Combining Ability Analysis for Early Maturity and *Phaeosphaeria* Leaf Spot Resistance in Regional Maize Germplasm

By

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A thesis submitted in partial fulfillment of the requirements for the Master of Science Degree in Crop Science (Plant Breeding)

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October 2007

Abstract

Phaeosphaeria leaf spot (*P. maydis* Henn.) disease has the potential to cause substantial yield losses in maize (*Zea mays* L,). Maize is grown by smallholder farmers without fungicides; hence the need to breed for resistance in regional adapted germplasm. Sub-Saharan Africa has been characterised by low annual rainfall amounts. As such the demand for early maturing maize hybrids has been on the increase. No information is available on the combining ability of maize genotypes for *Phaeosphaeria* leaf spot resistance (PLS) and early maturity. In addition, there is virtually little information about the gene action determining PLS resistance in African maize germplasm. This study was therefore conducted to determine the combining ability of early maturity and PLS disease resistance in Sub-Saharan Africa maize germplasm. The maize inbred parents previously selected for their performance were crossed in a North Carolina Design II mating scheme. The twenty-five experimental hybrids that were generated were evaluated for general and specific combining abilities together with five check hybrids in a 5 x 6 rectangular lattice design during the 2006/7 summer season at two locations, Borrowdale and Kadoma in Zimbabwe. There was significant variation among hybrids ($P < 0.05$). General combining ability (GCA) effects were more important than specific combining ability (SCA) effects, reflecting the preponderance of additive gene action for days to maturity, *Phaeosphaeria* leaf spot disease resistance and grain yield. Results of GCA showed that E25 and E29 were the best general combiners for earliness (giving high negative GCA effects) at both locations. For PLS disease resistance, E31 and E18 were the best general combiners (giving high negative GCA effects), at Borrowdale and Kadoma, respectively. For SCA effects, the highest significant negative effect for earliness was shown by the crosses E28 x E29 and E32 x E25 at both locations. The highest SCA effect for PLS disease resistance was given by the cross E32 x E31 and E28 x E31 at Borrowdale and Kadoma, respectively. For grain yield, the highest SCA effects were given by E26 x E18 and E28 x E25 at Borrowdale and Kadoma, respectively. The hybrids showed a high range of performance for all characters investigated, and could be further exploited for their heterotic capacities and subsequent release in areas where PLS is prevalent. Early maturity and PLS disease resistance heritabilities were moderate (51 %) and high (68 %), respectively indicating that selection could be used to improve earliness and PLS resistance in this germplasm.

Dedication

In memory

Of my father, Noel (1942 -2001); my two sisters Febbie (1968 – 1996), Felistas (1984 – 2005) and Kudzi (1996 – 2007) who couldn't wait despite their insatiable quest to see me attain higher education. May their souls rest in eternal peace.

“The greatest service, which can be rendered to one country, is to add a useful plant to its culture” - T.F. Jefferson, USA President (1801 -1809)

Acknowledgements

I herewith acknowledge and offer sincere gratitude to my supervisors Dr. J. Derera and Dr Mutengwa for their time, instructions, invaluable advice, and assistance and for their participation in the course of the study. Their criticism and appraisal of the manuscript during the course of the study is highly appreciated.

My sincere gratitude to Mr C. Musvosvi of the University of Zimbabwe for his keen interest in the project, for sound and constructive suggestions, and discussions during the initiation of the study.

I would like to extend my sincere gratitude to Dr B. Vivek of the CIMMYT Maize program for discussions during the initiation of the study as well as providing seeds of CIMMYT – Zimbabwe maize lines. I am also grateful to Seed Co Zimbabwe for providing maize germplasm for the study, use of Kadoma Research Centre (KRC) facilities is also sincerely acknowledged. I would also want to thank staff at KRC especially Mr Governor Mateyo, who cooperated with me during production of crosses and trial management.

Many thanks to Kim Travis and Crystal Prettie of Agrobase in Canada for instructing me on the Agrobase software. I would also want to thank Dr A. Rossman of United States Department of Agriculture for providing literature on PLS. My sincere thanks to Mrs E. Vester, of the PRAIS Programme at the University of Free State for her cooperation and in providing literature for initiation of the study.

I am indebted to my colleagues and friends for their encouragement and assistance, especially Rabecca Rance for her assistance, criticism and appraisal of the manuscript. I

am proud to express my heartfelt appreciation to my mother, Mrs Catherine Mhembere for her love and patience during my study. I would also like to express my sincere gratitude to my brothers, Owen and Onward for their support throughout my study.

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ABBREVIATIONS

δ	standard deviation
δ^2	random error variance
δ^2_A	additive variance
δ^2_D	dominance variance
δ^2_f	genetic combining ability female variance
δ^2_{fme}	location by specific combining ability variance
δ^2_m	genetic combining ability male variance
δ^2_{me}	location be general combining ability variance
δ^2_{mf}	specific combining ability variance
µm	micrometer
ASI	anthesis to silking interval
CIMMYT	International Maize and Wheat Improvement Centre
cm	centimetres
Cov	covariance
DMP	days to mid-pollen shedding
DMS	days to mid-silking
DMT	days to maturity
e	number of locations
EH	ear height (cm)
EPP	ears per plant
GCA x E	General combining ability by environment interaction
GCA	General combining ability
GW	grain weight

GYLD	grain yield
H^2	broad sense heritability
h^2	narrow sense heritability
HS	half sib
kg ha^{-1}	kilogrammes per hectare
KZN	KwaZulu Natal
lha^{-1}	litres per hectare
masl	metres above sea level
mm	millimetre
mMT	Million metric tonnes
MO	moisture content
MS	mean square
NCDII	North Carolina design II
^oC	degree Centigrade
PC	plant count
PH	plant height (cm)
PLS	*Phaeosphaeria* leaf spot disease
PRAIS	Programme for Agriculture Information Services
QPM	Quality protein maize
r	number of replications
r_A	genetic correlation
r_P	phenotypic correlation
SCA x E	Specific combining ability by environment interaction
SCA	Specific combining ability
SSA	Sub-Saharan Africa
t ha^{-1}	tonnes per hectare

USA	United States of America
V_A	additive variance
V_G	genetic variance
V_P	phenotypic variance

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CHAPTER 1

INTRODUCTION

1.1. Background

Maize (*Zea mays* L.) is the number one food staple in Africa with about 90 % of it being used as food, except in South Africa where only 50 % is used as food (Eicher and Byerlee, 1997). In Southern Africa, maize provides 50 % of the calories in diets with a per capita consumption of 100 kg. In Eastern Africa, it provides 30 % of the calories with about 100 kg per capita consumption. In West and Central Africa, its consumption is 23 kg per capita, providing 13 % of the calories (Pandey, 1998).

Many African countries frequently experience maize shortages and approximately 100 million people are malnourished in Sub-Saharan Africa (SSA). Average maize yield is 1.3 t ha^{-1} (FAO statistics: www.fao.org, 2004). Today, SSA imports over 2.5 mMT of maize and by the year 2020 it is predicted to import 3.1 mMT of maize, an amount that should not be difficult to produce.

The major constraints responsible for this gap between demand and supply today, is attributable to increased pests and diseases, unreliable annual rainfall amounts, and lack of quality-improved germplasm. However, in SSA and Zimbabwe in particular, Phaeosphaeria leaf spot (PLS), a foliar fungal disease, commonly known as white leaf spot is proving to be of importance with increased incidence and severity of epidemics having been recorded since 1999.

Phaeosphaeria leaf spot (PLS) is a fungal disease caused by the ascomycete *Phaeosphaeria maydis* (Henn) on the maize crop. The disease was first identified in 1965 in India (Rane, Payak and Renfro, 1965), and secondly in Brazil in 1982 where it later developed to epidemic level in the 1990s (Fentin, 1994). The disease has occurred regularly in the United States of America (USA), in southern Florida particularly in winter maize breeding nurseries (Carson, 2001). In Africa, PLS was first identified in Kenya in 1996, Zimbabwe in 2001 and later in South Africa's KwaZulu-Natal (KZN), Mpumalanga and Gauteng regions where it has since attained epidemic levels (Flett, 2004).

Factors contributing to the rapid spread of PLS in the affected regions of the world include presence of inoculum, hot and humid conditions and extensive cultivation of susceptible host plants. Widespread use of minimum tillage techniques also contributes to the regional prevalence of PLS. This is because these practices leave fields covered with infected stover that serve as a source of disease inoculum for the next maize crop (Casela, 1998). Continuous extensive cropping of maize is also common and most currently available cultivars are susceptible to PLS. Hence favourable conditions, cultural practices and extensive planting of susceptible varieties have contributed towards high prevalence of the disease.

In addition, the past five years in SSA have been characterized by low annual rainfall amounts. Rain seasons have been short, limiting maize cultivation. As such, the demand for early maturing maize (varieties that flower between 55 days and 60 days, and mature physiologically at 120 days after emergence at Harare, Zimbabwe: 1500m.a.s.l, latitude 17,48^{o}S and longitude 31^{0}E) has been on the increase, in the main season (CIMMYT-Zimbabwe, 2000). Today, in Eastern and SSA, early maturing varieties are being planted to an estimated total area of 2.7 million hectares which translates to 3.5 mMT of grain annually capable of feeding 40 million people per year (average consumption = 87 kg/ person) (Pingali, 2001).

Farmers are growing early maturing varieties because such varieties:

- Are ideal for off-season plantings in drying riverbeds;
- Provide an early harvest to bridge the “hungry season” before harvest of a full season crop. This is especially important in areas where there are two growing seasons;
- Can be used to produce a crop during the secondary short rains, which enables the planting of a full season maize crop or other crops in the following main season (mainly in Eastern Africa);
- Are ideal for intercropping as they provide less competition for moisture, light and nutrients than later maturing varieties (CIMMYT-Zimbabwe, 2000);
- Offer flexibility in planting dates, which enables:
    - Multiple plantings in a season to spread risk of losing a single crop to drought;
    - Late plantings during delayed onset of rainfall; and
    - Avoidance of known terminal drought periods during the cropping season.

Whilst this is commendable, the increase in demand for early maturing varieties is coming against a background of increased incidence and severity of PLS particularly in SSA. Unfortunately, many early maturing maize breeding programs that have been initiated are relatively young with little information on combining abilities of lines for both

PLS resistance and early maturity. There are only a few maize cultivars that have been released in Zimbabwe since about 1930; when maize research began in Zimbabwe. There has been little emphasis in breeding for disease resistance in early generation maize as breeders focused on medium to late maturing germplasm which has been bred for resistance to late season diseases such as grey leaf spot (GLS).

1.2. Justification

Maize is an important food crop in SSA and presently ranks first among the grain commodities in volume of production and value. Unfortunately, the contribution of maize in enhancing regional food security is among other factors, being derailed by the advent of PLS, a widely disseminated disease in tropical and sub-tropical maize producing areas in the world (Do Amaral, 2005; Silva and Moro, 2004; Carson, 2001; Silva, 1997). Although there is little published information about PLS, its ability to cause damage to maize in SSA, and other areas of the world, make the recent observation of the disease a concern to the whole of the SSA region.

In addition, grain yield losses can be expected where PLS is endemic particularly if the disease occurs earlier during the seedling stages. Pinto (1995) reported a decrease of 63.16 % in maize grain yield in susceptible cultivars in Brazil due to PLS. This impacts negatively on food security and hence merits urgent efforts to develop effective and affordable strategies to protect against these losses. Resistant cultivars and/or fungicide sprays can be used to minimize yield losses caused by PLS. Many farmers, however, cannot afford the expense of fungicides, which can also be an environmental hazard with possible adverse effect on health. Maize cultivars resistant to PLS are therefore required either as a sole solution or as a contribution in an integrated management approach to deal with this problem.

Concomitant to that is the realization of the increased demand for early maturing maize varieties in SSA because of short rainy seasons, recorded in the past five years. Evidently, early maturing maize can provide farmers in different agro-ecological zones with flexibility in date of planting and is suitable for filling the hunger gap after a long dry period. However, this increased demand is coming against a background of increased incidence and severity of PLS, and early maturing germplasm resistant to PLS is virtually unknown. As a result, early maturing maize varieties resistant to PLS are therefore required, as available commercial maize varieties are susceptible.

To develop resistant cultivars it is important to understand the inheritance of resistance. Maize has great diversity for resistance to pathogens, which makes the use of resistant cultivars the most economic and efficient form of disease control (Balmer and Pereira, 1987; Silva, 2001).

Furthermore, the application of concepts of heterosis, general and specific combining abilities (i.e. GCA and SCA, respectively) has been utilised for grain producing crop breeding. These concepts are useful for the characterisation of lines in crosses and for establishing heterotic standards between maize populations (Hallauer and Miranda, 1988). Thus, knowledge of gene action determining inheritance of PLS resistance in maize would be important in designing breeding strategies to develop PLS resistant early maturing hybrids. This also allows better understanding of the genetic systems controlling inheritance since effective selection can only be achieved when the genetic basis of resistance is known.

Moreover, knowledge of gene action controlling PLS will potentially lead to more efficient development of resistant cultivars and deployment of germplasm sources. Hence, the need to investigate the mode of inheritance for PLS resistance in regional early maturing maize germplasm becomes of paramount importance as it enhances the success of breeding programs that focus on disease resistance, which is appealing to farmers in SSA.

1.3. Objectives

1.3.1. Main objective

The main objective of this study was to conduct genetic studies for early maturity and PLS resistance in regional maize germplasm.

1.3.2. Specific objectives

The specific objectives evaluated in this study were as follows:

a. to determine combining ability effects for early maturity and PLS resistance in maize;
b. to identify early maturing maize inbred lines with high level of resistance to PLS; and
c. to estimate heritability of PLS resistance and early maturity in regional maize germplasm.

1.3.3. Hypotheses

Hypotheses tested in the study were as follows:

a. There are significant combining ability effects for early maturity and PLS resistance among the regional maize germplasm.

b. There is a sizable number of inbred lines with high levels of early maturity and PLS resistance.
c. Heritability of early maturity and PLS resistance in regional maize germplasm is high.

CHAPTER 2

LITERATURE REVIEW

2.1. Distribution and Occurrence of Phaeosphaeria Leaf Spot

Phaeosphaeria Leaf Spot (PLS) is a widely disseminated disease in tropical and sub-tropical maize producing areas in the world (Do Amaral, 2005; Silva and Moro, 2004; Carson, 2001; Silva, 1997). The disease primarily occurs in tropical highlands with altitudes above 600 m where rainfall is abundant and temperature moderate. Shurtleff (1984) and Silva (1997) reported that favourable conditions are prevalent in areas of Brazil, Colombia, Costa Rica, Ecuador, Himalayas, northern India, eastern and southern Africa, the USA, and Mexico.

Phaeosphaeria Leaf Spot (PLS) has become an increasingly important disease of maize in eastern and southern Africa, mainly in Cameroon, Kenya, Malawi, South Africa, Zambia and Zimbabwe in the past six years. In Kenya, first reports were made in 1996, and since then incidence and severity has been reported in Thika, Nyeri, Muranga and Kirinyaga districts of the Central province. In South Africa, this disease occurs most frequently in KwaZulu-Natal, the eastern parts of Mpumalanga and western parts of Gauteng (Flett, 2004). Occurrence in Zimbabwe has been reported in the Highveld and Middleveld areas, particularly following high rainfall ([1]Mhike, *personal communication*, 2004). It has occurred regularly in Marondera, Harare, and Zvimba mainly in summer maize breeding nurseries and trials, since the year 2000. Further reports have suggested an increase in disease incidence in Mazowe, Mvurwi and Goromonzi districts of Zimbabwe. As such, there is a rising concern of PLS amongst breeders and

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[1] Mhike is a Plant Breeder and also the Head of Maize Program at the Crop Breeding Institute, AREX Department, Zimbabwe.

pathologists in SSA.

Do Amaral (2005) reviewed that prior to the 1990s the disease occurred at the end of the maize growing season without damaging maize quality or reducing grain yield and therefore was considered of secondary importance. However, a more recent report has shown that the disease can occur at three to five leaf stage of development, causing a threat to food security in SSA (Silva and Moro, 2004). In addition, during the 1990s PLS was considered the most severe among the leaf spots in the central, south-eastern, and southern regions of Brazil (Do Amaral, 2005). Thus, PLS is a leaf disease, which has recently become more common in most of the maize producing areas of the world.

Further reports have suggested that the increase in incidence and severity is favoured by late sowing, absence of crop rotation and zero tillage practices mainly with the use of overhead irrigation (Do Amaral, 2005; Casela, 1998). As a result this has seen an increase in disease incidence and severity.

2.2 Phaeosphaeria Leaf Spot

2.2.1 Etiology

Phaeosphaeria leaf spot of maize is caused by theascomycete *Phaeosphaeria maydis* (Henn), Rane, Payak and Renfro (syn. *Sphaerulinia maydis* = *Leptosphaeria zeae maydis* Saccas; *Metasphaeria maydis* (Henn) Höhnel, anarmorphous stage: *Phyllosticta* spp) (Silva and Moro, 2004; Casela, 1998; Carson, 2001; Rane, Payak and Renfro, 1965). Different viewpoints have been advanced in the past regarding the causal agent, though. Recently, the *P. maydis* anamorph has been attributed to *Phoma maydis*, D.C. Arny and R.R Nelson (syn. *Phoma zea-maydis* Mukunya and Boothroyd), the causal

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agent of Yellow Leaf Blight (Do Amaral, 2005).

However Do Amaral (2005) concluded the domination of the anamorph, *Phyllosticta*, observed with studies *on P. maydis* Anhembi. This was further synthesised from confirmations made by CABI-BioScience, which identified the anamorph of *P. maydis* as Phyllosticta, *zea-maydis*, as reported by Do Amaral (2005). Hence, the anamorph of this ascomycete has been adopted as due to the *Phyllosticta*.

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2.2.2 Description of the Pathogen, *P.maydis*

Casela (1998); Parentoni, Tavares, Maguavaca, Gama, Lopes, Evaristo, Santos, Eleuterio and Oliveira (1994); Shurtleff (1980), and Rane, Payak and Renfro (1965), reported that the pathogen, *P. maydis* is characterised by spherical to subglobose perithecia with papillate ostioles. The asci are hyaline, clavate or cylindrical, bitunicate, truncate at the base, thickened at the apex, straight or curved, eight-spored, measuring 44.5-70 x 7.5-8.5 µm. The ascospores are biseriate but may become overlappingly uniseriate, hyaline, fusiod, and straight or slightly curved, three-septate, and slightly constricted at the septa, measuring 14.5-17.5 x 3.5-5.0 µm. If cultured, the fungus produces white mycelium that later becomes dark grey with the presence of numerous pycinidia.

During the pycnidial stage, the pycnidia are spherical or globose, dark brown to black with a round ostiole and measure 74 to 151 µm in height and 67 to 159 µm in width. The spores are hyaline, ellipsoid, elongate or round measuring 3.2-9 x 2.4-3.2 µm.

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2.2.3 Disease symptoms and their Development

Standard description of PLS symptoms indicate that the leaf spots first appear as pale green areas. As the disease progresses, these turn into larger bleached or dried lesions with dark brown irregular margins. The spots are round, elongated to oblong, measuring 3 – 20 mm and are found scattered over the leaf. These lesions may coalesce and become irregularly shaped (Casela, 1998; Shurtleff, 1980; Rane et al., 1965; Parentoni et al., 1994). Perithecia and less frequently, pycinidia develop in the lesions (Casela, 1998; Shurtleff, 1980). Conversely, Do Amaral (2005) found that in Brazil, these symptoms are described as white to straw-coloured lesions, 1 – 20 mm in diameter, and not always with dark brown margins.

Do Amaral (2005) further reports that the symptoms of the disease develop on the basal leaves and progresses rapidly to the tip as the plant advances in the season (Figure 2.1). The lesions generally appear after flowering; however, when the infection occurs in young plants it can damage grain quality and reduce yield. These findings warrant urgent efforts to develop resistant cultivars in order to safeguard food security.

Figure 2.1. PLS infected maize plants in Zimbabwe (Source: Mhembere, 2007)

2.2.4 Epidemiology

The fungus persists in cultural debris in diseased plant parts in the field. Under favourable environmental conditions, high rainfall and relatively low night temperatures, the spores can germinate and infect maize leaves (Carson, 2001; Casela, 1998). Casela (1998) indicates that under conditions of Sele Lagoas, Brazil, the disease was more severe when crops were sown between May and October. This has also been observed at Rattray Arnold Research Station, in Acturus, near Harare, Zimbabwe. In the same vein, Casela (1998) found a strong correlation between plant age, temperature (maximum and minimum), relative humidity and disease incidence. In addition, Fernandes and Sans (1994) reported that night temperatures 14°C and relative humidity above 70 % are sufficient for disease development. As a result, this correlation provides favourable conditions for the development of PLS.

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2.3 Economic Importance of Phaeosphaeria Leaf Spot

PLS is a potentially serious foliar disease of maize that is widely distributed in Central and South America, Asia, and Africa (Silva and Moro, 2004; Carson, 2001). Fernandes and Oliveira (1997) reported that the incidence and severity of this disease has increased significantly during the 1990s, and today it is found in practically all maize producing regions of the world. The disease under favourable conditions of moisture and high temperatures can lead to senescence of leaves, a reduced plant cycle, and a considerable reduction in photosynthetic leaf area resulting in sharp decreases in grain size and weight (Fernandes, Oliveira and Pinto, 1995). Although yield loss assessments have not been conducted in SSA, substantial yield losses have been reported in Brazil. Pinto (1995) reported a decrease of 63.16 % in grain yield in susceptible cultivars, while Carson (2005b) reported 11 % to 13 % in the USA as a result of PLS damage. These yield reductions are attributed to the non-translocation of nitrogen, accelerated leaf senescence, reduced development period, and decreased grain size and weight in infected plants (Fernandes and Oliveira, 1997). Godoy, Amorin and Filho (2001) observed a 40 % reduction in net photosynthesis rate with disease severity between 10 and 20 %. As such, reduction in transpiration rate was proportional to reduction of healthy leaf area due to the disease. Thus a negative linear relation (r^2 from 0.59 to 0.75 for different materials) between transpiration rate and disease severity, was established (Godoy *et al*., 2001).

Although the importance of this disease has been considered minor, its occurrence, spread and severity in recent seasons raises the question if the impact of the disease on the industry has been underestimated. Observations in other areas of the world where PLS occurs indicates notable losses in yield and this disease is of growing concern for pathologists and breeders in the maize industry.

In addition, Pandey (1998) reports that the population of Africa will increase to 1.2 billion by the year 2020, and yet this comes against a background of increased PLS. The major implication is that maize is the number one food staple in Africa with about 90 % of it used as food, except in South Africa where 50 % of it is used as food (Eicher and Byerlee, 1997). In southern Africa, maize provides 50 % of the calories with a per capita consumption of 100 kg. In eastern Africa, it provides 30 % of the calories with about 100 kg per capita consumption. In west and central Africa, its consumption is 23 kg per capita, providing 13 % of the calories.

This average per capita consumption and the demand of maize for feed are likely to increase by 2020. Hence there is an urgent requirement to curb losses attributable to

PLS to enhance food security for Africa, and in particular SSA. Work on inheritance of the disease can help mitigate this eminent challenge.

2.4 Control Strategies for Phaeosphaeria Leaf Spot

2.4.1 Resistance to Phaeosphaeria Leaf Spot

Disease resistance helps to ensure stable yields for smallholder farmers. Such smallholder farmers have little or no cash income and face hunger after a simple crop failure. Hence, protecting their harvests from diseases, even at relatively low yield levels often contributes more to household income and food security than getting higher yields in disease free years. As such, it is against this background that studies have been conducted to identify PLS resistant maize varieties (both hybrid and open-pollinated). However, such studies have been limited to the USA and Brazil. Research on PLS disease resistance in Zimbabwe, in general and SSA, in particular, is still in its infancy, an imminent threat on food security to the already challenged maize producing smallholder farmers.

However, in Brazil, a number of experimental hybrids possessing good high levels of resistance were developed by Centro Nacional de Pesquisa de Milho e Sorgo of Empressa Brasileira de Pesquisa Agropecuáriá (CNPMS/EMBRAPA) especially some quality protein maize (QPM) materials: 93HD3QPM, 93HD30QPM, 94HD32QPM, 94HT31QPM, and 92HD1QPM (Casela, 1998). In addition, progress has been made towards the development of a PLS resistant open pollinated maize variety. Das, Sinhamahaptra and Bask (1989) reported that the crosses Nabin x CompH3, Diara x Vijay, and Super 1 x Vijay, presented the highest levels of resistance to *P.maydis* whilst working in a diallel cross comprising eight open pollinated varieties of maize exposed to

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natural infection.

In addition, in a diallel cross involving nine lines, Silva and Moro (2004) observed that hybrid combinations with the greatest level of PLS resistance were obtained from crosses of line DAS95 with lines DAS41, DAS86, DAS72 and DAS2 in a multi-location trial carried out in Brazil, mainly in Taquarituba, Cravinhos and Irai de Minas. Carson (2001) reported that inbred lines related to B73 were particularly susceptible to PLS, whereas inbred lines related to Mo17 are highly resistant. These findings depict the abundance of PLS resistance sources that need to be explored in order to develop resistant varieties. Unfortunately, these studies on inheritance of PLS have been conducted using American and Brazilian materials, which do not have a direct application to SSA. In SSA, the area grown to USA and Brazilian germplasm is not of any significance; hence the need to breed for resistance in regionally adapted germplasm. Such breeding programs (directed towards genetic resistance) will potentially lead to the estimation of genetic parameters that control resistance allowing the introduction of resistance into susceptible germplasm to be clearly focused (Casela, 1998; Zhang, Haley & Jin 2001; Silva and Moro, 2004). This potentially leads to more efficient development of resistant varieties that will be appealing to farmers in SSA.

2.4.2 Use of Fungicide Sprays

There is no doubt that a major benefit from the use of fungicides has been that farmers had the freedom to grow relatively disease susceptible varieties reliably, to produce high yields and/or grain quality demanded by the market, the world over. Today, world economic trends have seen the price of maize grain plummeting as input costs inevitably increase with escalations in inflation. This has paved way for maize breeders to improve current varieties for disease resistance in order to cut variable costs of production. However, new diseases are coming up and one such disease is PLS. Few studies have been conducted in Brazil to identify effective fungicides for use in the control of PLS. Pinto (1999) reported that the control of PLS was achieved through the use of fungicides primarily in seed production fields and breeding nurseries in Brazil. The fungicide mancozeb (2.4 kgha^{-1} was found to be effective and efficient in controlling *P. maydis* thereby increasing maize grain yield by 63.1 % (Pinto, 1999). However, such studies are yet to be conducted in Zimbabwe, and SSA, in particular.

Whilst this is commendable, it is disheartening to note that many smallholder farmers in SSA cannot afford the expense of fungicides considering the low producer price of maize grain and the meagre farm incomes realised every year. This also comes against the background that fungicides can be an environment hazard with possible adverse effect on health. Moreover, research has concluded that breeding for resistance is the best strategy for the control of this disease (Casela, 1998). As such, an alternative to farmers in SSA is to grow resistant maize varieties that are less costly in terms of production costs whilst at the same time protecting their harvests.

2.5 Gene Action that Determines Resistance to *P. maydis*

Research on the genetic control of resistance to PLS is still in its early stages, with few studies having been conducted. Carson (2001) determined that additive and to a lesser extent, dominance gene action, plays a role in the inheritance of reaction to PLS. In the study, Carson (2001) identified a resistant source in Mo17 and its genetic study indicated that resistance to PLS was quantitatively inherited (mainly additively) and that three to four genes controlled resistance to PLS. Casela (1998) established that resistance was determined by a recessive gene. More recently, the result of a diallel analysis involving 36 F_1 maize hybrids and their nine inbreds in Brazil reaffirmed the same findings suggesting that genetic control of resistance to PLS disease is due to genetic additive effects (Silva and Moro, 2004). In congruence, Pegoraro *et al*., (2002) reported two major independent genes that controlled PLS resistance in an additive manner whilst working with Brazilian maize. These findings indicate a preponderance of additive, with less important, but significant non-additive gene action that also contributes to resistance. This implies that single cross hybrids will be sufficiently resistant when both parents are resistant to PLS.

Therefore, knowledge of gene action determining inheritance of PLS resistance in maize is important in designing breeding strategies to develop PLS resistant hybrids. This also creates better understanding of the genetic systems controlling inheritance since effective selection can only be achieved when the genetic basis of resistance is known.

2.6 Heritability and Correlation

2.6.1 Heritability

Success of breeders in changing the characteristics of a population depends on the degree of correspondence between phenotypic and genotypic values (Falconer, 1989; Dabholkar, 1992; Singh and Ceccarelli, 1995). A quantitative measure, which provides information about the correspondence between genotypic variance and phenotypic variance, is heritability (Dabholkar, 1992). The term heritability has been further divided into broad sense and narrow sense, depending on whether it refers to the genotypic or breeding value, respectively (Falconer, 1989). The ratio of genetic variance to phenotypic variance (V_G/V_P) is heritability in the broad sense or genetic determination. It expresses the extent to which individual phenotypes are determined by the genotypes. A large percentage for a character is regarded as highly heritable whereas if it is smaller, some environmental agency is considered responsible for phenotypic manifestation of the character (Dabholkar, 1992).

On the other hand, the ratio of additive variance to phenotypic variance (V_A/V_P) is called heritability in the narrow sense. This expresses the extent to which phenotypes are determined by the genes transmitted from the parents. It also expresses the magnitude of genotypic variance in the population, which is mainly responsible for changing the genetic composition of a population through selection (Falconer, 1989; Dabholkar, 1992).

A broad sense heritability estimate based on various components of variance provides information on the relative magnitudes of genetic and environmental variation in the germplasm (Dudley and Moll, 1969). However, the type of gene action involved in the expression of a character has a significant role in determining heritability values. Characters that are controlled largely by genes acting in an additive fashion have higher values of heritability than values that are governed by genes with large non-additive effects (Hanson, 1963; Falconer, 1989; Dabholkar, 1992). According to Dabholkar (1992), it is important to note that heritability is a property not only of the character being studied, but also the population being sampled and the environmental circumstances to which individuals have been subjected. More variable environmental conditions also reduce the magnitude of heritability while more uniform conditions increase it (Blum, 1988; Rosielle and Hamblin, 1981). Even the unit used in reporting, influences the magnitude of heritabilities (Hanson, 1963). Furthermore, in predicting response to selection, heritability estimates are used to identify optimum environments for selection

(Singh and Ceccarelli, 1995).

A large number of studies have been conducted on maize to estimate both broad (H^2) and narrow sense (h^2) heritabilities of various traits. More recently, inheritance studies on PLS resistance estimated high heritabilities of 70 – 85 % for both narrow and broad sense (Carson, 2001; Carson, 2005a). Hence selection should be highly effective in developing inbred lines with adequate levels of resistance to PLS. This could see the development of resistant hybrids and deployment of resistant germplasm that will curb the current damage of PLS on the maize crop.

2.6.2 Correlation

Relationships between two metric characters can be positive or negative, and the cause of correlation between traits in crop plants can be genetic or environmental (Hallauer and Miranda, 1988; Falconer, 1989). Two types of correlations, phenotypic and genetic, are commonly discussed in plant breeding. Phenotypic correlation (r_p) involves both genetic and environmental effects. It can be directly observed from measurements of the two characters in a number of individuals in a population (Hallauer and Miranda, 1988). Genetic correlation (r_A) is the association of breeding values (i.e., additive genetic variance) of the two characters (Falconer, 1989). Both measure the extent to which the same genes or closely linked genes cause co-variation in two different characters (Hallauer and Miranda, 1988). Estimation of genetic and phenotypic correlations is based on components of variances and covariances that are estimated from analysis of variance and covariance, respectively. However, genetic correlations inherently have large errors because of difficulties to avoid the directional effects of confounding factors on additive correlation estimates. A line’s performance is correlated with its performance in crosses, to some extent depending on how much of the variance is due to additive genes. Thus evidence to date indicates that improvement in inbreds *per se* will play an increasingly large role in improving the perfomance of hybrids (Falconer, 1989; Duvick, 1999).

Genetic correlation in particular determines the degree of association between traits and how they can enhance selection. It is useful if indirect selection gives greater response to selection for traits than direct selection for the same trait. It is suggested that indirect selection would be effective if heritability of the secondary trait is greater than that of the primary trait and genetic correlation between them is substantial (Falconer, 1989). Similarly, Rosielle and Hamblin (1981) also indicated that magnitudes of selection responses and correlated responses will depend on heritabilities and phenotypic standard deviations as well as genetic correlations. Hallauer and Miranda (1988) established negative correlation (r = -0.52) between days to flowering and grain yield for Iowa Stiff Stalk Synthetic maize variety. Inbreeding that delays flowering has been considered as the main reason for this trend because it was estimated from two sets of unselected inbred progenies. However, the associations between grain yield and traits such as PLS and days to maturity (DMT) are not well known, especially for maize germplasm in SSA. Hence, the nature of these associations was investigated in this study.

2.7 Combining Ability Effects

Combining ability is an important concept especially useful in the study and comparison of the performance of lines in hybrid combinations (Hallauer and Miranda, 1988; Griffing, 1956; Sprague and Tatum, 1942). Sprague and Tatum (1942) developed the concept of combining ability and coined two terms, general and specific combining ability (GCA and

SCA, respectively). The term general combining ability (GCA) is used to designate the average performance of a line in hybrid combination. Thus, GCA is estimated from the individual line mean when averaged over all combinations involving a given line. It is primarily a measure of additive effects, which are amenable to selection (Hallauer and Miranda, 1988; Griffing, 1956; Sprague and Tatum, 1942). The term specific combining ability (SCA) is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Thus, SCA is a measure of the residual as well as dominance, epistatic and interaction effects.

In addition, combining ability allows plant breeders to screen for elite lines for potential use in hybrids. It also facilitates effective phenotypic elimination of lines that have poor combining ability. Hence combining ability of inbred lines is the ultimate factor determining future usefulness of the lines for hybrids and population improvement in maize breeding.

2.7.1 Combining Ability for Phaeosphaeria Leaf Spot

Studies aimed at resistance to diseases and grain productivity have shown that GCA and SCA can interact with the environment (Rojas and Sprague, 1952; Matziger *et al*., 1959; Parodas and Hayes, 1971; Nelson and Scott, 1973). Findings by Silva and Moro (2004) assert the same viewpoints. They found highly significant effects ($P<0.01$) for GCA and GCA x E and non-significant SCA and SCA x E effects. The significance of mean square effects for GCA x E suggested the necessity to select parental lines to obtain hybrids in specific environments as indicated by differences in the greatest GCA values obtained from the different environments.

In the same paper, the authors alluded to the fact that choice of parents based on the mean PLS for the GCA effects can be done if there is interest in simple hybrids adapted to all environments. As a result Silva and Moro (2004) deduced that GCA effects were more important than SCA effects. This gave an indication that genetic additive effects are, for the most part, responsible for the source variation for resistance to this disease.

Consequently, as reiterated by Silva and Moro (2004), emphasis should be placed on the mean performance of the line in hybrid combinations during selection, for the breeding to advance toward resistance to PLS. In a diallel evaluation comprising six Tuxpeno and flint lines, Parentoni *et al*., (1984), measured the general combining ability (GCA) between -1.04 and -1.03 for the Tuxpeno genotypes, and from -1.83 to -1.67 for the flint lines. These (negative GCA values) indicated the most resistant genotypes. They observed a marked trend for less disease severity when the cross-involved lines with negative values of GCA, and that resistance was determined by a recessive gene. The negative GCA estimates indicated the usefulness of the genotypes in producing progenies resistant to PLS and such genotypes may possibly be considered as parents where PLS resistance is desired.

However, the absence or small magnitude of non-additive genetic effects for resistance to a number of diseases has been reported by several authors (Hughes and Hooker, 1971; Lim and Hooker, 1976; Kappelman Jr and Thompson, 1981). The smaller expression of the non-additive genetic effects for the characters under evaluation should be attributed to the absence of deleterious genes that cause endogamic depression, even though these effects, on the average, have smaller importance than additive effects. However, in specific hybrid combinations, they can be of paramount importance (Hallauer and Miranda, 1988).

2.7.2 Combining Ability for Early Maturity

Early maturity is an essential trait for maize production in both dry and humid areas. Unfortunately, many early maturing maize breeding programs that have been initiated are relatively young with little information on combining abilities of lines for early maturity. Sujiprihati, Saleh and Ali (2001) found significant negative GCA and SCA effects ($P<0.01$) whilst working with twelve maize inbred parents. The high negative GCA effects for days to tasselling, especially exhibited by the lines, UPM-TW-5 and UPM-TW-12 indicated that the lines were the best general combiners for earliness (Sujiprihati *et al*., 2001).

In addition, the highest SCA effects for days to maturity indicated the expression of genes for earliness in maturity. As such, Sujiprihati *et al* (2001) depicted that both additive and non-additive gene action were important in expressing the operative gene action. However, they established that SCA variances were higher than those for GCA, indicating that non-additive gene effects were greater than the additive ones.

CHAPTER 3

MATERIALS AND METHODS

3.1. Research Sites

Field research was conducted in Zimbabwe at Kadoma Research Centre, Kadoma (latitude 18^{o}, 32'S, longitude 30^{o}, 9'N) in winter 2006, and Borrowdale (latitude 17^{0}, 48'S longitude 31^{0}E) in the 2006/7 summer season.

3.2. Germplasm

Ten maize inbred lines, derived from Seed Co Zimbabwe and CIMMYT-Zimbabwe, were selected based on preliminary field observation for reaction to PLS and days to tasselling in the 2004/5 and 2005/6 summer seasons. Description of this germplasm is shown in Table 3.1.

Table 3.1. Description of maize parents used in the North Carolina Design II.

Genotype	Days to Mid-Pollen	PLS Score	Infection response
E31	48	1	R
E21	51	1	R
E23	53	2	R
E26	42	1	R
E28	48	1	R
E32	55	3	MR
E18	41	5	MS
E29	40	6	MS
E20	43	8	S
E25	44	8	S

R= resistant, MR= moderately resistant, MS= moderately susceptible, S= susceptible.

3.3. Formation of Hybrids

The 10 parents were hand crossed at Kadoma in winter 2006 using North Carolina Design II (NCDII) mating scheme, with five male and five female inbred lines, as shown in Table 3.2. The hand pollination procedure followed that of Russel and Halluer (1980). A total of 25 cross combinations were obtained through hand pollination of the inbred parental lines.

Table 3.2. F1 hybrids made using North Carolina Design II in winter 2006

Female Parent	**Male Parent**				
	E18	E20	E25	E29	E31
E21	E21*E18	E21*E20	E21*E25	E21*E29	E21*E31
E23	E23*E18	E23*E20	E23*E25	E23*E29	E23*E31
E26	E26*E18	E26*E20	E26*E25	E26*E29	E26*E31
E28	E28*E18	E28*E20	E28*E25	E28*E29	E28*E31
E32	E32*E18	E32*E20	E32*E25	E32*E29	E32*E31

3.4 Agronomic Management

3.4.1. Land Preparation and Planting

The land was ploughed using a tractor drawn heavy disc plough in March (2006) at Kadoma and May (2006) at Borrowdale. A pre-marked wire was used to mark planting hills at a spacing of 0.75 m between rows and 0.50 m within rows. Seeds were sown by hand (four seeds per hill) and seedlings were thinned to two, three weeks after planting resulting in a final plant density of approximately 53 333 plants per hectare.

3.4.2. Fertility and Water Management

A basal application of 500 kg/ha of compound D (7 %N, 14 %P_2O_5, 7 % K_2O, 8.5 %S) fertiliser was broadcast and disc-incorporated by a tractor. Ammonium nitrate (34.5 %N) was split applied at 250 kg ha^{-1}. The first application of 100 kg ha^{-1} was done at three weeks after emergence and the remainder at five weeks after emergence. The trial was rain-fed, but a light irrigation was applied immediately after planting to facilitate seed germination and seedling emergence. Irrigation was also applied in the case of a long dry spell.

3.4.3. Weed control

Throughout the season, trials were kept weed free. A mixture of Atrazine (2-chloro-4-ethylamino-6-isopropyl-amino-1,3,5-triazine), Lasso (2-chloro-2',6'-diethyl-N-(methoxymethyl acetamide) and Gramoxone (1,1'-dimethyl-4,4-bipyridinium ion) at 4.0l, 2.0l and 2.0l ha^{-1}, respectively, was applied as a post-planting pre-emergence spray for the weed control. From five weeks on, the field was kept weed free by hand weeding.

3.4.4. Pest control

Carbofuran/Curator (2,3-dihydro-2,2-dimethyl-benzofuran-7-yl methylcarbamate) (Worthing, 1979) mixed with sand in a ratio of three parts chemical to four parts sand was applied in each planting hole for the control of leafhoppers grubs and cutworms. At four weeks after crop emergence, scouting for the maize stalkborer (*Busseola fusca* Fuller) started and Dipterex (dimethyl 2, 2, 2-trichloro-1-hydroxyethylphosphonate) granules at 2 kg ha^{-1} were applied to each maize plant whorl.

3.5. Disease Production and Evaluation

The trial at Borrowdale was artificially inoculated at four weeks after emergence with PLS infected leaves originating from field collections in the 2005/6 growing season at Rattray Arnold Research Station, near Harare. The infected leaves were ground just prior to infestation. Inoculation was accomplished by placing a pinch of inoculum into the whorl of each plant. All disease scores were done on a whole plant basis for the entire plot at milk to soft dough stage. A 9-class rating system was used in which 1 = no symptoms to 2 %, 2 = 2 to 4 %, 3 = 4 to 7 %, 4 = 7 to 15 %, 5 = 15 to 35 %, 6 = 35 to 65 %, 7 = 65 to 85 %, 8 = 85 to 95 %, and 9 = >95 % leaf area infected, respectively.

3.6. Design and Experimentation

Twenty five F_1 hybrids produced from a 5 x 5 NCDII in winter 2006, were evaluated in summer 2006/7 as treatments laid in a 5 x 6 rectangular lattice design (an incomplete block partially balanced lattice design with two replications) with 5 local checks (Appendix 1).

Plots were represented by two 4.0 m long rows, spaced at 0.75 m, with 32 plants per plot, two plants per hill, and an in-row spacing of 0.50 m. This gave a plant population density of 53 333 plants ha^{-1}, with an effective plot area of 3 m^2.

3.7. Statistical Analyses

General Analysis of Variance of the 5 x 6 rectangular lattice design for all the quantitative traits measured was done using Agrobase statistical package (Agronomix, 2007). Significant quantitative traits were analysed using Line x Tester procedure of Agrobase (Agronomix, 2007) to derive GCA and SCA estimates for the parents.

3.8. Heritability Estimation

Estimate of heritability in the narrow sense, was calculated as follows: $h^2 = \dfrac{2\sigma_m^2}{\dfrac{\sigma^2}{re} + \dfrac{\sigma_{fme}^2}{e} + \dfrac{2\sigma_{me}^2}{e}\sigma_{mf}^2 + 2\sigma_m^2}$ because the parents were almost fully inbred (beyond S_8 generation; F = 1); where σ_m^2 = GCA male variance, σ^2 = random error variance; σ_{mf}^2 = SCA variance; σ_{fme}^2 = location x SCA variance; σ_{me}^2 = location x GCA male variance; r = number of replications and e = number of locations (Hallauer and Miranda, 1988).

Additive (σ_A^2) and dominance variances (σ_D^2) were estimated using the formula: $\sigma_m^2 = \sigma_f^2$ =Cov. Half sib families (HS) = σ_A^2, and σ_{mf}^2 = Cov. Full sib families – Cov. HS_m – Cov.HS_f = σ_D^2, because F = 1 (where m = male and f = female parents) (Hallauer and Miranda, 1988). Average dominance of genes (d) will be estimated using the formula: d = $(2\sigma_{mf}^2 / \sigma_m^2)^{1/2}$ (Hallauer and Miranda, 1988).

3.9. Measurements

Measurements were taken on whole plot basis (Appendices 2 and 3). Days from planting to mid-pollen (DMP) shedding and mid-silking (DMS) were calculated from the date on which 50 % of the plants had begun shedding pollen or had silks emerging from the husk. Anthesis-silking interval (ASI) was obtained by subtracting DMP from DMS. Three weeks after anthesis, plant (PH) and ear height (EH) were measured as the distance from ground level to the first tassel branch (for PH) or the base of the uppermost ear (for EH) using five plants per plot. At the same time, the number of primary tassel branches was counted on five randomly selected plants per plot.

Days to maturity (DMT) were calculated as days from planting to physiological maturity (black-layer formation). Number of plants (PC) per plot were counted at three weeks after planting and physiological maturity, ears were harvested, shelled and grain weight (GW) recorded per plot in kilograms (kg) and simultaneously, moisture percentage (MO) was determined by using a Dickey John moisture tester. The grain yield was recorded in tonnes per hectare (t ha^{-1}) after being adjusted to the standard of 12 % moisture content. Disease scores for PLS were recorded at the mid-dent stage using a Class 9 rating system.

CHAPTER 4

RESULTS

4.1 Disease Development and Hybrid Resistance

The severity and development of PLS was moderate in the 2006/7 summer season. This was attributable to moderate rainfall and temperature regimes that characterised the whole season (Figure 4.1).

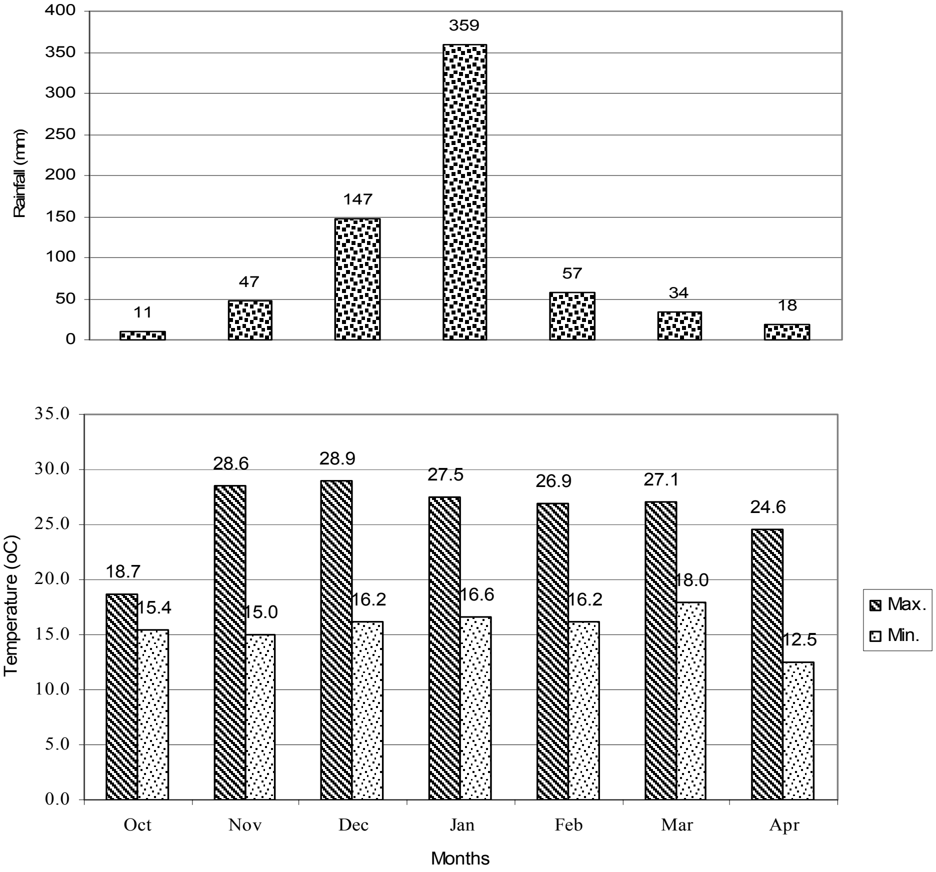

Figure 4.1. Rainfall and temperature distribution for the 2006/7 summer season at Borrowdale, near Harare.

Generally most of the hybrids evaluated were fairly resistant to PLS and only 3.3 % of the hybrids had PLS ratings greater than 5.0 (Figure 4.2).

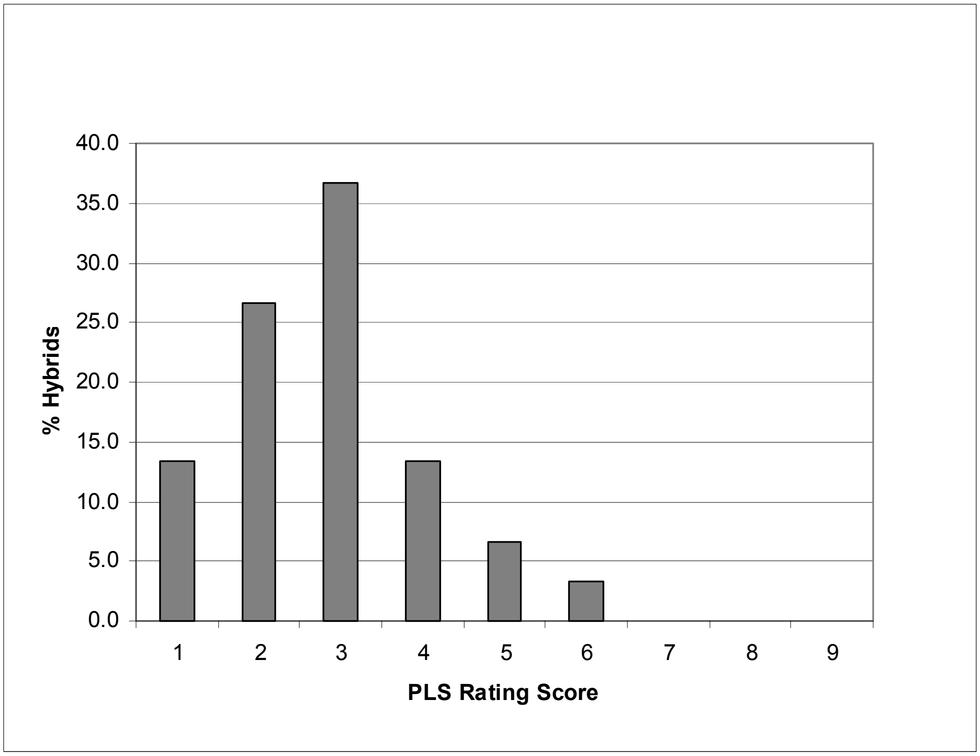

Figure 4.2. Frequency distribution of mean *Phaeosphaeria maydis* scores in 30 maize hybrids

Hybrid resistance to PLS was expressed by reduced disease severity, reduced number and size of lesions on the plant tissues. In the field, the first lesions were observed on the leaves above the ear in some entries but in most hybrids on the lower leaves. Disease scores ranged from one to six, and this was adequate to discriminate the hybrids for resistance.

4.2 Analyses of Variance for the Quantitative Traits Measured

Significant differences ($P < 0.05$) between hybrids were observed for all the quantitative traits measured at Kadoma and Borrowdale (Table 4.1). There was appreciable variability amongst the hybrids.

Table 4.1. Analyses of variance for Days to maturity, *Phaeosphaeria maydis* disease scores and Grain yield at Kadoma and Borrowdale during the 2006/7 summer season

Source of Variation	d.f.	Mean Square					
		Days to Maturity		Phaeosphaeria Leaf Spot (Score)		Grain Yield (t ha^{-1})	
Site 1: Borrowdale							
Reps	1	3.267	ns	0.267	ns	4.933	*
Hybrids (unadj.)	29	110.887		4.669	*	1.660	
Blocks (adj.)	10	35.504		0.150		1.651	
Intra-Block Error	19	17.036		0.381		1.106	
Hybrids (adj.)	24	124.198	*	0.000		2.167	*
Total	59						
Site 2: Kadoma							
Reps	1	18.150	ns	5.400	*	6.609	*
Hybrids (unadj.)	29	154.465		4.862		1.934	
Blocks (adj.)	10	28.550		1.021		1.236	
Intra-Block Error	19	17.887		0.810		0.849	
Hybrids (adj.)	24	182.544	*	5.734	*	2.140	*
Total	59						

* Significant at $P < 0.05$

4.2.1 Grain Yield

Grain yield for hybrids ranged from 3.8 to 7.3 t ha^{-1} across environments (Table 4.2), whilst mean grain yield ranged from 4.7 to 8.3 t ha^{-1} (Table 4.3), and 2.6 to 6.2 t ha^{-1} (Table 4.4) at Borrowdale and Kadoma, respectively. Across environments, hybrid EMO36 had the highest mean grain yield of 7.3 t ha^{-1}, whilst EMO34 had the lowest yield of 3.8 t ha^{-1}. Furthermore, most of the experimental hybrids (48 %) out yielded the local check hybrids (SC403, SC407, SC513, ZS259 and ZS257) at Borrowdale, while 36 % performed better than the conventional check hybrids at Kadoma.

4.2.2 Phaeosphaeria Leaf Spot

Hybrid differences were observed for PLS infection response for both within and across environments. The frequency distribution of the PLS scores in the 30 maize hybrids was skewed towards resistance (Figure 4.2). Across environments, 40 % of the hybrids had a PLS rating of ≤ 2, indicating a high level of resistance but only 13.3 % of the hybrids displayed trace symptoms of PLS. About 23.7 % of the hybrids had a score of 4 to 6 and could be regarded as moderately susceptible to susceptible; while another 36.7 % had a moderate score of 3 for PLS.

While there were no hybrids with scores of seven to nine across location (Figure 4.2), the check hybrid, SC403 had a high disease level (8.0) at Borrowdale. Two check hybrids, SC403 and ZS257 were among the most susceptible. Hybrids EMO97, EMO58, EMO19 and EMO34 were observed to be highly resistant to PLS with mean PLS rating of 1.0.

Table 4.2. Across site performance of 30 maize hybrids (ranked by yield data).

Entry	Hybrid	Cross Combination	Days to Maturity	Phaeosphaeria Leaf Spot (Score)	Grain Yield (t ha^{-1})	Rank
3	EMO36	E26/E18	117.0	1.8	7.3	1
24	EMO97	E28/E31	116.0	1.3	7.1	2
23	EMO95	E26/E31	105.0	3.8	6.3	3
25	EMO115	E32/E31	114.5	1.8	6.1	4
1	EMO8	E21/E18	120.0	2.0	6.0	5
6	EMO10	E21/E20	114.0	2.8	5.9	6
10	EMO103	E32/E20	117.5	2.5	5.8	7
17	EMO67	E23/E29	102.8	1.8	5.8	8
21	EMO90	E21/E31	106.0	1.5	5.5	9
5	EMO101	E32/E18	119.0	3.8	5.5	10
18	EMO70	E26/E29	102.0	3.0	5.5	11
13	EMO42	E26/E25	106.5	3.8	5.4	12
14	EMO58	E28/E25	112.5	1.3	5.3	13
22	EMO92	E23/E31	107.8	4.0	5.2	14
9	EMO55	E28/E20	125.0	2.0	5.1	15
2	EMO17	E23/E18	116.5	1.8	5.0	16
15	EMO109	E32/E25	102.0	3.3	5.0	17
4	EMO53	E28/E18	118.0	2.5	4.9	18
8	EMO37	E26/E20	118.0	2.8	4.9	19
7	EMO19	E23/E20	118.5	1.3	4.7	20
20	EMO113	E32/E29	115.0	3.3	4.6	21
16	EMO65	E21/E29	116.0	2.8	4.4	22
11	EMO32	E21/E25	108.5	2.8	4.0	23
19	EMO72	E28/E29	101.8	4.8	3.9	24
12	EMO34	E23/E25	110.5	1.3	3.8	25
Check Variety						
27	SC407	Check hybrid	124.0	2.5	5.4	
26	SC403	Check hybrid	122.5	6.3	5.0	
28	SC513	Check hybrid	135.0	2.5	5.0	
30	ZS259	Check hybrid	122.0	2.0	4.2	
29	ZS257	Check hybrid	122.0	4.8	4.2	
Mean			114.5	2.7	5.2	

Table 4.3. Performance of 30 maize hybrids evaluated at Borrowdale, Harare (ranked by yield data)

Entry	Hybrid	Cross Combination	Days to Maturity	Phaeosphaeria Leaf Spot (Score)	Grain Yield (t ha^{-1})	%Check	Rank
3	EMO36	E26/E18	120.9	1.5	8.3	138.3	1
24	EMO97	E28/E31	120.1	1.0	8.1	136.3	2
17	EMO67	E23/E29	105.5	1.0	8.1	135.7	3
23	EMO95	E26/E31	109.7	1.0	7.6	127.3	4
13	EMO42	E26/E25	110.6	2.0	7.0	117.6	5
6	EMO10	E21/E20	120.1	2.0	6.8	113.2	6
25	EMO115	E32/E31	118.0	1.0	6.8	113.1	7
18	EMO70	E26/E29	105.4	3.0	6.7	111.5	8
1	EMO8	E21/E18	122.3	2.0	6.6	110.9	9
5	EMO101	E32/E18	121.2	4.0	6.6	110.1	10
10	EMO103	E32/E20	121.6	3.5	6.4	108.0	11
22	EMO92	E23/E31	111.0	1.0	6.3	105.4	12
15	EMO109	E32/E25	104.2	3.5	6.2	104.6	13
2	EMO17	E23/E18	119.2	2.0	6.2	104.0	14
21	EMO90	E21/E31	112.3	1.0	5.9	99.4	15
14	EMO58	E28/E25	117.7	1.0	5.9	98.7	16
7	EMO19	E23/E20	122.1	1.0	5.8	96.5	17
9	EMO55	E28/E20	128.1	1.5	5.6	93.5	18
16	EMO65	E21/E29	119.8	2.0	5.5	92.0	19
8	EMO37	E26/E20	122.4	2.0	5.4	91.0	20
20	EMO113	E32/E29	119.3	3.5	5.3	89.0	21
4	EMO53	E28/E18	119.4	2.5	5.3	88.5	22
12	EMO34	E23/E25	116.9	1.0	5.0	84.0	23
11	EMO32	E21/E25	111.5	2.5	4.7	78.4	24
19	EMO72	E28/E29	105.9	3.5	4.7	78.2	25
Check Variety							
28	SC513	Check hybrid	134.5	3.0	6.3		
27	SC407	Check hybrid	125.6	3.0	6.2		
30	ZS259	Check hybrid	121.0	2.5	6.1		
26	SC403	Check hybrid	123.9	7.5	6.0		
29	ZS257	Check hybrid	121.9	6.0	5.2		
Mean			117.7	2.4	6.2		
S.E.			2.9	0.4	0.7		
$LSD_{0.05}$			8.6	1.1	2.2		

Table 4.4. Performance of 30 maize hybrids evaluated at Kadoma (ranked by yield data)

Entry	Hybrid	Cross Combination	Days to Maturity	Phaeosphaeria Leaf Spot (Score)	Grain Yield (t ha^{-1})	%Check	Rank
3	EMO36	E26/E18	112.2	2.1	6.2	167.8	1
24	EMO97	E28/E31	111.6	1.4	5.9	159.6	2
25	EMO115	E32/E31	110.5	2.6	5.5	148.7	3
23	EMO95	E26/E31	102.8	6.5	5.4	145.5	4
1	EMO8	E21/E18	115.0	2.1	5.4	145.2	5
21	EMO90	E21/E31	103.7	2.0	5.3	142.8	6
10	EMO103	E32/E20	113.5	1.5	5.2	141.9	7
6	EMO10	E21/E20	111.3	3.5	5.1	139.0	8
18	EMO70	E26/E29	99.9	3.0	4.5	122.3	9
22	EMO92	E23/E31	103.7	6.8	4.5	121.2	10
9	EMO55	E28/E20	120.4	2.6	4.4	119.9	11
14	EMO58	E28/E25	108.5	1.5	4.4	118.2	12
8	EMO37	E26/E20	114.4	3.6	4.3	117.4	13
5	EMO101	E32/E18	113.8	3.3	4.3	116.1	14
4	EMO53	E28/E18	112.2	2.5	4.0	109.1	15
17	EMO67	E23/E29	101.3	2.5	3.8	101.7	16
7	EMO19	E23/E20	114.4	1.6	3.7	101.4	17
13	EMO42	E26/E25	102.6	5.6	3.7	99.7	18
15	EMO109	E32/E25	97.1	3.1	3.7	99.1	19
16	EMO65	E21/E29	112.0	3.4	3.6	97.8	20
20	EMO113	E32/E29	111.1	3.1	3.6	97.1	21
2	EMO17	E23/E18	111.6	1.5	3.5	94.5	22
11	EMO32	E21/E25	103.9	3.1	3.3	90.7	23
19	EMO72	E28/E29	97.3	6.1	2.9	79.5	24
12	EMO34	E23/E25	108.2	1.5	2.6	70.5	25
Check Variety							
27	SC407	Check hybrid	125.2	2.0	4.8		
26	SC403	Check hybrid	123.0	4.9	4.2		
28	SC513	Check hybrid	134.6	2.1	3.5		
29	ZS257	Check hybrid	122.0	3.4	3.4		
30	ZS259	Check hybrid	121.6	1.4	2.6		
Mean			111.3	3.0	4.2		
S.E.			3.0	0.6	0.7		
$LSD_{0.05}$			8.8	1.9	1.9		

4.2.3 Days to Maturity

The F1 hybrids evaluated showed greater preponderance for early maturity, both within and across environments. DMT ratings at Borrowdale ranged from 104 to 135 days to maturity (Table 4.3), while at Kadoma, DMT ratings ranged from 97 to 135 days (Table 4.4). Across environments, 60 % of the hybrids had DMT ratings of ≤ 120 days. Hybrid EMO109 was the earliest, maturing at 104 days; whereas EMO55 matured later at 128 days. This indicated a high degree of ultra-early maturity of the evaluated germplasm when comparing with the check varieties, SC403, SC407 and SC513 which matured later at 123, 125 and 134 days, respectively

4.3 Combining Ability Analysis

Significant GCA effects ($P < 0.05$) were observed for both male and female inbred lines in the expression of DMT, PLS and GYLD (Table 4.5). However, male GCA was not significant ($P<0.05$) for DMT at Kadoma and Borrowdale, while female GCA effects was not significant for GYLD at Borrowdale. SCA effects were not significant ($P<0.05$) for DMT and GYLD at both locations; with significance having been recorded for PLS alone.

Across site SCA effects were significant for both DMT and PLS except for GYLD (Table 4.6). Generally, the most resistant hybrids were crosses between resistant lines, while the most susceptible hybrids were crosses between susceptible lines. However, environment x GCA interactions were not significant for DMT, PLS and GYLD.

Table 4.5. Mean squares for combining ability for characters measured from a 10-line NCDII mating scheme evaluated at two locations in Zimbabwe

Source of Variation	**d.f.**	**Mean Square**					
		Days to Maturity		**Phaeosphaeria Leaf Spot (Score)**		**Grain Yield (t ha^{-1})**	
Site 1:Borrowdale							
Replication	1	5.780		0.320		8.404	
GCA Male	4	49.630	ns	3.800	*	5.160	*
GCA Female	4	324.180	*	4.700	*	1.970	ns
SCA	16	51.180	ns	2.730	*	0.879	ns
Error	24	27.820		0.320		0.915	
Site 2: Kadoma							
Replication	1	25.920		3.920		7.220	
GCA Male	4	29.380	ns	4.780	*	6.480	*
GCA Female	4	282.130	*	3.530	*	2.980	ns
SCA	16	43.960	ns	5.670	*	0.868	ns
Error	24	25.380		1.003		1.012	

* Significant at P<0.05

Table 4.6. Across site analyses of variance for days to maturity, Phaeosphaeria maydis disease scores and grain yield at Borrowdale and Kadoma during 2006/7 summer season

Source of Variation	**d.f.**	**Mean Square**					
		Days to Maturity		**Phaeosphaeria Leaf Spot (Score)**		**Grain Yield (t ha^{-1})**	
Location	1	1482.250	*	3.610	ns	42.772	*
Replication/Location	2	15.850	ns	2.770	ns	8.612	*
GCA Male	4	77.410	*	7.700	*	4.057	*
GCA Female	4	604.010	*	10.000	*	10.488	*
SCA	16	94.016	*	11.325	*	1.779	ns
Location x GCA Male	4	1.600	ns	0.110	ns	0.001	ns
Location x GCA Female	4	2.300	ns	0.010	ns	0.001	ns
Location x SCA	16	1.119	ns	0.135	ns	0.000	ns
Error	48	26.600		0.978		0.942	

* Significant at P<0.05

4.3.1 Estimates of GCA Effects of Inbred Lines used as Parents

Estimates of GCA effects at both locations presented in Table 4.7. Most parents showed significant GCA effects with different magnitudes and directions. This suggested the presence of adequate diversity in the genetic constitution of parents for most of the measured traits. Two inbred lines E25 and E29 consistently showed high negative GCA effects for days to maturity at both locations, indicating that they were good general combiners because their maturity dates were less than the mean.

Inbred lines E31 and E26 also had the highest positive GCA effects for grain yield at both locations, measuring 0.91 and 0.43, respectively at Borrowdale; and 0.96 and 0.46, respectively at Kadoma, hence they were not good combiners because they matured later than most genotypes (i.e. maturity date greater than mean).

With regard to Phaeosphaeria leaf spot, E20 and E18 gave the highest negative GCA effects at Kadoma (estimated as -0.54 and -0.74, respectively), while at Borrowdale, the highest negative values were given by E31 and E23 (estimated as -1.00 and -0.80, respectively). These lines were good combiners for PLS resistance.

Table 4.7. Estimates of GCA effects measured on 10 maize inbred lines, in a NCDII evaluated at Borrowdale and Kadoma.

Inbred line	GCA effects		
	Days to Maturity	**Phaeosphaeria Leaf Spot (Score)**	**Grain Yield (t ha^{-1})**
Site 1: Borrowdale			
E18	5.94	0.40	0.39
E20	6.34	0.00	0.16
E25	-4.16	0.00	-0.72
E29	-5.46	0.60	-0.73
E31	-2.66	-1.00	0.91
E21	0.64	-0.10	0.17
E23	-1.56	-0.80	-0.75
E26	-2.96	-0.10	0.43
E28	2.54	-0.10	0.10
E32	1.34	1.10	0.05
Site 2: Kadoma			
E18	5.44	-0.74	0.36
E20	6.04	-0.54	0.36
E25	-4.66	-0.14	-0.84
E29	-4.36	0.56	-0.84
E31	-2.46	0.86	0.96
E21	0.34	-0.24	0.26
E23	-0.86	-0.24	-0.94
E26	-2.46	1.06	0.46
E28	1.94	-0.24	0.06
E32	1.04	-0.34	0.16

4.3.2 Estimates of SCA effects for the various traits

The SCA effects shown by the crosses on the characters studied at Borrowdale and Kadoma are presented in Tables 4.8 and 4.9. At Borrowdale, high positive SCA effects for grain yield were shown by the crosses E26 x E18 (EMO36, 1.04), E28 x E25 (EMO58, 1.00) and E23 x E25 (EMO34, 0.86) (Table 4.7). At Kadoma, the crosses E28 x E29 (EMO58), E26 x E18 (EMO36) and E23 x E29 (EMO67) gave high positive SCA effects, with estimates of 0.94, 0.84 and 0.94, respectively (Table 4.9). The cross E26 x

E18 (EMO36), one of the best specific combiners, also revealed the best performance for grain yield across environments.

Table 4.8. Estimates of SCA effects for characters evaluated at Borrowdale

Hybrid	Cross Combination	SCA effects		
		Days to Maturity	Phaeosphaeria Leaf Spot (Score)	Grain Yield (t ha^{-1})
EMO32	E21 x E25	-0.24	0.60	0.47
EMO17	E23 x E18	-0.14	0.40	-0.36
EMO95	E26 x E31	-2.64	0.10	-0.41
EMO101	E32 x E18	-0.54	0.50	-0.51
EMO72	E28 x E29	-7.34	1.00	-0.78
EMO113	E32 x E29	6.86	-0.20	-0.09
EMO58	E28 x E25	2.36	-0.90	1.00
EMO42	E26 x E25	1.36	0.10	-0.39
EMO55	E28 x E20	3.86	-0.40	-0.28
EMO115	E32 x E31	3.56	-1.10	0.08
EMO97	E28 x E31	3.86	0.10	0.64
EMO90	E21 x E31	-4.24	0.10	-0.03
EMO70	E26 x E29	-3.34	0.50	0.47
EMO10	E21 x E20	-5.24	0.10	0.55
EMO36	E26 x E18	2.26	-0.80	1.04
EMO103	E32 x E20	-2.44	0.40	0.54
EMO65	E21 x E29	8.56	-0.50	-0.46
EMO53	E28 x E18	-2.74	0.20	-0.59
EMO19	E23 x E20	1.46	-0.20	-0.11
EMO92	E23 x E31	-0.54	0.80	-0.28
EMO8	E21 x E18	1.16	-0.30	0.41
EMO34	E23 x E25	3.96	-0.20	-0.11
EMO37	E26 x E20	2.36	0.10	-0.71
EMO67	E23 x E29	-4.74	-0.80	0.86
EMO109	E32 x E25	-7.44	0.40	-0.03

Table 4.9. Estimates of SCA effects for characters evaluated at Kadoma

Hybrid	Cross Combination	SCA effects		
		Days to Maturity	**Phaeosphaeria Leaf Spot (Score)**	**Grain Yield (t ha^{-1})**
EMO32	E21 x E25	0.260	0.340	-0.260
EMO17	E23 x E18	-0.640	-0.560	-0.260
EMO95	E26 x E31	-1.640	1.540	-0.260
EMO101	E32 x E18	-0.040	1.540	-0.360
EMO72	E28 x E29	-8.640	2.640	-0.560
EMO113	E32 x E29	5.760	-0.260	-0.160
EMO58	E28 x E25	2.160	-1.160	0.940
EMO42	E26 x E25	1.060	1.540	-0.460
EMO55	E28 x E20	4.460	0.240	-0.260
EMO115	E32 x E31	3.360	-1.060	0.040
EMO97	E28 x E31	3.960	-2.160	0.640
EMO90	E21 x E31	-4.440	-1.660	-0.060
EMO70	E26 x E29	-2.240	-1.660	0.540
EMO10	E21 x E20	-4.940	1.240	0.540
EMO36	E26 x E18	0.960	-1.360	0.840
EMO103	E32 x E20	-2.140	-0.660	0.640
EMO65	E21 x E29	7.460	0.140	-0.760
EMO53	E28 x E18	-1.940	0.440	-0.760
EMO19	E23 x E20	0.760	-0.760	-0.260
EMO92	E23 x E31	-1.240	3.340	-0.360
EMO8	E21 x E18	1.660	-0.060	0.540
EMO34	E23 x E25	3.460	-1.160	-0.060
EMO37	E26 x E20	1.860	-0.060	-0.660
EMO67	E23 x E29	-2.340	-0.860	0.940
EMO109	E32 x E25	-6.940	0.440	-0.160

For days to maturity, E28 x E29 and E32 x E25 were the best specific combiners at Borrowdale (SCA effects of -7.34 and -7.44, respectively) and Kadoma (-8.64 and -6.94, respectively). They both gave best negative SCA estimates, indicating earliness at both locations.

In terms of PLS, the highest negative SCA effects were given by E32 x E31 and E28 x E25 at Borrowdale (SCA effects of -1.1 and -0.9, respectively), while it was E28 x E31 at Kadoma (SCA effects of -2.16).

4.3.3 Heritability estimates

Heritability estimates (both broad and narrow sense) are presented in Table 4.10 Relatively high narrow sense heritability estimates were observed for Phaeosphaeria leaf spot, while days to maturity gave moderate narrow sense heritability. As expected, heritability for grain yield was low.

Table 4.10. Heritability estimates for characters evaluated at Borrowdale and Kadoma

Character	Narrow sense heritability (h^2)
Days to maturity	51.22 %
Phaeosphaeria leaf spot	67.76 %
Grain yield	39.41 %

4.3.4 Correlation estimates

Pearson’s phenotypic correlation coefficients of PLS, DMT and GYLD are presented in Table 4.11.

Table 4.11. Correlation estimates for characters evaluated at Borrowdale and Kadoma

Matrix characters	Pearson's correlation coefficient	P-value
Days to maturity and Grain yield	0.1284	0.3367
Days to maturity and Phaeosphaeria leaf spot	0.1898	0.1536
Grain yield and Phaeosphaeria leaf spot	-0.1199	0.3700

Pearson's correlation coefficients for PLS and DMT; GYLD and DMT were weak, positive and not significant (P>0.05), while PLS and GYLD was weak, negative and not significant.

CHAPTER 5

DISCUSSION

The present study permitted the investigation of combining ability effects for early maturity and Phaeosphaeria leaf spot. Findings from this study will be useful in initiating the development of maize with high levels of resistance to PLS and hybrids that are early maturing. One important strategy is the utilisation of genetic resources to develop cultivars with high levels of resistance. Estimation of heritability and determination of gene action are important for developing breeding strategy in modern day plant breeding. Thus, knowledge of the inheritance of resistance to PLS would be useful to better understand the genetic systems controlling that inheritance since effective selection can only be achieved when the genetic basis of resistance is known. This chapter, therefore, discusses the findings from the current study.

5.1 Disease Development and Hybrid Resistance

Significant PLS incidence and severity was attributable to the prevalence of moderately favourable environmental conditions. The moderate rainfall and temperature regimes that prevailed between October and April promoted moderate disease development. Although there were moderate environmental conditions, the results indicated that there is an inherent relation between disease development and temperature as reported by Casela (1998) and Fernandes and Sans (1994). This further supports the findings made by Casela (1998) who found a strong correlation between plant age, temperature (maximum and minimum), relative humidity, and disease incidence.

Furthermore, field results indicated that the first lesions were observed on the leaves above the ear in some entries but in most hybrids on the lower leaves. This suggests that the fungus was mainly spreading from the soil to the lower leaves of the host, but there was also an airborne spread.

5.2 Combining Ability Effects

5.2.1 Grain Yield

Significant genetic variation for grain yield was observed ($P<0.05$). This implied that crosses were different in grain yield. These differences were mainly due to both male and female GCA with greater dominance of maternal effects. As such, additive gene effects were important for grain yield expression. Specific combining ability (SCA) effects were not significant. Total variation among the crosses for grain yield was however attributed more to GCA differences existing among parents than SCA effects. The GCA sums of squares were five times larger than SCA sums of squares. Environment x GCA interaction was not significant suggesting low genotype x environment interaction. As a result, significant GCA effects suggest that the recurrent selection programme described by Hallauer and Miranda (1988) can be employed to develop inbred lines for use in the hybrid program.

5.2.2 Days to Maturity (DMT)

Significant genetic variation ($P < 0.05$) for DMT among the crosses was found to exist. Differences among crosses for DMT were due to both maternal and paternal GCA effects. Specific combining ability (SCA) effects were also significant, though marginal. As such, there was a preponderance of additive gene effects for DMT in this group of inbred lines. Environment x GCA interaction was not significant suggesting low GxE interaction.

In general and as is expected, early maturing parents had greater negative GCA effects than late maturing ones. Inbreds E29 and E25 were found to have the most negative GCA estimates, indicating their usefulness in producing early maturing progenies and may possibly be considered as parent sources where early maturity is desired from a cross.

5.2.3 Phaeosphaeria Leaf Spot (PLS)

Significant variation (P<0.05) was found among crosses for PLS ratings. Differences among crosses for PLS rating were completely due to both GCA effects and SCA effects. However, the mean square value for SCA effects was smaller than the GCA effects, hence a preponderance of additive genetic effects. As such, additive genetic effects controlled PLS resistance in this group of inbred lines. Maternal GCA sums of squares were larger than paternal GCA sums of squares suggesting that additive maternal effects were important for resistance to PLS. Environment x GCA interaction was not significant suggesting low GxE interaction. Low GxE interactions were also reported in the USA (Carson, 2001; 2005b) and in Brazil by Silva and Moro (2004). As expected, resistant parents had greater negative effects than susceptible parents. E31 and E18 had the most negative GCA estimates indicating their usefulness in producing progenies resistant to PLS and may possibly be considered as parents where PLS resistance is desired. Furthermore, the most resistant experimental hybrids had a constituent of two common parents, E23 and E28 indicating that they can be used as sources of PLS resistance in breeding programmes. The most susceptible experimental hybrids had E25, E29, E32 and E29 as common parents; suggesting that these lines require improvement for PLS resistance.

In addition, the predominance of additive gene effects in local maize germplasm is consistent with findings by Carson (2001; 2005b) who reported that resistance to PLS is controlled by additive gene action whilst working on the derivatives from the cross B73 x Mo17, and those made by Silva and Moro (2004). However, for this group of germplasm the isolation of PLS resistant homozygous lines is the most effective breeding method for PLS resistance.

5.3 Heritability Estimates

5.3.1 Grain Yield

The narrow sense heritability estimate for grain yield at harvest was 39.41 % and relatively high as compared to the generally low heritable nature of the trait. This was attributed to the large variance within inbred lines. However, this can be expected given the high levels of management of the area and great potential of the agro-ecological setting in which the area is situated, although the contribution of genotypes cannot be ignored due to the partial dominance of the trait.

5.3.2 Days to Maturity (DMT)

Heritability estimate was moderate (51.22 %) in the narrow sense. This was attributable to the small variance within inbred lines. This is further demonstrated by the relatively high estimates of additive genetic variance.

5.3.3 Phaeosphaeria Leaf Spot

The relatively high additive genetic variance and the low dominance variance demonstrated predominance of additive over non-additive gene action. As a result estimate of narrow sense heritability was high (67.76 %). The high heritability estimate for PLS further substantiate the additivity obtained from North Carolina Design II analysis and this variation can be fixed and selected for by breeding. These results agree with those reported by Carson (2001), who reported heritability of 85 % in the narrow sense.

5.4 Correlations

Phenotypic correlation between grain yield (GYLD) and days to maturity (DMT) was estimated to be weakly positive and not significant ($P < 0.05$). The same was observed between PLS and DMT. This indicated that early maturing hybrids did not necessarily give rise to low yielding hybrids and vice-versa. The same results also indicated that early maturing hybrids did not necessarily give PLS resistance hybrids and vice-versa. However, the association between PLS and GYLD was weakly negative indicating that PLS resistant hybrids did not necessarily give rise to high yielding hybrids and vice-versa.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Although the parent lines used in crosses were a representative sample of germplasm used in regional breeding programs, interpretations of results from this study was limited to this particular set of 10 inbred lines and their crosses and five commercial check hybrids. The following conclusions were drawn from this study:

1 Significant variation for PLS resistance and early maturity exists in regional maize germplasm and hence, there is potential to improve the maize germplasm for resistance to Phaeosphaeria leaf spot and early maturity;

2 Heritability of early maturity and PLS resistance was moderate (51 %) and high (68 %), respectively in regional maize germplasm implying that early maturity and PLS resistance can be fixed and improved by selection in a breeding program leading to effective deployment of resistant and ultra-early maturing cultivars to the resource-poor farmers in SSA;

3 Inheritance of PLS resistance and early maturity in regional maize germplasm was predominantly determined by additive gene action, indicating that the resistance in regional germplasm can be further improved through recurrent selection procedures to generate PLS resistant maize inbred lines, and then followed by crossing to form commercial hybrids. The high additive effects were also reflected by high heritability estimates;

4 The inbred lines that revealed strong negative GCA effects for PLS scores could further be utilised as sources for population improvement towards the accumulation of favourable additive genes in their base populations. Those that displayed strong negative SCA effects for PLS could be advanced for hybrid variety release after other yield stability factors have been considered;

5 This group of germplasm has demonstrated to be a good source for the extraction of lines resistant to PLS and early maturity because of the wide genetic variability and the significant combining ability effects existing for PLS resistance, yield and maturity dates;

6 The single cross hybrids tested in this study showed a high range of performance for the characters investigated. As such, they could be exploited further for their heterotic capacities and subsequent release in areas where PLS is prevalent and ;

7 The weak associations of grain yield, Phaeosphaeria leaf spot disease and days to maturity indicated that amongst these traits, there was little association. Hence, they can be selected independently in breeding programs in SSA.

6.2 Recommendations

1 Breeders should be able to select genotypes with at least moderate to high level PLS resistance and early maturity to focus PLS resistance breeding.

2 Simple recurrent selection should be used to concentrate the frequency of PLS resistance and early maturity genes in the regional breeding populations.

3 Future studies focusing on improving *per se* performance of inbred lines before testing for combining ability should be advanced.

4 Future studies should also investigate the levels of grain loss caused by PLS in SSA.

5 Future studies on the epidemiology of PLS disease resistance should be clearly focused in order to draw accurate predictions on the potential for PLS to cause widespread damage.

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Appendices

Appendix 1: 5 x 6 Rectangular Lattice Design with 2 reps.

REP 1

PLOT

ENTRY

BLOCK					
1	1 ***6***	2 ***14***	3 ***12***	4 ***21***	5 ***27***
2	10 ***5***	9 ***16***	8 ***29***	7 ***30***	6 ***22***
3	11 ***3***	12 ***13***	13 ***20***	14 ***19***	15 ***28***
4	20 ***2***	19 ***25***	18 ***7***	17 ***10***	16 ***8***
5	21 ***15***	22 ***9***	23 ***11***	24 ***4***	25 ***1***
6	30 ***26***	29 ***24***	28 ***23***	27 ***18***	26 ***17***

REP 2

BLOCK					
1	31 ***20***	32 ***12***	33 ***29***	34 ***9***	35 ***8***
2	40 ***1***	39 ***7***	38 ***28***	37 ***27***	36 ***17***
3	41 ***22***	42 ***26***	43 ***6***	44 ***10***	45 ***19***
4	50 ***13***	49 ***21***	48 ***16***	47 ***23***	46 ***11***
5	51 ***24***	52 ***2***	53 ***4***	54 ***14***	55 ***5***
6	60 ***30***	59 ***18***	58 ***15***	57 ***3***	56 ***25***

NB: 30 TREATMENTS, 2 REPS

Appendix 2: Raw Data for Borrowdale site

PLOT	ENTRY	EXP$	LOC$	BLOC	IBLOCK	HYBRID$	PARENTAGE$	PC	DMS	DMP	ASI	DMT	PHT	CHT	LPP	PTB	RUST	PLS	GLS	CC	GW	MO	GYLD
1	6	MSC PROJECT	BORROWDALE	1	1	EMO10	E21/E20	32	63	63	0	114	2.30	1.00	12	11	1	2	2	33	5.10	16.50	7.2
2	14	MSC PROJECT	BORROWDALE	1	1	EMO58	E28/E25	32	58	58	0	111	2.40	1.10	11	18	1	1	1	33	3.10	15.00	4.5
3	12	MSC PROJECT	BORROWDALE	1	1	EMO34	E23/E25	32	59	59	0	115	2.00	0.70	12	11	1	1	1	35	2.81	17.00	3.9
4	21	MSC PROJECT	BORROWDALE	1	1	EMO90	E21/E31	32	56	55	1	104	2.20	0.70	13	8	1	1	1	31	4.20	14.00	6.1
5	27	MSC PROJECT	BORROWDALE	1	1	SC407	SC407	32	71	72	-1	124	2.30	0.80	12	9	3	3	1	33	4.50	18.60	6.2
6	22	MSC PROJECT	BORROWDALE	1	2	EMO92	E23/E31	32	63	63	0	119	1.90	0.75	13	11	1	1	2	28	3.90	16.00	5.5
7	30	MSC PROJECT	BORROWDALE	1	2	ZS259	ZS259	32	66	65	1	121	2.30	1.00	12	8	2	3	1	33	4.60	16.20	6.5
8	29	MSC PROJECT	BORROWDALE	1	2	ZS257	ZS257	21	63	63	0	123	2.30	0.70	12	11	1	6	2	24	3.80	16.80	5.4
9	16	MSC PROJECT	BORROWDALE	1	2	EMO65	E21/E29	27	60	59	1	121	1.80	0.40	10	7	1	1	2	27	4.25	17.10	6.0
10	5	MSC PROJECT	BORROWDALE	1	2	EMO101	E32/E18	32	69	68	1	123	1.90	0.70	11	13	1	4	2	33	5.23	14.10	7.6
11	3	MSC PROJECT	BORROWDALE	1	3	EMO36	E26/E18	26	68	68	0	122	1.90	0.80	12	10	2	1	3	26	6.40	14.30	9.3
12	13	MSC PROJECT	BORROWDALE	1	3	EMO42	E26/E25	32	65	65	0	117	1.90	0.90	12	14	1	2	3	39	6.70	17.20	9.4
13	20	MSC PROJECT	BORROWDALE	1	3	EMO113	E32/E29	32	62	62	0	119	2.20	0.80	12	9	1	4	3	35	4.05	18.10	5.6
14	19	MSC PROJECT	BORROWDALE	1	3	EMO72	E28/E29	32	61	61	0	105	2.00	0.75	10	14	1	3	3	31	4.25	19.50	5.8
15	28	MSC PROJECT	BORROWDALE	1	3	SC513	SC513	22	73	73	0	135	2.45	1.10	14	19	1	3	4	25	5.23	20.70	7.0
16	8	MSC PROJECT	BORROWDALE	1	4	EMO37	E26/E20	32	67	67	0	123	1.95	0.70	12	10	1	2	2	34	4.25	14.10	6.2
17	10	MSC PROJECT	BORROWDALE	1	4	EMO103	E32/E20	32	67	67	0	123	2.05	0.90	13	13	1	4	3	31	4.80	16.40	6.8
18	7	MSC PROJECT	BORROWDALE	1	4	EMO19	E23/E20	32	66	64	2	122	1.95	0.75	12	12	2	1	2	34	4.00	17.40	5.6
19	25	MSC PROJECT	BORROWDALE	1	4	EMO115	E32/E31	32	64	64	0	120	2.10	0.90	12	8	2	1	2	35	4.65	15.70	6.6
20	2	MSC PROJECT	BORROWDALE	1	4	EMO17	E23/E18	32	68	66	2	120	1.75	0.60	12	15	1	1	1	33	5.00	16.20	7.1
21	15	MSC PROJECT	BORROWDALE	1	5	EMO109	E32/E25	32	67	64	3	106	2.00	0.70	12	11	1	3	2	34	5.26	20.10	7.1
22	9	MSC PROJECT	BORROWDALE	1	5	EMO55	E28/E20	32	67	67	0	135	2.10	1.00	13	11	3	2	1	32	4.40	19.60	6.0
23	11	MSC PROJECT	BORROWDALE	1	5	EMO32	E21/E25	32	60	61	-1	121	1.95	0.60	11	19	1	3	1	31	3.40	13.10	5.0
24	4	MSC PROJECT	BORROWDALE	1	5	EMO53	E28/E18	25	67	67	0	123	2.10	0.80	11	14	4	2	1	28	4.00	13.70	5.8
25	1	MSC PROJECT	BORROWDALE	1	5	EMO8	E21/E18	32	65	65	0	124	1.95	0.75	11	14	1	2	1	35	5.50	14.00	8.0
26	17	MSC PROJECT	BORROWDALE	1	6	EMO67	E23/E29	31	61	61	0	104	1.95	0.60	10	11	1	1	1	32	5.80	14.70	8.4
27	18	MSC PROJECT	BORROWDALE	1	6	EMO70	E26/E29	32	62	62	0	104	2.00	0.55	12	13	3	3	3	33	4.70	15.20	6.7
28	23	MSC PROJECT	BORROWDALE	1	6	EMO95	E26/E31	30	65	65	0	104	2.05	0.80	12	10	3	1	1	32	4.95	15.80	7.1
29	24	MSC PROJECT	BORROWDALE	1	6	EMO97	E28/E31	32	62	62	0	116	2.20	1.00	12	14	2	1	1	35	4.40	16.20	6.2
30	26	MSC PROJECT	BORROWDALE	1	6	SC403	SC403	32	67	67	0	121	2.55	1.20	13	16	2	7	2	33	4.55	17.00	6.4
31	20	MSC PROJECT	BORROWDALE	2	1	EMO113	E32/E29	23	66	65	1	119	1.95	0.50	10	7	2	3	2	25	3.91	14.70	5.6
32	12	MSC PROJECT	BORROWDALE	2	1	EMO34	E23/E25	21	65	64	1	114	1.75	0.55	8	9	2	1	1	24	4.10	13.80	6.0
33	29	MSC PROJECT	BORROWDALE	2	1	ZS257	ZS257	25	65	65	0	121	2.00	1.40	12	12	3	6	1	23	3.75	17.20	5.3
34	9	MSC PROJECT	BORROWDALE	2	1	EMO55	E28/E20	26	68	68	0	123	2.10	0.85	12	10	2	1	1	27	3.95	16.10	5.6
35	8	MSC PROJECT	BORROWDALE	2	1	EMO37	E26/E20	23	71	72	-1	121	1.95	0.75	10	10	1	2	1	23	3.45	15.50	4.9
36	17	MSC PROJECT	BORROWDALE	2	2	EMO67	E23/E29	27	62	62	0	105	1.90	0.50	12	10	1	1	2	27	5.10	14.80	7.4
37	27	MSC PROJECT	BORROWDALE	2	2	SC407	SC407	32	71	72	-1	124	2.30	0.75	12	10	3	3	2	32	4.30	21.50	5.7
38	28	MSC PROJECT	BORROWDALE	2	2	SC513	SC513	26	73	73	0	135	2.60	1.25	15	10	1	3	1	25	4.50	23.10	5.9
39	7	MSC PROJECT	BORROWDALE	2	2	EMO19	E23/E20	23	70	68	2	123	1.95	0.70	12	14	1	1	2	27	4.00	14.30	5.8
40	1	MSC PROJECT	BORROWDALE	2	2	EMO8	E21/E18	24	66	66	0	124	1.85	0.50	11	15	1	2	1	23	3.65	14.50	5.3
41	22	MSC PROJECT	BORROWDALE	2	3	EMO92	E23/E31	31	65	65	0	104	1.90	0.70	13	11	1	1	1	31	4.95	17.00	7.0
42	26	MSC PROJECT	BORROWDALE	2	3	SC403	SC403	26	70	70	0	124	2.50	1.00	10	9	1	8	1	24	3.60	13.20	5.3
43	6	MSC PROJECT	BORROWDALE	2	3	EMO10	E21/E20	31	66	66	0	122	1.85	0.70	11	11	2	2	1	30	4.20	16.80	5.9
44	10	MSC PROJECT	BORROWDALE	2	3	EMO103	E32/E20	32	68	68	0	120	2.05	0.80	13	9	1	3	1	32	4.35	17.70	6.1
45	19	MSC PROJECT	BORROWDALE	2	3	EMO72	E28/E29	26	59	60	-1	107	1.95	0.60	9	12	1	4	1	25	2.80	18.10	3.9

Appendix 2: Raw Data for Borrowdale site (cont…)

YEAR	PLOT	ENTRY	EXP$	LOC$	BLOC	IBLOCK	HYBRID$	PARENTAGE$	PC	DMS	DMP	ASI	DMT	PHT	CHT	LPP	PTB	RUST	PLS	GLS	CC	GW	MO	GYLD
2007	46	11	MSC PROJECT	BORROWDALE	2	4	EMO32	E21/E25	28	63	61	2	104	1.85	0.65	11	12	1	2	1	29	3.15	19.50	4.3
2007	47	23	MSC PROJECT	BORROWDALE	2	4	EMO95	E26/E31	30	68	68	0	112	2.10	0.80	13	10	1	1	3	28	5.35	16.60	7.6
2007	48	16	MSC PROJECT	BORROWDALE	2	4	EMO65	E21/E29	29	62	62	0	119	1.85	0.70	11	12	1	3	2	31	3.50	20.10	4.7
2007	49	21	MSC PROJECT	BORROWDALE	2	4	EMO90	E21/E31	22	62	62	0	116	1.90	0.90	11	7	2	1	3	23	3.55	14.30	5.2
2007	50	13	MSC PROJECT	BORROWDALE	2	4	EMO42	E26/E25	32	65	66	-1	104	1.85	0.65	12	7	1	2	1	35	3.45	18.20	4.8
2007	51	24	MSC PROJECT	BORROWDALE	2	5	EMO97	E28/E31	32	61	62	-1	124	2.45	1.05	13	13	1	1	4	35	7.21	17.40	10.1
2007	52	2	MSC PROJECT	BORROWDALE	2	5	EMO17	E23/E18	32	66	66	0	121	2.00	0.70	11	18	1	3	1	31	4.00	15.70	5.7
2007	53	4	MSC PROJECT	BORROWDALE	2	5	EMO53	E28/E18	19	65	64	1	121	2.10	0.85	13	14	4	3	1	26	3.65	14.30	5.3
2007	54	14	MSC PROJECT	BORROWDALE	2	5	EMO58	E28/E25	29	64	64	0	123	2.00	0.65	12	14	1	1	2	30	5.11	14.90	7.4
2007	55	5	MSC PROJECT	BORROWDALE	2	5	EMO101	E32/E18	26	68	68	0	123	2.00	0.70	13	16	1	4	1	26	4.10	15.10	5.9
2007	56	25	MSC PROJECT	BORROWDALE	2	6	EMO115	E32/E31	32	64	65	-1	117	2.25	1.00	12	9	2	1	3	32	4.80	16.50	6.8
2007	57	3	MSC PROJECT	BORROWDALE	2	6	EMO36	E26/E18	32	67	67	0	121	1.80	0.75	12	11	1	2	1	30	5.21	14.70	7.5
2007	58	15	MSC PROJECT	BORROWDALE	2	6	EMO109	E32/E25	32	63	62	1	106	2.05	0.90	11	11	1	4	3	33	3.80	14.90	5.5
2007	59	18	MSC PROJECT	BORROWDALE	2	6	EMO70	E26/E29	25	62	62	0	105	1.95	0.80	12	10	1	3	2	24	4.25	14.60	6.1
2007	60	30	MSC PROJECT	BORROWDALE	2	6	ZS259	ZS259	27	66	65	1	123	2.80	1.10	12	11	3	2	2	30	3.90	15.60	5.6

Appendix 3: Raw Data for Kadoma site

YEAR	PLOT	ENTRY	EXP$	LOC$	BLOC	IBLOCK	HYBRID$	PARENTAGE$	PC	DMS	DMP	ASI	DMT	PHT	CHT	LPP	PTB	RUST	PLS	GLS	CC	GW	MO	GYLD
2007	1	6	MSC PROJECT	KADOMA	1	1	EMO10	E21/E20	32	55	55	0	106	2.1	0.9	12	11	3	4	2	33	4.1	14.25	5.95
2007	2	14	MSC PROJECT	KADOMA	1	1	EMO58	E28/E25	31	50	50	0	103	2.2	1	11	18	3	2	1	33	3.65	12.75	5.39
2007	3	12	MSC PROJECT	KADOMA	1	1	EMO34	E23/E25	32	51	51	0	107	1.8	0.6	12	11	3	2	1	35	2.8	14.75	4.04
2007	4	21	MSC PROJECT	KADOMA	1	1	EMO90	E21/E31	32	48	47	1	96	2	0.6	13	8	3	2	1	31	4.7	11.75	7.02
2007	5	27	MSC PROJECT	KADOMA	1	1	SC407	SC407	28	63	64	-1	124	2.30	0.80	12	9	3	2	1	28	3.62	13.60	5.3
2007	6	22	MSC PROJECT	KADOMA	1	2	EMO92	E23/E31	32	55	55	0	111	1.7	0.65	13	11	3	8	1	28	2.9	13.75	4.23
2007	7	30	MSC PROJECT	KADOMA	1	2	ZS259	ZS259	32	58	57	1	121	2.30	1.00	12	8	2	2	1	32	1.20	14.13	1.7
2007	8	29	MSC PROJECT	KADOMA	1	2	ZS257	ZS257	31	55	55	0	123	2.30	0.70	12	11	1	4	2	31	1.80	14.21	2.6
2007	9	16	MSC PROJECT	KADOMA	1	2	EMO65	E21/E29	27	52	51	1	113	1.6	0.3	10	7	3	5	1	27	2.25	14.85	3.24
2007	10	5	MSC PROJECT	KADOMA	1	2	EMO101	E32/E18	32	61	60	1	115	1.7	0.6	11	13	3	5	2	33	2.65	11.85	3.96
2007	11	3	MSC PROJECT	KADOMA	1	3	EMO36	E26/E18	26	60	60	0	114	1.7	0.7	12	10	4	1	2	26	5.4	12.05	8.04
2007	12	13	MSC PROJECT	KADOMA	1	3	EMO42	E26/E25	32	57	57	0	109	1.7	0.8	12	14	3	5	2	39	2.7	14.95	3.89
2007	13	20	MSC PROJECT	KADOMA	1	3	EMO113	E32/E29	32	54	54	0	111	2	0.7	12	9	3	3	3	35	3.05	15.85	4.35
2007	14	19	MSC PROJECT	KADOMA	1	3	EMO72	E28/E29	32	53	53	0	97	1.8	0.65	10	14	3	6	3	31	2.4	17.25	3.36
2007	15	28	MSC PROJECT	KADOMA	1	3	SC513	SC513	27	64	64	0	135	2.45	1.10	14	19	1	3	4	27	2.12	15.71	3.0
2007	16	8	MSC PROJECT	KADOMA	1	4	EMO37	E26/E20	32	59	59	0	115	1.75	0.6	12	10	3	4	2	34	3.25	11.85	4.85
2007	17	10	MSC PROJECT	KADOMA	1	4	EMO103	E32/E20	32	59	59	0	115	1.85	0.8	13	13	3	1	3	31	3.8	14.15	5.52
2007	18	7	MSC PROJECT	KADOMA	1	4	EMO19	E23/E20	32	58	56	2	114	1.75	0.65	12	12	4	2	2	34	3	15.15	4.31
2007	19	25	MSC PROJECT	KADOMA	1	4	EMO115	E32/E31	32	56	56	0	112	1.9	0.8	12	8	4	3	2	35	3.65	13.45	5.35
2007	20	2	MSC PROJECT	KADOMA	1	4	EMO17	E23/E18	32	60	58	2	112	1.55	0.5	12	15	3	1	1	33	1.95	13.95	2.84
2007	21	15	MSC PROJECT	KADOMA	1	5	EMO109	E32/E25	32	59	56	3	98	1.8	0.6	12	11	3	3	2	34	2.3	17.85	3.20
2007	22	9	MSC PROJECT	KADOMA	1	5	EMO55	E28/E20	32	59	59	0	127	1.9	0.9	13	11	5	3	1	32	3.4	17.35	4.76
2007	23	11	MSC PROJECT	KADOMA	1	5	EMO32	E21/E25	32	52	53	-1	113	1.75	0.5	11	19	3	3	2	31	2.4	10.85	3.62
2007	24	4	MSC PROJECT	KADOMA	1	5	EMO53	E28/E18	25	59	59	0	115	1.9	0.7	11	14	6	2	2	28	3	11.45	4.50
2007	25	1	MSC PROJECT	KADOMA	1	5	EMO8	E21/E18	32	57	57	0	116	1.75	0.65	11	14	3	2	2	35	4.5	11.75	6.72
2007	26	17	MSC PROJECT	KADOMA	1	6	EMO67	E23/E29	31	53	53	0	103	1.75	0.5	10	11	3	3	1	32	2.9	12.45	4.30
2007	27	18	MSC PROJECT	KADOMA	1	6	EMO70	E26/E29	32	54	54	0	102	1.8	0.45	12	13	5	5	1	33	3.7	12.95	5.45
2007	28	23	MSC PROJECT	KADOMA	1	6	EMO95	E26/E31	30	57	57	0	100	1.85	0.7	12	10	5	7	1	32	3.95	13.55	5.78
2007	29	24	MSC PROJECT	KADOMA	1	6	EMO97	E28/E31	32	54	54	0	108	2	0.9	12	14	4	1	1	35	3.4	13.95	4.95
2007	30	26	MSC PROJECT	KADOMA	1	6	SC403	SC403	32	59	59	0	121	2.55	1.20	13	16	2	5	2	33	3.30	13.00	4.9
2007	31	20	MSC PROJECT	KADOMA	2	1	EMO113	E32/E29	23	58	57	1	111	1.75	0.4	10	7	4	3	2	25	1.9	12.45	2.82
2007	32	12	MSC PROJECT	KADOMA	2	1	EMO34	E23/E25	21	57	56	1	106	1.55	0.45	8	9	4	1	1	24	0.95	11.55	1.42
2007	33	29	MSC PROJECT	KADOMA	2	1	ZS257	ZS257	32	57	57	0	121	2.00	1.40	12	12	3	3	1	32	2.56	16.20	3.6
2007	34	9	MSC PROJECT	KADOMA	2	1	EMO55	E28/E20	26	60	60	0	115	1.9	0.75	12	10	4	2	1	27	2.75	13.85	4.01
2007	35	8	MSC PROJECT	KADOMA	2	1	EMO37	E26/E20	23	63	64	-1	113	1.75	0.65	10	10	3	3	1	23	2.45	13.25	3.60
2007	36	17	MSC PROJECT	KADOMA	2	2	EMO67	E23/E29	27	54	54	0	99	1.7	0.4	12	10	3	2	2	27	2.1	12.55	3.11
2007	37	27	MSC PROJECT	KADOMA	2	2	SC407	SC407	32	63	64	-1	124	2.30	0.75	12	10	3	2	2	32	3.11	14.50	4.5
2007	38	28	MSC PROJECT	KADOMA	2	2	SC513	SC513	32	65	65	0	135	2.60	1.25	15	10	1	1	1	32	2.80	17.25	3.9
2007	39	7	MSC PROJECT	KADOMA	2	2	EMO19	E23/E20	23	62	60	2	115	1.75	0.6	12	14	3	1	2	27	2	12.05	2.98
2007	40	1	MSC PROJECT	KADOMA	2	2	EMO8	E21/E18	24	58	58	0	116	1.65	0.4	11	15	3	2	1	23	2.65	12.25	3.94
2007	41	22	MSC PROJECT	KADOMA	2	3	EMO92	E23/E31	31	57	57	0	97	1.7	0.6	13	11	3	6	1	31	2.95	14.75	4.26
2007	42	26	MSC PROJECT	KADOMA	2	3	SC403	SC403	32	62	62	0	124	2.50	1.00	10	9	1	5	1	32	2.42	13.20	3.6
2007	43	6	MSC PROJECT	KADOMA	2	3	EMO10	E21/E20	31	58	58	0	114	1.65	0.6	11	11	4	3	1	30	3.2	14.55	4.63
2007	44	10	MSC PROJECT	KADOMA	2	3	EMO103	E32/E20	32	60	60	0	112	1.85	0.7	13	9	3	2	1	32	3.35	15.45	4.80
2007	45	19	MSC PROJECT	KADOMA	2	3	EMO72	E28/E29	26	51	52	-1	98	1.75	0.5	9	12	3	6	1	25	1.8	15.85	2.56
2007	46	11	MSC PROJECT	KADOMA	2	4	EMO32	E21/E25	28	55	53	2	96	1.65	0.55	11	12	3	3	1	29	2.15	17.25	3.01

Appendix 3: Raw Data for Kadoma site (cont…)

YEAR	PLOT	ENTRY	EXP$	LOC$	BLOC	IBLOCK	HYBRID$	PARENTAGE$	PC	DMS	DMP	ASI	DMT	PHT	CHT	LPP	PTB	RUST	PLS	GLS	CC	GW	MO	GYLD
2007	47	23	MSC PROJECT	KADOMA	2	4	EMO95	E26/E31	30	60	60	0	104	1.9	0.7	13	10	3	6	2	28	3.35	14.35	4.86
2007	48	16	MSC PROJECT	KADOMA	2	4	EMO65	E21/E29	29	54	54	0	111	1.65	0.6	11	12	3	2	2	31	2.5	17.85	3.48
2007	49	21	MSC PROJECT	KADOMA	2	4	EMO90	E21/E31	22	54	54	0	108	1.7	0.8	11	7	4	2	2	23	2.55	12.05	3.80
2007	50	13	MSC PROJECT	KADOMA	2	4	EMO42	E26/E25	32	57	58	-1	96	1.65	0.55	12	7	3	6	1	35	2.45	15.95	3.49
2007	51	24	MSC PROJECT	KADOMA	2	5	EMO97	E28/E31	32	53	54	-1	116	2.25	0.95	13	13	3	2	3	35	5	15.15	7.18
2007	52	2	MSC PROJECT	KADOMA	2	5	EMO17	E23/E18	32	58	58	0	113	1.8	0.6	11	18	3	2	1	31	3	13.45	4.40
2007	53	4	MSC PROJECT	KADOMA	2	5	EMO53	E28/E18	19	57	56	1	113	1.9	0.75	13	14	6	3	1	26	2.65	12.05	3.95
2007	54	14	MSC PROJECT	KADOMA	2	5	EMO58	E28/E25	29	56	56	0	113	1.8	0.55	12	14	3	1	2	30	2.75	12.65	4.07
2007	55	5	MSC PROJECT	KADOMA	2	5	EMO101	E32/E18	26	60	60	0	115	1.8	0.6	13	16	3	2	1	26	3.1	12.85	4.57
2007	56	25	MSC PROJECT	KADOMA	2	6	EMO115	E32/E31	32	56	57	-1	109	2.05	0.9	12	9	4	2	2	32	3.8	14.25	5.52
2007	57	3	MSC PROJECT	KADOMA	2	6	EMO36	E26/E18	32	59	59	0	111	1.6	0.65	12	11	3	3	1	30	3	12.45	4.45
2007	58	15	MSC PROJECT	KADOMA	2	6	EMO109	E32/E25	32	55	54	1	98	1.85	0.8	11	11	3	3	3	33	2.8	12.65	4.14
2007	59	18	MSC PROJECT	KADOMA	2	6	EMO70	E26/E29	25	54	54	0	97	1.75	0.7	12	10	3	1	2	24	2.4	12.35	3.56
2007	60	30	MSC PROJECT	KADOMA	2	6	ZS259	ZS259	32	58	57	1	123	2.80	1.10	12	11	3	1	2	32	2.10	13.67	3.1