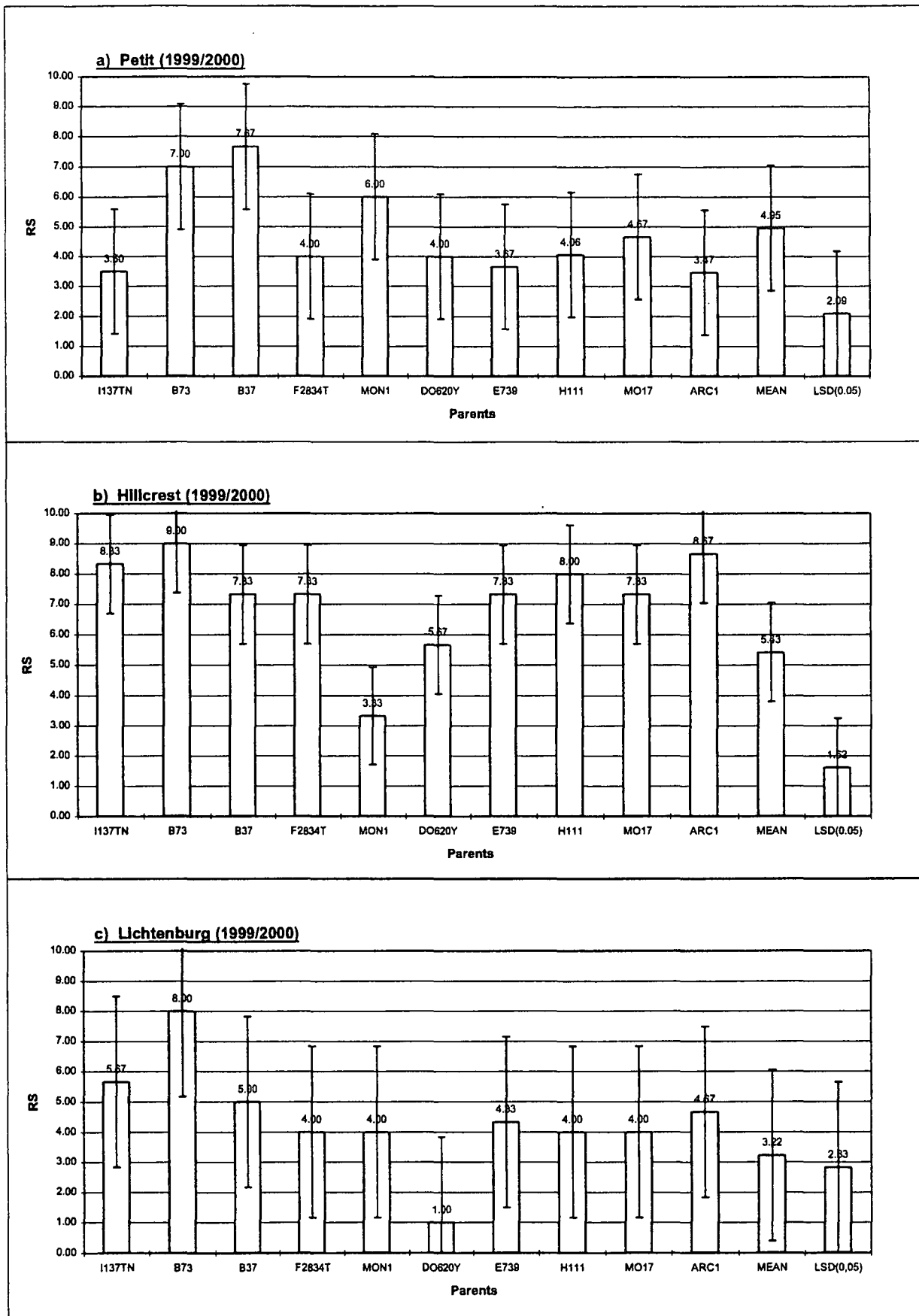


Figure 4.3 Infection severity index (RS) with LSD values for the inbreds at Pett, Hillcrest and Lichtenburg (1999/2000)

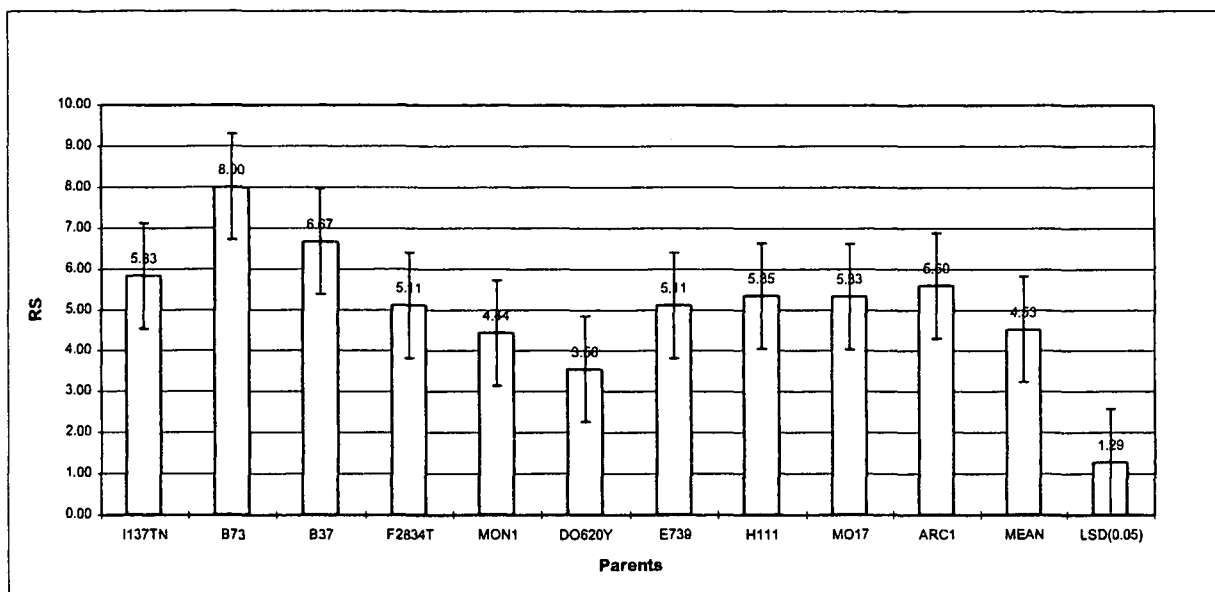


Figure 4.4 Combined values for infection severity index (RS) with LSD values for the inbreds at Petit, Hilicrest and Lichtenburg (1999/2000)

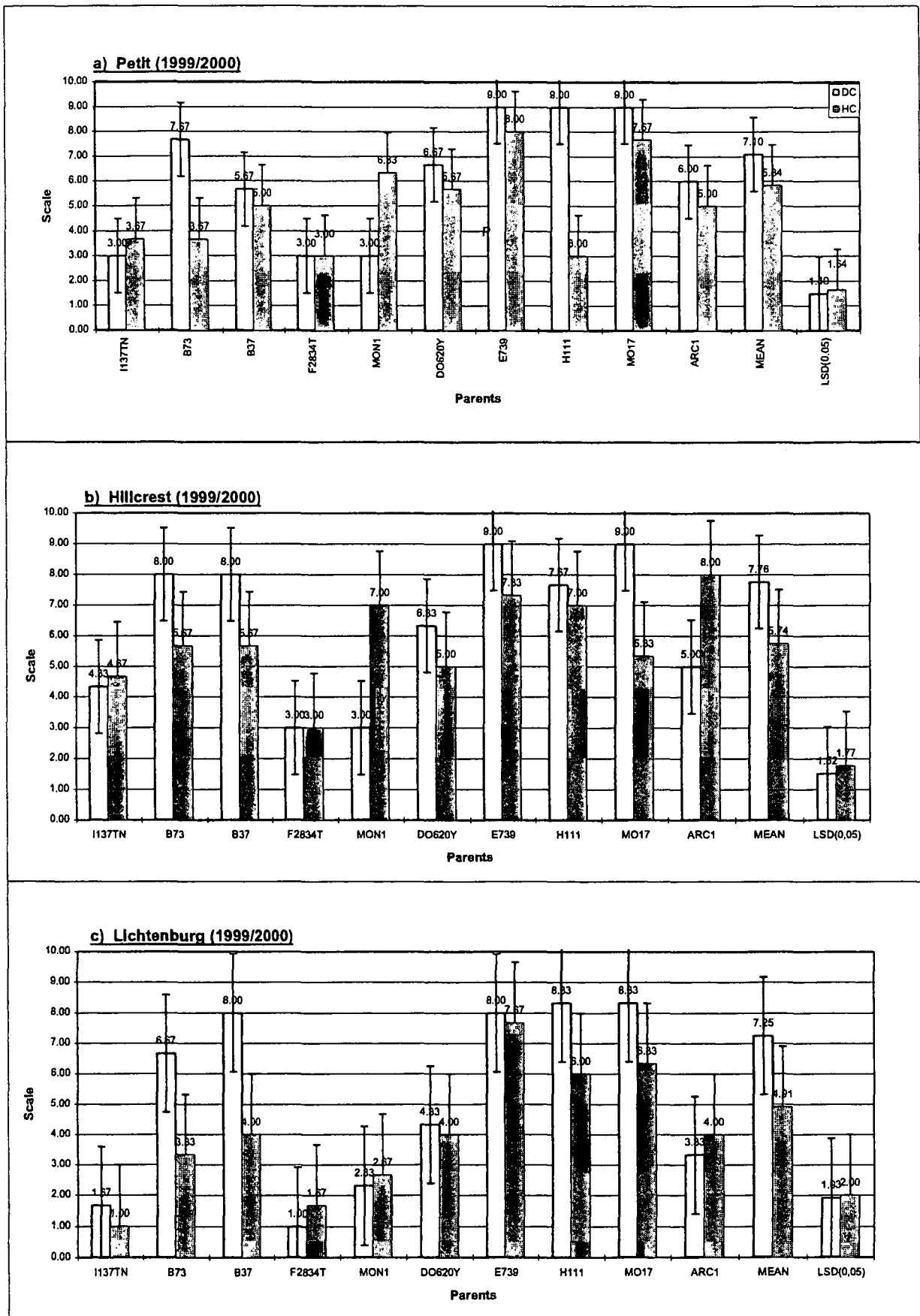


Figure 4.5 Ear declination (DC) and husk cover and tightness (HC) with LSD values for the inbreds at Petit, Hillcrest and Lichtenburg (1999/2000)

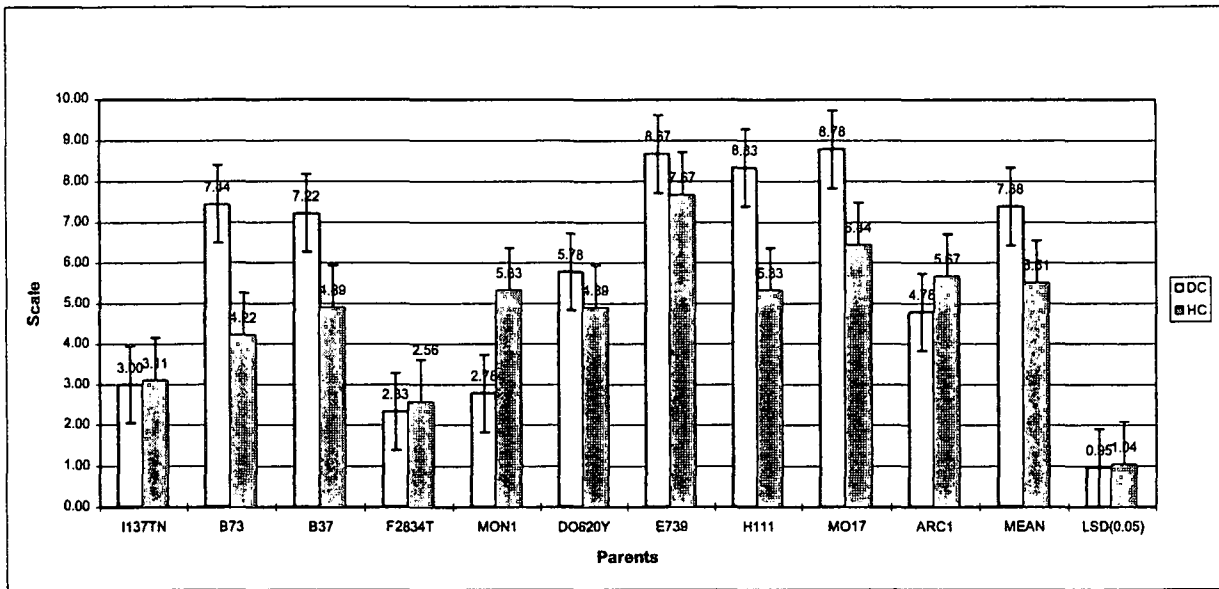


Figure 4.6 Combined values for ear declination (DC) and husk cover and tightness (HC) with LSD values for the inbreds at Petit, Hillcrest and Lichtenburg (1999/2000)

SA

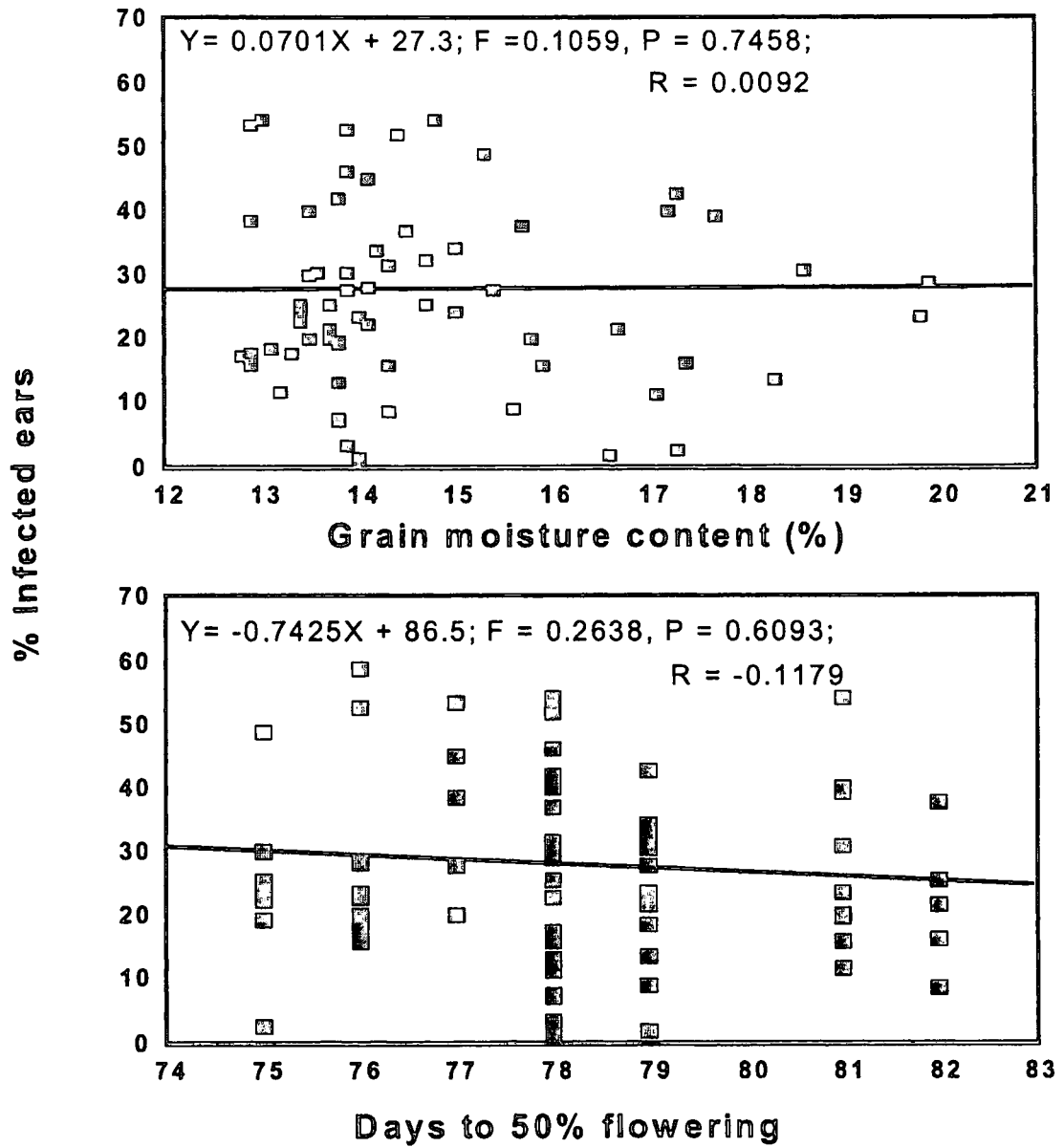


Figure 4.7 Percentage infected ears, grain moisture and days to 50 % flower for South African developed hybrids

# SA x Exotic

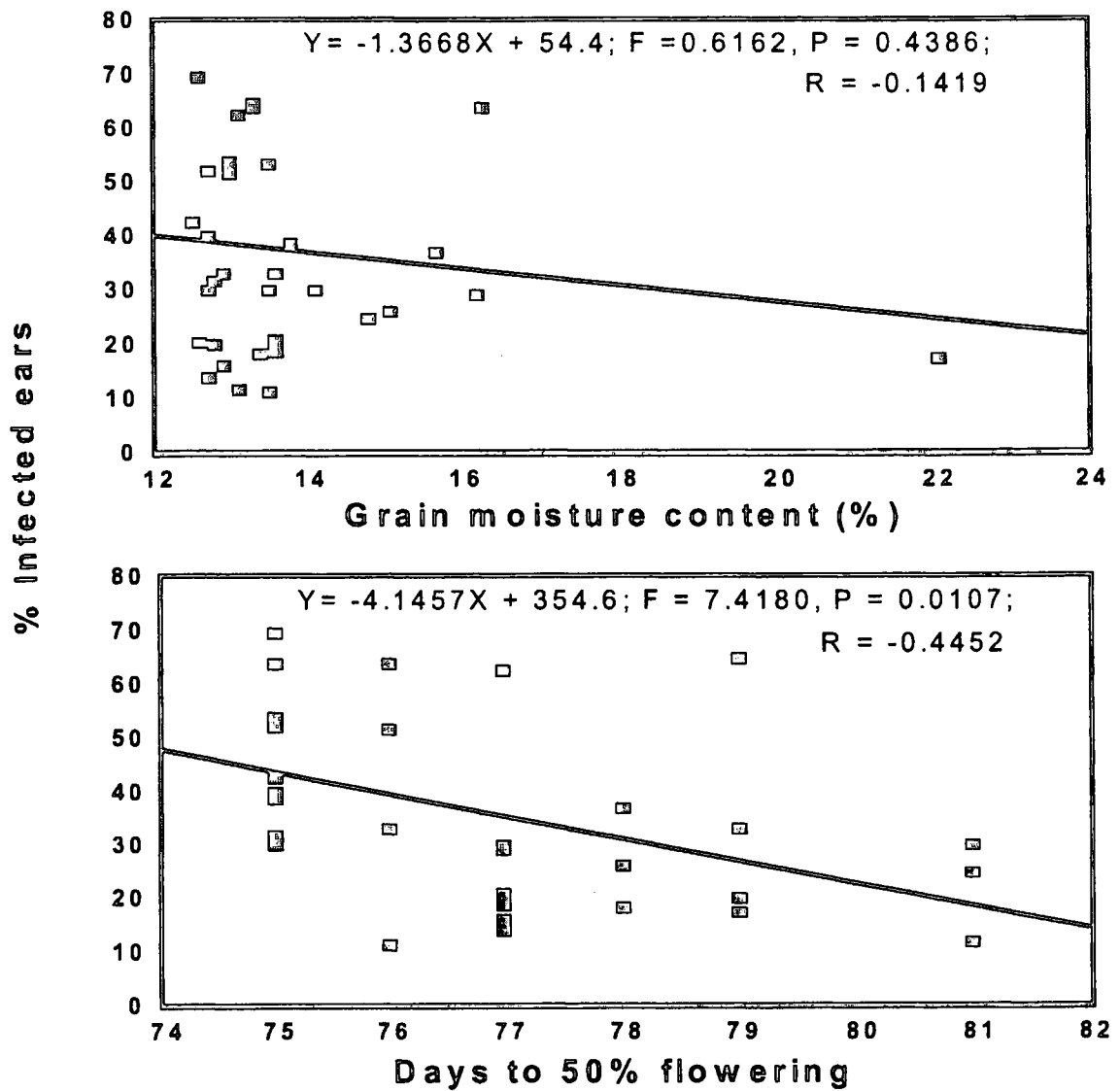
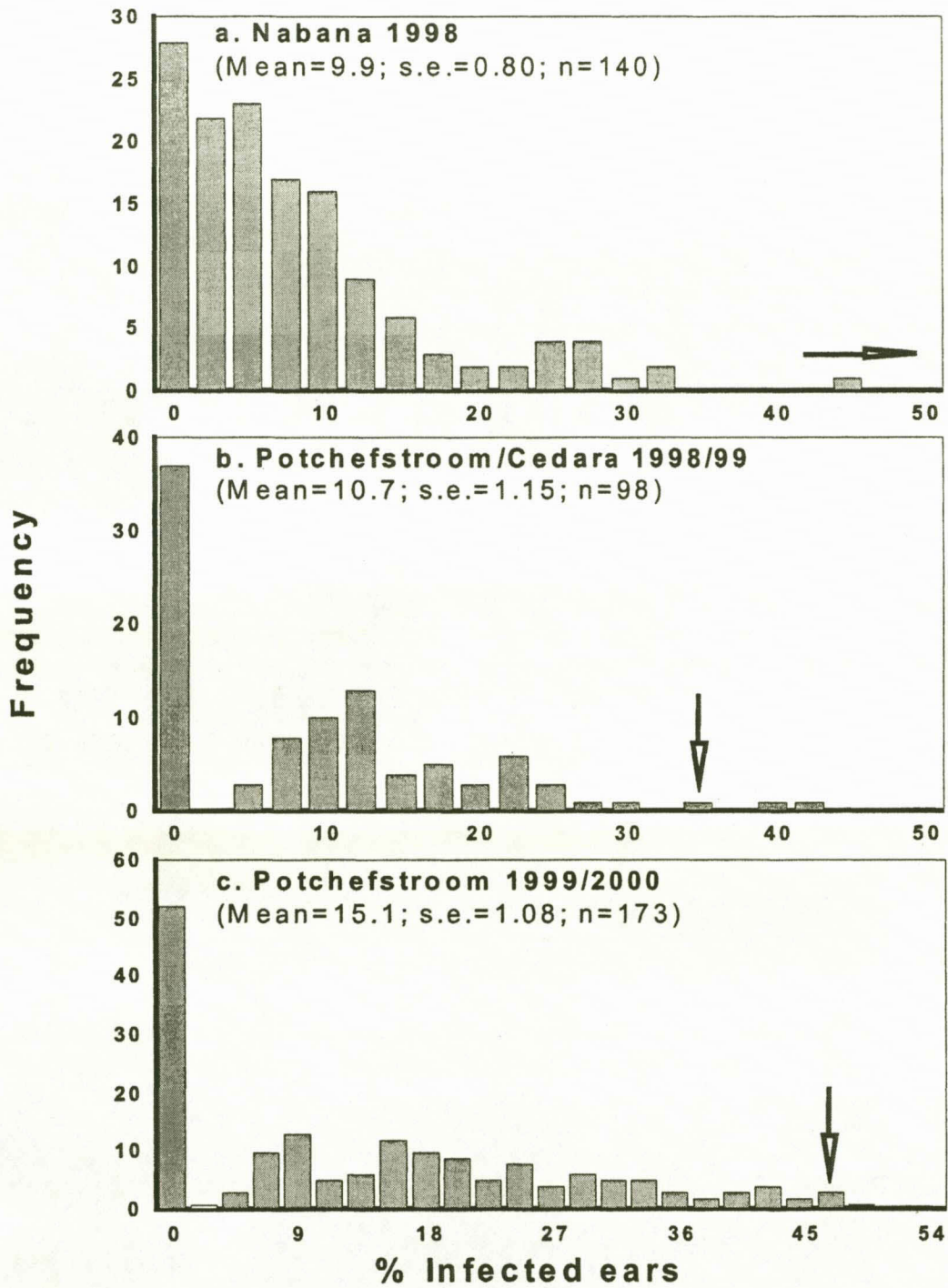


Figure 4.8 Percentage infected ears, grain moisture and days to 50 % flower for crosses between South African developed germplasm those of exotic and temperate origin

**B37/DO620Y/E739**



**Figure 4.9** Frequency of percentage infected ears for each cycle of selection for the B37/DO620Y/E739 complex

**B2/B2P22/A2P31**

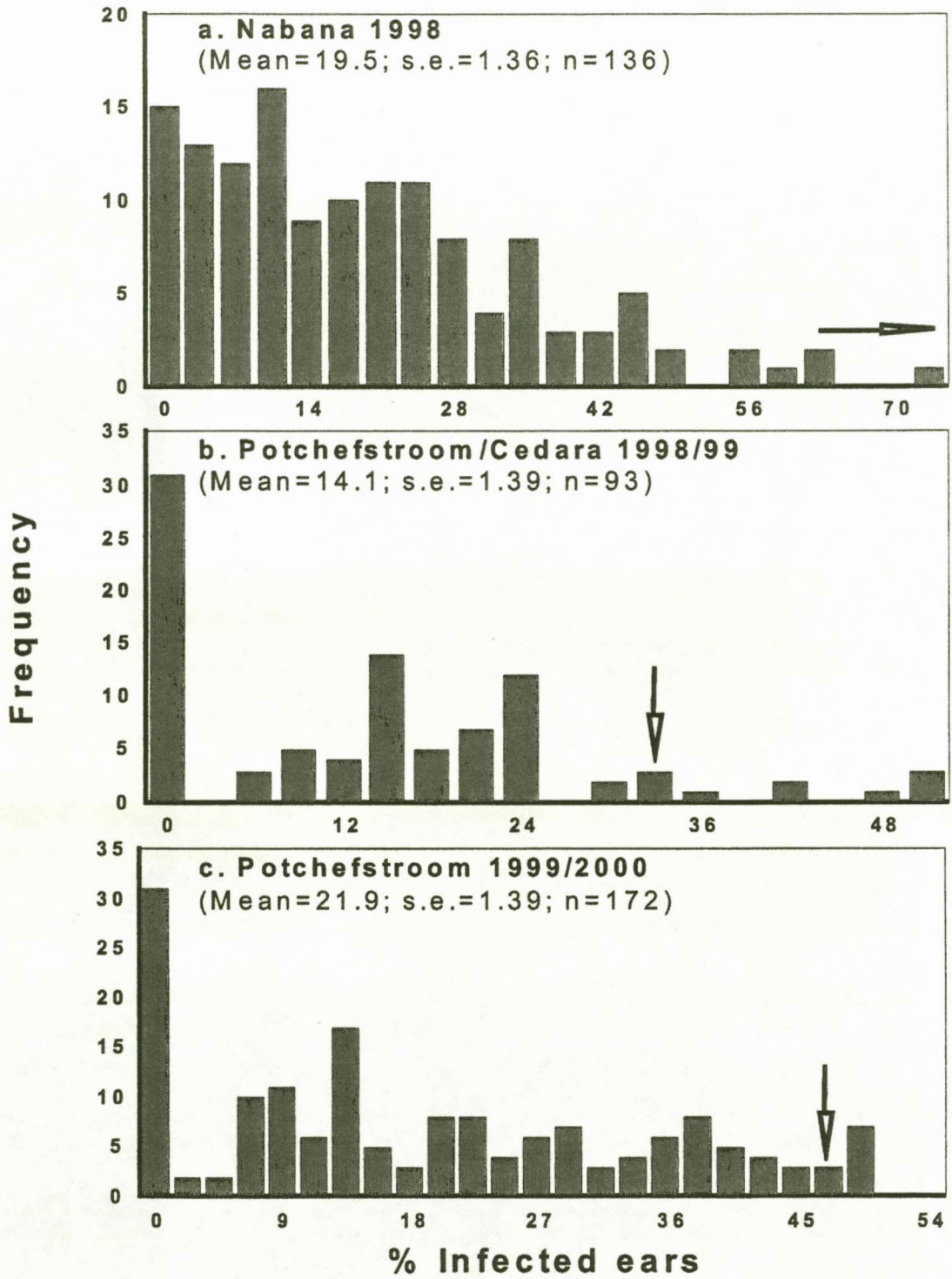
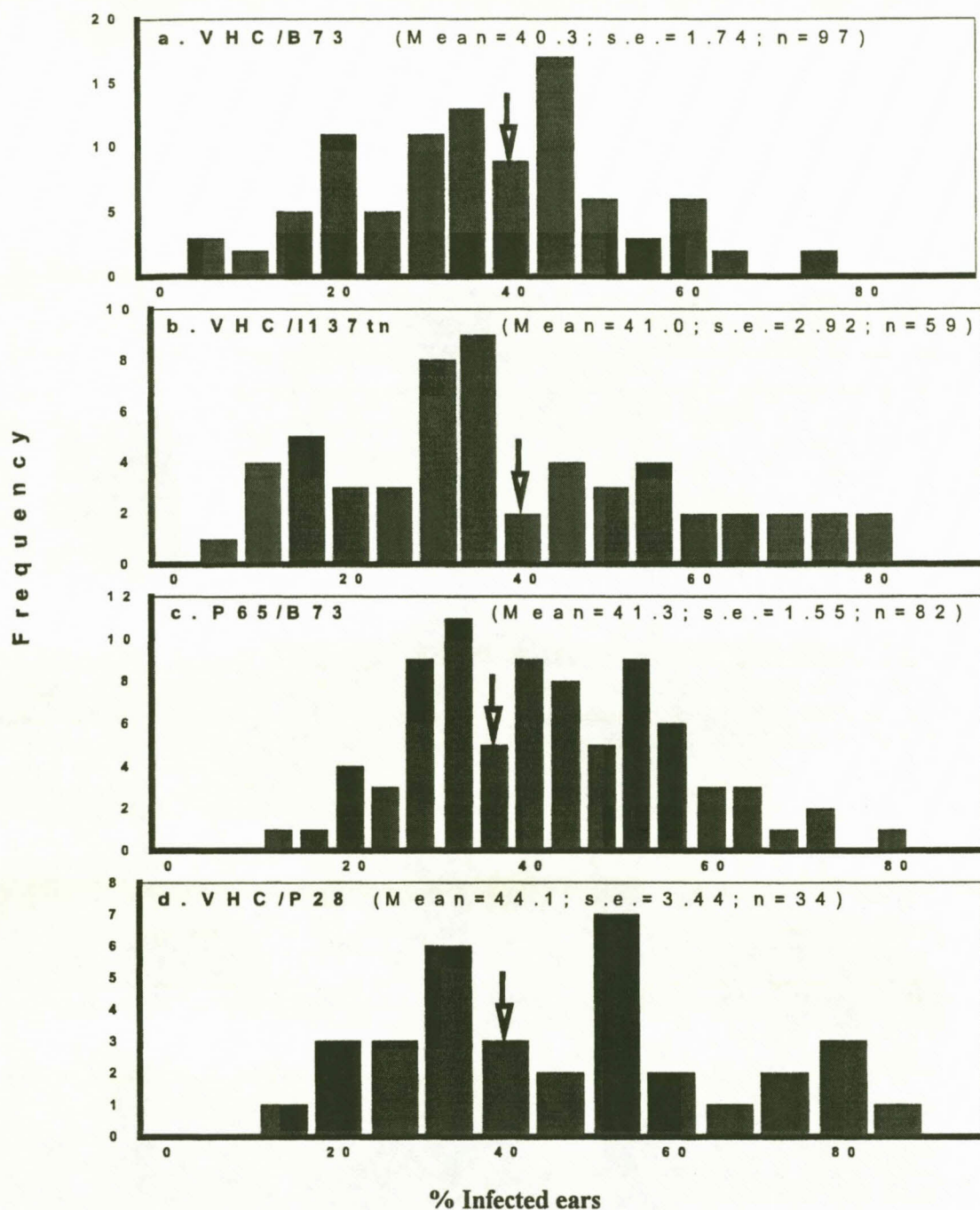


Figure 4.10 Frequency of percentage infected ears for each cycle of selection for the B2/A2P22/A2P31 complex



**Figure 4.11** Frequency of percentage infected ears for each cycle of selection for the susceptible complexes

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