EVALUATION AND CHARACTERISATION OF TWENTY-TWO SOYABEAN [*Glycine max* (L) MERRILL] LINES UNDER RUST INFESTED AND NON-INFESTED CONDITIONS

by

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ABSTRACT

Soyabean [*Glycine Max* (L) Merril] is an important leguminous crop, mainly used for human nutrition and livestock feed, as well as improving soil. The major constraint or threat to soyabean production is soyabean rust, a devastating disease that can reduce yield by up to 100% in susceptible varieties. Soyabean rust resistant varieties could be a major component of an integrated soyabean rust management, if resistance can be identified in adapted and productive germplasm. An experiment was planted out at Rattray Arnold Research Station[longitude $31^{0}13^{1}$S,latitude $17^{0}16^{1}$E, altitude 1360m] to characterize available sources of soyabean rust resistance by screening them under infested and non infested conditions.The experiment consisted of twenty-two soyabean lines that were planted in a split plot design with three replications. The main plot was the fungicide with 2 levels and sub-plot was variety with 22 levels. Punch Extra (Flusilazole/Carbendazim) was applied at a rate of 400 ml in 425 litres of water at 50, 70 and 90 days after planting. The gross plot was 21.6 m^2 and net plot was 7.2 m^2. Measurements taken included number of days from planting to 95% pod maturity, pod clearance scores, plant height in centimetres, lodged plants at maturity, mass of 100 seeds in grams, seed appearance scores, percentage crude protein content,green stem scores at first pod shattering and seed yield in kilograms per hectare. Significant differences were obtained for most variables measured ($P<0.001$). Thirteen varieties were identified as resistant to soyabean rust. These varieties were S731/6/57, SS722/6/28, S727/6/20, SS744/6/17, S717/6/17, S727/6/41, S748/6/96, S744/6/29, S727/6/55, S727/6/33, S726/6/9, S723/6/8 and S727/6/60. The study showed that seed mass; visual scores and seed yield in kilograms per hectare were indicators of rust resistance or susceptibility. For instance, the seed mass of a resistant variety under infested and non-infested conditions does not change much and therefore such a trait can be used to predict rust resistance and susceptibility. It is recommended that these varieties be used as sources of resistance in soyabean-breeding programmes.

Dedication

To my wife, Judith Mushoriwa whose encouragement, counsel and vision remain my greatest inspiration and challenge in meeting the desired goals

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CONTENTS

LIST OF ABBREVIATIONS

PLHT=Plant height
GS=Green stem scores
SAP= Seed appearance scores
SMA= Seed appearance scores
SMA= Seed mass in grams
LRP=Position of leaf rust on the plant
RD= Density of rust lesions on the plant
DFL= Number of days from planting to 50% flowering
DMAT= Number of days from planting to 95% pod maturity
OIL= Percentage crude protein content in air dry seed on a dry matter basis
CP= Percentage crude oil content in air dry seed on a dry matter basis
SYLD= Seed yield in kilograms per hectare

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

Soyabeans and other legumes are cheaper sources of protein relative to other sources. Animal protein are out of reach for most of the population in developing countries as it requires a lot of plant material to produce for every unit weight of protein (Kanyangwa-Luma, 1997). Plants are more efficient in protein production. Animals use about 7 kg of plant protein to produce 1 kg of animal protein. For instance, a cow that is fattened in a feedlot requires about 15 kg of plant protein to produce 1 kg of animal protein (Kanyangwa-Luma, 1997). In Zambia 1 hectare of land can be used to grow soyabeans, which yields about 800 kg of protein in a period of 4-5 months whereas, 1 hectare of land for cattle grazing for a year can produce only 40 kg of animal protein (Kanyangwa-Luma, 1997). For this reason, the household is therefore encouraged to produce soyabean so that they can use it for household consumption with a view to access proteins.

Soyabean seed contains 40-50 % protein, 14-24 % oil, 1.0-23.9 % carbohydrates, 2.8-6.3 % fibre and 3.3-6.4 % ash (Mbewe, 1996). The seed, also contains an appreciable amount of vitamin B complex (Mbewe, 1996). Soyabean can therefore be used as a protein supplement to the low protein cereal based diets. Based on WHO/FAO standards, up to 500kg of soyabean can provide the basic annual protein requirements for a family of ten (Javhaheri, 1992). The oil is used primarily in manufacturing of margarine, salad oils and cooking oil. In Zimbabwe, soyabeans account for 40 % of the material edible vegetable oil and seed cake output (Whingwiri 1989). Some common food uses of soyabean are bakery products, infant food, beverages, meat products, flavouring agents and dietary food (Zharare, 1996).

One of the major constraints to increased soyabean production both nationally and globally is soyabean rust. Soyabean Rust is caused by a fungus called *Phakopsora pachyrhizi* Sydow. It is a foliar disease that lowers soyabean seed yield through premature defoliation and by decreasing the number of filled pods per plant, the number of normal pods per plant, the number of seeds per plant and the weight of seeds per plant. It also lowers the quality of seeds produced. However, the severity of loss and the particular components of yield affected depend primarily on the time of disease onset and the intensity of disease at particular growth stages of the soyabean crop. Severity of loss also depends upon the variety. An experiment that was done at Asian Vegetable Research and Development Centre (AVRDC) clearly indicated that soyabean rust could cause substantial yield losses. The impact on yield was realized on four soyabean cultivars that were naturally infected with *Phakopsora* (Ford and Sinclair, 1977). The measurements taken were total seed weight, the 100 seed weights and disease index. This yield loss quantification was done using Dithane M-45 (a fungicide), comparing treated and non-treated plants, a 50 % yield reduction resulted from non protected cultivars (Ford and Sinclair, 1977).

In Zimbabwe, soyabean rust was first recorded in 1997/98 seasons. (Tichagwa[s] *personal communication)*. However, most severe outbreaks of this disease were in 1998/99, 1999/2000, 2000/2001. All locally bred cultivars are highly susceptible to soyabean rust. Studies conducted to quantify the yield loss attributable to soyabean rust resulted in yield losses of up to 80 % (Tichagwa[s], 1998 *personal communication*). Sonata, a Seed-co variety gave a yield loss of up-to 90 % under severe infestation levels in a fungicide trial (Tichagwa and Tattersfield, 1998 *unpublished*).

S=Soyabean Breeding Programme Manager Seedco Zimbabwe

Changes in cropping patterns have been reported in some countries due to soyabean rust due to rust infestation (Ford and Sinclair, 1977). Some farmers have reduced the hectares under soyabean shifting to other crops. Therefore, this justifies the need to control the disease through the use of breeding varieties with resistance or tolerance to soyabean rust. The devastating nature of soyabean rust disease led to failure of soyabean establishment in other countries for example, in Kenya (Tichagwa[s] personal communication, 2000). Non Governmental Organizations had identified soyabean as a potential crop for addressing poverty and soil amelioration but when rust became endemic, farmers lost interest in the crop and the project was terminated.

Furthermore, soyabean rust has become epidemic, for example, in some production areas such as Glendale and Enterprise the disease has become epidemic (Tichagwa[s], *personal communication*). Currently, recommended control measures require the costly use of chemicals, which increase the cost of production. In Zimbabwe chemicals are imported, which places a strain on foreign currency reserves. In Brazil, billions of dollars have been lost to chemicals. Some of the chemicals that can be used to control soyabean rust to give optimum control are Punch Extra, Folicur, Shavit, Tilt and Score. In Brazil more than 25 million hectares are put to soyabean and thus the impact of soyabean rust on production is quite high. The cost of chemicals makes it a deterrent to most farmers wishing to produce soyabean in the smallholder sector. Moreover, reduced production levels will result in importation of soyabean from other countries. The long-term solution is to develop varieties that are resistant hence controlling the disease through genetics. Host plant resistance has to become part of an integrated control strategy involving appropriate technologies. If used alone, host resistance can also easily breakdown through the development of new biotypes or races.

S=Soyabean Breeding Programme Manager Seedco Zimbabwe

Objectives of the Project

1. To characterize available sources of soyabean rust resistance by screening them under infested and non-infested field conditions.
2. To identify soyabean lines that are either resistant or tolerant to soyabean rust.
3. To estimate yield loss of each of the soyabean lines by simultaneously evaluating them under non- infested and infested conditions.
4. To determine the traits or method that can be used to predict soyabean rust resistance/susceptibility

Hypotheses

H_1:

1 All the available sources of soyabean rust resistance exhibit the different performance under infested and non-infested conditions with respect to soyabean rust infestation.

2) There are differences in the response of soyabean lines to soyabean rust infestation

3 There are some yield losses between the varieties under infested and non-infested conditions.

4 There are differences between the traits or methods that can be used to determine soyabean rust resistance/susceptibility.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soyabean Production

Soyabean is adapted to a wide range of climatic conditions and does well in areas of good rainfall or where irrigation is available. As a general rule, soyabean grows well in the same areas that maize grows well. Deep and well drained soils are recommended, varying in texture from sandy loam to clay loam. Heavy clays are also suitable provided that they are well drained and soil capping does not impede germination. Light sands are not recommended. Soyabean crops are very sensitive to soil acidity and for maximum yields the soil pH ($CaCl_2$) should be above 5.3.

Traditionally, soyabean has been a crop of the large-scale commercial farmer. Prior to the agrarian reform programme, production from the large scale commercial farmer used to account for 95 % and the remainder was from the smallholder sector (CSO of Zimbabwe, 2000). Now, the smallholder farmers (A1 farmers) are contributing about 15 % of the total output (CSO of Zimbabwe, 2005). Soyabean is mainly produced in high potential areas viz, Mashonaland Central, Mashonaland west, Mashonaland east, part of Manicaland, and lowveld areas under irrigation.

2.2 Constraints to Soyabean Production in Zimbabwe

There are a number of factors that contribute to low production levels of soyabean. Inadequate extension services, for example, farmers in the smallholder sector have been starved of information on improved varieties. Ideally, extension in better agronomic practices in soyabean production has lagged behind than in other crops such as maize (Mpepereki and Makonese, 1996). The use of low fertilizer levels, low plant populations and non-inoculated seed is a clear testimony of inadequate extension services. In addition, non-availability of inoculant is also another factor. The inoculant is not readily accessible and it requires costly storage facilities. Inoculant is very sensitive to light and temperature during storage, hence the recommendation to store it in a refrigerator. Such facilities are not commonly found in the communal areas making storage of the inoculant difficult.

Another constraint pertains to limited knowledge on utilization of the crop at household level. This adversely affects the adoption of soyabean by the small-holder farmers. Farmers have little or no knowledge on how to process and prepare various dishes from soyabeans at household level.

In addition, marginal soil fertility and erratic rains and frequent droughts affect the production of soyabeans. Generally, good soils require 0 kg per hectare Nitrogen (N), 20-30 kg per hectare Phosphorous (P), 20-30 kg Potassium (K) which is the ideal soil fertility for soyabean production, whereas medium soil requires 20 kg per hectare N, 30-40 kg per hectare P and 30-40 kg per hectare K and finally poor soil requires 40-60 kilograms per hectare potassium (Oilseed handbook,1995). In general, this is a constraint to farmers in agro-ecological regions III, IV and V. These smallholder farmers are located on poor soils. Hence the main issue is on whether the farmer can afford the cost of fertilizers so that they can use adequate levels of fertilizers. Prices of fertilizers are normally beyond reach for most of the smallholder farmers and therefore it becomes a barrier to soyabean production. Furthermore, drought in these areas is a major constraint. This is coupled with erratic rains which reduces the yields. Soyabean requires about 550-600 ml of rainfall, which should adequately be distributed throughout the life of the crop. However, regions IV and V receive rainfall which is normally below that range and which is poorly distributed.

Another constraint to soyabean production is non-availability of soyabean pureline varieties. Certified soyabean seed has not been readily available within the smallholder input outlets if compared to other crop seeds (Mpepereki, 1996). This has contributed greatly to the lack of participation by smallholder farmers in soyabean production as they prefer other crop options for which they could readily acquire seed. However, promiscuous soyabean varieties could be another option to explore, which smallholder farmers could use if the varieties are readily available. Promiscuous varieties fix nitrogen using any indigenous bacteria and hence do not require the use of inoculants. In Zambia some of the smallholder farmers use promiscuous varieties to produce soyabean. In Zimbabwe this technology has not been popular because the promiscuous varieties available are lower yielding relative to those varieties that require the use of inoculants. It could also be a challenge to breeders where they should improve these varieties.

Another important constraint to soyabean production is soyabean rust disease. Soyabean rust is a devastating disease capable of reducing yields by up to 90 % in highly susceptible varieties (Tichagwa[s], *personal communication*). In areas where the disease is epidemic, and given favourable conditions for the development of the disease it has become a perennial problem. Farmers have only one option of controlling the disease, that is chemical control. But, the problem here is on the cost. Chemicals are costly thus increasing the variable costs.

2.2 The Soyabean Rust Problem

The obligate parasitic fungi called *Phakospora pachyhizi* Sydow and *Phakospora meibomiae* Sydow cause Soyabean Rust. However, *Phakospora paechyrhizi* Sydow is the one responsible for significant yield losses and is the more aggressive of the two pathogens (Tschanz, 1984). The pathogen is an air-borne fungus. It was first recorded and reported in Japan in 1902 (AVRDC, 1992). However, by then it was not of economic importance. *Phakaspora pachyrhizi* Sydow has a wide host range, which includes soyabeans and other Glycine species. According to Bromfield (1984) it is reported that there are over 95 species known to be hosts, covering 45 genera in the Leguminosae family.

The most common symptoms of the disease are tan to dark brown or reddish brown polygonal lesions that are about 0.5 mm in length with one to many erumpent, globose, ostiolate uredia (AVRDC, 1992). In Zimbabwe, the reddish brown lesions occur. In some countries both the reddish brown and the tan symptoms occur, for example, in Brazil. However, the commonest lesions are to reddish brown. However, occurrences of these lesions depend on the environment. Early symptoms appear as small water-soaked chlorotic spots on soyabean leaves which gradually increase in size, turning from grey to reddish-brown lesions containing uredia which produces the uredo-spores of rust fungus (AVRDC 1992). Again, early symptoms would appear on the lower leaves and then progress up the plant until all leaves are infected. Infection levels can be high, resulting in defoliation of plants. Lesions can appear on petioles, pods and stems but are most abundant on leaves, particularly on the lower surface. In the more advanced stages of infection, lower and middle leaves become distinctly yellow and the plants look “diseased”. Brown scaring appear on the underside of leaves both as pin-points and extensive lesions. In addition, in hot dry weather, a light brown cloud of spores forms within and above the canopy, tip firing and sun scorch of the leaves also occurs. In general, the cumulative effect of rust on yield is lower seed weight and fewer pods and seed (Bromfield, 1984).

The development of rust is affected by temperature, precipitation or leaf surface wetness and humidity (Tschanz, 1982). Humidity should be as high as 75 % for rust to develop. Rust development is inhibited by dry conditions and mean daily temperatures greater than 30 ^{o}C and/or less than 15 ^{o}C. Temperature above 27 ^{o}C for extended periods retard rust development even with adequate free moisture on leaf surface (Tschanz, 1982). Some work on rust development indicated that a severe rust epidemic requires about 10 hours of leaf wetness and mean daily temperature of 18-26 ^{o}C. Mean night temperatures consistently below 14 ^{o}C prevented or greatly inhibited rust development while mean night temperatures above 25.5 ^{o}C had little effect on rust development when they occurred in conjunction with frequent, long leaf wetness periods (Tschanz, 1984). Free moisture on the plant surface is a pre-requisite for uredospore germination and infection. Although infection can occur within a 16 hour dew period when temperatures are between 10.5 ^{o}C and 26 ^{o}C, temperatures above 28 ^{o}C during the dew period appear to inhibit or prevent infection (AVRDC, 1982). At optimum temperatures between 20 ^{0}C and 25 ^{o}C, infection of a susceptible host can occur during six hours of leaf surface wetness. Within this temperature range, maximal infection occurs within 10-12 hours of leaf wetness. It is also important to note that increased periods of leaf wetness are necessary for infection when temperatures fall outside the optimum temperature range (Marchetti, 1976). It is interesting to note that most of the production areas in Zimbabwe possess conditions that are ideal for the development of soyabean rust during the summer period. Thus, rust is a real threat to soyabean production in Zimbabwe.

2.3 Current Control Methods

The commercial varieties currently in use are highly susceptible to rust (Seed-co, 2000). Many methods can be exploited to control soyabean rust, though the most important prominent one and effective is chemical control. There are many chemicals which have been registered by agro chemical companies that offer effective control of rust. Some of the chemicals include Folicur, Punch Xtra, Score, Shavit, Tilt, Alto and Funginex. The timing of fungicide application was found to be critical (Preez and Rij, 2000). Two or more sprays were found to give better results than only one spray (Levy, 2001) The length of fungicide control ranged from 14 to 18 days, hence the spray interval of 21 days was found to be optimal, especially considering that the chemicals have a curative effect. Spraying is normally recommended to start at first flower to act as which acts as a preventative measure and the two subsequent sprays at an interval of 20 days. The general recommendation is that farmers should come in with the first spray at 50 days, then 70 days and 90 days (Levy*, personal communication).*

Other options such as the practice of controlling of alternate hosts, adjusting planting space and density can also be integrated to give enhanced control of soyabean rust. In addition, sanitation measures can be employed that is, all plant debris of hosts of the fungus should be destroyed after harvest either by burning, ploughing under or chemical treatment. Constant surveillance and inspection of endemic areas and inspection of exported and imported host materials including seeds is necessary for local, regional and international control of this pathogen (Ford and Sinclair, 1988).

Furthermore, cultural practices such as planting of non-host barriers can also be used that is in endemic areas, non host plant barriers should be planted around soyabean fields or larger production areas to reduce the amount of air-borne inoculum. Crop rotations can also offer effective control of the pathogen because of short-lived nature of aeciospores.

2.5 Use of Resistant Cultivars to Control Soyabean Rust

The use of resistant varieties is the cheapest, easiest, safest and most effective means of controlling plant diseases in crops (Agrios, 1988). Cultivation of resistant varieties not only eliminates losses from diseases, but also eliminates expenses incurred from using chemicals for spraying and from using other methods of disease control. Use of resistant varieties also avoids the contamination of the environment with toxic chemicals that would otherwise be used to control plant diseases.

Producers exploit both tolerant and resistant varieties. Tolerance to disease is the ability of plants to produce a good crop even when they are infected with a pathogen, whereas immunity is the failure of a pathogen to establish itself successfully in a plant. Resistance is genetically controlled by the presence of one, a few or many genes. Resistant or tolerant varieties have been developed and are still being developed in countries where rust is of economic importance. For example, in Uganda one tolerant variety has been registered and released for commercial production. Soyabean rust resistant varieties can offer an economically feasible and culturally sustainable technology for soyabean producers (Ford and Sinclair, 1977).

s—Senior Soyabean Pathologist, Commercial Farmers Union

2.5 Sources of Soyabean Rust Resistance

The initial step in the breeding for rust resistance is to obtain sources of resistance for use in a breeding programme (Bromfield, 1980). Variation in the reaction of soyabeans to soyabean rust has been observed. Susceptible varieties are characterized by rapid necrosis and spreading of the disease up the plant and throughout the whole field of the soyabean crop. Variation in total yield, 100 seed weight and days to maturity was noted following some work that was done at Asian Vegetable Research and Development Centre (Tschanz, 1982). Following that work it was noted that soyabean rust can delay maturity by up to seven days. Furthermore, it was observed that seed mass can be reduced by between 10 % to 25 % (Tschanz, 1982). Sources of resistance can be obtained from any place where soyabean research work on rust resistance has been done. Scores of successes have been made in Thailand, Taiwan, India, China with respect to breeding for rust resistance. Seed-co Zimbabwe is also making considerable progress and hopes to release a rust resistant variety in the near future. One such variety has been identified and registered in South Africa. Intensive screening of soyabean germplasm sources is required to identify and quantify those genotypes that are resistant or susceptible (Tschanz, 1982). Screening is done using fungicides to determine yield loss caused by the disease. The screening technique of using fungicides involves spraying one plot and unprotect the other plot of same variety (that is sprayed and unsprayed plots of similar varieties are evaluated). In some cases the screening work can give rise to varieties if they have good resistance to rust coupled with good agronomic characteristics (Ford and Sinclair, 1977).

Four dominant independently inherited genes were found to be responsible for resistance to *Phakospora pachyrhiz,* Sydow. These only confer specific resistance to a few rust isolates that have been tested. These were named *Rpp1, Rpp2, Rpp3 and Rpp4*. However, they are popularly known as

P1 200492, P1230970, P14623/2 and P1 459025 respectively (Sinclair and Backman, 1989). These popular sources of resistance were not useful to Zimbabwe as they were all susceptible. The sources of resistance were found to be specific to a given environment (Tichagwa[s], 2004 *personal communication*). For example, some genotypes that were found to be resistant here in Zimbabwe were found to be susceptible under Brazilian conditions.

Resistance is also linked to the type of lesions available, for example, in Zimbabwe only the reddish brown lesions exist, and as such varieties are identified and selected as resistant, if sent to Brazil, where both the reddish brown and the tan exist, they maybe found to be susceptible. The other obvious thing is that the soyabean rust races might be different in different environments.

Genes for resistance also occur among the wild *Glycine* species form Australia (Sinclair and Backman, 1989). For example, resistance genes were also identified in *Glycine tomentella* Hayata (accession PI 483218, 2n=78), where intersubgeneric hybrids have been created between *Glycine max* (cv. Altona and *Glycine tomentella* accession. Moreover, Amphiploid hybrid lines were the result of this hybridization and when further backcrossed to *Glycine max* (cv. Clark 63), derived fertile lines (2n= 40) were also generated. (Hartman, 2007) Rate reducing resistance has been demonstrated but however, it is difficult to evaluate because the rate of rust development is dependent on soyabean development and maturity (Ford and Sinclair 1977).

s =Senior Soyabean Breeding Programme Manager, Seedco, Zimbabwe

The evaluation of soyabeans on the basis of their ability to sustain lower rust induced yield losses is a promising method of developing improved cultivars. This method has been used at AVRDC to develop resistant varieties that produce more stable yields across different environments.

2.7 Mechanisms of Resistance to Soybean Rust

Plants defend themselves against pathogens by a combination of methods mainly divided into structural and biochemical pathways (Agrios, 1988). Structural characteristics act mainly as physical barriers, inhibiting entry and spread of the pathogen whereas biochemical reactions result in production of substances that are either toxic to the pathogen or create conditions that inhibit growth of the pathogen in the plant.

There are many mechanisms by which plants minimize the impact of disease organisms on their development and reproduction. A plant may resist the establishment of the pathogen in its tissue, it may resist the growth and reproduction of the pathogen that becomes established, or it may develop and reproduce well despite the activity of the pathogen (Fehr, 1987). Commonly the first two mechanisms are considered forms of resistance and the last is described as tolerance. In addition, a hypersensitive response/reaction has been noted which relates to the visual symptoms of dramatic cell necrosis, associated with penetration in resistant host cultivars. Furthermore, an incompatible response was also observed. It occurs in incompatible combinations of host plants and the rust fungi. Incompatible response was found to be heritable.

2.7 Breeding for Rust Resistance

Cultivar resistance has been exploited and is actively being pursued in many nations. The Taiwan Agricultural Research Institute (TARI) initiated its breeding work, culminating in the release of rust resistant cultivars namely, kaohsuing 3, Tainung 3 and Tainung 4. These were used as sources of resistance in other breeding progammes. A number of breeding institutions have made use of the original sources of resistance namely P.I. 200451, P.1 200 490 and P.1 200 492. (Ford and Sinclair, 1977).

The incorporation of durable soyabean rust resistance into agronomically desirable and high yielding varieties is a goal being actively pursued at breeding locations throughout the world. Rust resistance is a complex trait being controlled by many genes. However, in Zimbabwe progress has been made in terms of generating material with rust resistance. Some of these materials from rust resistant background are now being evaluated in Brazil and South Africa where rust incidence and occurrence is high.

2.8 Methods of screening for rust resistance

Basically, there are two methods that are used for rust screening viz, visual assessment of disease lesions on the leaves and use of fungicides (Tichagwa, 2004). Visual assessments of the disease lesions are made to determine the presence and severity of rust. This rating notation used universally ranges from 1 to 4 where, **1** denotes absence of disease lesions and **4** heavy lesion density (Ford and Sinclair,1977). Fungicides are used to determine the damage, if any, that the disease may cause. As a way of identifying resistance to soyabean rust, the use of fungicides has been found to be reliable and consistent. This technique takes into account the effect of the disease on seed mass. Ideally, the seed mass or seed size of a resistant line or genotype does not change much in the presence of soyabean rust even if the disease is not controlled with fungicides. Therefore, seed mass can be used as an indicator of resistance or susceptibility of a genotype to rust. In the screening procedure for rust resistance some breeders rely on natural occurrence of the disease whereas others do artificial inoculations. Screening could either be done in the field or in the greenhouse. Growth chambers have also become popular structures for rust screening.

2.10 Rust Assessment

In order to standardize soyabean rust evaluation, a rating system containing a two digit scientific notation was adopted by the International Working Group on Soyabean Rust (Ford and Sinclair, 1977). This is used to rate infections observed both in the field and the greenhouse by soyabean researchers. The rating notation is explained as;

First digit- this denotes examined leaf position of the soyabean plant. This is rated on a scale of 1 to 3, where; 1 is bottom third soyabean leaves measured from ground level

2 is middle third soyabean leaves measured from ground level

3 is upper third soyabean leaves measured from ground level

Second digit- this denotes the density of rust lesions on the examined leaves. This is rated on a scale of 1 to 4, where,

1 is no disease lesions

2 represents light lesion density

3 represents medium lesion

4 stands for heavy lesion density

For example, 1,4- means bottom third leaves heavily covered with rust.

CHAPTER 3

MATERIALS AND METHODS

3.1 Site

The experiment was conducted at Rattray Arnold Research Station located in Natural Region II A with an altitude of 1360 m longitude 31^0 13^1 South and latitude 17^0 16^1 East. The experiment was established in the field. The names of the 22-soyabean varieties that were entered in the trial are presented in Table 3.1

Table 3.1 List of experimental lines, which were used in the study

ENTRY NO.	ENTRY NAME	GROWTH HABIT
1	S731/6/57	I
2	S722/6/28	I
3	S748/6/20	D
4	S727/6/20	I
5	S740/6/68	D
6	S723/6/3	I
7	S744/6/17	D
8	S717/6/17	I
9	S727/6/41	I
10	S748/6/96	D
11	S744/6/29	D
12	S727/6/55	I
13	SOLITAIRE	I
14	S708/6/15	I
15	S727/6/25	I
16	S726/6/8	I
17	S727/6/33	I
18	SERENEDE	I
19	S727/6/5	I
20	S726/6/9	I
21	S723/6/8	I
22	S727/6/60	I

N.B. 'D' stands for determinate varieties and 'I' stands for indeterminate varieties. Determinate varieties are those varieties that cease to grow vegetatively after flowering and indeterminate varieties are those that continue to grow after flowering. Indeterminate varieties are normally recommended for production in high potential areas where the environments are cool, if produced in warm environments they will produce tall plants and subsequently they will lodge.

These varieties were bred and developed in Zimbabwe and were generated through crossbreeding, involving creation of some populations which were then advanced using the single seed descent method. One of the parents used in each cross was resistant to soyabean rust and the other parent used had good agronomic characteristics as well as being high yielding. At F6 single plant selections were taken, as homozygosity of most loci is normally achieved at this stage. About twenty-five lines were collected from many countries and used as sources of rust resistance. These were then evaluated in a non-replicated trial. The commercial variety called SC Solitaire was included as a control. Solitaire has some tolerance to rust and will give 40 % to 50 % of its yield potential in the presence of rust (that is when rust is not controlled by using fungicides). Serenade is another commercial variety used which has been recently released and is susceptible to rust, therefore it was used as a susceptible check.

3.2 Experimental Design

The experimental design used was a split plot arrangement in a randomised complete blocks design with three replications. The main plot was the fungicide with two levels that is level-1 nothing was applied and level-2, Punch Extra (Flusilazole/Carbendazim) was applied at a rate of 400 ml in 425 litres of water at 50,70 and 90 days after planting and variety was the subplot with 22 levels. The gross plot was four rows that were spaced at 0.9 m apart and 6 m long (= 21.6 m^2) and net plot was 2 rows that were 0.9 m apart and 4 m long (= 7.2 m^2).

3.3 Fungicide Spray Applications

The fungicide was applied with a knapsack sprayer fitted with an A.N 2.0 fan jet regulated to 2-bar pressure. The application rate was approximately 425 litres per hectare. Agral 90 spreader was added at the rate of 1 ml per 7.5 litres of water. Agral 90 was used so that the chemical could stick on to the soyabean leaves.

3.4 General Trial Management

The fields were ploughed first and then compound L (5 % N: 17 % : P_2O_5 : 10 % K_2O and 0.01 % B was disked in at a rate of 250 kg per hectare.The seed was inoculated with *Brandyrhyzobium japomicum* inoculant strain number 1491 from Grasslands Research Station. A 5 % sugar solution was prepared first and then the inocolant was poured into the solution and mixed together. This was then applied to the packet containing the seed and was then shaken to ensure that the seed had come into contact with the seed. The inoculation process was done under the shade. The seed was planted at a rate of 300 000 viable seeds per hectare on 11 December 2006. Lasso and gramoxone herbicides were applied at 4 *l*/ha and 1 *l*/ha respectively as a pre-emergency spray. The two herbicides are compatible so they were mixed together and applied simultaneously. Weeding was done only once.

3.4 Measurements and observations Recorded

The records that were taken are as follows;

1. Number of days from planting to 95 % pod maturity. This is when 95 % of the pods have dried.

2. Pod clearance scores: The clearance between the soil and the lowest pods. A scale of 0 to 4 was be used, where 0=0-5cm, **1**=5-10cm, **2**=10-15cm, **3**=15-20cm and **4** = over 20cm.

3. Plant height in centimetres. This refers to the mean height of **3-5** modal plants to the top of the main stem of upright plants, in centimetres.

4. Percentage lodged plants at maturity. This is a percentage of plants leaning over more than 45^{o}

5. Green stem scores at first pod shattering, where; **0** = All stems dry at shattering date. **1=**Up to 50 % of stems green at shattering date and **2** = almost all plants with green stems and also with some green leaves on the plants at shattering date.

6. Seed yield- This refers to seed yield in grams per net plot, of air dry seed.

7. Mass of 100 seeds in grams.

8. Seed appearance scores: This is quality variable rated on a scale of **1 to 5 where 1** = very good quality and **5** = very poor quality.

9. Percentage crude protein – This refers to protein content in the seed on a dry matter basis.

10. Percentage crude oil – This refers to oil content in the seed on a dry matter basis.

N.B Crude protein content and oil content was measured using a Zeltech Analyser.

3.5 Rust Assessment

The plots were be scored for rust when they reached the R6 stage of growth. This is a reproductive stage at which the pod cavity is fully filled with seed. The R6 stage was chosen because at this stage one can separate lines that are susceptible and those that are resistant on the basis of how well the pods are filled. The lines with pods that are properly filled under high infestation levels would suggest that such lines are resistant. A two digit number score system will be used for rating rust infections (adapted from Shanmugnsundaramm, 1977).

First Digit- denotes examined leaf position of the soyabean plant.

1. Bottom third of the leaves on the plant measured from the ground level.
2. Middle third of the leaves on the plant measured from the ground level.
3. Upper third of the leaves on the plant measured from the ground level.

Second Digit- denotes the density of rust lesions on the examined leaves.

1. No lesions
2. Light lesion density
3. Medium lesion density
4. Heavy lesion density.

3.6 Data Analysis

General analyses of variances were performed for all the varieties including controls using IRRISTAT version 5.0 (2005) computer package for agronomic traits and grain yield data.

CHAPTER FOUR
RESULTS

Analysis of variance of the main effects on varieties that were evaluated and the interaction of variety by fungicide is presented on Table 4.1. In addition, the means of the main factors that is variety by fungicide is presented in Table 4.2.

4.1 Number of days from planting to 95 % pod maturity

There were significant differences ($P<0.001$) for number of days from planting to 95 % pod maturity (Table 4.1). Number of days from planting to 95 % pod maturity ranged from 113 to 127 days. However, the average number of days from planting to 95 % pod maturity is 118 (Table 4.2).

4.2 Percentage crude protein in air-dry seed on a dry matter basis

Significant differences were noted on crude protein ($P<0.001$) as shown in Table 4.1. Crude protein ranged from 47.1 % to 52.3 %. SC Solitaire yielded 47.7 % under sprayed conditions and 48.2 when not protected by a chemical. SC Serenade gave a protein content of 48.9 under sprayed conditions and 48.5 % when sprayed by a chemical (Table 4.2). Generally, quite a number of new lines yielded higher protein content than the standards.

Table 4.1 Mean Square Values of main effects for each variate for the twenty-two varieties

Source of Variation	Df	Mean Squares										
		PLHT	GS	SAP	SMA	LRP	RD	DFL	DMAT	OIL	CP	SYLD
		cm			g			days	days	%	%	Kg ha^{-1}
Rep	2	138.83*	1.09*	0.21*	1.84ns	0.22ns	0.30ns	0.30ns	28.21*	0.19ns	3.44*	364659*
MP (Fungicide)	21	537.15***	2.37***	1.43***	44.94***	1.28***	0.79***	29.0***	83.03***	1.69***	5.82***	406140***
Rep*Var	42	38.60***	0.26***	0.851***	0.178ns	0.27ns	0.86ns	0.82***	6.69***	0.25ns	0.25	103618ns
SP (Variety)	1	1.70ns	1.70***	0.66ns	2.14***	18.19***	34.0***	0.52ns	69.81***	2.06**	1.65ns	36.1173**
(Fung*Variety)	21	3.978*	0.38***	0.37***	146.8***	1.28***	0.46**	0.27***	4.80***	0.183ns	0.88ns	217156ns
Error	44	1.78	0.60	0.23	7.72	0.53	0.17	0.15	0.94	0.196	1.05	0.20

Df=Degrees of freedom, Rep=Replication, MP = Main Plot, Var = Varieties, SP = Subplot, Fung = Fungicide, PLHT = Plant height, GS = Green stem scores, SAP = Seed appearance scores, SMA = Seed appearance scores, SMA = Seed mass in grams, LRP = Position of leaf rust on the plant, RD = Density of rust lesions on the plant, DFL = Number of days from planting to 50% flowering, DMAT = Number of days from planting to 95% pod maturity, OIL = Percentage crude protein content in air dry seed on a dry matter basis, CP = Percentage crude oil content in air dry seed on a dry matter basis, SYLD = Seed yield in kilograms per hectare. * = Significant differences at 0.05, ** = Significant differences at 0.01 and *** = Significant differences at 0.001.

Table 4.2 Summary of Means of Main Effects for the measured variates

Factors		PLHT	GS	SAP	SMA	LRP	RD	DFL	DMAT	OIL	CP	SYLD
Variety	Fung	cm			g			days	days	%	%	Kg ha^{-1}
S731/6/57	1	80.3	2.0	3.0	24.1	1.0	1.7	46.0	114	18.7	48.1	2730
	2	81.3	2.0	3.0	25.8	1.0	1.0	46.0	115	18.7	48.1	2837
S722/6/28	1	80.0	2.0	2.0	25.8	1.0	1.7	48.7	117	18.4	49.2	2800
	2	79.6	2.0	2.0	25.8	1.0	1.0	48.7	119	18.2	49.8	2751
S748/6/21	1	58.7	1.0	3.0	22.7	1.0	1.3	52.0	115	18.3	48.3	2368
	2	58.3	1.0	3.0	26.8	1.0	1.0	52.0	115	17.8	48.4	2503
S727/6/20	1	81.0	1.0	2.7	24.1	1.0	1.7	46.0	114	18.7	47.5	2691
	2	79.7	1.0	2.7	22.5	1.0	1.0	46.0	114	18.8	48.0	3008
S740/6/68	1	54.3	0.7	3.0	21.4	2.3	2.0	46.0	115	17.7	48.7	2707
	2	53.7	0.7	3.0	24.4	1.0	1.0	46.0	115	17.8	48.5	2720
S723/6/3	1	70.3	0.3	3.0	21.3	3.0	3.0	48.7	114	18.0	49.0	2577
	2	73.0	1.0	3.0	24.3	1.0	1.0	48.7	115	18.2	48.4	3019
S744/6/17	1	67.3	1.3	3.0	24.4	1.0	1.7	52.0	119	18.1	49.9	3017
	2	67.8	1.3	3.0	25.9	1.0	1.0	52.0	121	18.6	49.8	3186
S717/6/17	1	85.0	2.0	3.0	22.2	1.0	2.0	45.7	115	18.2	49.2	2567
	2	84.0	2.0	3.0	23.6	1.0	1.0	45.7	116	18.7	49.6	2982
S727/6/41	1	72.0	2.0	3.0	23.8	1.3	2.0	45.3	113	18.5	48.4	3140
	2	70.7	2.0	3.0	23.5	1.0	1.0	45.3	113	19.1	50.0	2830
S748/6/96	1	71.0	1.0	3.0	21.0	1.0	1.0	50.0	117	17.3	51.8	2830
	2	72.0	1.0	3.0	23	1.0	1.0	50.0	119	17.0	52.3	2961
S744/6/29	1	61.7	0.3	3.0	18.6	1.0	1.7	50.0	115	17.7	50.0	2968
	2	62.3	0.3	3.0	18.6	1.0	1.0	50.0	115	18.1	49.5	3278
S727/6/55	1	84.0	2.0	3.0	27.7	1.0	2.0	49.3	123	18.9	49.4	2828
	2	84.0	2.0	3.0	27.6	1.0	1.0	49.3	127	18.7	49.1	2499
SOLITAIRE	1	70.3	0.0	3.0	19.7	3.0	3.0	46.0	115	19.1	48.2	2370
	2	68.0	0.3	3.0	23.8	1.0	1.0	46.0	115	19.8	47.7	3408
S708/6/15	1	82.0	2.0	3.0	19.0	3.0	3.0	45.0	115	18.5	48.3	2359
	2	80.3	2.0	3.0	23.2	1.0	1.3	45.0	115	19.1	47.1	2829
S727/6/25	1	84.7	2.0	3.0	27.8	1.0	2.0	48.7	123	18.4	48.8	3007
	2	86.7	2.0	3.0	30.8	1.0	1.0	48.7	127	18.5	47.5	3491
S726/6/8	1	88.0	1.0	2.3	23.5	3.0	3.0	50.0	122	17.5	49.9	1937
	2	85.7	1.0	2.3	26.5	1.0	1.7	50.0	126	18.0	49.0	2594
S727/6/33	1	77.3	1.3	1.0	26.7	1.0	1.7	46.0	115	17.8	50.4	2506
	2	78.0	1.7	1.0	26.8	1.0	1.0	46.0	115	18.2	50.1	3305
SERENADE	1	72.7	0.0	3.0	23.0	3.0	3.0	48.7	120	18.7	48.9	2101
	2	71.0	2.0	3.0	31.8	1.0	1.3	48.7	126	19.1	48.5	3160
S727/6/5	1	80.3	2.0	3.0	24.7	1.3	2.0	47.3	115	19.2	48.1	2455
	2	77.0	2.0	3.0	25.7	1.0	1.0	47.3	115	18.9	49.1	2376
S726/6/9	1	81.3	0.0	2.3	22.0	3.0	3.0	50.0	118	18.0	49.1	2001
	2	84.0	1.3	2.3	26.4	1.0	1.0	50.0	121	18.2	48.2	2445
S723/6/8	1	88.7	1.0	3.0	18.6	3.0	2.0	50.0	118	17.5	50.2	2360
	2	90.0	1.3	3.0	21.4	1.0	1.0	50.0	122	18.1	48.9	3131
S727/6/60	1	82.3	2.0	3.0	28.4	1.7	2.0	46.0	115	18.3	50.2	2554
	2	81.3	2.0	3.0	28.9	1.3	1.7	46.0	115	19.0	49.1	2839
Grand Mean		75.9	1.3	2.8	24.2	1.4	1.6	48.1	118	18.3	49.1	2751
$LSD_{(0.05)}$		2.1	0.4	0.8	2.5	0.4	0.7	0.2	1.6	0.2	0.2	449
CV		1.8	18.4	0.0	6.2	16.6	26.1	0.0	9.9	0.7	9.9	9.9

4.3 Plant height in centimetres

Plant height was highly significant (P<0.001) and the interaction (i.e. variety* fungicide) was also significant (P<0.05). Most of the experimental lines were taller than the two control varieties. Plant height is an important attribute with regards to lodging. Too tall plants may succumb to lodging especially if the plant population is too high. However, if a variety is a robust one with strong stems lodging may not occur or maybe minimal. Lodged plants are difficult to harvest.

4.4 Green stems scores at maturity

Significant differences for green stem scores were noted (P<0.001) and the interaction (variety * fungicide for) was also significant (P<0.001). Some varieties had some green stems at maturity. However, its interesting to note that SC Serenade, a standard variety had some green stems at maturity on the sprayed plots.

4.5 Visual scores

This covers the scores for the position of soyabean rust on the plant and density of rust lesions on the plant. There were significant differences between varieties for soyabean rust visual scores (P<0.001) and the interaction of variety * fungicide was also significant (P<0.01) for both density of soyabean rust and leaf rust position.

Table 4.3. The reaction of seed mass to fungicide application, in view rust position and rust density.

Variety	Fungicide applied	Rust Position scores	Rust Density	Mass of seed for a 100g sample	% change in seed mass
S731/6/57	1	1.0	1.7	24.1	
	2	1.0	1.0	25.8	7.1
S722/6/28	1	1.0	1.7	25.8	
	2	1.0	1.0	25.8	0
S748/6/21	1	1.0	1.3	22.7	
	2	1.0	1.0	26.8	18.1
S727/6/20	1	1.0	1.7	24.1	
	2	1.0	1.0	22.5	-6.6
S740/6/68	1	2.3	2.0	21.4	
	2	1.0	1.0	24.4	14.0
S723/6/3	1	3.0	3.0	21.3	
	2	1.0	1.0	24.3	14.1
S744/6/17	1	1.0	1.7	24.4	
	2	1.0	1.0	25.9	6.1
S717/6/17	1	1.0	2.0	22.2	
	2	1.0	1.0	23.6	6.3
S727/6/41	1	1.3	2.0	23.8	
	2	1.0	1.0	23.5	-1.3
S748/6/96	1	1.0	1.0	21.0	
	2	1.0	1.0	23	1.0
S744/6/29	1	1.0	1.7	18.6	
	2	1.0	1.0	18.6	0
S727/6/55	1	1.0	2.0	27.7	
	2	1.0	1.0	27.6	-0.4
SOLITAIRE	1	3.0	3.0	19.7	
	2	1.0	1.0	23.8	15.6
S708/6/15	1	3.0	3.0	19.0	
	2	1.0	1.3	23.2	22.1
S727/6/25	1	1.0	2.0	27.8	
	2	1.0	1.0	30.8	11
S726/6/8	1	3.0	3.0	23.5	
	2	1.0	1.7	26.5	12.8
S727/6/33	1	1.0	1.7	26.7	
	2	1.0	1.0	26.8	0.4
SERENADE	1	3.0	3.0	23.0	
	2	1.0	1.3	31.8	38.3
S727/6/5	1	1.3	2.0	24.7	
	2	1.0	1.0	25.7	4.0
S726/6/9	1	3.0	3.0	22.0	
	2	1.0	1.0	26.4	0.2
S723/6/8	1	3.0	2.0	18.6	
	2	1.0	1.0	21.4	15;1
S727/6/60	1	1.7	2.0	28.4	
	2	1.3	1.7	28.9	1.8
Variety Means		1.4	1.6	24.2	
S.E(Mean)		0.13	0.24	0.8	
F.test		***	***	***	
L.S.D		0.4	0.7	2.5	
C.V		16.6	26.1		

Table 4.4. The reaction of seed yield to fungicide application, in view of rust position and rust density

Variety	Fungicide Applied	Rust Position scores	Rust Density	Seed yield Kg/ha	% Yield change
S731/6/57	1	1.0	1.7	2730	
	2	1.0	1.0	2837	3.9
S722/6/28	1	1.0	1.7	2800	
	2	1.0	1.0	2751	-1.8
S748/6/21	1	1.0	1.3	2368	
	2	1.0	1.0	2503	5.7
S727/6/20	1	1.0	1.7	2691	
	2	1.0	1.0	3008	11.8
S740/6/68	1	2.3	2.0	2707	
	2	1.0	1.0	2720	0.4
S723/6/3	1	3.0	3.0	2577	
	2	1.0	1.0	3019	17.2
S744/6/17	1	1.0	1.7	3017	
	2	1.0	1.0	3186	5.6
S717/6/17	1	1.0	2.0	2567	
	2	1.0	1.0	2982	16.2
S727/6/41	1	1.3	2.0	3140	
	2	1.0	1.0	2830	9.9
S748/6/96	1	1.0	1.0	2830	
	2	1.0	1.0	2961	4.6
S744/6/29	1	1.0	1.7	2968	
	2	1.0	1.0	3278	10.4
S727/6/55	1	1.0	2.0	2828	
	2	1.0	1.0	2499	11.7
SOLITAIRE	1	3.0	3.0	2370	
	2	1.0	1.0	3408	43.8
S708/6/15	1	3.0	3.0	2359	
	2	1.0	1.3	2829	19.9
S727/6/25	1	1.0	2.0	3007	
	2	1.0	1.0	3491	16.1
S726/6/8	1	3.0	3.0	1937	
	2	1.0	1.7	2594	33.9
S727/6/33	1	1.0	1.7	2506	
	2	1.0	1.0	3305	31.9
SERENADE	1	3.0	3.0	2101	
	2	1.0	1.3	3160	50.4
S727/6/5	1	1.3	2.0	2455	
	2	1.0	1.0	2376	-3.5
S726/6/9	1	3.0	3.0	2001	
	2	1.0	1.0	2445	22.2
S723/6/8	1	3.0	2.0	2360	
	2	1.0	1.0	3131	32.7
S727/6/60	1	1.7	2.0	2554	
	2	1.3	1.7	2839	11.2
Variety Means		1.4	1.6	2751	
S.E.(mean)		0.13	0.24	157.5	
F test		***	***	**	
L.S.D		0.4	0.7	449	
C.V.		16.6	26.1	9.9	

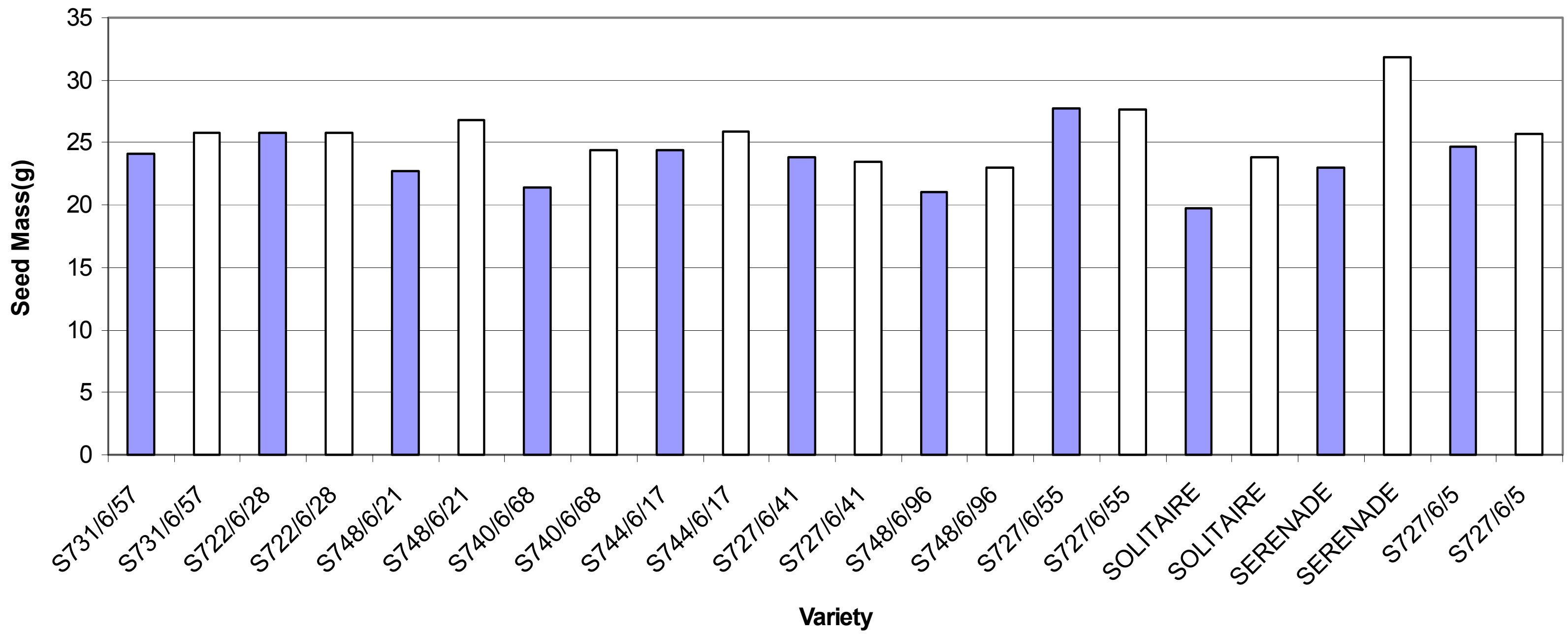

Fig 4.1 Relationship between seed mass of tolerant or resistant varieties under infested and non-infested conditions

Key

Shaded bars- denotes the varieties to which soyabean rust was not controlled.

Plain bars—represent varieties that were protected against soyabean rust

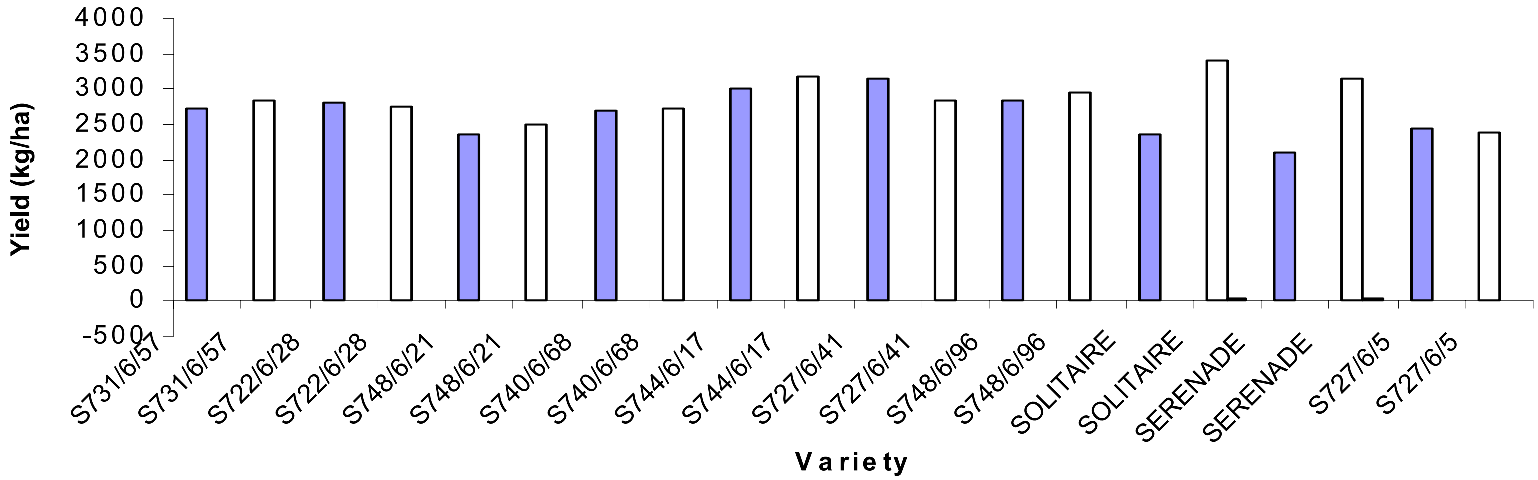

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Figure 4.2 Relationship of the yield of tolerant or resistant varieties under infested and non-infested condition

Key

Shaded bars- denote the varieties to which soyabean rust was not controlled.

Plain bars—represent varieties that were protected against soyabean rust

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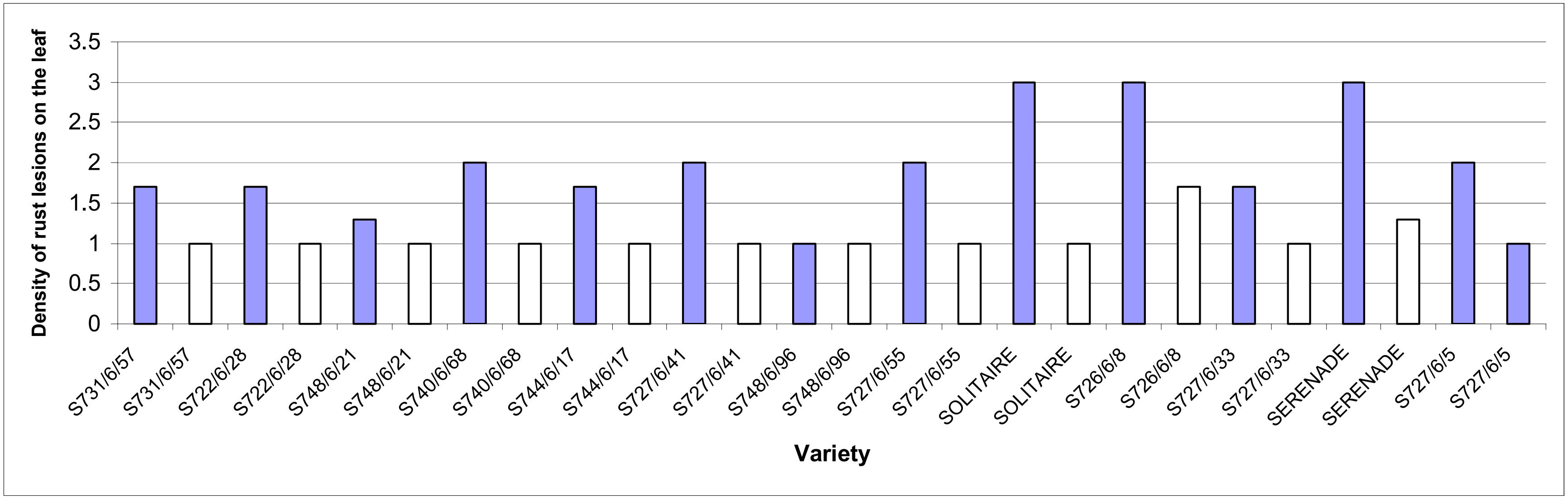

Figure 4.3 Comparison of selected tolerant or resistant varieties under infested and non-infested conditions

Key

Shaded bars- denote the varieties to which soyabean rust was not controlled.

Plain bars—represent varieties that were protected against soyabean rust

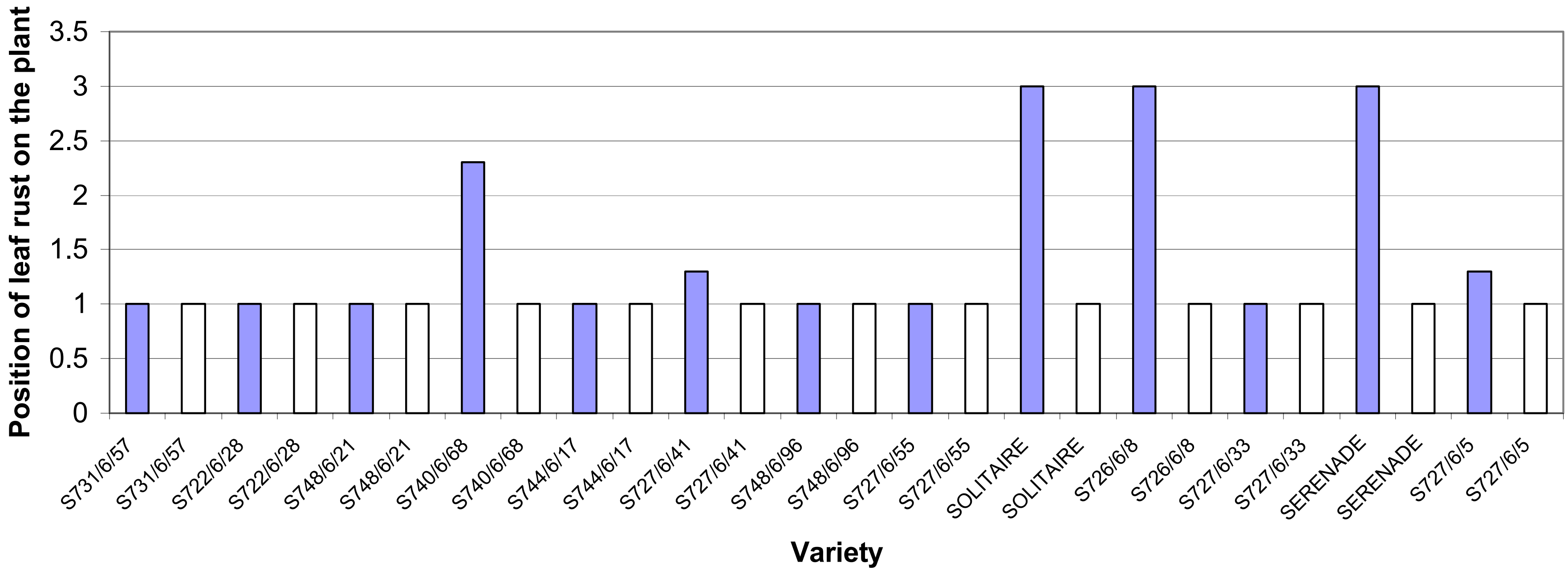

Figure 4.4 Comparison of selected tolerant or resistant varieties under infested and non-infested conditions in view of leaf rust position

Key

Shaded bars- denotes the varieties to which soyabean rust was not controlled.

Plain bars—represent varieties that were protected against soyabean rust.

Figure 4.5 Relationship between seed mass and seed yield

The relationship between seed mass and seed yield is presented (Fig 4.5) to which a linear equation was fitted to the data. The linear equation was not significantly correlated (R^2=0.0531)

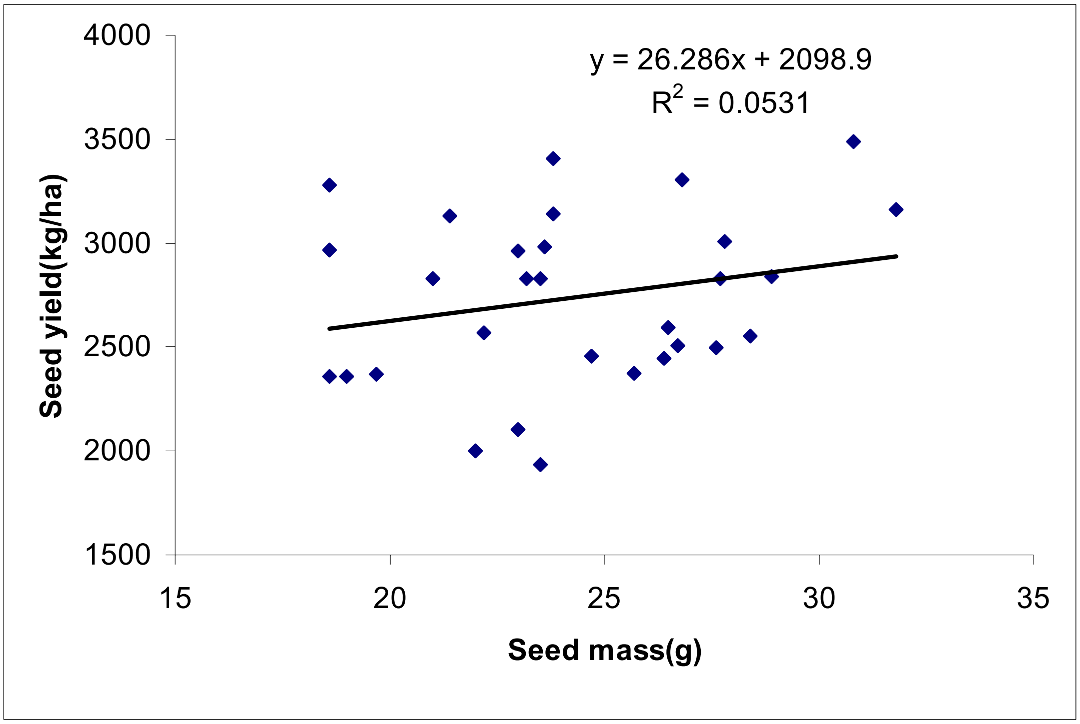

Figure 4.5 Relationship between seed mass and seed yield

Figure 4.6 The effect of visual scores on tolerant or resistant varieties (in view of position of leaf rust on the plant).

The relationship between tolerant or resistant varieties and position of leaf rust on the plant is presented (Figure 4.6) and a linear equation is fitted to the data and no relationship was found.

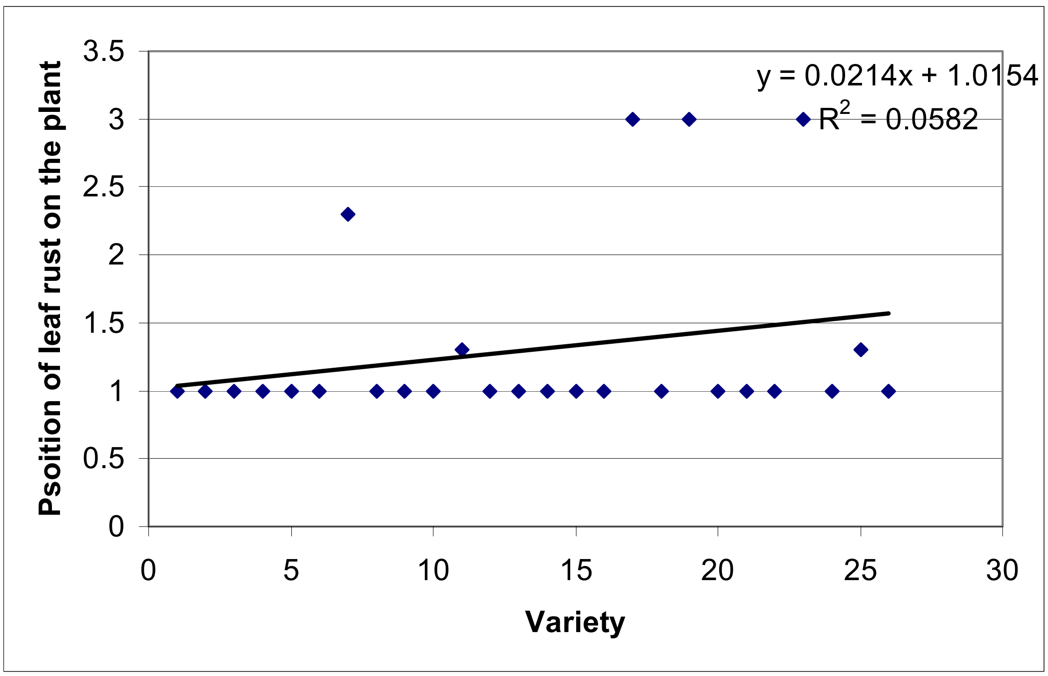

Figure 4.6 Relationship between tolerant or resistant varieties and position of leaf rust on the plant

Figure 4.6 The effect of visual scores on tolerant or resistant varieties (in view of density of rust lesions on the leaf).

The relationship between tolerant or resistant varieties and density of rust lesions is presented (Figure 4.7) and no relationship was again found.

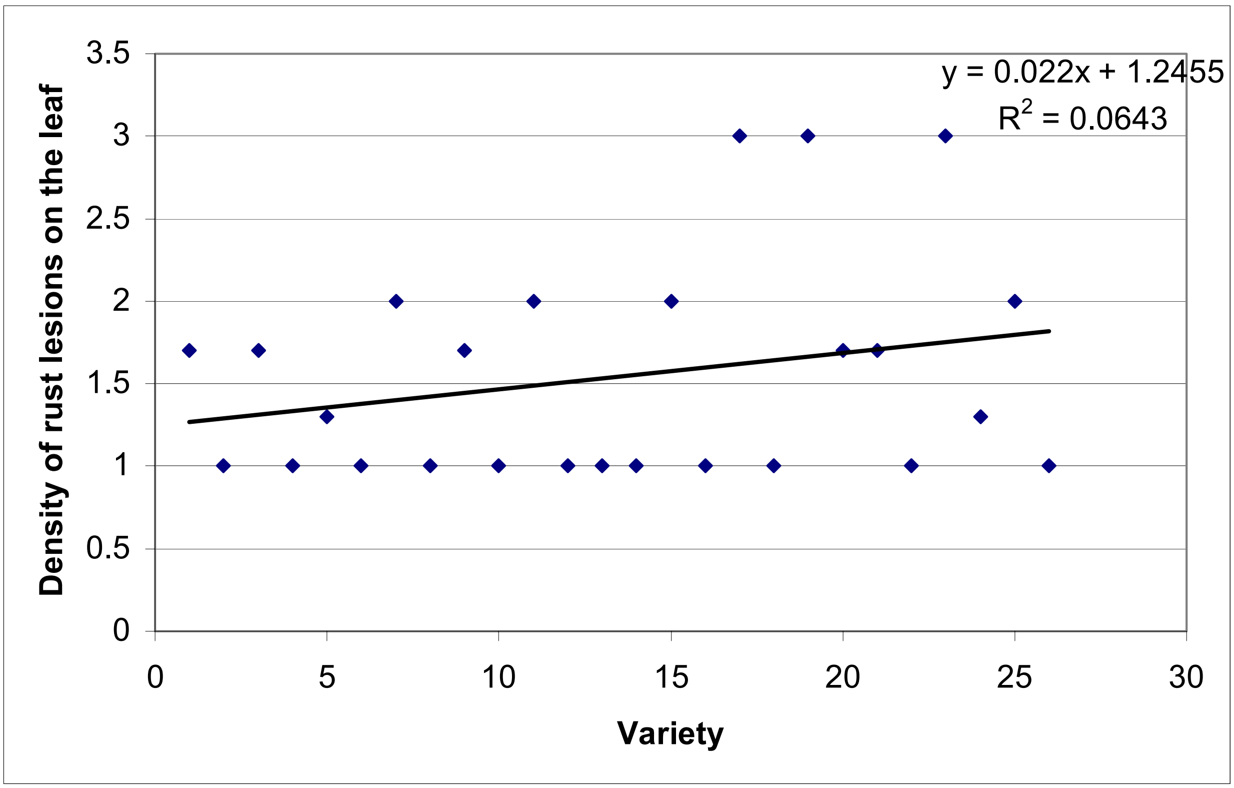

Figure 4.7 Relationship between tolerant or resistant varieties and density of rust lesions

Figure 4.8 Relationship between plant height and seed yield

The relationship between seed yield and plant height is presented (Figure 4.8) to which a linear equation was fitted to the data. The linear equation was not significantly correlated (R^2=0.0198).

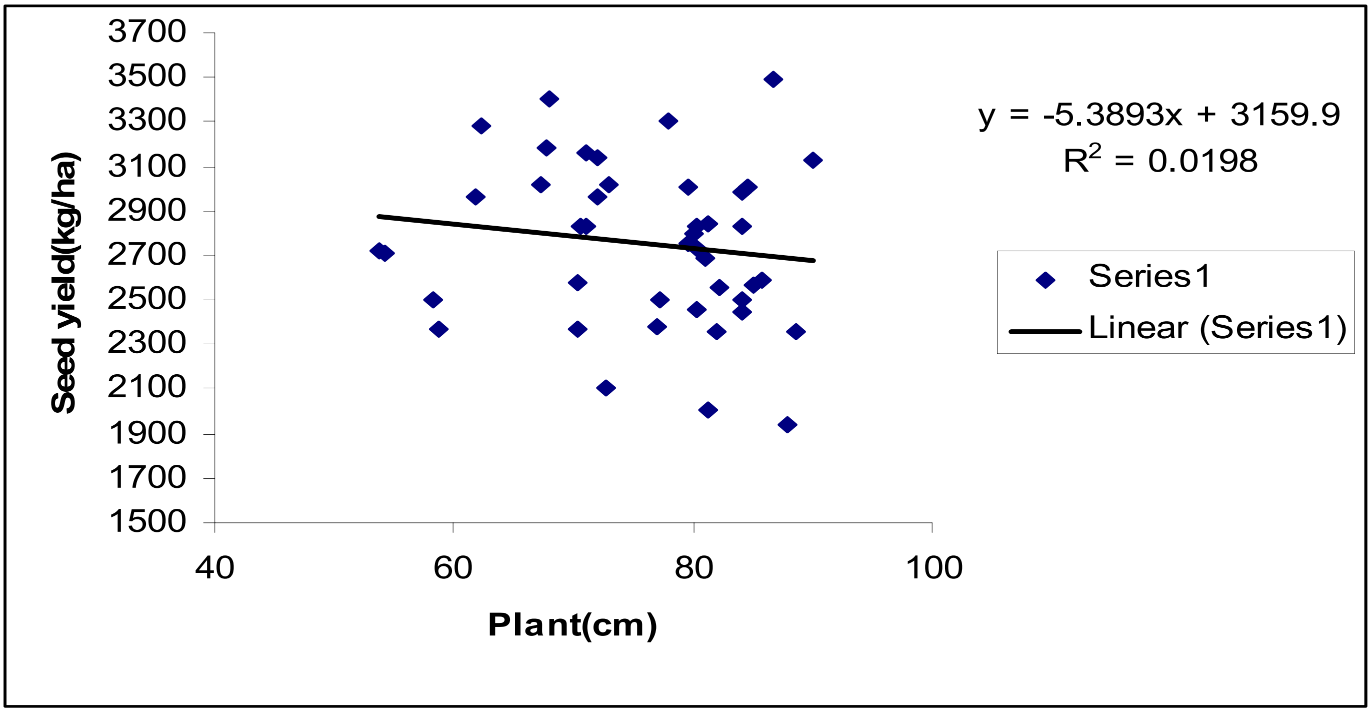

Figure 4.8 Relationship between plant height and seed yield

CHAPTER 5

DISCUSSION

The season was characterised by outbreaks of severe soyabean rust. This presented a good opportunity to identify varieties that are resistant or tolerant and susceptible to soyabean rust**.**

The most notable observation during the study period was that fungicide application yielded significant differences ($P<0.05$) on the measured variables. Significant differences were found on pod height, plant height, green stems at maturity, seed appearance scores, percentage purple stained seed, mass of 100 seeds in grams, bacterial blight scores downy mildew scores, red leaf blotch scores, position leaf rust on the plant, density of rust lesions on the plant, number of days from 50 % flowering, number of days from planting to 95 % pod maturity, percentage crude oil content in the seed on a dry matter, percentage crude protein content in the seed on a dry matter basis and seed yield in kilograms per hectare. In addition, the interaction of varieties and fungicide were significant on all the measured attributes except pod heights, red leaf blotch, crude protein and oil content.

5.1 Agronomic performance of the varieties

5.1.1 Pod clearance scores

All the varieties had a pod clearance between 15 and 20 centimetres (Appendix 1). In general, pod height is an attribute which is important for combine harvesting and combines are set in such a way that they start to cut at 10 centimetres above the ground and in this case all the varieties are suitable for combine harvesting. If varieties have pods that touch the ground and if they happen to mature when the rains have not stopped falling off then losses could be experienced due to rotting of such pods.

5.1.2 Green stem scores at shattering date

The results showed that some lines that were sprayed retained green stems at maturity for example, SC Serenade, S726/6/9 relative to the plots, which were not sprayed. This is probably attributed to the effect of the chemical on some of these varieties. Ideally, farmers would want varieties that have dry stems at maturity or shattering date because if a variety is green at maturity the implication is that if a combine harvester is used moisture released from a green stem may get into contact with the soil and that would stain the seed. Hand harvesting is also difficult when dealing with green stems.

5.1.3 Reaction of the varieties to diseases. (purple seed stain, bacterial blight scores, downy mildew, red leaf blotch scores and soyabean rust).

Most of the varieties had low ratings for purple seed stain and the general appearance for the varieties was a score of 3, which denotes an appeal score that is moderate. In terms of diseases, low scores were obtained for downy mildew, bacterial blight and red leaf blotch. Some of the varieties such as S731/6/57, S722/6/28 S727/6/25, S708/6/15, S726/6/8, S726/6/9 and S723/6/8 gave an immune reaction to red leaf blotch. In addition, S727/6/60 and S722/6/28 also gave an immune reaction to downy mildew. Such material is good where these diseases are a threat to soyabean production. With regards to soyabean rust, the two standard varieties, i.e., SC Solitaire and SC Serenade were all susceptible. However, SC 748/6/96 gave an immune reaction, in other words it was found to be resistant. Varieties S726/6/9, S708/6/15, S726/6/8 and S723/6/3 were all susceptible as they gave scores of 3:3, i.e., the disease was observed at the upper third of the leaves on the plant measured from the ground level with heavy lesions.

5.1.4 Number of days from planting to 95 % pod maturity

On average most of the varieties took about 48 days from planting to 50 % flowering. Some of the varieties were earlier than SC Serenade in terms of flowering. As far as maturity is concerned, some varieties in non-sprayed plots matured earlier than the sprayed plots, for example, SC serenade reached maturity in 120 days under non-sprayed conditions relative to 126 days under sprayed conditions. S723/6/8 reached maturity in 118 days under unsprayed conditions versus 122 days under sprayed conditions. These variances were attributed to stress emanating from soyabean rust.

5.1.5 Percentages crude protein content and crude oil content

The values for crude protein content were quite high whereas the values for oil content were lower. In general, crude protein content is formed first before oil content and for susceptible varieties such as S726/6/8 the oil content is lower. Therefore crude protein content increases and crude oil content decreases in a susceptible variety if rust is controlled.

5.2 Reaction of seed mass to fungicide application

With respect to the reaction of seed mass to fungicide, 11 varieties (Figure 4.5) have been identified as resistant. These varieties are S731/6/57, S722/6/28, SS727/6/20, S744/6/17, S717/6/17, SS727/6/41, S748/6/96, S744/6/29, S727/6/55, S727/6/33, S726/6/9, and S727/6/60. According to Tichagwa, 2004 a cut off point of 10 % is reasonable in view of loss of seed mass. This means that if a variety loses its seed mass by 10 % reduction or less of its potential weight under the pressure of soyabean rust, then it resistant or tolerant. Seed mass of a variety is more consistent than any other attribute (Tichagwa, 2004) for example, seed yield represents the yield recovered from a given harvest, some of the yield could be lost through shattering, combining losses, etc. Therefore, seed mass is an indicator of resistance or susceptibility to soyabean rust. On the basis of seed mass, all the standard varieties were found to be susceptible to soyabean rust (Table 4.3 and Figure 4.1), with SC Serenade responding to fungicide application by 38.3 %. A comparison of the seed mass of tolerant or resistant varieties under infested and non-infested conditions (Figure 4.1) confirmed that there were no marked differences. It is interesting to note that some of the varieties gave negative responses where rust was not controlled namely, S722/6/28 (-6.6 %) and S727/6/5 (-1.3 %). This could be a result of phyto-toxicity emanating from the effect of the chemical. This probably means that certain varieties are sensitive to certain chemicals.

5.3 Seed yield in kilograms per hectare at 11% moisture

Some of the new lines performed better than the controls. The mean yield was 2 751 kg per hectare (Table 4.4). The controls gave higher responses to fungicide application (SC solitaire 43.8 % and SC Serenede 50.4 %, Table 4.4). This therefore, means that in areas where soyabean rust is prevalent susceptible varieties can only be produced viably through the use of chemicals. Considering a cut off point of 10 % eight varieties have been identified as resistant to soyabean rust. These are S731/6/57 (3.9 %), S722/6/28 (-1.8 %), S748/6/21 (5.7 %), S740/6/68 (0.4 %), S744/6/17 (5.6 %), S727/6/41 (9.9 %), S748/6/96 (4.6 %) and S727/6/5 (-3.5 %). From Figure 4.2 a comparison between the grain yield of tolerant /resistant varieties under infested and non-infested conditions displayed no significant differences The point to note here is that with a cut off point of 10 % it means that if a variety losses its yield potential by 10 % or less under the pressure of a disease then its considered resistant. This was also confirmed with visual scores for position of leaf rust on the plant and density of rust lesions on the leaf whose ratings were also lower. The study showed existence of high variability for soyabean rust resistance and yield in the evaluated germplasm. Breeders can effectively utilise the genes from this germplasm and enhance the resistance and yield in regionally adapted germplasm. Therefore, breeders should not look beyond the region in search of resistant germplasm that lack adaptation. These results are quite exciting because the breeders are making significant progress in breeding for resistance since 1997/98 season when the disease was first recorded in Zimbabwe. The challenge that remains is to improve seed yield as some of resistant material are yielding lower than the overall mean. The following varieties exhibited high yield potential relative to the mean (2 751 kg/ha): S744/6/17 (relative yield = 110% of overall mean yield) S727/6/41 (relative yield = 114% of overall mean yield) and S748/6/96 (relative yield = 103%). These varieties, which showed high yield potential (≥ 100% relative yield) and high level of resistance can be used as donors of resistance in the soyabean breeding programme. Farmers on the other hand should exploit these varieties once they have been commercialised, as they would reduce the cost of producing the crop

5.4 Correlation between seed mass and seed yield of tolerant or resistant varieties under infested and non-infested conditions

From Figure 4.5, there were no significant correlations (R^2 = 0.0531) between seed mass and grain yield on varieties that were evaluated. This means that the genes that tend to enhance 100-grain weight do not increase grain yield per plant. However, Bowen (1983) evaluated 100-gram seed mass and found a positive correlation (R^2 = .075) between the two variables.

5.5 Correlation between grain yield and plant height

The correlation between grain yield and plant height was not significant (R^2 = 0.0198). Regression analyses indicated that as plant height increased, grain yield was decreasing (Figure 4.8). Results confirmed previous study by Bowen (1983) who reported lack of correlation between the two variables (R^2 = 0.0150).

5.6 Comparison of selected tolerant or resistant varieties under infested and non-infested conditions in view visual scores

Most of the varieties gave lower ratings for leaf rust position on the plant and density of rust lesions on the plant leaves relative to the protected varieties. Controls had higher ratings for both indicating that they are susceptible to soyabean rust. S740/6/68 and S726/6/8 had higher ratings for both traits yet they the percentages changes in seed mass and seed yield are lower, this suggests that they are tolerant to soyabean rust.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

CONCLUSION

a) The study revealed that variation existed between the varieties in their reaction to soyabean rust. Some varieties showed higher levels of resistance (e.g S722/6/28 and S744/6/29, Table 4.3 where an immune reaction was obtained) and others were susceptible (e.g SC solitaire and SC Serenede).

b) Thirteen varieties were identified as resistant or tolerant to soyabean rust (S731/6/57, S722/6/28, SS727/6/20, S744/6/17, S717/6/17, SS727/6/41, S748/6/96, S744/6/29, S727/6/55, S727/6/33, S726/6/9, and S727/6/60). Thus breeding for rust resistance is quite feasible. Many varieties exhibited high levels of resistance to soyabean rust presenting an opportunity to select. The new lines/varieties showed significantly high levels of resistance to rust relative to the standard varieties. This is quite a good progress in terms of genetic gains or improvements.

c) Grain yield losses emanating from soyabean rust varied from variety to variety (ranged from -3,5 % to 50,4 %). Some new lines did not lose their yields in the presence of soyabean rust.

d) Seed mass, visual scores and seed yield have been found to be indicators of soyabean rust resistance and or susceptibility. However, seed mass is regarded as the best indicator because the seed mass of a resistant variety does not change much in the presence of soyabean rust even if the disease is not controlled.

RECOMMENDATIONS

1. The varieties, which have been identified as resistant, can be advanced for further testing.

2. In addition, these varieties (S722/6/28, SS727/6/20, S744/6/17, S717/6/17, SS727/6/41, S748/6/96, S744/6/29, S727/6/55, S727/6/33, S726/6/9, and S727/6/60) can be used as sources of resistance. To that effect, they can also be used for making crosses hence, generating segregating populations upon which genotypes with resistance or tolerance can identified and selected and advanced for further testing.

3. Furthermore, I recommend that these varieties (S722/6/28, SS727/6/20, S744/6/17, S717/6/17, SS727/6/41, S748/6/96, S744/6/29, S727/6/55, S727/6/33, S726/6/9, and S727/6/60) should be sent for fingerprinting so as to give protection to breeders in view of Intellectual Property Rights (IPR). This means that anybody found with any of the above material can face the wrath of law.

4. Moreover, molecular markers that are tightly linked to gene(s) responsible for soyabean resistance should be identified and mapped and this will pave way for marker- assisted selection.

5. Visual scores, seed yield and seed mass should be used as traits for prediction of rust resistance/susceptibility. However, seed mass is the best trait in terms of prediction of rust resistance or susceptibility.

6. I also recommend that genetic studies should be done to characterise the resistance.

Implications of the study to breeding

The study identified adequate variation for soyabean rust resistance with respect to levels of resistance even though genetic analysis was not done. This suggests that the material with high levels of resistance can be used for breeding purposes.

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APPENDICES

Appendix 1 Pod heights in centimeters

Variety	Fungicide Applied	Rust Position scores	Rust Density	Pod height
S731/6/57	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S722/6/28	1	1.0	1.7	3.3
	2	1.0	1.0	3.3
S748/6/21	1	1.0	1.3	2.7
	2	1.0	1.0	2.7
S727/6/20	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S740/6/68	1	2.3	2.0	2.3
	2	1.0	1.0	2.7
S723/6/3	1	3.0	3.0	3.0
	2	1.0	1.0	3.0
S744/6/17	1	1.0	1.7	2.7
	2	1.0	1.0	2.7
S717/6/17	1	1.0	2.0	3.0
	2	1.0	1.0	3.0
S727/6/41	1	1.3	2.0	3.0
	2	1.0	1.0	3.0
S748/6/96	1	1.0	1.0	3.0
	2	1.0	1.0	3.0
S744/6/29	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S727/6/55	1	1.0	2.0	3.3
	2	1.0	1.0	3.3
SOLITAIRE	1	3.0	3.0	2.7
	2	1.0	1.0	2.7
S708/6/15	1	3.0	3.0	3.0
	2	1.0	1.3	3.3
S727/6/25	1	1.0	2.0	3.3
	2	1.0	1.0	3.3
S726/6/8	1	3.0	3.0	3.3
	2	1.0	1.7	3.3
S727/6/33	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
SERENADE	1	3.0	3.0	2.3
	2	1.0	1.3	2.3
S727/6/5	1	1.3	2.0	3.0
	2	1.0	1.0	3.0
S726/6/9	1	3.0	3.0	4.0
	2	1.0	1.0	4.0
S723/6/8	1	3.0	2.0	3.3
	2	1.0	1.0	3.3
S727/6/60	1	1.7	2.0	3.0
	2	1.3	1.7	3.0
Variety Means		1.4	1.6	3.0
S.E(mean)		0.13	0.24	0.71
F test		***	***	***
L.S.D		0. 4	0.7	0.2
C.V		16.6	26.1	4.1

Appendix 2 Plant heights in centimeters

Variety	Fungicide Applied	Rust Position scores	Rust Density	Plant height
S731/6/57	1	1.0	1.7	80.3
	2	1.0	1.0	81.3
S722/6/28	1	1.0	1.7	80.0
	2	1.0	1.0	79.6
S748/6/21	1	1.0	1.3	58.7
	2	1.0	1.0	58.3
S727/6/20	1	1.0	1.7	81.0
	2	1.0	1.0	79.7
S740/6/68	1	2.3	2.0	54.3
	2	1.0	1.0	53.7
S723/6/3	1	3.0	3.0	70.3
	2	1.0	1.0	73.0
S744/6/17	1	1.0	1.7	67.3
	2	1.0	1.0	67.8
S717/6/17	1	1.0	2.0	85.0
	2	1.0	1.0	84.0
S727/6/41	1	1.3	2.0	72.0
	2	1.0	1.0	70.7
S748/6/96	1	1.0	1.0	71.0
	2	1.0	1.0	72.0
S744/6/29	1	1.0	1.7	61.7
	2	1.0	1.0	62.3
S727/6/55	1	1.0	2.0	84.0
	2	1.0	1.0	84.0
SOLITAIRE	1	3.0	3.0	70.3
	2	1.0	1.0	68.0
S708/6/15	1	3.0	3.0	82.0
	2	1.0	1.3	80.3
S727/6/25	1	1.0	2.0	84.7
	2	1.0	1.0	86.7
S726/6/8	1	3.0	3.0	88.0
	2	1.0	1.7	85.7
S727/6/33	1	1.0	1.7	77.3
	2	1.0	1.0	78.0
SERENADE	1	3.0	3.0	72.7
	2	1.0	1.3	71.0
S727/6/5	1	1.3	2.0	80.3
	2	1.0	1.0	77.0
S726/6/9	1	3.0	3.0	81.3
	2	1.0	1.0	84.0
S723/6/8	1	3.0	2.0	88.7
	2	1.0	1.0	90.0
S727/6/60	1	1.7	2.0	82.3
S727/6/60	2	1.3	1.7	81.3
Variety Means		1.4	1.6	75.9
S.E(mean)		0.13	0.24	0.77
F test		***	***	***
L.S.D		0. 4	0.7	2.1
C.V		16.6	26.1	1.8

Appendix 3 Green stem scores at maturity

Variety	Fungicide Applied	Rust Position scores	Rust Density	Green stem score
S731/6/57	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S722/6/28	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S748/6/21	1	1.0	1.3	1.0
	2	1.0	1.0	1.0
S727/6/20	1	1.0	1.7	1.0
	2	1.0	1.0	1.0
S740/6/68	1	2.3	2.0	0.7
	2	1.0	1.0	0.7
S723/6/3	1	3.0	3.0	0.3
	2	1.0	1.0	1.0
S744/6/17	1	1.0	1.7	1.3
	2	1.0	1.0	1.3
S717/6/17	1	1.0	2.0	2.0
	2	1.0	1.0	2.0
S727/6/41	1	1.3	2.0	2.0
	2	1.0	1.0	2.0
S748/6/96	1	1.0	1.0	1.0
	2	1.0	1.0	1.0
S744/6/29	1	1.0	1.7	0.3
	2	1.0	1.0	0.3
S727/6/55	1	1.0	2.0	2.0
	2	1.0	1.0	2.0
SOLITAIRE	1	3.0	3.0	0.0
	2	1.0	1.0	0.3
S708/6/15	1	3.0	3.0	2.0
	2	1.0	1.3	2.0
S727/6/25	1	1.0	2.0	2.0
	2	1.0	1.0	2.0
S726/6/8	1	3.0	3.0	1.0
	2	1.0	1.7	1.0
S727/6/33	1	1.0	1.7	1.3
	2	1.0	1.0	1.7
SERENADE	1	3.0	3.0	0.0
	2	1.0	1.3	2.0
S727/6/5	1	1.3	2.0	2.0
	2	1.0	1.0	2.0
S726/6/9	1	3.0	3.0	0.0
	2	1.0	1.0	1.3
S723/6/8	1	3.0	2.0	1.0
	2	1.0	1.0	1.3
S727/6/60	1	1.7	2.0	2.0
	2	1.3	1.7	2.0
Variety Means		1.4	1.6	1.3
S.E(mean)		0.13	0.24	0.14
F test		***	***	***
L.S.D		0. 4	0.7	0.4
C.V		16.6	26.1	18. 4

Appendix 4 Seed appearance scores

Variety	Fungicide Applied	Rust Position scores	Rust Density	Seed Appearance scores
S731/6/57	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S722/6/28	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S748/6/21	1	1.0	1.3	3.0
	2	1.0	1.0	3.0
S727/6/20	1	1.0	1.7	2.7
	2	1.0	1.0	2.7
S740/6/68	1	2.3	2.0	3.0
	2	1.0	1.0	3.0
S723/6/3	1	3.0	3.0	3.0
	2	1.0	1.0	3.0
S744/6/17	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S717/6/17	1	1.0	2.0	3.0
	2	1.0	1.0	3.0
S727/6/41	1	1.3	2.0	3.0
	2	1.0	1.0	3.0
S748/6/96	1	1.0	1.0	3.0
	2	1.0	1.0	3.0
S744/6/29	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S727/6/55	1	1.0	2.0	3.0
	2	1.0	1.0	3.0
SOLITAIRE	1	3.0	3.0	3.0
	2	1.0	1.0	3.0
S708/6/15	1	3.0	3.0	3.0
	2	1.0	1.3	3.0
S727/6/25	1	1.0	2.0	3.0
	2	1.0	1.0	3.0
S726/6/8	1	3.0	3.0	2.3
	2	1.0	1.7	2.3
S727/6/33	1	1.0	1.7	1.0
	2	1.0	1.0	1.0
SERENADE	1	3.0	3.0	3.0
	2	1.0	1.3	3.0
S727/6/5	1	1.3	2.0	3.0
	2	1.0	1.0	3.0
S726/6/9	1	3.0	3.0	2.3
	2	1.0	1.0	2.3
S723/6/8	1	3.0	2.0	3.0
	2	1.0	1.0	3.0
S727/6/60	1	1.7	2.0	3.0
	2	1.3	1.7	3.0
Variety Means		1.4	1.6	2.8
S.E(mean)		0.13	0.24	0.27
F test		***	***	***
L.S.D		0. 4	0.7	0.8
C.V		16.6	26.1	0.0

Appendix 5 Pod heights in centimeters

Variety	Fungicide Applied	Rust Position scores	Rust Density	Percentage Purple stained seed
S731/6/57	1	1.0	1.7	0.5
	2	1.0	1.0	0.7
S722/6/28	1	1.0	1.7	1.1
	2	1.0	1.0	0.2
S748/6/21	1	1.0	1.3	0.1
	2	1.0	1.0	0.0
S727/6/20	1	1.0	1.7	3.5
	2	1.0	1.0	1.4
S740/6/68	1	2.3	2.0	0.2
	2	1.0	1.0	0.3
S723/6/3	1	3.0	3.0	0.7
	2	1.0	1.0	0.7
S744/6/17	1	1.0	1.7	0.2
	2	1.0	1.0	0.0
S717/6/17	1	1.0	2.0	0.5
	2	1.0	1.0	0.0
S727/6/41	1	1.3	2.0	0.6
	2	1.0	1.0	1.2
S748/6/96	1	1.0	1.0	0.2
	2	1.0	1.0	0.1
S744/6/29	1	1.0	1.7	0.0
	2	1.0	1.0	0.0
S727/6/55	1	1.0	2.0	5.7
	2	1.0	1.0	1.7
SOLITAIRE	1	3.0	3.0	0.2
	2	1.0	1.0	0.2
S708/6/15	1	3.0	3.0	0.3
	2	1.0	1.3	0.0
S727/6/25	1	1.0	2.0	0.3
	2	1.0	1.0	0.4
S726/6/8	1	3.0	3.0	0.3
	2	1.0	1.7	0.0
S727/6/33	1	1.0	1.7	10.7
	2	1.0	1.0	2.2
SERENADE	1	3.0	3.0	0.1
	2	1.0	1.3	0.2
S727/6/5	1	1.3	2.0	2.3
	2	1.0	1.0	0.5
S726/6/9	1	3.0	3.0	0.6
	2	1.0	1.0	0.2
S723/6/8	1	3.0	2.0	1.0
	2	1.0	1.0	0.3
S727/6/60	1	1.7	2.0	0.4
	2	1.3	1.7	0.1
Variety Means		1.4	1.6	3.0
S.E(mean)		0.13	0.24	0.71
F test		***	***	***
L.S.D		0. 4	0.7	0.2
C.V		16.6	26.1	4.1

Appendix 6 Seed mass in grams

Variety	Fungicide applied	Rust Position scores	Rust Density	Mass of seed for a 100g sample	% change in seed mass
S731/6/57	1	1.0	1.7	24.1	
	2	1.0	1.0	25.8	7.1
S722/6/28	1	1.0	1.7	25.8	
	2	1.0	1.0	25.8	0
S748/6/21	1	1.0	1.3	22.7	
	2	1.0	1.0	26.8	18.1
S727/6/20	1	1.0	1.7	24.1	
	2	1.0	1.0	22.5	-6.6
S740/6/68	1	2.3	2.0	21.4	
	2	1.0	1.0	24.4	14.0
S723/6/3	1	3.0	3.0	21.3	
	2	1.0	1.0	24.3	14.1
S744/6/17	1	1.0	1.7	24.4	
	2	1.0	1.0	25.9	6.1
S717/6/17	1	1.0	2.0	22.2	
	2	1.0	1.0	23.6	6.3
S727/6/41	1	1.3	2.0	23.8	
	2	1.0	1.0	23.5	-1.3
S748/6/96	1	1.0	1.0	21.0	
	2	1.0	1.0	23	1.0
S744/6/29	1	1.0	1.7	18.6	
	2	1.0	1.0	18.6	0
S727/6/55	1	1.0	2.0	27.7	
	2	1.0	1.0	27.6	-0.4
SOLITAIRE	1	3.0	3.0	19.7	
	2	1.0	1.0	23.8	15.6
S708/6/15	1	3.0	3.0	19.0	
	2	1.0	1.3	23.2	22.1
S727/6/25	1	1.0	2.0	27.8	
	2	1.0	1.0	30.8	11
S726/6/8	1	3.0	3.0	23.5	
	2	1.0	1.7	26.5	12.8
S727/6/33	1	1.0	1.7	26.7	
	2	1.0	1.0	26.8	0.4
SERENADE	1	3.0	3.0	23.0	
	2	1.0	1.3	31.8	38.3
S727/6/5	1	1.3	2.0	24.7	
	2	1.0	1.0	25.7	4.0
S726/6/9	1	3.0	3.0	22.0	
	2	1.0	1.0	26.4	0.2
S723/6/8	1	3.0	2.0	18.6	
	2	1.0	1.0	21.4	15;1
S727/6/60	1	1.7	2.0	28.4	
	2	1.3	1.7	28.9	1.8
Variety Means		1.4	1.6	24.2	
S.E(Mean)		0.13	0.24	0.8	
F.test		***	***	***	
L.S.D		0.4	0.7	2.5	
C.V		16.6	26.1		

Appendix 7 Bacterial blight scores

Variety	Fungicide Applied	Rust Position scores	Rust Density	Bacterial blight scores
S731/6/57	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S722/6/28	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S748/6/21	1	1.0	1.3	2.0
	2	1.0	1.0	2.0
S727/6/20	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S740/6/68	1	2.3	2.0	2.0
	2	1.0	1.0	2.7
S723/6/3	1	3.0	3.0	2.7
	2	1.0	1.0	2.0
S744/6/17	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S717/6/17	1	1.0	2.0	2.0
	2	1.0	1.0	2.0
S727/6/41	1	1.3	2.0	2.0
	2	1.0	1.0	2.0
S748/6/96	1	1.0	1.0	2.0
	2	1.0	1.0	2.0
S744/6/29	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S727/6/55	1	1.0	2.0	2.0
	2	1.0	1.0	2.7
SOLITAIRE	1	3.0	3.0	2.7
	2	1.0	1.0	2.0
S708/6/15	1	3.0	3.0	2.0
	2	1.0	1.3	2.0
S727/6/25	1	1.0	2.0	2.0
	2	1.0	1.0	2.0
S726/6/8	1	3.0	3.0	2.3
	2	1.0	1.7	2.3
S727/6/33	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
SERENADE	1	3.0	3.0	2.3
	2	1.0	1.3	2.3
S727/6/5	1	1.3	2.0	2.0
	2	1.0	1.0	2.0
S726/6/9	1	3.0	3.0	2.0
	2	1.0	1.0	2.0
S723/6/8	1	3.0	2.0	2.0
	2	1.0	1.0	2.0
S727/6/60	1	1.7	2.0	2.3
	2	1.3	1.7	2.3
Variety Means		1.4	1.6	2.1
S.E(mean)		0.13	0.24	0.93
F test		***	***	*
L.S.D		0. 4	0.7	0.3
C.V		16.6	26.1	0.0

Appendix 8 Downy mildew scores

Variety	Fungicide Applied	Rust Position scores	Rust Density	Downy mildew scores
S731/6/57	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S722/6/28	1	1.0	1.7	1.0
	2	1.0	1.0	1.0
S748/6/21	1	1.0	1.3	2.0
	2	1.0	1.0	2.0
S727/6/20	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S740/6/68	1	2.3	2.0	1.3
	2	1.0	1.0	1.3
S723/6/3	1	3.0	3.0	3.0
	2	1.0	1.0	3.0
S744/6/17	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S717/6/17	1	1.0	2.0	1.3
	2	1.0	1.0	1.3
S727/6/41	1	1.3	2.0	2.0
	2	1.0	1.0	2.0
S748/6/96	1	1.0	1.0	3.0
	2	1.0	1.0	3.0
S744/6/29	1	1.0	1.7	3.0
	2	1.0	1.0	3.0
S727/6/55	1	1.0	2.0	1.7
	2	1.0	1.0	1.7
SOLITAIRE	1	3.0	3.0	2.0
	2	1.0	1.0	2.0
S708/6/15	1	3.0	3.0	1.3
	2	1.0	1.3	1.3
S727/6/25	1	1.0	2.0	1.0
	2	1.0	1.0	1.0
S726/6/8	1	3.0	3.0	2.0
	2	1.0	1.7	2.0
S727/6/33	1	1.0	1.7	1.3
	2	1.0	1.0	1.3
SERENADE	1	3.0	3.0	1.3
	2	1.0	1.3	1.3
S727/6/5	1	1.3	2.0	1.7
	2	1.0	1.0	1.7
S726/6/9	1	3.0	3.0	1.7
	2	1.0	1.0	1.7
S723/6/8	1	3.0	2.0	1.3
	2	1.0	1.0	1.3
S727/6/60	1	1.7	2.0	1.0
	2	1.3	1.7	1.0
Variety Means		1.4	1.6	1.8
S.E(mean)		0.13	0.24	0.67
F test		***	***	***
L.S.D		0. 4	0.7	0.1
C.V		16.6	26.1	0.0

Appendix 9. Red leaf blotch scores.

Variety	Fungicide Applied	Rust Position scores	Rust Density	Red leaf blotch scores
S731/6/57	1	1.0	1.7	1.0
	2	1.0	1.0	1.0
S722/6/28	1	1.0	1.7	1.7
	2	1.0	1.0	1.7
S748/6/21	1	1.0	1.3	1.7
	2	1.0	1.0	1.7
S727/6/20	1	1.0	1.7	1.7
	2	1.0	1.0	1.7
S740/6/68	1	2.3	2.0	2.0
	2	1.0	1.0	2.0
S723/6/3	1	3.0	3.0	1.7
	2	1.0	1.0	1.7
S744/6/17	1	1.0	1.7	2.3
	2	1.0	1.0	2.3
S717/6/17	1	1.0	2.0	1.3
	2	1.0	1.0	1.3
S727/6/41	1	1.3	2.0	2.3
	2	1.0	1.0	2.3
S748/6/96	1	1.0	1.0	2.0
	2	1.0	1.0	2.0
S744/6/29	1	1.0	1.7	2.0
	2	1.0	1.0	2.0
S727/6/55	1	1.0	2.0	1.7
	2	1.0	1.0	1.7
SOLITAIRE	1	3.0	3.0	1.7
	2	1.0	1.0	1.7
S708/6/15	1	3.0	3.0	1.0
	2	1.0	1.3	1.0
S727/6/25	1	1.0	2.0	1.0
	2	1.0	1.0	1.0
S726/6/8	1	3.0	3.0	1.0
	2	1.0	1.7	1.0
S727/6/33	1	1.0	1.7	1.3
	2	1.0	1.0	1.3
SERENADE	1	3.0	3.0	1.3
	2	1.0	1.3	1.3
S727/6/5	1	1.3	2.0	1.3
	2	1.0	1.0	1.3
S726/6/9	1	3.0	3.0	1.0
	2	1.0	1.0	1.0
S723/6/8	1	3.0	2.0	1.0
	2	1.0	1.0	1.0
S727/6/60	1	1.7	2.0	2.0
	2	1.3	1.7	2.0
Variety Means		1.4	1.6	1.5
S.E(mean)		0.13	0.24	0.0
F test		***	***	**
L.S.D		0. 4	0.7	0.0
C.V		16.6	26.1	0.0

Appendix 10. Number of days from planting to 50% flowering

Variety	Fungicide Applied	Rust Position scores	Rust Density	Days from planting to 50% flowering
S731/6/57	1	1.0	1.7	46.0
	2	1.0	1.0	46.0
S722/6/28	1	1.0	1.7	48.7
	2	1.0	1.0	48.7
S748/6/21	1	1.0	1.3	52.0
	2	1.0	1.0	52.0
S727/6/20	1	1.0	1.7	46.0
	2	1.0	1.0	46.0
S740/6/68	1	2.3	2.0	46.0
	2	1.0	1.0	46.0
S723/6/3	1	3.0	3.0	48.7
	2	1.0	1.0	48.7
S744/6/17	1	1.0	1.7	52.0
	2	1.0	1.0	52.0
S717/6/17	1	1.0	2.0	45.7
	2	1.0	1.0	45.7
S727/6/41	1	1.3	2.0	45.3
	2	1.0	1.0	45.3
S748/6/96	1	1.0	1.0	50.0
	2	1.0	1.0	50.0
S744/6/29	1	1.0	1.7	50.0
	2	1.0	1.0	50.0
S727/6/55	1	1.0	2.0	49.3
	2	1.0	1.0	49.3
SOLITAIRE	1	3.0	3.0	46.0
	2	1.0	1.0	46.0
S708/6/15	1	3.0	3.0	45.0
	2	1.0	1.3	45.0
S727/6/25	1	1.0	2.0	48.7
	2	1.0	1.0	48.7
S726/6/8	1	3.0	3.0	50.0
	2	1.0	1.7	50.0
S727/6/33	1	1.0	1.7	46.0
	2	1.0	1.0	46.0
SERENADE	1	3.0	3.0	48.7
	2	1.0	1.3	48.7
S727/6/5	1	1.3	2.0	47.3
	2	1.0	1.0	47.3
S726/6/9	1	3.0	3.0	50.0
	2	1.0	1.0	50.0
S723/6/8	1	3.0	2.0	50.0
	2	1.0	1.0	50.0
S727/6/60	1	1.7	2.0	46.0
	2	1.3	1.7	46.0
Variety Means		1.4	1.6	48.1
S.E(mean)		0.13	0.24	0.71
F test		***	***	***
L.S.D		0. 4	0.7	0.2
C.V		16.6	26.1	0.0

Appendix 11. Number of days from planting to 95% pod maturity

Variety	Fungicide Applied	Rust Position scores	Rust Density	Days to 95% pod maturity
S731/6/57	1	1.0	1.7	114
	2	1.0	1.0	115
S722/6/28	1	1.0	1.7	117
	2	1.0	1.0	119
S748/6/21	1	1.0	1.3	115
	2	1.0	1.0	115
S727/6/20	1	1.0	1.7	114
	2	1.0	1.0	114
S740/6/68	1	2.3	2.0	115
	2	1.0	1.0	115
S723/6/3	1	3.0	3.0	114
	2	1.0	1.0	115
S744/6/17	1	1.0	1.7	119
	2	1.0	1.0	121
S717/6/17	1	1.0	2.0	115
	2	1.0	1.0	116
S727/6/41	1	1.3	2.0	113
	2	1.0	1.0	113
S748/6/96	1	1.0	1.0	117
	2	1.0	1.0	119
S744/6/29	1	1.0	1.7	115
	2	1.0	1.0	115
S727/6/55	1	1.0	2.0	123
	2	1.0	1.0	127
SOLITAIRE	1	3.0	3.0	115
	2	1.0	1.0	115
S708/6/15	1	3.0	3.0	115
	2	1.0	1.3	115
S727/6/25	1	1.0	2.0	123
	2	1.0	1.0	127
S726/6/8	1	3.0	3.0	122
	2	1.0	1.7	126
S727/6/33	1	1.0	1.7	115
	2	1.0	1.0	115
SERENADE	1	3.0	3.0	120
	2	1.0	1.3	126
S727/6/5	1	1.3	2.0	115
	2	1.0	1.0	115
S726/6/9	1	3.0	3.0	118
	2	1.0	1.0	121
S723/6/8	1	3.0	2.0	118
	2	1.0	1.0	122
S727/6/60	1	1.7	2.0	115
	2	1.3	1.7	115
Variety Means		1.4	1.6	118
S.E(mean)		0.13	0.24	0.56
F test		***	***	***
L.S.D		0. 4	0.7	1.6
C.V		16.6	26.1	9.9

Appendix 12. Percentage crude protein in the seed on a dry matter basis

Variety	Fungicide Applied	Rust Position scores	Rust Density	Protein content
S731/6/57	1	1.0	1.7	48.1
	2	1.0	1.0	48.1
S722/6/28	1	1.0	1.7	49.2
	2	1.0	1.0	49.8
S748/6/21	1	1.0	1.3	48.3
	2	1.0	1.0	48.4
S727/6/20	1	1.0	1.7	47.5
	2	1.0	1.0	48.0
S740/6/68	1	2.3	2.0	48.7
	2	1.0	1.0	48.5
S723/6/3	1	3.0	3.0	49.0
	2	1.0	1.0	48.4
S744/6/17	1	1.0	1.7	49.9
	2	1.0	1.0	49.8
S717/6/17	1	1.0	2.0	49.2
	2	1.0	1.0	49.6
S727/6/41	1	1.3	2.0	48.4
	2	1.0	1.0	50.0
S748/6/96	1	1.0	1.0	51.8
	2	1.0	1.0	52.3
S744/6/29	1	1.0	1.7	50.0
	2	1.0	1.0	49.5
S727/6/55	1	1.0	2.0	49.4
	2	1.0	1.0	49.1
SOLITAIRE	1	3.0	3.0	48.2
	2	1.0	1.0	47.7
S708/6/15	1	3.0	3.0	48.3
	2	1.0	1.3	47.1
S727/6/25	1	1.0	2.0	48.8
	2	1.0	1.0	47.5
S726/6/8	1	3.0	3.0	49.9
	2	1.0	1.7	49.0
S727/6/33	1	1.0	1.7	50.4
	2	1.0	1.0	50.1
SERENADE	1	3.0	3.0	48.9
	2	1.0	1.3	48.5
S727/6/5	1	1.3	2.0	48.1
	2	1.0	1.0	49.1
S726/6/9	1	3.0	3.0	49.1
	2	1.0	1.0	48.2
S723/6/8	1	3.0	2.0	50.2
	2	1.0	1.0	48.9
S727/6/60	1	1.7	2.0	50.2
	2	1.3	1.7	49.1
Variety Means		1.4	1.6	49.1
S.E(mean)		0.13	0.24	1.69
F test		***	***	***
L.S.D		0. 4	0.7	0.2
C.V		16.6	26.1	9.9

Appendix 13. Percentage oil content in the seed on a dry matter basis

Variety	Fungicide Applied	Rust Position scores	Rust Density	Crude oil content
S731/6/57	1	1.0	1.7	18.7
	2	1.0	1.0	18.7
S722/6/28	1	1.0	1.7	18.4
	2	1.0	1.0	18.2
S748/6/21	1	1.0	1.3	18.3
	2	1.0	1.0	17.8
S727/6/20	1	1.0	1.7	18.7
	2	1.0	1.0	18.8
S740/6/68	1	2.3	2.0	17.7
	2	1.0	1.0	17.8
S723/6/3	1	3.0	3.0	18.0
	2	1.0	1.0	18.2
S744/6/17	1	1.0	1.7	18.1
	2	1.0	1.0	18.6
S717/6/17	1	1.0	2.0	18.2
	2	1.0	1.0	18.7
S727/6/41	1	1.3	2.0	18.5
	2	1.0	1.0	19.1
S748/6/96	1	1.0	1.0	17.3
	2	1.0	1.0	17.0
S744/6/29	1	1.0	1.7	17.7
	2	1.0	1.0	18.1
S727/6/55	1	1.0	2.0	18.9
	2	1.0	1.0	18.7
SOLITAIRE	1	3.0	3.0	19.1
	2	1.0	1.0	19.8
S708/6/15	1	3.0	3.0	18.5
	2	1.0	1.3	19.1
S727/6/25	1	1.0	2.0	18.4
	2	1.0	1.0	18.5
S726/6/8	1	3.0	3.0	17.5
	2	1.0	1.7	18.0
S727/6/33	1	1.0	1.7	17.8
	2	1.0	1.0	18.2
SERENADE	1	3.0	3.0	18.7
	2	1.0	1.3	19.1
S727/6/5	1	1.3	2.0	19.2
	2	1.0	1.0	18.9
S726/6/9	1	3.0	3.0	18.0
	2	1.0	1.0	18.2
S723/6/8	1	3.0	2.0	17.5
	2	1.0	1.0	18.1
S727/6/60	1	1.7	2.0	18.3
	2	1.3	1.7	19.0
Variety Means		1.4	1.6	18.3
S.E(mean)		0.13	0.24	0.26
F test		***	***	***
L.S.D		0. 4	0.7	0.2
C.V		16.6	26.1	0.7

Appendix 14. Seed yield in kilograms per hectare at 11% moisture

Variety	Fungicide Applied	Rust Position scores	Rust Density	Seed yield Kg/ha	% Yield change
S731/6/57	1	1.0	1.7	2730	
	2	1.0	1.0	2837	3.9
S722/6/28	1	1.0	1.7	2800	
	2	1.0	1.0	2751	-1.8
S748/6/21	1	1.0	1.3	2368	
	2	1.0	1.0	2503	5.7
S727/6/20	1	1.0	1.7	2691	
	2	1.0	1.0	3008	11.8
S740/6/68	1	2.3	2.0	2707	
	2	1.0	1.0	2720	0.4
S723/6/3	1	3.0	3.0	2577	
	2	1.0	1.0	3019	17.2
S744/6/17	1	1.0	1.7	3017	
	2	1.0	1.0	3186	5.6
S717/6/17	1	1.0	2.0	2567	
	2	1.0	1.0	2982	16.2
S727/6/41	1	1.3	2.0	3140	
	2	1.0	1.0	2830	9.9
S748/6/96	1	1.0	1.0	2830	
	2	1.0	1.0	2961	4.6
S744/6/29	1	1.0	1.7	2968	
	2	1.0	1.0	3278	10.4
S727/6/55	1	1.0	2.0	2828	
	2	1.0	1.0	2499	11.7
SOLITAIRE	1	3.0	3.0	2370	
	2	1.0	1.0	3408	43.8
S708/6/15	1	3.0	3.0	2359	
	2	1.0	1.3	2829	19.9
S727/6/25	1	1.0	2.0	3007	
	2	1.0	1.0	3491	16.1
S726/6/8	1	3.0	3.0	1937	
	2	1.0	1.7	2594	33.9
S727/6/33	1	1.0	1.7	2506	
	2	1.0	1.0	3305	31.9
SERENADE	1	3.0	3.0	2101	
	2	1.0	1.3	3160	50.4
S727/6/5	1	1.3	2.0	2455	
	2	1.0	1.0	2376	-3.5
S726/6/9	1	3.0	3.0	2001	
	2	1.0	1.0	2445	22.2
S723/6/8	1	3.0	2.0	2360	
	2	1.0	1.0	3131	32.7
S727/6/60	1	1.7	2.0	2554	
	2	1.3	1.7	2839	11.2
Variety Means		1.4	1.6	2751	
S.E.(mean)		0.13	0.24	157.5	
F test		***	***	**	
L.S.D		0.4	0.7	449	
C.V.		16.6	26.1	9.9	

Key

For all the tables from 2-16

1—No fungicide was applied, 2—Fungicide was applied, 3--* significance at $P<0.05$, 4--** significance at $P<0.01$, 5--*** significance at $P<0.001$