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Determination and Quantification of Susceptibility of Heritance Resistance to Root Rot of Eight Commercial Genotypes of Maize (*Zea mays L.*)

Lazaro José Quintas[1], Neal Walker McLaren[2]

[1]Free State University, Blofoontein and Crops Research Institute, Potchefstroom, South Africa
[2]Grain Crops Research Institute, Potchefstroom, South Africa
Email: quintas112000@yahoo.com

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Abstract

Maize is susceptible to a number of diseases that can infect all plant organs and serve as a constraint on cereal production. The reduction in cereal production caused by disease is estimated at an average of 9.4%. Corn root rot contributes greatly to the reduction in grain production and quality. The main objective of this work was to review the research on root rot in maize to determine the susceptibility of genotypes to root rot and to quantify the inheritance of resistance to root rot in maize. The methodology used was a complete 8 × 8 diallel design planted during the year 1999/2000. Root discoloration, plant length, root volume, effective volume and yield were the evaluated parameters. To analyze the data and determine the combinatorial abilities, genetic correlations, heritability and correlated response, diallel analysis was used. Eight parental lines; P28, I137TN, MP706, E739, MO17, B37, B73, and B14 were planted. The lines were crossed into each other, all combinations according to the complete diallel model (Model 1). The F1 was harvested after maturation. For statistical analysis, the version of the Agrobase program (2016) was used. Results show that F1 hybrids showed significant differences in root rot discoloration, plant height, root volume, effective root volume and yield. The P28 line and the B73XE739 cross had, respectively, the highest general and specific combinations. Root discoloration had the highest genetic correlation (r_A = 0.47) with plant length. Broad and narrow heritability for root rot discoloration were, respectively, h^2 = 0.81 and h_2 = 0.51. Root rot discoloration showed the highest correlated response (C_R = 0.14) on plant length.

Keywords

Maize (*Zea mays L.*), Discoloration, Inheritance, Hybrid, Inbreeds Lines

1. Introduction

Maize (*Zea mays L.*) is one of the most important food crops among the world's cereal crops, such as wheat, rice, maize and sorghum. Maize ranks second after wheat in world production [1]. According to [2], maize is used for three purposes, namely as a staple human food, feed for livestock and as raw material for many industrial products. In tropics maize is a major source of human nutrition. In Latin America, Africa and Asia, several hundred million people depend on maize for their daily food. It is a source of dietary protein and is a major source of calories. Much of maize grown in temperate and developed countries maize is used for animal feed [2].

Maize is grown on more than 100 million ha each year, with an annual production of about 250 million metric tons [1]. Maize grows throughout the temperate, subtropical, and tropical zones where rainfall or irrigation is adequate. Maize is fairly low water requirement per unit of dry matter produced, but also has low drought tolerance. It is important to maintain an adequate soil moisture regime through water conservation or irrigation. Maize is susceptible to a number of diseases that can infect all plant organs and serve as a constraint in grain production. Reduction in grain production caused by diseases is estimated to an average of 9.4% [3]. Root rot of maize contributes to yield reduction and reduced grain quality [4]. In general, losses due to root rots are subtle and it is only when lodging and wilting occurs that these losses become conspicuous. Etiology is complex and includes several fungi and bacteria, the spectrum depending to a large extent on environmental conditions [5].

Despite the paucity of research on maize root rot from 1940 until 1950, researchers have concluded that the majority of the fungi occurring in the root rot complex are soil inhabiting fungi that infect maize roots under various environmental conditions [6]. Factors such as soil, temperature, moisture, nutrients and soil physical properties could contribute to maize root rot [5].

The severity of root rot is dependant to some extent on plant stress, most of which have yet to be quantified. Stress reduction can be achieved by ensuring optimum soil fertility, optimum tillage practices and relevant planting date. Effective weed and insect control are also necessary for optimum conditions and should be included in crop production [7]. The objective of this study was to review maize root rot research to determine susceptibility of commercial genotypes to root rot and to quantify the heritance of resistance to root rot.

2. Pathogens Involved in the Maize Root Rot Complex

Numerous fungal species are known to infect maize and cause roots to rot. Root discoloration is the most distinct symptom of root rot, and various forms of disease ratings have been based on this symptom [5]. The contradictory results on the pathogenicity of Fusarium spp. Emphasizes the complexity of the root rot problem. Many *Fusarium* species are viewed as opportunistic pathogens, capable only of attacking plants weakened by some stress factors [8]. Among the *Fusarium spp*. Pathogens find the *Fusarium moniliforme* considered as the strongest pathogenic on maize roots in South Africa [8]. [9] considered *Fusarium graminearum* as an important pathogen in the maize root rot-complex.

Although the *Fusarium oxysporum* is not the important pathogen of maize, it causes wilting in many crops, and in maize rots except in sterile soil with a high inoculums potential. According [5] the *Pythium spp.* has been common on maize roots since the early years of research in maize. [10] showed that *Pythium graminicola* is both a prevalent and virulent pathogen on maize roots. *Rhizoctonia spp.* is also a major fungus in the maize root rot complex. *Rhizoctonia solani*, *Rhizoctonia Zea* and binucleate *Rhizoctonia* sp. are the most pathogens of *Rizoctonia spp*. group in maize roots. [11] isolated *Helminthosporium pedicellatum* in South Africa and found that it caused severe root rot of plants in inoculated soil.

3. Symptoms Associated with Maize Root Rot

Symptoms associated with maize root rot, particularly aerial symptoms, can be very deceptive. It is therefore essential to inspect root systems for signs of discoloration and poor root development. Root rot symptoms on maize occur in following sequence: seminal root rot, forming lens-shaped lesions, the onset of general browning, necrosis of root tips longitudinal fissuring of the cortex, discoloration and eventually complete discoloration of the roots. Effective root rot control is difficult because of the wide spectrum of pathogens associated with this disease. Chemical control is often not economically justifiable [12]. Breeding for resistance is the only effective long-term control strategy [13].

4. Predisposition and Influence of Environmental Conditions to Root Rot Complex

The occurrence of environmental conditions detrimental to optimal plant growth is considered to cause plant stress. It may influence plant disease through is effect on the pathogen, or susceptibly interaction [14]. Stress such as water stress, temperature stress, nutrient stress, and influence of tillage practices and other stress seem to have pronounced effects, alone or in combination on the susceptibility of plants to disease.

4.1. Water Stress

Water deficits and through may influence plant disease through the effect on pathogen, host susceptibility, and host-pathogen interaction. Variations in precipitation and the availability of moisture for plant growth are the factors that may influence in predisposition of stress water. Major changes in climate over a period of years have been implicated as stress factors affecting the severity of many diseases [14].

4.2. Temperature Stress

Temperature is considered the major factor that affects host susceptibility to disease. It appears in temperature stress what is considered the major factor that affects host susceptibility to disease. Root rot can be severe under conditions of high temperature or low temperature although the spectrum of fungi involved in each of these conditions will differ considerably depending of different pathogen [15].

4.3. Nutrient Stress

Nitrogen, Phosphorus and Potassium elements are reported in both situations, such as increased and decreased as susceptibility to root and stalk rots. The relationship between nutrition and diseases development is extremely complex [14].

4.4. Tillage Practices

Crop residues often associated with conservation-tillage practices have been shown to reduce soil surface temperature [5], which in turn, affects the direction of root growth [2]. Reduce tillage and crop rotation may affect the severity of maize stalk and root associated with *Fusarium ssp.*

5. Disease Associated in Stalk and Root Rot of Maize

Stalk and root rots are the main stem rots in corn can occur before the grain filling phase, in young and vigorous plants, or, after the physiological maturation of the grains, in senescent plants [11]. The main diseases are as follows:

5.1. Stenocarpella Rot

Stenocarpella, macrospora rot can also cause leaf lesions in maize. Plants infected by any of these fungi present, externally, close to the lower internodes, light brown, almost black lesions, in which it is possible to observe the presence of small black nodes (pycnidia). Internally, the pith tissue acquires a brown color and may disintegrate, leaving intact only the woody vessels on which it is also possible to observe the presence of pycnidia [9].

Treatments: Use of resistant cultivars and crop rotation, mainly in areas where the direct planting system is used. Avoid high sowing densities. Fertilize according to technical recommendations to avoid nutritional imbalances in corn plants.

5.2. Fusarium Rot

Fusarium rot is a disease caused by several Fusarium species including *F. moni-*

liforme and *F. moniliforme* var. subglutinans, which also cause pink ear rot. In infected plants, the tissue of the lower internodes usually acquires a reddish color that progresses uniformly and continuously from the base towards the upper part of the plant. Infection can start at the roots and is favored by wounds caused by nematodes or subterranean pests. Disease management is the use of resistant cultivars. Avoid high sowing densities. Fertilize according to technical recommendations to avoid nutritional imbalances in corn plants [5] [9].

5.3. Anthracnose of the Stem

This rot is caused by the fungus *Colletotrichum graminicola* which can infect all parts of the maize plant, resulting in different symptoms on the leaves, stem, ear, roots and tassel. Symptoms: although this pathogen can infect plants in the early stages of their development, symptoms are more visible after flowering. Stem rot is characterized by the formation of soggy, narrow, vertically elliptical or oval lesions on the bark. Later they become reddish brown and finally dark brown to black. Lesions may coalesce, forming extensive dark-glossy necrotic areas. The internal tissue of the calm presents, in a continuous and uniform way, a dark brown color and can disintegrate, leading the plant to premature death and lodging. Disease management is the use of cultivars resistant not only to stem rot by *C. graminicola*, but also to foliar diseases. Crop rotation is essential in the No-Tillage System. Seed treatment with fungicides. Fertilize according to technical recommendations to avoid nutritional imbalances in corn plants. Plowing and harrowing are practices that, associated with crop rotation, significantly reduce the amount of pathogen inoculums in the soil and consequently the intensity of the disease in the next sowings [10].

5.4. Dry Rot of the Stalk

Dry stem rot is caused by the fungus *Macrophomina phaseolina*. The infection of plants starts at the roots. Although this infection can occur in the first stages of plant development, the symptoms are visible in the lower internodes, after pollination. Internally, the marrow tissue disintegrates, leaving only the ligneous vessels intact [4].

Disease management use of resistant cultivars promotes adequate irrigation in years of low rainfall. Avoid high sowing densities. Fertilize according to technical recommendations to avoid nutritional imbalances in corn plants.

5.5. Rot Caused by Pythium

It is caused by the fungus *Pythium aphanidermatum*. Symptoms: this rot is of the watery type, resembling bacterial rots. It differs from these in that it is typically restricted to the first internodes. Diseases in Maize Crops above ground, while bacterial diseases affect several internodes. The plants, before toppling over, usually suffer a torsion. Fallen plants remain green for some time as the woody pots remain intact [16].

5.6. Bacterial Rots

Several bacterial species of the genera Pseudomonas and Erwinia cause stalk rots in maize plants. Rots caused by bacteria are of the watery type and, when caused by Erwini, typically give off an unpleasant odor. In general, they start at the internodes close to the ground and quickly reach the upper internodes. Disease management: proper management of irrigation water.

6. Methodology

To determine the genetic variability and inheritance for root rot resistance in maize, an 8 × 8 full diallel was planted. Infection was dependent on natural inoculums. Root rot discoloration, plant length, root volume, effective volume and yield were measured. A diallel analyses was used to analyze the data and determine combining abilities, genetic correlations, heritabilities and correlated response.

6.1. Experimental Material

Eight parental inbreeds lines P28, I137TN, MP706, E739, MO17, B37, B73, and B14 were planted in greenhouse at ARC-Grain Crops Institute at Potchefstroom, Northwest Province of South Africa. The inbred lines were crossed in all combinations according to a complete Diallel (Model 1) of [17]. The F1-hybrid seed were harvested after maturity. Data were analyzed using the analysis of variance in the Agrobase statistical programme version 2016.

6.2. Experimental Draw

The 56 F1-hybrid combinations and their eight parental lines were planted in a randomized complete block trial with three replications at Potchefstroom Station of Grain Crops Research Institute in North West Province of South Africa. Each plot consisted of 30 plants with an intra row spacing of 10 cm and an inter-row spacing of 1.2 meters. Fertilizer compound N, P, K was given using 300 Kg/ha 2:3:2. For top dressing, 250 Kg/ha LAN was applied 4 - 6 weeks after emergence. The trial was conducted under dry land conditions and irrigated only when absence of rain dictated. Weed and insect control were applied as required.

6.3. Calculated Characters

The characters measured on single plants were: root discoloration (RRD), root volume (RV), plant length (PL), effective root volume (ERV) and yield.

6.3.1. Root Discoloration (RD)

Six weeks after planting, five randomized plants per plot, were selected. The roots of the plants were washed in running tap water to remove adhering soil. A visual assessment of the percentage of root discoloration was done on each plant separately to quantify root discoloration a scale from one to five was used (**Table 1**),

Table 1. Numerical and percentage values of the scale for visualizing root rot discoloration.

Numerical value		Percentage value
1	≤	2%
2	=	2% - 10%
3	=	11% - 50%
4	≥	50%
5	=	dead plants

where 1 = or <25; 2 = 2% - 10%; 3 = 11% - 50%; 4 = or >50%, discoloration and decayed roots and 5 = dead plants. Table 1 above is the demonstrative of numerical and percentage values used for visualizing root rot discoloration [18].

6.3.2. Root Volume (RV)

Recovered root volume was determined using water displacement. A bucket of 10 liters with a small spout in the top of the bucket was used. The roots were put into the bucket filled with water and then covered with a lid. The water that runs through the spout was collected up in another small container. The amount of water in the container was measured in milliliters.

6.3.3. Plant Length (PL)

Plant length was measured in centimeter using a tape measure. The lengths were measured from the crown to the tip of the upper leaf. Twenty random plants per replicate were measured and the mean per replicate was determined.

6.3.4. Effective Root Volume (ERV)

Effective root volume was calculated by putting the values for root rot severity and root volume in the following equation;

$$\text{ERV} = ((100 - \text{root rot severity})/100) * \text{root volume}$$

where ERV is the effective root volume (ml).

6.3.5. Yield (Ton/Ha)

Grain yield was calculated as shelled grain mass per plot adjusted to 12.5% grain moisture and converted to tons per hectare, according to the following formula [18]

$$\text{GY} = \left(\text{Wt Kg}/\text{Np}\right) * \text{Pp} * \left(100 - \text{H\%}\right)/87.5\% * 1\ \text{t}/100\ \text{Kg}$$

GY is grain yield in t/ha; Wt is grain mass in Kg; Np is final stand (number harvested plants); Pp is plant population (total number of plants/hectar) calculated from plot size; H% is the moisture percentage taken after harvest and; 87.55 is the moisture correction coefficient (100% - 12.5%).

6.4. Statistical Analyzes of Variance (ANOVA)

The Agrobase 2016 computer program was used to conduct various statistical analyses on the data. The following analyses were conducted. An analysis of variance was calculated on each data set for each of the five characters measured. To test for significant differences between means the LSD (0.05) of Tukey was used.

6.4.1. Diallel Analysis of F1 Progeny

The F1 data obtained for each of the five characters measured was analyzed according to the variance analyses [17] model 1. The Diallel analysis of the F1 Progeny proceeded to analyze the variance of ability for the general and specific combination, as well as the reciprocal effects.

6.4.2. Combining Abilities (General-GCA and Specific-SCA)

The GCA and SCA, as well as the relationship between these two values, were calculated. In the combining ability analysis, the variety effects are considered in terms of GCA and SCA effects, such that:

$$V_{ij} = g_i + g_j + S_{ij} \quad \text{combining}$$

where: V_{ij}-value; g_i-general combining and S_{ij}-specific.

The mathematical model for the combining ability analysis is assumed to be

$$X_{ij} = u + g_i + g_j + S_{ij} + 1/bc\sum_k \sum_i e_{ijkl} \text{ ,}$$

where $i, j = 1, \cdots, p$ and $k = 1, \cdots, b$.

u = population mean and $(g_i)g_j$ = GCA effect;

$$l = 1, \cdots, c\ ;$$

where S_{ij} = SCA effect.

Therefore the effect was estimated as following:

$$g_i - 1/p + 2\left(X_i + X_{ij} - 2/p\,X\cdots\right)$$

The LSD between GCA was calculated as

$$\text{LSD} = q\alpha; t, f \cdot \sqrt{S_E^2}\Big/r;\ \left(t = 0.5\right)$$

where: $q\ \alpha$; t, f = α value at t treatment's degree of freedom and error degrees of freedom.

For SCA effects:

$$S_{ij} = X_{ij} - 1/p + 2\left(X_i + X_{ii} + X_j + X_{jj}\right) + 2/\left(p+1\right)\left(p+2\right)X\cdots.$$

The LSD between SCA effects was calculated:

$$\text{LSD} = q\alpha; t, f \cdot \sqrt{S_E^2}\Big/r;\ \left(t = 0.5\right)$$

where: $q\ \alpha$; t, f = α value at t treatment's degree of freedom and error degrees of freedom.

6.4.3. GCA: SCA Ratio's

The GCA: SCA ratio's indicates whether GCA or SCA effects are predominant and which factor plays a more important role in exercising genetic control. This ratio also indicates whether a character is mainly under the control of additive/non-additive (dominant) gene action.

6.4.4. Genetic Correlations

The genetic correlation is the correlation between the additive variances of two characters. A genetic correlation matrix was calculated for all five characters measured. It was done using the additive variance components obtained, analysis of variance. Genetic correlations can arise from pleiotropy, linkage or introduction of genes involved into a population.

6.4.5. Heritability

Heritability is in fact a regression coefficient of genotypic values G on phenotypic values P. It is defined as the ratio of genotypic variance thus the portion of phenotypic variation among individuals due to genetic differences between them. Broad and narrow sense heritability was determined by followings formulas.

The broad sense heritability is the extent to which the genotype influences the phenotype, and is therefore calculated from the ratio of the total genetic variance to phenotypic variance according to the formula:

$$h^2 = \sigma_g^2 / \sigma_p^2 = v(G)/v(P)$$

The marrow sense heritability expresses the extent to which the phenotypes are determinated by the genes transmitted from the parents, and was estimated from the ratio of the additive portion of genetic variance to the phenotypic variance according to the formula: $h^2 = \sigma_A^2 / \sigma_p^2$; where $\sigma_A^2 \; - 2\sigma^2$ GCA.

The variance components were calculated according to [6]

$$\sigma_G^2 = 2\sigma_{GCA}^2 + 2\sigma_{SCA}^2$$

where: $\sigma_{GCA}^2 = (MS_{GCA} - MS_{SCA})/P - 2$ and $\sigma_{SCA}^2 = MS_{SCA} - MS_E$ and $\sigma_P^2 = \sigma_G^2 + 2\sigma^2$.

6.4.6. Correlated Response

The correlated response was calculated according the changeable of the correlated characters Y to another character X. This changeable is done by the regression of character y on breeding value of X.

The regression is:

$$b_A YX = Cova / \sigma_{AX}^2 = r_A \sigma_{AX}^2 = r_A \sigma_{AY}^2 / \sigma_{AX}^2$$

The response of character X, directly selected is: $R_x = \backslash ih2 \times \sigma_{AX}$.

Therefore calculated response for character Y is:

$$CR_y = ih_2 \times r_A \sigma_{AY}$$

by putting $\sigma_{AY} = h_y^2 \sigma_{AY}$ the correlated response become:

$$CR_y = ih \times h_y r_A \sigma_{py}$$

Thus the response of a correlated character can be predicted if the heritabilities and genetic correlation of two characters are known.

7. Results and Discussion

The obtained results show that the F1-hybrids showed significant differences for root rot discoloration, plant length, root volume, effective root volume and yield. Inbred line P28 and the cross B73XE739 had, respectively the highest general and specific combining abilities. Root discoloration had the highest genetic correlation ($r_A = 0.47$) with plant length. The broad and narrow sense heritabilities for root rot discoloration were respectively $h^2 = 0.81$ and $h^2 = 0.51$. Root rot discoloration had the highest correlated response ($C_R = 0.14$) with plant length, as shown in followings the tables below [18].

7.1. Analysis of Variance of Root Rot Discoloration, Plant Length, Root Volume, Effective Root Volume and Yield

The results of analysis of variance of root rot discoloration, plant length, root volume, effective root volume and yield are showed in (**Table 2**).

It shows that highly significant differences between blocks existed for root rot discoloration, plant length, root volume, effective root rot and yield. Significant differences between entries were recorded for plant length, root volume, effective root volume and yield. There was no significant differences existed among entries for root rot discoloration. A highly positive correlation was found between root volume and plant length ($R = 0.53$). A highly positive correlation between effective root volume and plant length was also recorded ($R^2 = 0.50$). Yield was poorly correlated with root discoloration, root volume, plant length and root volume, yielding no significant correlation coefficients [18].

7.2. General and Specific Combining Abilities of the Parents and Crosses (F1)

Table 3 below are the analysis of ANOVA for general e specific combining abilities that indicates no having significant differences for both combining ability effects.

Table 2. ANOVA-Mean squares for root rot discoloration, Plant length, root volume effective root volume [Mc LAREN, N. W. 1999].

Source	Df	Characters				
		RRD	PL	RV	ERV	Yield
Total	191					
Block	2	1300.42**	4270.64**	2286.75**	927.25**	6.67**
Entry	63	34.24*	558.93**	494.53**	380.72**	4.37**
Residual	126	44.32	263.24	273.23	205.68	1.86
Media		9.93	123.53	34.12	30.30	4.49
C. V. (%)		67.00	13.13	48. 44	47.33	30.36

RRD-root rot discoloration, PL-Plant length, RV-root volume, ERV-effective root volume. **indicates the probability of significant differences; *indicates the probability of significant differences.

Table 3. ANOVA for general and specific combining abilities effects for root rot discoloration, Plant length, root volume effective root volume.

Source	Df	Characters				
		RRD	PL	RV	ERV	Yied
Total	63					
GCA	7	19.80	33339.23**	280.6**	213.4**	1.31*
SCA	28	9.80	209.67**	151.90*	115.50*	2.20**
Reciprocal	28	10.94	123.78*	147.10*	17.00*	1.68**
Residual	126	14.80	88.40	92.50	68.90	0.62

**LSD (p = 0.01), *LSD (p = 0.05).

The GCA and SCA were observed for root discoloration as shows. Highly significant differences for general combining ability effects were found for plant length, root volume and effective root volume. Significant differences for general combining ability effects were observed for yield. Highly significant differences for specific combining ability effects were observed for plant length, yield, root volume and effective root volume. No significant differences for reciprocal effects were observed for root rot discoloration significant differences for reciprocal effects were observed for plant length, root volume and effective root volume. Highly significant differences for reciprocal effects were observed for yield [18].

General combining abilities effects for root rot discoloration, Plant length, root volume effective root volume of the parents and crosses (F1) was calculated and the results are presented in the (**Table 4**).

The results show that the inbred lines 1137TN (−1.22) and E739 (−1.08) had the lowest general combining ability effects for root rot discoloration thus indicating that they probably the best to use for improvement of root rot resistance in maize. The inbred P28 (1.77) had the highest general combining ability effect of the parental lines for root rot discoloration, in this case the use of P28 in F1-hybrids will probably lead to increase in root rot discoloration. However no significant differences existed between the eight inbred lines with regard to their general combining ability effects. The inbred lines B14 (6.66) and B73 (5.81) had respectively the highest general combining abilities for plant length. These two inbreeds can be successful used to increase plant length maize hybrid.

The inbred line with the lowest general combining ability effect for plant length was 1137TN. It could therefore be successful used in crosses to reduce plant height. The general combining ability of 1137TN differs significantly from inbred lines B14 and B73.

For root volume the inbred line B14 (6.17) had the highest general combining ability effect of the inbred lines. The general combining ability effect of B14 inbred line exceeded that of inbreed line 1137TN (−6.86) significantly.

Table 4. General combining abilities effects for root rot discoloration, Plant length, root volume effective root volume.

		Characteristics				
Entry	Parent	RRD	PL	RV	ERV	Yield
1	B14	−0.18	6.66	6.17	5.42	−0.28
2	B37	−0.83	−1.62	3.25	3.59	−0.01
3	B73	0.82	5.81	1.79	1.30	0.01
4	E739	−1.08	−3.98	−2.00	−1.55	−0.49
5	I137TN	−1.22	−6.60	−6.86	−5.59	0.15
6	MO17	1.13	−2.35	1.08	−1.46	0.31
7	MP706	−0.41	0.60	−3.53	−3.30	0.35
8	P28	1.78	1.47	2.35	1.59	−0.04
LSD (p = 0.05)		8.11	8.92	9.13	7.88	0.74

While the highest general combining ability effect for effective root volume was found in inbred line B14 (5.42) followed by B37 (3.59). Their general combining ability effects were significantly higher than the inbred line 1137TN (−5.59). According to these data the inbred lines B14 and B37 would probably be the best to use in crosses to reduce root discoloration in a maize resistance breeding programme.

The inbreeds (−0.49) and B14 (−0.28) had the lowest general combining ability effects for yield followed by P28 (−0.04) and B37 (−0.01). While the inbred lines with the highest general combining ability effects for yield were MP706 (0.35), MO17 (0.31) followed by 1137TN (0.15). These results indicate that these inbred lines are probably the best to use in maize breeding programme for increasing yield [18].

7.3. Specific Combining Ability (SCA) Effects for the Parents

In the same way was calculated the specific combining ability effects which the results are presented too in (Table 4) above. As the table as showing for root rot discoloration the cross B37XB73 (−5.42) there had the lowest specific combining ability effect, followed by the cross E739XMO17 (−3.48). The results indicate that these crosses are the best crosses for developing F1-hybrids resistant to maize rot disease.

The crosses B73XE739 (3.82), MP706XP28 (3.70) and B14XMO17 (3.28) followed by B73XI137TN (2.64) and B73XP28 (2.30) showed the highest specific combining effects for root rot of all the cross. Therefore the high level of root rot susceptibility in these crosses is an indication that the use of these crosses will cause an increase in root discoloration in F1-hybrids. The cross B14XMO17 (20.90) had the highest specific combining ability effect and its effect was significantly higher than 26 of the other crosses.

The crosses B37XMO17 (14.34) and B73XMO17 (9.58) and B37XP28 (9.18) had the second, third and fourth largest specific combining ability effects for plant length. The effects of these four crosses exceeded the effects of 12 other crosses significantly.

Two crosses showed highest specific combining ability effects for root volume, and there are B14XMO17 (14.18) and B37XP28 (13.50). Their specific combining ability effects exceeded those of four other crosses significantly. It indicates that the parents involved in these two crosses carry specific genes which will enhance root volume when they are combined. The crosses B37XI137TN (−8.65) and B37XE739 (−7.88) had the lowest combining ability effects for root volume indicating weaker root development in these two crosses.

Significant differences existed between the specific combining abilities of the crosses for effective root volume. The crosses with the highest specific effects were B37XP28 (11.07), B14XE739 (10.96) followed by B37XMO17 (8.92), B14XE739 (7.71) and B37XB73 (7.36). These results indicate that the parents involved in these crosses also carried specific genes, which can enhance root rot resistance when they are combined into one hybrid.

The crosses with the lowest specific effects for root efficiency were B37XI137TN (−7.45), B37XE739) (−7.28), MP706XP28 (−6.87) and MO17XP28 (−5.37). It can be assumed that these crosses might also show a tendency to be less tolerant to root rot. Significant differences with regard to their specific effects for yield were observed between crosses. The crosses I137TnXMP706 (1.58), B14XMO17 (1.16) and B37XP28 (1.06) had the highest specific combining ability effects for yield.

The specific combining ability effect of cross I137TNXMP706 for yield is significantly higher than 20 of the other crosses. Specific combining ability effects for yield of combinations B14XMP706 (−0.99), B73XMP706 (−0.72) and MO17XMP706 (−0.58) were negative and very low [18].

The GCA: SCA ratios's for root rot discoloration indicated that additive effect was twice as large as the effect due to dominance and interaction. These results indicated that there were a fair amount of additive genes involved in the expression of this characteristic.

The GCA: SCA ratio's for length (16:1), root volume (1.8:1), and effective root volume (1.8:1) showed that the additive effect exceeded the effects due to dominance and interaction effects. For yield the GCA: SCA ratio's were close to one indicating that the additive and dominance effects were of equal importance as showed in Table 4.

7.4. Genetic Correlations (r_A)

Table 5 shows the genetic correlations between root rot discoloration, plant length root volume, root efficiency and yield was defined as the.

There is seen that the effective root volume was highly significantly correlated with root volume (r_A = 0.99). Since root volume is one of the parameters used in

Table 5. Genetic correlations between root rot discoloration, plant length root volume, root efficiency and yield.

Character	RRD	PL	RV	ERV
RRD				
PL	0.47			
RV	0.33	0.78*		
ERV	0.29	0.72*	0.99**	
Yield	0.25	−0.15	−0.41	−0.453

**indicates the probability on highly significant differences. *indicates the probability of significant differences.

the calculation of effective root volume, a relatively high correlation is expected between these two characters. Effective root volume was also significantly correlated with plant length ($r_A = 0.72$), which meant that there was a relationship between the effective root volume made up by the rot volume and plant length. This was confirmed by the significant positive correlation between root volume and plant length ($r_A = 0.78$). Root discoloration was positively but not significantly correlated with plant length, root volume and effective root volume: This could be explained by overall low levels of root discoloration that occurred in the trial, indicating that the level of discoloration was too low to have any significant effect on these characteristics.

The Yield was not significantly correlated with root discoloration, and it was negatively correlated with plant length, root volume and effective root volume. Therefore it shows that any increase in root discoloration may decrease yield [18].

7.5. Inheritance of Root Rot Resistance

The broad and narrow sense heritabilities for root rot discoloration, plant length, root volume, effective root volume and yield are represented in **Table 6** below.

The values of broad sense heritabilities were relatively high in comparison with the narrow sense heritabilities. These varied from $h^2 = 0.81$ for root discoloration to $h^2 = 0.93$ for root volume. The results show that the narrow sense heritabilities for root rot discoloration ($h^2 = 0.51$), plant length ($h^2 = 0.62$) and effective root volume ($h^2 = 0.58$) were relatively high. These results indicate that a plant breeder can select effectively for a low root rot discoloration as well as for high effective root volume that will probably enhance rot root resistance in maize. The narrow sense heritabilities for root volume ($h^2 = 0.37$) and yield ($h^2 = 0.30$) were relatively low. This could be explained by quantitative type of inheritance of these characters and the large effect of environmental variances [18].

Table 6. Inheritance of root rot discoloration, Plant length, root volume and effective root volume.

	Characters				
Inheritance	RRD	PL	RV	ERV	Yield
h_b^2	0.81	0.92	0.94	0.91	0.93
h_n^2	0.51	0.62	0.37	0.58	0.30

h_b^2 -broad sense inheritance, h_n^2 -narrow sense heritance.

7.6. Correlated Response (C_R)

The last was calculated and discussed the correlation response (C_R) between root rot discoloration, Plant length, root volume effective root volume and yield, which the results are demonstrated in Table 7.

The results indicate that selecting for root discoloration will not bring about major changes in root volume, effective volume or yield. However, selecting for root discoloration will have a small effect on plant length ($C_R = 0.14$). Yield was negatively affected by an increase in root discoloration. The correlated response between plant length and effective root volume was relatively high ($C_R = 0.25$), indicating that root efficiency can be increased by at least 25% when indirect selection for plant length is applied to a maize population. The correlated response between plant length and root volume equaled 14%, indicating that selecting for taller plants will also cause an increase of 14% in root volume. The correlated response between yield and plant length ($C_R = -0.04$) was for all practical reasons non-existent.

The correlated response between root volume and effective volume ($C_R = 0.21$) is relatively high, indicating that an increase in effective root volume will enhance root rot volume by 21%. The correlated response between root volume and yield ($C_R = -0.05$) was low and negative. The correlated response between effective volume and yield is very low and negative. It indicated that an increase in effective root volume will not necessarily cause an increase in the yield. This could be explained by the fact that high yields are also a function of the genotypic yielding ability of the maize plant.

Below, the graphics that show the evaluation of the relationship between yield and color, root volume, rot effectiveness and plant height based in the dilled crossing method (Model 1) [18].

Figure 1 below represents the relationship between root rot discoloration and length in the diallel crossing method (Model 1), which shows that the R^2 of variance of root rot to plant length were evaluated in 9%, what is indicate no significant influence to plant crossing.

Figure 2 is representing the relationship between root volume and length of maize plants, what shows that R^2 is 53% of the total volume rooted, which shows significant influence to plant length crossing.

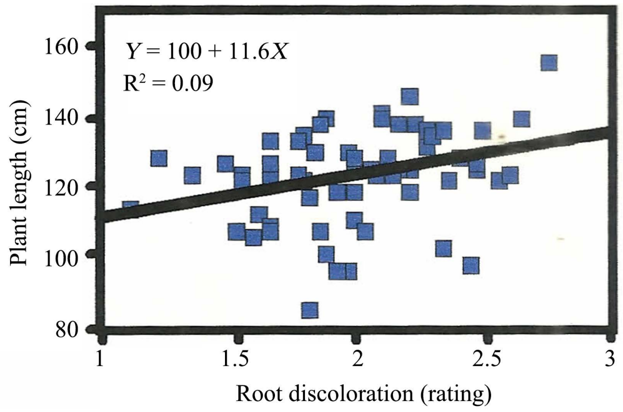

Figure 1. Relatioship between root discoloration and length of maize plants evaluated in a diallel cross (Model 1).

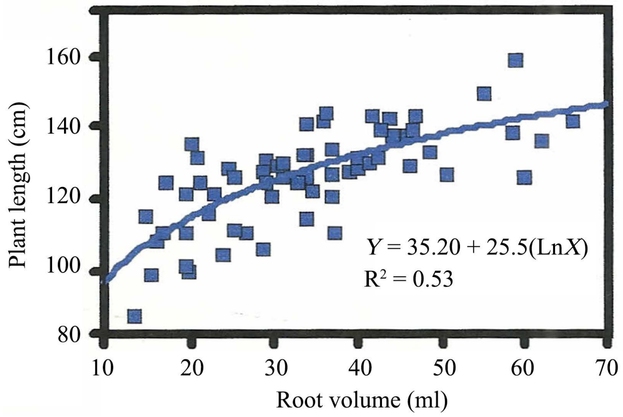

Figure 2. Relatioship between root volume and length of maize plants evaluated in a diallel cross (Model 1).

Table 7. Correlated response (C_R) between root rot discoloration, Plant length, root volume effective root volume and yield.

Characters	RRD	PL	RV	ERV
RRD				
PL	0.149			
RV	0.064	0.177		
ERV	0.085	0.258	0.214	
Yield	−0.038	−0.035	−0.046	−0.080

While **Figure 3** demonstrates the relationship between effective and root rot volume which indicates the equal results of R^2 50%, where the indicator shows that the effective root volume were significant to the plant crossing.

The relatioship between root discolouration and yield of maize evaluated in a diallel cross, where the results of R^2 wehere equal 1% what shows to be highly insignificant to influence the yield of plant (**Figure 4**).

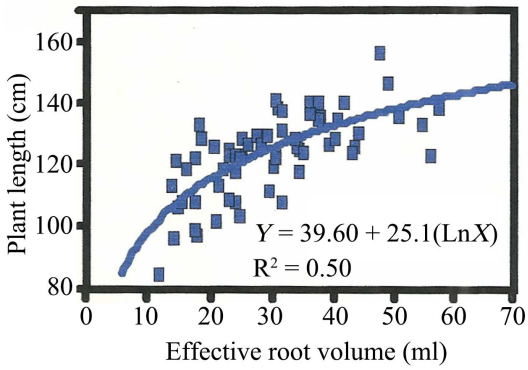

Figure 3. Relatioship between effective root rot volume and length of maize plants evaluated in a diallel cross (Model 1).

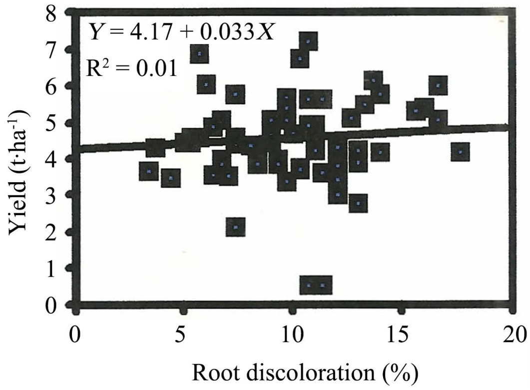

Figure 4. Relatioship between root discoloration and yield of maize evaluated in a diallel cross (Model 1).

Figure 5 below is the representative of the relatioship between root volume and yield of maize evaluated in a diallel cross, where R^2 represents only 1%, showing highly insignificant result of effect of root volume to yield in maize breeding [18].

In the same way was evalueted the relatioship between effective root volume and yield of maize evaluated in a diallel cross as demostrating in Figure 6. The result shows that only 2% of effect of root volume. This indicator of root volume was highly insignificant to affect yield in maize breeding [18].

The effect of plant length to yield wehe mensuered and evalueted in a diallel cross and the results is demosntrated in Figure 7 below. This result shows that very low effect was determineted R^2 equal 4% in crossing and this indicator were insignificant to influence the yield [18].

The Yield is the most important indicator for the results in plant breeding, therefore it has to be considerate as primary indicator to the breedrs put in first intance. The study shows that the results of relationships betuwen root discolouration, root volume, effect volume and plant lenght with yield shows to be highly insignificant, which can be understood that the selected lines for breeding had effectiveness to be a good performance lines.

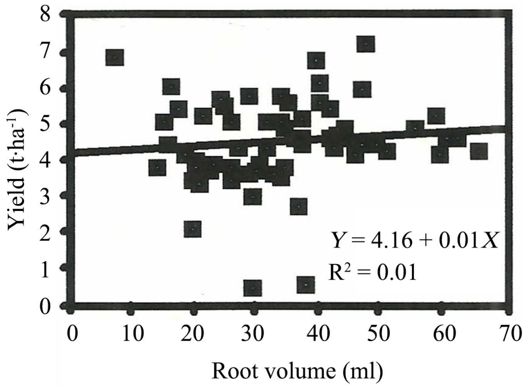

Figure 5. Relatioship between root volume and yield of maize evaluated in a diallel cross (Model 1).

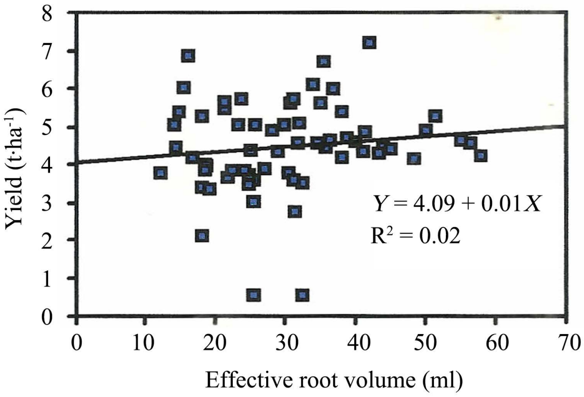

Figure 6. Relatioship between effective root volume and Yield of maize evaluated in a diallel cross (Model 1).

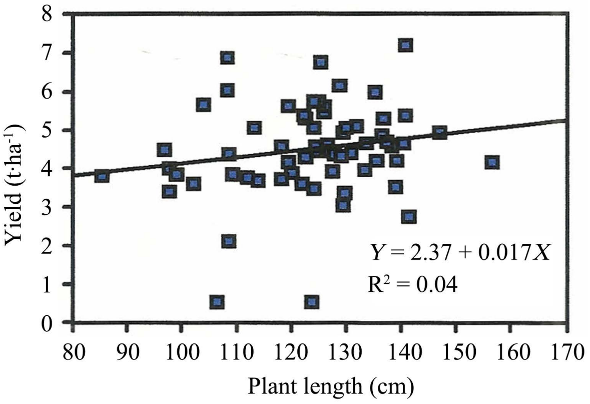

Figure 7. Relatioship between plant length and yield of maize evaluated in a diallel cross (Model 1).

8. Conclusions

The study concluded that maize is a crop susceptible to fungal contamination through contaminated soils that colonize the roots. There are few studies related to this colonization, due to its low visibility and quantification.

It is concluded, however, that root rot requires more extensive studies in more than one location, at different stages of plant growth, in order to obtain viable and reliable results. A follow-up study was carried out to assessment of field resistance to root rot in maize

Despite the little attention given to corn root rot studies this must be considered as one of the major areas of study that requires urgent attention, with the main focus being the quantification of corn root rot, due to its influence on the reduction of productivity in the loss of grain quality and consequent yield.

The study further concluded that genetic improvement for root rot resistance is the best and long term measure of disease control from transferring resistant lines to susceptible lines.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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