

GENE ACTION AND INHERITANCE OF RESISTANCE TO
RHIZOCTONIA SOLANI AND PYTHIUM ULTIMUM IN COTTON SEEDLINGS

A Dissertation

BY

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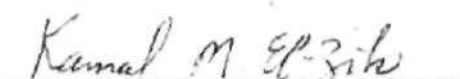
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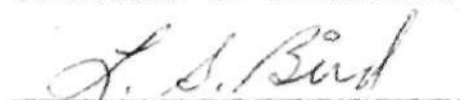
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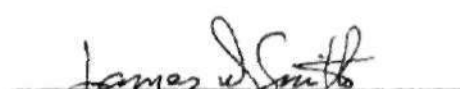
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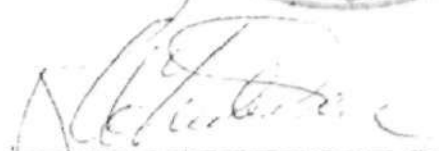
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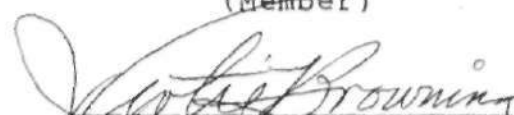

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ABSTRACT

Gene Action and Inheritance of Resistance to Rhizoctonia solani and Pythium ultimum in Cotton Seedlings

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Six cotton cultivars, three multi-adversity resistant (MAR) and three non-MAR, and their 15 F₁ and 15 F₂ progenies obtained from a diallel set of crosses (no reciprocals) were used to determine the genetic system controlling traits associated with resistance to R. solani and P. ultimum. Experiments were conducted for two years in a field naturally infested with both pathogens, and in temperature controlled water bath tanks, using soil artificially inoculated with each of R. solani and P. ultimum separately at two inoculum densities. Genetic information based on the diallel analyses of Hayman, Jinks and Griffing for the data collected in the field were inconclusive. However, measures of gene action and interaction, and the inheritance of resistance to the two pathogens were obtained from the temperature tank experiments.

Independent action of non-allelic genes (no epistasis) was the only genetic assumption of the diallel analysis that was not valid for all traits for both pathogens. Dominance effects (H_1 and H_2) were the most predominant in the F_1 and F_2 diallel analyses for most traits associated with resistance to both *R. solani* and *p. ultimum*. The additive effects (D) were smaller in magnitude than the dominance effects. Average degree of dominance ranged from partial to overdominance with different responses to both pathogens. The analysis of F_2 data detected a significant epistatic effects for all traits and for both pathogens.

Heritabilities in the narrow sense were low, ranging from 0.0% to 20.7% for *R. solani*. For *P. ultimum*, heritabilities ranged from 0.0% to 10.2%. General combining ability effects were important for the expression of resistance to *R. solani* and specific combining ability effects for *P. ultimum*.

The results indicated that resistance in cotton seedlings to both *R. solani* and *P. ultimum* was polygenically inherited and conditioned by a complex of minor genes. Extension of the genetic analysis to the F_2 provided more reliable information on the genetic system.

The most important trait associated with final stand establishment of cotton seedlings in the presence of *R. solani* was post-emergence damping-off, explaining 92% of

the variability in final stand. Pre-emergence damping-off due to *P. ultimum*, explained 62% of the variability in final stand.

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This dissertation is dedicated to my wife, Comfort, for her untiring physical and moral support during the course of the study and to the author's parents, brothers and sisters for their keen interest and encouragement over the past four years.

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INTRODUCTION

As in other crop plants, cotton production in the growing regions of the world has witnessed appreciable setbacks due to many biotic and abiotic factors. These multi-adversities, which include plant pathogens, insects and environmental stresses, have over the years limited realization of the genetic potential for yield and fiber quality of adapted cotton cultivars lacking resistance and escape mechanisms. Faced with these serious challenges, scientists have intensified their efforts to develop cultivars possessing resistance to many of the biotic and abiotic factors, and yet retain their genetic potential for yield and quality.

The seed and seedling disease complex of cotton induced by Rhizoctonia solani Kuhn and Pythium ultimum Trow. is of major importance in the United States and other cotton-growing regions of the world (24). Under favorable conditions of cool and wet periods, a single or combined effect of the recognized phase(s) of the disease syndrome can cause a significant reduction in stand establishment that result in reduced yield. The seedling disease complex caused an estimated average yield loss of 2.8% annually over the last ten years in the United States (24).

This dissertation follows the style and format of Crop Science.

The multi-adversity resistance (MAR) program of the Texas Agricultural Experiment Station has, through concerted direct and indirect genetic improvement approaches, developed cottons possessing higher levels of resistance and escape mechanisms than are possessed by most of the commercial cotton cultivars to the seed and seedling disease complex (14,47).

The mode of inheritance, gene action and interactions involved in the expression of resistance to the seed and seedling pathogens in the MAR cottons and some commercial cultivars are yet to be investigated. The understanding of the inheritance and the genetic system(s) controlling resistance mechanisms will provide basic information on the MAR system. The objectives of this investigation were to:

1. Determine gene action and the inheritance of resistance to R. solani and P. ultimum in cotton seedlings.
2. Determine which traits and measurements are the best for ascertaining the inheritance of resistance to the cotton seedling disease pathogens.

LITERATURE REVIEW

Causal Organisms

The seed and seedling disease of cotton is caused by a relatively complex interaction among young cotton plants, disease causing organisms, and the environment (5,7,15,57). A host of seed and soil-inhabiting pathogens are known to induce the various disease symptoms singularly or in combinations (15,25,47). The primary pathogens are Rhizoctonia solani Kuhn, Pythium spp., Thielaviopsis basicola (Berk. & Br.) Ferr. and Glomerella gossypii Edg. The secondary pathogens such as Fusarium spp., Aspergillus spp., Rhizopus sp. and Alternaria spp. and bacteria may attack predisposed seed and seedlings. The role of Meloidogyne spp. in the seedling disease complex is that of seedling predisposition to infection by R. solani and P. ultimum. R. solani and P. ultimum are considered the major seedling disease pathogens based on the incidence and severity of the disease, and the isolation frequency of the two pathogens from infected cottonseed and seedlings (25,41,42).

Symptomatology

R. solani and P. ultimum are capable of inducing singularly or in combination the seed and seedling disease complex of cotton characterized by different manifesta-

tions named according to the infected plant part (5,15,41,56,57). The syndrome includes seed root (decay of the seed), pre-emergence damping-off (death of the young seedling before emergence), post-emergence damping-off (seedling death after emergence), hypocotyl rot (partial or complete necrotic girdling of the hypocotyl), and root rot (small lesions to complete necrosis of the primary and lateral roots on surviving seedlings).

Surviving plants damaged by seedling pathogens often are unthrifty, late in maturing, and produce low yields. They are more susceptible to other pests and to environmental stresses. Replanting and associated problems resulting from delayed crop maturity and harvesting contribute to the losses incurred.

Factors Influencing Disease Development and the Expression of Resistance

The influence of temperature on disease development involves direct effects on the host, the pathogen, and host-pathogen-temperature interactions (15). Christiansen (22) provided evidence that increased membrane permeability and high levels of root exudation are associated with the temporary blockage of respiratory activity due to cold. Hayman (37) showed that more carbohydrates (glucose, fructose, galactose, and sucrose) were exuded at any given physiological age at 12°C and 18°C than at 24, 30 or 36°C. He reported that pre-emergence damping-off was 100%

at 18°C, 69% at 24°C and 38% at 30°C. The seed, root and hypocotyl exudates are competitively used to increase inoculum potential by the pathogens, resulting in increased pathogenesis (39). However, exudates from seed coat, seedling and plant roots, and fluids in tissues of MAR cottons have been reported to be nutritionally unfavorable and exhibit antibiosis to certain pathogens (14,20). The exudates are selectively favorable for rhizoplane-rhizosphere bacteria, actinomycetes, and fungi that are highly competitive with root pathogens, resulting in reduced pathogenesis (14,20). Pathogenicity and virulence of isolates of R. solani and Pythium spp. on cotton seedlings varies over a wide range of temperatures. R. solani is capable of infection and damage within the range of 18-33°C; however, P. ultimum infects and causes damage within the range of 18-27°C (6). Johnson (41) differentiated resistant and susceptible cultivars to P. ultimum at temperatures of 18-21°C but no significant difference could be ascertained at 24-27°C. Bird (15) used 18-20°C in controlled temperature tanks and early season plantings in the field when daily average soil temperature range from 14-18°C for assessing resistance to R. solani. Lifshitz and Hancock (46) observed an exponential decline (death rate) of P. ultimum germinable propagules (oospores and sporangia) with temperature. The rate of decline was

higher at extreme temperatures of 9°C and 27°C than at intermediate temperatures of 15°C and 21°C.

With high quality seed, which gives optimum expression of seed-seedling cold resistance, plantings made early in the season when night to day soil temperatures vary from 13 to 18°C have a potential of disease escape and reduced disease development (15). Under these conditions the pathogens are at a greater disadvantage than the host. This is an application of the concept of escape by planting cold resistant crops when soil temperatures are sub-optimum as proposed by Leach (45). Low quality cottonseed loses the ability to perform at reduced temperatures. They should not be planted until soil temperatures exceed 18-24°C which is near-optimum for the pathogens but more advantageous to the host.

Studies on the effect of soil moisture levels on the expression and development of the disease syndrome indicate that under constant and favorable soil temperatures R. solani is favored by low to medium moisture levels (42) and P. ultimum by a high moisture level (54). Based on its evolutionary background, it is suggested that Pythium, a phycomycete, should be well adapted to a semi-aquatic environment with resultant low oxygen tensions, while Rhizoctonia is favored by high oxygen and low CO₂ tensions (16).

In a study of the effects of pathogen virulence and inoculum density on seedling resistance, Bird (15) showed that a Texas isolate of R. solani adjusted to a soil inoculum density of 43.4 and 39.5 propagules per 100 g of soil was less virulent than a California isolate at the same inoculum density. Significant differences among cultivars for resistance were measured at the same inoculum densities with the Texas but not with the California isolate. Bush, et al. (21) were able to differentiate MAR cultivars in soils infested with 42 propagules and not with 100 propagules per 100 g of soil. At inoculum densities of 100 propagules/g of soil in the field and 60 propagules/g of soil in the greenhouse, DeVay, et al. (25) showed that a highly virulent isolate of P. ultimum gave 50% seedling death.

Control of the Seedling Disease Complex

Walla and Bird (55) recommended five measures that should be practiced in an integrated approach to reduce losses from the seedling disease complex. These included the planting of high-quality seed, consideration of soil temperature in the selection of planting date, planting of chemically treated seed, the use of soil fungicides applied in the covering soil at planting for extended protection during seedling development, and the use of MAR

cultivars which have seed and seedling cold resistance and partial resistance to the seedling pathogens.

High quality seed are more resistant to low temperatures and their seedlings less susceptible to attack by soilborne organisms. In selecting planting date relative to soil temperature, it is recommended that only high quality seed be used in early plantings since they can escape the disease when soil temperatures (16-18°C) are less favorable to the pathogens. Bird (12) attributed a 77% gain in yield to disease escape from cottons developed in the MAR program. It is recommended that a combination of two or more fungicides (both seed treatment and soil granule formulations) effective against both R. solani and P. ultimum be utilized (15,31,47,55). These include among others, Pentachloronitrobenzene (PCNB), and Chloroneb (demosan) for R. solani, and Fenaminosulf, Apron, and Captan for P. ultimum.

Resistance to the Seedling Disease Complex

Several researchers in the United States and other parts of the world have reported resistance to seedling pathogens. In screening 650 strains and cultivars of cotton from several countries, for cold tolerance and resistance to the seedling disease complex, it was shown that some Arkot lines exhibited resistance to P. ultimum and moderate tolerance to R. solani (30). Hefner (38)

reported variation among cotton lines with similar seed history for resistance to pre-emergence and post-emergence damping-off induced by R. solani. Johnson (41) found eight out of 27 commercial cultivars assessed for hypocotyl resistance to P. ultimum to be significantly more resistant than Stoneville 603; however, all cultivars were susceptible to R. solani. Dixie King III has been shown to possess resistance to both P. ultimum and R. solani (15). Resistance levels among the MAR cottons to the seedling disease complex have been increased and diversified (15). Minton and Garber (47) reported that three MAR cotton cultivars had significantly higher numbers of surviving seedlings than the Acala's and a Mississippi commercial cultivar in a California field naturally infested with R. solani, P. ultimum and T. basicola. Bush, et al. (21) observed variability in resistance to R. solani in soils infested with 42 propagules/100 g of soil amongst 37 MAR cultivars, with Tamcot CAMD-E and TX-LEBO-1-76 being most resistant. In assessing the resistance of 15 cultivars to R. solani under two temperatures and inoculum levels of 30 and 62 propagules/100 g of soil, Wallace, et al. (56,57) found that the MAR cultivars GN-8-76, Tamcot CAMD-E and Tamcot SP 37 had 73%, 63% and 64% higher emergence, respectively, than the non-MAR cultivars DES 56 (33%) and Lankart 611 (35%). Tamcot SP-37 and Tamcot SP-21S produced high stands at both temperatures. The MAR

cottons had lower incidence of damping-off and seed rot than non-MAR cultivars (56,57).

Interrelationships of Seed and Seedling Traits
with Seedling Disease

The genetic improvement of cotton in the MAR program is based on the proper combinations of favorable seed and seedling traits that are interrelated and associated with resistance to several pathogens, stand establishment, earliness and yield (14). Seed and seedling traits that have been shown to be positively and/or negatively associated with the seedling disease complex include seed weight, seed mold, seed rot, damping-off, root length, root grade, rate of germination, seedling emergence, weight of seedling and cotyledons, and components of seed and root leachates (10,13,20,53,58). Bird (13) established a relationship of surviving cotton plants with weight/100 g of seed of seven cotton cultivars. A negative association between seed weight and final stand and a positive relationship between seed weight and post-emergence damping-off was demonstrated. Slow seed germination and low moldy seed in a laboratory germinator, are favorably associated with field stands 28-45 days after planting (13,14). Post-emergence damping-off was positively related with early emergence. Tsai and Bird (53) reported that a combination of low concentrations of magnesium and sodium ions in the seed leachate, low dry

weight of seedling roots, low concentration of carbohydrate and sodium ions and high concentration of calcium and magnesium in the root leachates indirectly, through advantageous microbial competition, resulted in low frequencies of R. solani on seedlings. High bacterial populations and high actinomycete populations were associated with low and high seedling root disease grade, respectively. Low post-emergence damping-off and high stands (seedling survival) were associated with high bacterial and low actinomycetes population. In laboratory germinator studies, Batson (10) showed high coefficient of velocity of germination (rapid germination) to be associated with low pre-emergence damping-off and high emergence. Cotton strains with high percentages of abnormal radicles could have a high incidence of pre-emergence damping-off in the field. Batson (10) associated low post-emergence damping-off in a field study at McGregor, Texas to slow germination, low leachate resistance and a low succulence index. The combination of a rapidly germinating seed and a hardening-off of a root-hypocotyl tissue is believed to favor low post-emergence damping-off. Of the two locations used, disease incidence was low at McGregor and high at College Station. High initial emergence was associated with high final stand at McGregor, but not at College Station, indicating that in the presence of a severe disease condition, rapid emergence was

undesirable. Using 23 MAR and two non-MAR cotton cultivars, Bush (20) found that a high ratio of rhizoplane bacteria to rhizoplane actinomycetes from 18-day-old plants were associated with high incidence of damping-off. Increased numbers of rhizosphere and rhizoplane actinomycetes from 18-day-old plants were associated with high stands. High levels of calcium ion in the root zone was associated with less damage to cotton seedlings by R. solani; however, high levels of sodium ion and rhizosphere actinomycetes increased root damage by R. solani (20). In studying the relationships between laboratory and field measurements for seed and seedling traits from selected MAR and non-MAR cotton cultivars, Wallace, et al. (58) found that coefficient of velocity of germination (C.V.G) at 17°C in a laboratory germinator was negatively correlated with emergence and stand in the field. Low emergence and stand, and high seed rot, measured in the temperature tank at 17°C, were associated with high stand in the field. Low damping-off and healthy roots (low root grade) at 20°C, and long roots at 17°C in the temperature tank, were associated with high stands in the field. Variability in field emergence was best explained by slow seedling emergence (low C.V.E), high stand, healthy roots, and high damping-off in the temperature tank. The same traits with the addition of long roots and a high C.V.G explained 97% of the variability in field stand. High

damping-off in the temperature tank was associated with high emergence and stand in the field. Low damping-off in the field was best explained by slow rate of seedling emergence (low C.V.E), less seed rot, long and healthy roots in the temperature tank and a fast germination (high C.V.G) in the germinator (56).

Inheritance of Seed and Seedling Disease Traits
Associated with Resistance to the Seedling Disease Complex

Within the framework of the MAR program, associations among genes conditioning resistance to the different cotton pathogens have been measured and these form the genetic interrelations which are the basis for the selection procedures used (11,14). These associations include genes conditioning resistance to two or more pathogens, and genes conditioning a mechanism which is effective against several pathogens.

Abd-Alla (2) showed that most seed and seedling disease escape traits were polygenically inherited. Overdominance was indicated for electrical resistance of seed leachates, moldy seed, and days to emergence; complete dominance for seed weight; and partial dominance for percent germination and days to germination. None of the genetic components for percent emergence, damping-off and final stand were significant. A complex of minor and modifying genes has a direct favorable effect on electrical resistance of seed leachates, percent moldy seed, days

to emergence, and root types which indirectly affects the control of cotton seedling disease (2). In a four parent diallel cross it was found that maternal effect was significant only for moldy seed and non-maternal reciprocal differences were indicated for mold growth on seed (1,3,4). No maternal effect was measured for seed weight, days to germination, electrical resistance of seed leachates and root types (1,3,4). In a seven-parent diallel set of crosses, Abd-Alla (2) reported maternal and paternal effects for some of the traits studied. Maternal effects were significant for percent moldy seed and days to germination but not significant for percent emergence, damping-off and final stand.

Bourland (17) showed that seed weight was controlled by large additive and dominance effects, while duplicate gene action and epistasis were proposed for root grade and stand establishment in temperature tank tests. He concluded that low seed weight and short root length are important traits in explaining variability in damping-off and stand establishment in the field. El-Zik and Bird (28) showed that stand ability of cotton is quantitatively inherited and mainly attributed to the dominance effect of genes. Coefficient of velocity of emergence (C.V.E) was found to be greatly influenced by environment. Emergence and final stand were controlled by a minimum of four and three genes, respectively, that exhibit overdominance or

epistasis (28). Studies to determine the number of genes controlling post-emergence damping-off were inconclusive (28). Inheritance studies (26) indicated that large amounts of additive, dominance, and additive by additive epistatic effects were present for seedling root length and relative root weight. It was reasoned that plants with long roots and high relative root weight should possess increased levels of a mechanical resistance to the seedling disease complex (26).

The Diallel Crossing System - Theory and Analysis

The term "diallel analysis" refers to any one of several procedures by which genetic variances are partitioned from diallel crosses. Griffing (32) defined a diallel crossing system as one in which a set of (p) inbred or homozygous lines are chosen and all possible crosses among them are made. A complete diallel has p^2 combinations including parents, one set of F_1 's and reciprocal F_1 's. A "diallel table" is an arrangement in a square of p^2 measurements corresponding to the crossing combination on a one-to-one basis. Each row and column is an array. An array is defined as one parental line and all the crosses involving it.

The diallel crossing system has been recognized as a valuable tool by plant and animal breeders, geneticists and other related disciplines, in early generation evalua-

tion of parental materials, the investigation of general and specific combining abilities, genotype-environmental interactions and the investigation of the mode of inheritance and gene action conditioning the expression of quantitative traits (23,32,33,34,35,36,40,60).

The diallel analysis of Jinks (40) and Hayman (33,34,35,36) provides information about the genetic systems controlling the expression of biometrical traits amongst sets of parental lines and their group of crosses. This analysis gives information about the average additive effects of genes, effects of heterozygosity, and dominance effects (interallelic interactions) of genes. High expression of a trait in a cross can thus be attributed to either heterozygosity, additivity of gene action, or non-additivity of gene action, that is, epistasis if the non-additivity is between loci or to dominance relationships if the non-additivity is within loci. Where the dominance relationships are expressed, the high manifestation may be due to dominant genes, to recessive genes, or to a balanced grouping of dominant and recessive genes.

The diallel assumptions on which Hayman (34) and Jinks (40) based their biometrical genetic model are:

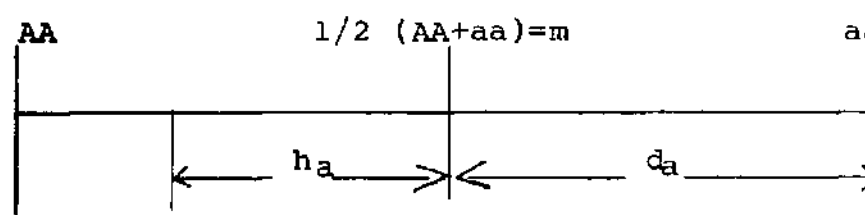
1. Homozygous parental lines or inbreds
2. Diploid segregation
3. Only environmental differences between reciprocal crosses

4. Independent action of non-allelic genes, that is, no epistasis
5. No multiple allelism
6. Genes independently distributed between the parents, that is, uncorrelated gene distributions

Valid and adequate statistical analysis and their corresponding genetic interpretations is to be based on whether or not the parents chosen are from a fixed or random populations (9). In fixed models, the parental lines constitute the whole population about which inferences are to be made, while in random models, the parents are random sample from the population.

When parental and F_1 populations are used, the analysis of variance of the diallel tables provides a test for additive, dominance, and maternal effects, as well as reciprocal differences. Alternatively, the genetic system can be analyzed and estimates of the genetic parameters D , $\hat{F}$, $\hat{H}_1$, and $\hat{H}_2$ and h obtained, whose genetic content is interpretable on the basis of the diallel theory. Graphs may also be constructed and the data interpreted in terms of the genetic control of the character under investigation. An extension of the analysis to the F_2 generation by Hayman (35,36) provides adequate investigation of the presence of epistatic effects (non-allelic interactions) in the F_2 diallel analysis which may not be detected in the F_1 diallel analysis.

When the validity for the assumptions of the diallel analysis is satisfied, the contribution of one locus represented by two alleles (A,a) to the family means in a p^2 diallel cross may be described in terms of the parameters $\hat{u}_a$, $\hat{v}_a$, $\hat{d}_a$, and $\hat{h}_a$, where $u+v=1$ and illustrated on a basis of additive-dominance model using a scale below:



Here, $\hat{u}_a$ is the frequency of parents that are AA, $\hat{v}_a$ is the frequency of parents that are aa, $\hat{d}_a$ is the estimator of the additive phenotypic increment of the alleles A and a, and h_a is the estimator of dominance phenotypic increment of the allele A. $\hat{d}_a$ and $\hat{h}_a$ measure additive and dominance deviations, respectively, from the mid-homozygote (m) at locus A. When $h=0$, dominance is absent and the genetic variance is totally additive and when $h=d$, dominance is complete. For genetic traits under the control of many genes, dominance variation is the summation of the individual dominance components. Dominance may occur in a positive or negative direction, by increasing and decreasing the phenotypic expression of the trait, respectively. Thus, the overall effect of dominance summation may even be the apparent absence of dominance.

By using F_1 data, the diallel cross components of variance, D (additive gene effects), H_1 or H_2 (dominance gene effects), h^2 (the summation of dominance deviations over all loci) and F (the mean covariation of additive and dominance effects over all arrays and an indicator of the relative frequencies of dominant and recessive alleles in the parents) can be estimated (33,34,40). All of these components are overall measures of gene action. The component E is an estimate of non-heritable or environmental effects. The F_2 diallel analysis provides estimates of D , F , H_1 and H_2 and the test of epistasis (35).

Another important feature of the diallel analysis is that genetic information can be obtained from the graphic analysis of V_r and W_r . V_r is the variance of the components of each parental array, that is, the offspring and W_r is the covariance between the offspring in each parental array and the non-recurrent parents. El-Zik (27) and Whitehouse, et al. (60) described how the genetic information can be estimated based on Jinks and Hayman models. If the assumptions of the diallel analysis are valid, the quantity $(W_r - V_r)$ is constant over arrays and equal to $1/4(D - H_1)$. Thus $W_r = V_r + \text{constant}$, and the regression of W_r and V_r is a straight line of unit slope. The relative positions of the array points along the regression line depend on the relative proportion of dominant and recessive alleles present in the common parent of each array. Thus,

points with lower values of V_r and W_r corresponds to dominant parents and points with higher values correspond to recessive parents. Consequently, the distance between the points provides indication of the genetical diversity among the parents.

As the regression of (V_r, W_r) agrees with slope of one, the genetic system can be deduced to be additive without the complication of gene interactions (27,60). If dominance of the gene(s) is complete, the line with slope $b=1$ would pass through the origin, while partial dominance ($H_1 < D$) shifts the line above the origin, and overdominance ($H_1 > D$) the line would cut the W_r axis below the origin. In the absence of dominance, the points would cluster about the position where the slope of the parabola ($W_r^2 = \bar{V}_p V_r$) is +1 and there is no regression. $\bar{V}_p$ is the variance of the parental means. The position of the line, being near to that of a tangent to the parabola, indicates little dominance. Non-allelic interactions leads to a deviation from the unit slope, giving a slope less than unity.

Combining ability analysis as proposed by Sprague and Tatum (52) and expanded by Griffing (32) is another approach of analyzing diallel data. Sprague and Tatum (52) defined "general combining ability" as the average performance of a parental line in hybrid combination and "specific combining ability" as those cases in which cer-

tain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines.

Griffing (32) defined four experimental methods of combining ability analysis based on both fixed and random effects models. These are: 1) parents, one set of F_1 's and reciprocal F_1 's are included (all p^2 combinations); 2) parents and one set of F_1 's are included but reciprocal F_1 's are not ($1/2 p (p+1)$ combinations); 3) one set of F_1 's and reciprocals are included but not the parents ($p (p-1)$ combinations); and 4) one set of F_1 's but neither parents nor reciprocal F_1 's is included ($1/2 p (p-1)$ combinations).

The experimental method 4 (fixed effect model) is the most common diallel crossing design for analyzing general (g.c.a) and specific (s.c.a) combining ability effects of parental and cross combinations, respectively. There are $a = p (p-1)/2$ different F_1 mean values. The model for the combining ability analysis is

$$x_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc} \sum_{kl} e_{ijkl}$$

where

x_{ij} = means of the F_1 resulting from crossing the i^{th} and j^{th} parent.

μ = population mean.

g_i and g_j = general combining ability (g.c.a) effects of the i^{th} and j^{th} lines

s_{ij} = s.c.a effect such that $s_{ij} = s_{ji}$

b = number of blocks

c = number of observations

e_{ijkl} = error effect peculiar to the $ijkl^{th}$ individual observation.

The restrictions imposed on the combining ability effects are:

$$\sum g_i = 0 \text{ and } \sum_{i \neq j} s_{ij} = 0 \text{ (for each } j \text{)}.$$

When a set of inbred lines are used in a diallel crossing system, a genetic interpretation in terms of quantitative inheritance is made possible by the fact that the analysis is really a "gamete" combining ability analysis (32). Thus, genetic properties of a diploid individual may be regarded as the combination of the genetic properties of the two gametes which united to form the individual (32). Griffing (32) considers the genotypic effects of an individual or parental line in the statistical analysis as the summation of effects contributed by each gamete, that is, set of genes in the gamete and the interaction between the set of genes.

MATERIALS AND METHODS

Genetic Material

Parental Selection

Six cotton cultivars were selected as parental material for this investigation. Three of the parents are MAR cultivars and represent different hybrid-pools of the MAR program. The other three are non-MAR cultivars. The cultivars possess a range of resistance and susceptibility to the seedling disease pathogens R. solani and P. ultimum. The following is a brief description of the six cotton cultivars used as parents in this investigation:

1. Dixie King III - a commercial (non-MAR) cultivar that possesses resistance to P. ultimum and R. solani.
2. Acala SJ-5 - a commercial (non-MAR) cultivar susceptible to R. solani and P. ultimum.
3. Lankart 57 - a commercial (non-MAR) cultivar susceptible to R. solani and P. ultimum.
4. Tamcot SP-37 - a commercial (MAR) cultivar with low to partial resistance to R. solani and P. ultimum.
5. Tamcot CAMD-E - a commercial (MAR) cultivar with resistance to R. solani and partial resistance to P. ultimum.
6. TX-LEBO-3-80 - a MAR cotton line with resistance to R. solani and partial resistance to P. ultimum.

Development of Genetic Population

All possible crosses among the six parents were made in the field in 1982 to produce the F_1 generation. The parents and F_1 's were then planted in the field in 1983 and all crosses made again with selfing of the parents and F_1 's to produce the necessary seed of the parents, F_1 and F_2 generations for a six-parent diallel cross with no reciprocals. This gave a total of 36 entries (six parents, 15 F_1 's and 15 F_2 's). Crossing was done by the thumbnail emasculatation-soda straw method, while selfing was accomplished by sealing flower corollas with a tagged wire prior to anthesis. Selfed seed were obtained from the parental plants used for crossing. The various populations were harvested in order of boll maturity and opening. These bolls were then bulked for each entry. The seed were ginned on a roller gin, acid-delinted, and stored in metal boxes in an air conditioned laboratory.

Inoculations and Disease Assessment

Inoculum Preparation

Choosing Isolates

Two isolates representing a range of variability in virulence of R. solani and P. ultimum were used in a preliminary evaluation to determine the reactions of the parental lines. The two isolates of R. solani were from

Texas and California. The P. ultimum isolates were from Texas and Tennessee. Both pathogens were isolated from diseased cotton seedlings. Four inoculum densities of 25, 50, 75, and 100 propagules of each pathogen were evaluated in the preliminary tests. The Texas isolates of both R. solani and P. ultimum adequately differentiated susceptibility and resistance among the parental lines at inoculum densities of approximately 48 propagules per 100g of soil and 50 propagules per 1.0g of soil, respectively. The Texas isolates and the 48 and 50 inoculum densities were used for the experiments conducted in the controlled temperature water bath tanks.

Increasing and Establishing Inoculum Densities

Inoculum for each fungal isolate was increased in non-sterile Houston black clay soil in plastic containers. Non-sterile soil was used to mimic natural field conditions. More importantly, studies (10, 20, 53) have indicated that resistance to seedling pathogens in MAR cultivars is due to selected favorable rhizoplane-rhizosphere bacteria, actinomycetes, and fungi populations which are highly competitive with root pathogens (20, 24). This natural interaction would not be possible if a sterilized soil medium was used. Inoculum densities for each fungus were thus increased with minimum disruption of the natural soil flora.

Rhizoctonia solani

For R. solani, cotton seedlings grown on potato carrot dextrose agar (PCDA) and infested with a 4 mm plug of the pure Texas isolate, was added to the Houston black clay soil after maceration and mixing prior to planting. The soil was densely planted to untreated seed of Lankart 57, a known susceptible cotton cultivar. Twenty-one days after planting, the stems and leaves of the damped-off seedlings were removed leaving the roots infested with R. solani in the soil. This soil was thoroughly mixed in a concrete mixer to insure uniform distribution of R. solani propagules. Determination of inoculum densities expressed as propagules per 100 g of soil (dry-weight basis) was made according to Weinhold (59). To establish appropriate inoculum densities for experimental covering soil, dilutions of the infested soil with non-sterile Houston black clay soil, and subsequent bioassays were conducted.

Pythium ultimum

A pure culture of the Texas P. ultimum isolate was used for increasing propagule levels (oospores and sporangia) prior to soil infestation. Four millimeter cores of the isolate was inoculated and grown in 12 ml V8-cholesterol (β -sitosterol) broth (200 ml V8 vegetable juice, 800 ml distilled water, and 2.5 g of CaCO_3 solution clarified by centrifugation at 13,000 g for 30 minutes) in

sterile petri dishes, and incubated in the dark at 20°C for three weeks (8). The culture mats with high populations of oospores and sporangia were then covered with non-sterile soil extracts to lyse the mycelial mats and induce conversion of "thick-walled" oospores to "thin-walled germinable oospores". Lysed mats were blended and suspensions passed through cheesecloth two or three times to remove most mycelial fragments. Non-sterile Houston black clay soil was infested with the suspensions of oospores and sporangia. Untreated cottonseed of Lankart 57 were then planted in the infested non-sterile Houston black clay soil in plastic containers. Twenty-one days after planting, the stems and leaves of damped-off seedlings were removed leaving the roots infested with P. ultimum in the soil. The infected soil was bioassayed to determine the inoculum density per gram of soil according to Mircetich and Kraft (49) using the selective medium developed by Mircetich (48). In establishing appropriate inoculum densities for the experimental covering soil, the infested soil was diluted with non-sterile Houston black clay soil, and subsequent bioassays were conducted.

Experiments

The experiments were conducted in controlled temperature water bath tanks and in the field.

Temperature Controlled Tank Experiments

The water of the tanks was controlled to maintain soil temperature at $20 \pm 1^{\circ}\text{C}$ for both R. solani and P. ultimum. Four replications for each pathogen were used in the experiment. Entries were assigned at random. Twenty acid-delinted seed of each entry were planted in metal trays (33x9x11.5 cm). Houston black clay soil was used as the planting medium. The metal trays were filled to three-quarters its volume. Using a two-row seed-template, the twenty seed of each entry were planted with a distance of 2 cm between seed within and between rows. For each fungal pathogen, the metal trays were then covered with infested non-sterile Houston black clay soil with the appropriate inoculum density to a depth of 1.9 cm. The trays were placed in the temperature tank with their soil lines at the water level. An initial watering of 300 ml was made by pouring water down a uniformly perforated plastic container, with bottom area matching that of the top of the metal trays. After 4-6 days, the frequency of watering was determined by the rate of evaporation from the soil-surface in the trays. For P. ultimum, the frequency of watering was higher than for R. solani. Two runs of the experiment were conducted for each of R. solani and P. ultimum.

Rhizoctonia solani

In the case of R. solani, the covering soil for run 1 and run 2 were adjusted to approximate inoculum densities of 49.5 and 48.9 propagules per 100 gram of soil, respectively. Run 1 was planted on 19 December, 1984 and run 2 on 17 January, 1985.

Pythium ultimum

For P. ultimum, run 1 and run 2 had inoculum densities of the covering soil adjusted to 50 and 52 propagules per 1.0 gram of soil, respectively. Seeds were planted on 19 March and 4 May, 1985 for run 1 and run 2, respectively. All experimental runs were terminated after 25 days.

The following traits were measured for each of R. solani and P. ultimum.

- a) Coefficient of velocity of emergence (C.V.E)-based on daily counts of emergence from planting through day 25, using the formula of Kotowski (44).
- b) Emergence - the number of emerged seedlings (cotyledons above the soil) expressed as a percentage of the number of planted seed.
- c) Pre-emergence damping-off - total number of seed that did not germinate and rot, and of young seedlings that died before emergence expressed as percent of seed planted.
- d) Post-emergence damping-off - emerged seedlings dead at the end of 25 days expressed as percent of all emerged seedlings.

- e) Hypocotyl lesion grade - the severity of the lesions was assessed on a 1-7 scale:
1. no apparent lesions on the hypocotyl
 2. small localized lesions
 3. small to medium coalesced necrotic lesions, less than 0.5 cm in length, $\leq$ 50% of hypocotyl girdled
 4. medium necrotic lesions, about 0.5 cm in length, 51-75% of hypocotyl girdled
 5. medium to large necrotic lesions, 0.5 - 1 cm in length, 76-100% of hypocotyl girdled; no apparent wilting of the seedlings
 6. severe and extensive necrotic lesions, 100% girdling of the hypocotyl, plants wilted with cotyledons drooping
 7. dead seedling
- f) Root grade - the extent of damage was assessed on a 1-7 scale:
1. no apparent lesions on root
 2. small localized lesions on root
 3. light discoloration of root
 4. moderate discoloration of root
 5. heavy discoloration of root
 6. death of most root system, seedling still alive
 7. dead seedling
- g) Final stand - the proportion of seed planted that gave live seedlings at the end of 25 days.

Field Experiments

Field experiments were conducted at College Station for two years (1984 and 1985). Acid-delinted seed of each

entry were planted in a completely randomized block design with four replications at a rate of 100 seed per plot. Each block consisted of 36 single-row plots measuring 12.2 x 1m. Seed were planted on 4 April, 1984 and on 5 April, 1985.

The following traits were measured:

- a) Emergence - determined 25 days after planting
- b) Pre-emergence damping off
- c) Post-emergence damping-off
- d) Final Stand - determined 50 days after planting

Statistical and Genetic Analyses

Data for each trait obtained from each experimental run for both R. solani and P. ultimum were analyzed by analysis of variance (ANOVA) using plot means. A combined ANOVA over runs was obtained for each pathogen. Significant differences among parents, F_1 and F_2 generations were determined by Duncan's multiple range test. Simple correlation coefficients and step-wise multiple regression coefficients were calculated to determine the associations among traits and identify traits that are best for measuring resistance. Significant differences among F_1 means for any trait was used as a basis for the analysis of combining ability effects.

The diallel analysis, as developed by Jinks (40) and Hayman (33,34) for parental and F_1 data was used to test

the validity of the assumptions upon which the biometrical model is based and also to estimate genetic parameters. The analysis of the data was accomplished by use of the F_1 (no reciprocals) FORTRAN diallel program developed by K.M. El-Zik and B.L. Lisenbe (unpublished, Texas A&M University Data Processing Center). Based on the diallel theory (34,36,40), the following tests and parameters were estimated:

1. Test of W_r-V_r for homogeneity. This was carried out by analysis of variance. The W_r-V_r must be homogeneous over arrays for the assumptions to be valid. Heterogeneity indicates failure of one or more of the assumptions.
2. Estimation of the genetic components of variance: D (additive component), F (indicator of excess of positive or negative alleles in parents), H_1 and H_2 (both are dominance components), h^2 (overall dominance component variation) and calculations of their standard errors. The environmental variances (E) were estimated from error mean squares from the ANOVA. For the combined data analysis, the parental and F_1 (E) values were obtained from ANOVA using averages over runs.
3. Genetic estimators and ratios - The following estimators and ratios were obtained:

$$i) (H_1/D)^{1/2} = \text{weighted measure of the average degree of dominance at each locus}$$

when

$H_1/D = 0$ indicates no dominance

$0 < H_1/D < 1$ indicates partial dominance

$H_1/D > 1$ indicates overdominance

ii) $H_2/4H_1 = \overline{uv} \leq 0.25$ is an estimator of the average frequency of negative versus positive alleles at loci exhibiting dominance. It has a maximum value of 0.25 when $u=v=1/2$

iii) $\frac{K_D}{K_R} = \frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$ = the ratio of the total number of dominant to recessive alleles in all parents

iv) $\frac{h^2}{\bar{H}_2}$ = an estimator of the number of groups of genes which control the trait and exhibit dominance to some degree

v) (W_r+V_r) = an estimator of the parental order of dominance. Low values indicate high levels of dominance, while high values indicate low dominance.

vi) Estimates of heritability were calculated using the formula of Crumpacker and Allard (23):

$$\text{Heritability} = \frac{1/4D}{1/4D - 1/4F + 1/4H_1 + E}$$

vii) $r(\bar{y}, W_r+V_r)$ = a measure of direction of dominance is indicated by the correlation of the mean parental phenotypic values ($\bar{y}$) and (W_r+V_r) values. A correlation of +1 indicates that the recessive genes have positive effects. Small r values indicate equal portions of the dominance genes have positive and negative effects (33,34).

Hayman's (35) F_2 diallel analyses were processed utilizing a FORTRAN program developed by K.M. El-Zik and B.L. Lisenbe (unpublished, Texas A&M University Data Processing

Center). Outputs from this program include genetic components of variation (D , F , H_1 and H_2) and environmental variances E_0 , E_1 and E_2 . Chi-square analysis for test of epistasis, and detailed analysis of variance of residuals to test for epistasis, multiple alleles, gene correlation, and parental heterozygosity were made.

Chi-square values were obtained from the $2L_2-L_1$ diallel table. An L_1 diallel table consists of the F_1 family means together with the parental means on the leading diagonal, while the table of the F_2 means with the parents on the diagonal again is the L_2 diallel table. Chi-square (χ^2) values with $1/2 n (n-1)$ degrees of freedom were obtained from the squares of the deviations of the parental, F_1 and F_2 means from their expectations on the basis of dominance deviations (positive and negative) of genes and additive contributions (positive and negative) of genes, all corrected for E_0 , E_1 , and E_2 . A chi-square value (based on 15 d.f.) were then calculated for each replication and a pooled chi-square was calculated (also based on 15 d.f.). A heterogeneity chi-square was obtained by subtraction (45 d.f.) from the sums of all chi-squares.

Griffing's (32) analysis of variance for combining ability was used to partition genotypic variances of F_1 means into general and specific combining ability effects. Method 4, (set of F_1 but neither parents nor reciprocal

F_1) model one (fixed effect) was used. The source of variation and degrees of freedom are as follows:

ANOVA for combining ability

Source	d.f.
GCA	$p-1 = 5$
SCA	$p(p-3)/2 = 9$
Error	$m = 42$

where p = number of parental lines.

The analysis is only possible when significant differences have been detected among F_1 means for any trait. The analysis was performed using a computer program developed by H.E. Schaffer and R.A. Usanis (51). Estimates of general combining ability effects (g) for each parental line was calculated as follows:

$$\hat{g}_i = \frac{1}{p(p-2)} [pX_{i.} - 2X_{..}],$$

where p = number of parental lines;

$X_{i.}$ = summation of F_1 family means for each i^{th} parental array.

$X_{..}$ = grand total for all F_1 family means

Specific combining ability effects ($\hat{s}_{ij}$) of F_1 cross combinations were estimated as follows:

$$\hat{s}_{ij} = x_{ij} - \frac{1}{p-2} (X_{i.} + X_{j.}) + \frac{2}{(p-1)(p-2)} X_{..};$$

where x_{ij} = family mean involving any two parental lines.

$x_{j.}$ = summation of F_1 family means for each j^{th} parental array

Standard errors to test differences between effects were calculated as follows:

$$(1) \quad \text{S.E. } (\hat{g}_{i.} - \hat{g}_{j.}) = \sqrt{\frac{2}{p-2} \cdot MS_E},$$

test for significant differences in g.c.a effects for any two parental lines.

$$(2) \quad \text{S.E. } (\hat{s}_{ij} - \hat{s}_{ij}) = \sqrt{\frac{2(p-3)}{p-2} \cdot MS_E},$$

test for significant differences in s.c.a effects between any two F_1 means involving the same parental line.

$$(3) \quad \text{S.E. } (\hat{s}_{ij} - \hat{s}_{kl}) = \sqrt{\frac{2(p-4)}{p-2} \cdot MS_E},$$

test for significant differences in s.c.a effects between any two F_1 means.

RESULTS

Statistical Analyses

Field Experiments

No significant differences were obtained among the parental lines and their F_1 and F_2 progenies for emergence, pre- and post-emergence damping-off, and final stand for the field experiments conducted at College Station in 1984 and 1985. This could be attributable to the unfavorable environmental conditions of soil temperature and moisture low inoculum density in the field, and variation of pathogen distribution from plot to plot. In 1983, lack of rainfall in the first three weeks after planting, although supplemental overhead sprinkler irrigation was applied, and soil temperatures above 18 - 20°C may have affected inoculum potential and hence disease expression. In 1985, favorable conditions conducive to disease development did not last for a prolonged period for adequate expression of resistance and susceptibility.

Temperature Controlled Tank Experiments

The results of the seed and seedling response of the parental lines and their offsprings to each fungal pathogen are presented for each experimental run and combined over runs. Eight seed and seedling traits for parental,

F₁ and F₂ populations inoculated with R. solani and P. ultimum were analyzed and interpretations made.

Rhizoctonia solani

Experimental Run 1

Significant differences among parental lines were obtained for post-emergence damping-off, final stand, C.V.E, hypocotyl grade, and root grade when inoculated with R. solani at an inoculum density of 49.5 propagules per 100 g of soil (Table 1). Significant replication effects were obtained for emergence, pre-emergence damping-off and C.V.E.

Presented in Table 2, are parental averages for the eight traits. Tamcot CAMD-E gave the highest seedling emergence of 90%, followed by Dixie King III, Lankart 57, TX-LEBO-3-80 and Acala SJ-5, however, the differences in emergence were not significant. Tamcot SP 37 had the lowest seedling emergence of 78.7%. Conversely, Acala SJ-5 had the highest pre-emergence damping-off (21.2%) and Tamcot CAMD-E, the lowest (10%). The fastest rate of seedling emergence (C.V.E) was that of Acala SJ-5, while Dixie King III had the slowest rate. The rates of emergence varied from 11.4 to 12.8. Significant differences among the parental lines were also obtained for post-emergence damping-off, which ranged from 16.1% to 86.7%. Post-emergence damping-off was the lowest for Acala SJ-5

Table 1. Mean squares for eight seedling traits for parental lines inoculated with 49.5 propagules of *R. solani* per 100 g of soil, run 1.

Source	d.f.	Mean Squares							
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade	Root grade
Replication	3	423.61**	423.61**	211.25	597.22	1.75**	8.69	0.39	5.83*
Entry	5	65.00	65.00	3980.55**	2887.50**	1.27**	11.72	10.33**	4.41*
Error	15	37.77	37.77	603.78	471.38	0.27	9.86	1.63	1.16
Total	23	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

† Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 2. Averages for eight seedling traits for parental lines inoculated with 49.5 propagules of *R. solani* per 100 g of soil, run 1.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade	Root grade
1. Dixie King III	85.0	15.0	21.0a§	68.7a	11.4c	4.6	3.3a	2.9ab
2. Acala SJ-5	80.0	20.0	13.3a	68.7a	12.8a	5.0	3.0a	2.8ab
3. Lankart 57	85.0	15.0	69.7b	26.2b	12.7ab	6.7	6.2b	4.5bc
4. Tancot SP37	78.7	21.2	86.7b	11.2b	11.6c	7.5	6.5b	4.8c
5. Tancot CMD-E	90.0	10.0	16.1a	76.2a	12.0bc	3.2	3.0a	2.4a
6. TX-LEBO-3-80	83.7	16.2	23.2a	63.7a	12.2a-c	3.6	3.9a	2.4a
Average	83.7	16.2	38.4	52.5	12.1	5.1	4.3	3.3
C.V.‡	7.3	37.8	63.9	41.3	4.2	60.9	29.2	32.3

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

(13.3%) and Tamcot CAMD-E (16.1%). Damping-off was significantly higher for Tamcot SP 37 (69.7%) and Lankart 57 (86.7%) than the other four parents. The fastest rate of post-emergence damping-off (C.V.D) was recorded for Tamcot SP 37 and Lankart 57, the two cultivars that had the highest post-emergence damping-off.

Final stand in the temperature tank ranged from 11.2% to 76.2%. Final stand establishment is the end result and cumulative action of seedling emergence, pre-and post-emergence damping-off. Differences among the parental lines in final stand were significant. Tamcot CAMD-E gave the highest stand (76.2%), followed by Dixie King III and Acala SJ-5 with equal values (68.7%) and TX-LEBO-3-80 (63.7%). Lankart 57 and Tamcot SP 37 gave the lowest final stand of 26.2% and 11.2%, respectively, which were significantly lower than the stand of the other four parental lines.

Hypocotyl grade ranged from 3.0 to 6.5. Hypocotyl grades of Tamcot CAMD-E, Acala SJ-5, Dixie King III, and TX-LEBO-3-80 were significantly lower than those of Lankart 57 and Tamcot SP 37. Generally, root grade followed the same pattern as hypocotyl grade. Average root grade was lowest for Tamcot CAMD-E and TX-LEBO-3-80 (2.4). Acala SJ-5 and Dixie King III had intermediate root grades. Lankart 57 and Tamcot SP 37 had significantly higher root grades of 4.5 and 4.8, respectively.

Analysis of variance for F_1 generation (Table 3), shows that significant differences were obtained for post-emergence damping-off, final stand, C.V.E, hypocotyl grade, and root grade. Similar results were obtained for the F_2 generation (Table 4). The lack of significant differences for emergence and pre-emergence damping-off among the parents is reflected in their offsprings in both generations.

Averages for traits of the F_1 and F_2 generations are presented in Table 5. The averages of nine F_1 's were higher in emergence than their mid-parents. Eight F_2 's had higher emergence than those of their mid-parents. Emergence of F_1 's ranged from 70% to 93.7%, while F_2 averages ranged from 77.5% to 93.7%. The results indicate that dominance deviation was more towards higher emergence. Overdominance and epistasis are also suggested. In the case of pre-emergence damping-off, nine of the F_1 's were lower than their mid-parent. Eight F_2 's gave lower pre-emergence damping-off than their mid-parental values. There was evidence of transgressive segregation in the F_2 towards higher and lower values. Pre-emergence damping-off for the F_1 's averaged 15.5%, and 16% for the F_2 's. Seven F_1 's and eight F_2 's had less post-emergence damping off than their mid-parents. There was also evidence of transgressive segregation in the F_2 towards both higher and lower incidence of damping-off.

Final stand of eight F_1 's and seven F_2 's was greater than their mid-parents, suggesting overdominance. Final stand ranged from 13.7% to 82.5% for the F_1 and from 1.2% to 87.5% for the F_2 . Dominance deviation was both in the direction of higher and lower final stand. Transgressive segregation was evident in the F_2 's.

Eight F_1 's and seven F_2 's had rates of emergence (C.V.E) that were lower than their mid-parents. Dominance deviation was in both directions, however, more was towards slower rates of emergence. There were no significant differences for the rate of post-emergence damping-off (C.V.D).

Hypocotyl grade, revealed that eight F_1 's and nine F_2 's had lower severity of hypocotyl rot than their mid-parents. Dominance deviation was more in the direction of less hypocotyl rot severity. Transgressive segregation in the F_2 was observed. Six F_1 's and eight F_2 's had root grade values lower than their mid-parents. Dominance deviation was more in the direction of less root rot. Some F_1 's and F_2 's had root grades that were approximately the same as their mid-parents. Both F_1 's and F_2 's averaged 3.4.

Experimental Run 2

The analysis of variance for parental lines inoculated with R. solani at an inoculum density of 48.9 propa-

Table 3. Mean squares for eight seedling traits for F_1 generations inoculated with 49.5 propagules of *R. solani* per 100 g of soil, run 1.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replication	3	75.97	75.97	1754.56	956.67	3.47**	8.85	3.78
Entry	14	161.49	161.49	2640.21**	2318.63**	1.89**	14.04	6.28**
Error	42	92.04	92.04	790.73	691.49	0.44	8.57	2.05
Total	59	-	-	-	-	-	-	-

[†] Coefficient of velocity of emergence

[‡] Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 4. Mean squares for eight seedling traits for F_2 generations inoculated with 49.5 propagules of *R. solani* per 100 g of soil, run 1.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D ⁺	Hypocotyl grade
Replication	3	21.11	21.11	626.95	597.08	4.61**	1.15	2.05
Entry	14	94.82	94.82	2948.64**	2224.88**	2.19**	7.12	6.21*
Error	42	116.65	116.64	896.01	822.98	0.26	10.47	2.51
Total	59	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

+ Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 5. Averages for eight seedling traits of mid-parents, F₁ and F₂ generations inoculated with 49.5 propagules of *R. solani* per 100 g of soil, run 1. (a) Emergence, Pre-emergence damping-off, Post-emergence damping-off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP ^ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	82.5	86.2	85.0	17.5	13.7	15.0	17.2	64.5a-cs	40.1a-d
1 x 3	85.0	76.2	77.5	15.0	23.7	22.5	45.4	36.9a-d	98.3e
1 x 4	81.9	93.7	80.0	18.1	6.2	20.0	53.9	11.9a	70.4de
1 x 5	87.5	82.5	86.2	12.5	17.5	13.7	18.6	45.8a-d	48.8a-d
1 x 6	84.4	85.0	81.2	15.6	15.0	18.7	22.1	40.4a-d	60.0a-e
2 x 3	82.5	82.5	85.0	17.5	17.5	15.0	41.5	22.5ab	11.6ab
2 x 4	79.4	80.7	80.0	20.6	11.2	20.0	50.0	8.0a	53.0a-e
2 x 5	85.0	87.5	90.0	15.0	12.5	10.0	14.7	27.9a-c	13.4a-c
2 x 6	81.9	88.7	82.5	18.1	11.2	17.5	18.3	19.6ab	15.6a-c
3 x 4	81.9	90.0	83.7	18.1	10.0	16.2	78.2	9.8a	16.5a-c
3 x 5	87.9	91.2	93.7	12.5	8.7	6.2	42.9	10.8a	6.8a
3 x 6	84.4	76.2	82.5	15.6	23.7	17.5	46.5	73.7cd	9.6ab
4 x 5	84.4	83.7	78.7	15.6	16.2	21.2	51.4	42.8a-d	62.9cd
4 x 6	81.2	83.7	92.5	18.7	16.2	7.5	55.0	76.9d	29.7a-d
5 x 6	86.9	70.0	81.2	13.1	30.0	18.7	19.7	81.3d	29.7a-d
Average		84.4	84.0		15.	16.0		38.2	37.9
C.V.%		11.3	12.8		61.5	67.5		73.5	79.1

^ψ Mid-parental values.

[§] Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 5. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)			C.V.E. ⁺			C.V.D. [‡]		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	68.7	31.2b-d§	53.7a-c	12.1	12.1c-f	12.2c-e	4.8	6.2	6.2
1 x 3	47.5	51.2a-d	1.2d	12.1	10.7a	11.5a-c	5.7	6.0	7.3
1 x 4	39.9	82.5a	26.2cd	11.5	11.9b-f	12.7ef	6.1	5.4	5.5
1 x 5	72.5	47.5a-d	46.2a-d	11.7	11.8b-f	12.4de	3.9	7.8	6.8
1 x 6	66.2	55.0a-d	37.5b-d	11.8	11.7a-f	12.8ef	4.1	3.5	6.7
2 x 3	47.5	63.7a-c	75.0ab	12.8	11.0ab	11.3ab	5.9	4.5	3.1
2 x 4	39.9	82.5a	38.7b-d	12.2	11.6a-d	12.4de	6.3	3.7	7.4
2 x 5	72.5	63.7a-c	78.7ab	12.4	11.2a-c	11.3ab	4.1	2.9	3.6
2 x 6	66.2	71.2ab	70.0a-c	12.5	12.3c-f	11.8a-c	4.3	3.4	5.9
3 x 4	18.7	81.2a	70.0a-c	12.2	11.4a-c	10.9a	7.1	8.6	4.9
3 x 5	51.2	81.2a	87.5a	12.4	11.4a-c	10.8a	4.9	3.1	5.4
3 x 6	44.9	21.2cd	75.0ab	12.5	12.7ef	11.7a-d	5.2	7.2	4.0
4 x 5	43.7	50.0a-d	33.7b-d	11.8	12.6d-f	13.4f	5.4	5.2	7.2
4 x 6	37.5	18.7d	65.0a-c	11.9	12.7ef	12.2c-e	5.6	7.1	5.5
5 x 6	69.9	13.7d	57.5a-c	12.1	13.0f	11.5a-c	3.4	7.3	5.6
Average		54.3	54.4		11.9	11.9		5.4	5.7
C.V.%		48.4	52.7		5.5	4.2		53.3	56.5

ψ Mid-parental values.

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 5. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade				Root grade			
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₂
1 x 2	3.2	5.7b-ef	4.3a-c	2.9	4.2ab	3.9a-c	2.9	4.2ab
1 x 3	4.8	4.0a-e	6.9d	3.7	3.6ab	6.0c	3.7	3.6ab
1 x 4	4.9	2.9a	5.9cd	3.9	2.1a	3.6a-c	3.9	2.1a
1 x 5	3.2	4.6a-e	5.1a-d	2.7	4.1ab	4.3a-c	2.7	4.1ab
1 x 6	3.6	4.1a-e	4.9a-d	2.7	4.0ab	5.0bc	2.7	4.0ab
2 x 3	4.6	3.9a-d	3.4a-c	3.7	2.7a	2.4a	3.7	2.7a
2 x 4	4.8	2.9a	5.1a-d	3.8	2.3a	3.7a-c	3.8	2.3a
2 x 5	3.0	3.7a-c	3.0ab	2.6	3.5ab	2.6ab	2.6	3.5ab
2 x 6	4.5	3.6ab	3.3a-c	2.6	3.0a	2.3a	2.6	3.0a
3 x 4	6.4	2.8a	3.2ab	4.7	2.1a	2.3a	4.7	2.1a
3 x 5	4.6	3.1a	2.7a	3.5	2.4a	2.0a	3.5	2.4a
3 x 6	5.1	6.1c-e	3.2ab	3.5	4.4ab	2.2a	3.5	4.4ab
4 x 5	4.8	4.7a-e	5.5b-d	3.6	3.8ab	4.2a-c	3.6	3.8ab
4 x 6	5.2	6.3de	3.8a-c	3.6	3.8a	2.7ab	3.6	3.8a
5 x 6	2.3	6.4e	3.8a-c	2.4	6.0a	3.6a-c	2.4	6.0a
Average		4.3	4.3		3.4	3.4		3.4
C.V. %		32.8	36.7		44.2	44.6		44.6

 ψ Mid-parental values.

5 Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

gules per 100g of soil, shows that only significant differences were indicated for hypocotyl grade and C.V.D (Table 6). Presented in Table 7, are parental averages for the eight traits. Dixie King III gave the highest emergence of 81.3%, followed by Tamcot CAMD-E with 76.3%. Acala SJ-5 had the lowest emergence of 63.8%. The fastest rate of emergence (C.V.E) of 12.4 was for Lankart 57, while the slowest rate was for Tamcot SP 37 with a C.V.E of 11.1.

Dixie King III gave the lowest pre-emergence damping-off of 18.8% and Acala SJ-5, the highest (36.3%). Post-emergence damping-off ranged from 14.1% to 45.9%. Tamcot CAMD-E gave the lowest post-emergence damping-off (14.1%). Tamcot SP 37 and Lankart 57 gave the highest damping-off of 45.9% and 37.9%, respectively. Significant differences among the parental lines was obtained for C.V.D. The slowest rate of damping-off (2.9) was for Acala SJ-5, and the fastest rate for Dixie King III (7.8).

Final stand ranged from 40% to 63.8%. Tamcot CAMD-E gave the highest stand (63.8%), followed by TX-LEBO-3-80 and Dixie King III with values of 61.3% and 60.0%, respectively. Tamcot SP 37 and Lankart 57 had the lowest final stand of 40% and 41.3%, respectively.

The differences among parental lines were significant for hypocotyl grade. Acala SJ-5 and TX-LEBO-3-80 gave the lowest hypocotyl grades of 3.6 and 4.1, respectively. The

Table 6. Mean squares for eight seedling traits for parental lines inoculated with 48.9 propagules of *R. solani* per 100 g of soil, run 2.

Mean Squares									
Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade	Root grade
Replication	3	39.93	39.93	372.92	289.38	2.36*	6.71	0.92	0.84
Entry	5	156.04	156.04	636.94	431.87	0.99.	14.59*	1.64*	1.49
Error	15	96.59	96.59	339.90	246.87	0.72	3.86	0.55	0.76
Total	23	-	-	-	-	-	-	-	-

[†] Coefficient of velocity of emergence.

[‡] Coefficient of velocity of post-emergence damping-off.

* Significant at the 0.05 level of probability.

Table 7. Averages for eight seedling traits for parental lines inoculated with 48.9 propagules of *R. solani* per 100 g of soil, run 2.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [‡]	Hypocotyl grade	Root grade
1. Dixie King III	81.3	18.7	25.7	60.0	11.2	7.8b [§]	4.3ab	3.4
2. Acala SJ-5	63.8	36.2	20.7	52.5	11.5	2.9a	3.65a	3.9
3. Lankart 57	67.5	32.5	37.9	41.3	12.4	7.5b	5.1b	4.2
4. Tamcot SP37	73.8	26.2	45.9	40.0	11.1	6.9b	5.1b	4.7
5. Tamcot CMD-E	76.3	23.7	16.4	63.8	11.5	7.7b	4.1ab	3.1
6. TX-LEBO-3-80	71.3	28.7	14.1	61.3	11.9	7.7b	3.8a	3.3
Average	72.3	27.7	26.7	58.1	11.6	6.8	4.3	3.8
C.V.%	13.6	35.5	68.8	29.5	7.3	28.9	17.2	23.2

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

significantly highest hypocotyl grade of 5.1 was for Lankart 57 and Tamcot SP 37. Average root grades were lowest for Tamcot CAMD-E (3.1) and TX-LEBO-3-80 (3.3). Lankart 57 and Tamcot 37 gave the highest root grades of 4.2 and 4.7, respectively.

Presented in Table 8 are the mean squares for the eight seedling traits for the F_1 generation. Significant differences among the F_1 's was indicated only for C.V.E. For all the other traits, the magnitude of the mean squares for replication and the error term were high. The analysis of variance for the F_2 generation reveals that C.V.E and C.V.D were the only traits with significant mean squares (Table 9).

Averages for traits of the F_1 and F_2 generations are presented in Table 10. Nine F_1 's and fourteen F_2 's had higher emergence than their mid-parents. Thus, the direction of dominance deviation was towards higher emergence and overdominance was apparent. Averages of F_1 ranged from 57.5% to 83.7%, while F_2 averages ranged from 70% to 86.3%. A similar trend towards lower pre-emergence damping-off was observed for the F_1 's and F_2 's. Dominance deviation was more towards lower pre-emergence damping-off. For post-emergence damping-off, seven F_1 's and ten F_2 's had values lower than their mid-parents. Dominance deviation was in both directions. Only three F_1 's and

four F_2 's had values that were lower than the lowest mid-parent. The F_1 's averaged 26.5%, and the F_2 's 20.8%.

Seven F_1 's and twelve F_2 's had higher final stand than those of their mid-parents. Dominance deviation was in both directions. The F_1 's averaged 54.3% and the F_2 's 64.5%. Six F_1 's and nine F_2 's had final stand lower than their mid-parents. Dominance deviation for C.V.E was in both directions of reduced and increased rates of emergence. The rate of post-emergence damping-off (C.V.D), of eleven F_1 's and F_2 's were lower than their mid-parent. Two F_1 's and eleven F_2 's had hypocotyl grade values lower than their mid-parents. Segregation in the F_2 's was more towards lesser hypocotyl rot severity. Similar trends as that of hypocotyl grade was obtained for root grade.

Combined Analysis Over Run 1 and Run 2

An analysis was made of the seedling trait data combined over the two runs. The combined data would be analagous to variation over locations and years which reflects environmental conditions and factors that may be favorable and unfavorable for disease development and the expression of resistance. It was observed, that while significant differences between parental F_1 's and F_2 's were obtained only for run 1, similar trends were obtained for run 2.

Table 8. Mean squares for eight seedling traits for F_1 generations inoculated with 48.9 propagules of *R. solani* per 100 g of soil, run 2.

Mean Squares									
Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade	Root grade
Replication	3	168.19	168.19	509.24	371.53	5.71**	3.49	0.78	1.69
Entry	14	187.02	187.02	391.27	260.54	0.95**	5.17	1.24	1.19
Error	42	168.61	128.61	425.91	373.31	0.20	8.03	0.76	0.95
Total	59	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 9. Mean squares for eight seedling traits for F_2 generations inoculated with 48.9 propagules of *R. solani* per 100 g of soil, run 2.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. ⁺	C.V.D. [‡]	Hypocotyl grade
Replication	3	79.31	79.31	1524.22	983.89	5.59**	11.69	2.59
Entry	14	122.14	122.14	476.31	499.82	1.63**	14.48*	1.57
Error	42	128.41	128.41	340.68	369.90	0.31	6.94	1.04
Total	59	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 10. Averages for eight seedling traits of mid-parents, F₁ and F₂ generations inoculated with 48.9 propagules of *R. solani* per 100 g of soil, run 2. (a) Emergence, Pre-emergence damping-off, Post-emergence damping-off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	72.5	68.8	76.3	27.6	31.3	23.8	23.2	31.4	34.7
1 x 3	74.4	77.5	82.5	25.7	22.5	17.5	31.8	31.8	36.5
1 x 4	77.6	57.5	86.3	22.6	42.5	13.8	35.8	30.2	7.2
1 x 5	78.8	83.7	85.5	21.3	16.3	15.0	21.1	44.6	11.6
1 x 6	76.3	70.0	78.8	23.8	30.0	21.3	19.9	31.4	15.8
2 x 3	65.7	75.0	77.5	34.4	25.0	22.5	29.3	20.5	26.7
2 x 4	78.8	73.8	86.3	31.3	26.3	13.8	33.3	12.9	17.2
2 x 5	70.1	68.8	82.5	30.1	31.3	17.5	18.6	24.3	20.8
2 x 6	67.6	75.0	70.0	31.6	25.0	30.0	17.4	27.7	23.1
3 x 4	70.7	81.3	72.5	29.4	18.8	27.5	41.9	38.5	13.4
3 x 5	71.9	77.5	71.3	28.2	22.5	28.8	27.1	31.5	42.0
3 x 6	69.4	63.8	86.3	30.7	36.3	13.8	25.9	14.8	2.6
4 x 5	75.1	78.8	80.0	25.1	21.3	20.0	31.2	6.9	20.9
4 x 6	72.6	77.5	75.0	27.6	22.5	25.0	30.0	24.5	16.7
5 x 6	73.8	72.5	78.8	26.3	27.5	21.3	15.3	32.5	15.1
Average		73.4	79.3		26.6	20.8		26.9	20.3
C.V. %		15.5	14.3		42.7	54.6		76.7	90.9

ψ Mid-parental values.

Table 10. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)			C.V.E. ⁺			C.V.D. [‡]		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	56.3	47.5	51.3	11.4	11.3b-d §	11.7ef	5.4	7.1	7.9a
1 x 3	50.7	52.5	53.3	11.8	10.5a	11.1c-e	7.7	6.7	5.4a-c
1 x 4	50.0	42.5	80.0	11.2	11.1b-d	11.2c-e	7.4	5.7	7.5bc
1 x 5	61.9	46.3	75.0	11.4	11.86d-h	12.3f	7.8	6.0	5.0a-c
1 x 6	60.7	48.8	66.3	11.6	12.2h	11.8ef	7.3	7.3	7.7c
2 x 3	46.9	60.0	60.0	11.9	10.7ab	11.4ef	5.2	5.5	5.1a-c
2 x 4	46.3	65.0	72.5	11.3	11.3	11.5ef	4.9	3.1	2.6ab
2 x 5	58.2	52.5	66.3	11.5	11.5c-g	10.7a-d	5.3	7.9	6.1bc
2 x 6	56.9	53.8	55.0	11.7	12.0gh	11.7ef	5.3	5.9	5.5a-c
3 x 4	40.7	51.3	62.5	11.8	11.1a-c	9.9a	7.2	5.7	4.2a-c
3 x 5	52.6	52.5	42.5	11.9	11.3c-e	10.2ab	7.6	5.4	6.3bc
3 x 6	51.3	55.0	83.8	12.2	11.6c-h	11.5e-f	7.6	6.2	1.4a
4 x 5	51.9	73.8	63.8	11.3	11.4c-f	10.4a-c	7.3	7.2	4.2a-c
4 x 6	50.7	62.5	62.5	11.5	11.9f-h	11.4d-f	7.3	5.8	3.0ab
5 x 6	62.6	50.0	72.5	11.7	11.9e-h	10.9b-e	7.7	6.9	6.3bc
Average		54.3	64.5		11.4	11.2		6.2	5.2
C.V.%		35.6	29.8		3.5	4.9		45.9	50.5

 ψ Mid-parental values.

+ Coefficient of velocity of emergence.

[‡] Coefficient of velocity of post-emergence damping-off.[§] Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 10. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade				Root grade			
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₂
1 x 2	3.9	4.4	4.9	3.7	3.8	4.1	3.7	4.1
1 x 3	4.7	4.5	4.5	3.8	4.1	4.0	3.8	4.0
1 x 4	4.7	4.8	3.3	4.1	4.4	2.8	4.1	2.8
1 x 5	4.2	5.4	3.6	3.3	4.4	2.9	3.3	2.9
1 x 6	4.1	4.7	3.9	4.1	4.7	3.6	4.1	3.6
2 x 3	4.4	4.5	4.2	4.3	4.0	3.6	4.3	3.6
2 x 4	4.4	3.5	3.6	3.8	2.9	3.0	3.8	3.0
2 x 5	3.9	4.5	3.9	3.5	3.9	3.9	3.5	3.9
2 x 6	3.7	5.0	4.8	3.6	4.0	3.9	3.6	3.9
3 x 4	5.1	5.2	3.0	4.6	4.5	2.9	4.6	2.9
3 x 5	4.6	4.8	5.2	3.7	4.4	4.5	3.7	4.5
3 x 6	4.5	4.1	3.0	3.8	3.7	2.7	3.8	2.7
4 x 5	4.6	3.4	4.3	3.9	2.8	3.8	3.9	3.8
4 x 6	4.5	4.9	4.0	4.0	3.7	3.4	4.0	3.4
5 x 6	3.9	4.8	3.8	3.2	4.4	2.9	3.2	2.9
Average		4.6	4.0		3.9	3.4		3.4
C.V. %		19.2	25.4		24.8	27.2		27.2

 ψ Mid-parental values.

Mean squares for the parental lines from the combined analysis of variance indicates significant differences for post-emergence damping-off, final stand, C.V.E, hypocotyl grade, and root grade (Table 11). Lack of significant differences between the parental lines for emergence and pre-emergence damping-off agrees with the results of run 1.

Emergence was highest for Tamcot CAMD-E and Dixie King III (83.1%) and lowest for Acala SJ-5 (71.3%) but this difference was not statistically significant (Table 12). Pre-emergence damping-off ranged from 16.9% to 28.7%; however, the differences among cultivars were not significant.

Post-emergence damping-off ranged from a low of 16.3% for Tamcot CAMD-E and 17.1% for Acala SJ-5, to a high of 53.8% for Lankart 57 and 66.3% for Tamcot SP 37. Tamcot CAMD-E, Acala SJ-5, TX-LEBO-3-80, and Dixie King III had significantly much less post-emergence damping-off than Lankart 57 or Tamcot SP 37.

Average final stand over runs was 52.8% (Table 12). The differential response in post-emergence damping-off, hypocotyl rot and root rot among cultivars was reflected in final stand. Tamcot CAMD-E had the highest final stand of 70%; however, it was not significantly different from Dixie King III (64.4%), TX-LEBO-3-80 (62.5%) or Acala SJ-5 (60.6%). The lowest final stands of 33.8% and 26.6% were

Table 11. Mean squares for eight seedling traits for parental lines inoculated with *R. solani*, combined over runs.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replication	3	300.52**	300.52	434.66	547.74	3.61**	2.55	0.82
Entry (E)	5	154.27	154.27	3802.10**	2698.44**	1.93**	11.79	9.67**
Run (R)	1	1575.52**	1575.52**	1619.51*	4.69	3.78**	32.30*	0.03
E * R	5	66.77	66.77	815.43	620.94	0.33	14.53	2.30*
Error	33	75.90	75.90	44.24	350.02	0.49	7.41	1.03
Total	47	-	-	-	-	-	-	-

* Coefficient of velocity of emergence

‡ Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 12. Averages for eight seedling traits for parental lines inoculated with *R. solani*, combined over runs.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [‡]	Hypocotyl grade	Root grade
1. Dixie King III	83.1	16.9	23.4a§	64.4a	11.4a	6.3	3.8a	3.2a
2. Acala SJ-5	71.3	28.7	17.1a	60.6a	12.2bc	4.0	3.3a	3.4ab
3. Lankart 57	76.3	23.7	53.8b	33.8b	12.6c	7.2	5.7b	4.4bc
4. Tamcot SP37	76.3	23.7	66.3b	26.6b	11.4a	7.3	5.8b	4.7bc
5. Tamcot CAMD-E	83.1	16.9	16.3a	70.0a	11.8ab	5.5	3.6a	2.8a
6. TX-LEBO-3-80	77.5	22.5	18.7a	62.5a	12.1a-c	5.7	3.9a	2.9a
Average	78.0	21.9	32.6	52.8	11.9	5.9	4.3	3.5
C.V.‡	11.2	39.6	64.5	35.4	5.9	45.6	23.5	28.8

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level.

for Lankart 57 and Tamcot SP 37, respectively, which were significantly lower than the other four parental lines.

A significantly slower rate of emergence (C.V.E) of 11.4 was indicated for Dixie King III and Tamcot SP 37. The fastest rate of emergence (12.6) was of Lankart 57. The parental lines did not differ in rates of post-emergence damping-off (C.V.D) although they ranged from 4.0 to 7.3.

Differences among the parental lines are reflected in the hypocotyl and root grades (Table 12). Hypocotyl grades ranged from 3.3 to 5.8. Acala SJ-5, Tamcot CAMD-E, Dixie King III, and TX-LEBO-3-80 had significantly lower hypocotyl grades than Lankart 57 and Tamcot SP 37. Similar trends among the parental lines were obtained for root grades, which ranged from 2.8 to 4.7. Tamcot CAMd-E had the lowest root grade of 2.8, while the highest grades were for Lankart 57 (4.4) and Tamcot SP 37 (4.7).

The combined test analysis of variance (Table 13), shows that the F_1 generations differed in post-emergence damping-off, final stand, C.V.E and hypocotyl grade. Similar results were obtained for the F_2 generation (Table 14), and root grades also differed. The F_1 generation mean squares for entry X run interaction were significant for post-emergence damping-off, final stand, and hypocotyl grade. The F_2 generation mean squares for the F_2 's X run interaction were significant for post-emergence damping-

Table 13. Mean squares for eight seedling traits for F_1 generations inoculated with *R. solani*, combined over runs.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade
Replication	3	92.50	92.50	1128.08	602.43	8.85**	4.44	2.12
Entry (E)	14	156.01	156.01	1481.39**	1248.16**	2.36**	9.94	3.60**
Run (R)	1	3630.00**	3630.00**	3841.57**	0.21	7.35**	14.03	1.10
E * R	14	192.50	192.50	1550.09**	1331.01**	0.49	9.27	3.92**
Error	87	111.75	111.75	626.51	539.07	0.30	8.29	1.44
Total	119	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

† Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 14. Mean squares for eight seedling traits for F_2 generations inoculated with R. solani, combined over runs.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replication	3	31.88	31.88	1450.27	1029.10	8.64**	7.96	3.48
Entry (E)	14	62.86	62.86	1759.04**	1179.85*	2.73**	11.84	3.64*
Run (R)	1	676.87*	676.87*	9193.62**	3050.21*	19.10**	7.70	2.85
E * R	14	154.11	154.11	1665.91**	1544.85**	1.09**	9.76	4.14**
Error	87	120.67	120.67	621.19	594.90	0.33	8.57	1.76
Total	119	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

‡ Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

off, final stand, and hypocotyl grade. Variation in inoculum potential due to fluctuations in temperatures and plot to plot differences of inoculum density between experimental runs are probably reasons for the significant interactions.

Averages for the seedling traits for the F_1 and F_2 generations, combined over runs, are presented in Table 15. There was no significant difference among the F_1 and F_2 entries (crosses) for emergence and pre-emergence damping-off. Average emergence of the F_1 was 78.9% and of the F_2 81.6%. Average pre-emergence damping-off ranged from 14.3 to 30.0% for the F_1 with an average of 21% and ranged from 13.7 to 23.7% for the F_2 with an average of 18.3%.

Post-emergence damping-off ranged from 10.5% to 56.9% for the F_1 with an average of 32.5% and a range of 6.1% to 67.4% for the F_2 with an average of 29%. Seven F_1 's and eight F_2 's had less damping-off than their mid-parents. Dominance deviation was in both directions. In the F_2 generation, transgressive segregation was more towards lower post-emergence damping-off.

Significant differences for final stand were obtained among the F_1 and also the F_2 entries. F_1 stand averaged 54.2% with a range of 31.8 to 73.7%. Stand of the F_2 ranged from 27.5% to 79.3%, and averaged 59.4%. Eight F_1 's and nine F_2 's had higher stand than their mid-

Table 15. Averages for eight seedling traits of mid-parents, F_1 and F_2 generations inoculated with *R. solani*, combined over runs. (a) Emergence, Pre-emergence damping-off, Post-emergence damping-off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP ψ	F_1	F_2	MP	F_1	F_2	MP	F_1	F_2
1 x 2	77.2	77.5	80.6	22.8	22.5	19.3	20.3	48.0bcg	37.4b
1 x 3	79.7	76.8	80.0	20.3	23.1	20.0	38.6	34.4a-c	67.4c
1 x 4	79.7	75.6	83.1	20.3	24.3	16.8	44.9	21.0ab	38.8b
1 x 5	83.1	83.1	85.6	16.9	16.8	14.3	19.9	45.2bc	38.2ab
1 x 6	80.3	77.5	80.0	19.7	22.5	20.0	21.1	35.8a-c	37.9b
2 x 3	73.8	78.7	81.2	26.2	21.2	18.7	35.6	21.5ab	19.1ab
2 x 4	73.8	81.2	83.1	26.2	18.7	16.8	41.7	10.5a	35.1ab
2 x 5	77.2	78.1	86.2	22.8	21.8	13.7	16.7	26.1ab	17.1ab
2 x 6	74.4	81.8	76.2	25.6	18.1	23.7	17.9	23.7ab	19.3ab
3 x 4	76.3	85.6	78.1	23.7	14.3	21.8	60.0	24.1ab	15.0ab
3 x 5	79.7	84.3	82.5	20.3	15.6	17.5	35.1	21.2ab	24.4ab
3 x 6	76.9	70.0	84.3	23.1	30.0	15.6	36.3	44.2bc	6.1a
4 x 5	79.7	81.2	79.3	20.3	18.7	20.6	41.3	24.9ab	41.9b
4 x 6	76.9	80.6	83.7	23.1	19.3	16.2	42.5	50.7bc	23.2ab
5 x 6	80.3	71.2	80.0	19.7	28.7	20.0	17.5	56.9c	22.4ab
Average		78.9	81.6		21.0	18.3		32.5	29.0
C.V.%		13.3	13.4		50.1	59.7		76.8	85.8

ψ Mid-parental values.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 15. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)				C.V.E. [†]				C.V.D. [‡]			
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	62.5	39.3b-d§	52.5a-c	11.8	11.7c-f	11.9ef	5.2	6.6	7.1	5.2	6.6	7.1
1 x 3	49.1	51.8a-d	27.5c	12.0	10.5a	11.3c-e	6.8	6.3	6.3	6.8	6.3	6.3
1 x 4	45.5	62.5a-c	53.1a-c	11.4	11.5c-e	11.9ef	6.8	5.5	6.5	6.8	5.5	6.5
1 x 5	67.2	46.8a-d	60.6ab	11.6	11.7c-g	12.3f	5.9	6.9	5.9	5.9	6.9	5.9
1 x 6	63.5	51.8a-d	51.8a-c	11.8	11.9d-h	12.3f	6.0	5.4	7.2	6.0	5.4	7.2
2 x 3	47.2	61.6a-c	67.5ab	12.4	10.8ab	11.3c-e	5.6	5.0	4.1	5.6	5.0	4.1
2 x 4	43.6	73.7a	55.6ab	11.8	11.4b-e	11.9ef	5.7	3.4	5.0	5.7	3.4	5.0
2 x 5	65.3	58.1a-d	72.5ab	12.0	11.3b-d	11.-bc	4.8	5.4	4.8	4.8	5.4	4.8
2 x 6	61.6	62.5a-c	62.5ab	12.2	12.1f-h	11.7d-f	4.9	4.7	5.7	4.9	4.7	5.7
3 x 4	30.2	66.2ab	66.2ab	12.0	11.2bc	10.4a	7.3	7.1	4.5	7.3	7.1	4.5
3 x 5	51.9	66.8ab	65.0ab	12.2	11.3b-d	10.5ab	6.4	4.2	5.8	6.4	4.2	5.8
1 x 6	48.2	38.1cd	79.3a	12.4	12.2gh	11.6c-e	6.5	6.6	2.6	6.5	6.6	2.6
4 x 5	48.3	61.8a-c	48.7bc	11.6	12.0e-h	11.9ef	6.4	6.2	5.7	6.4	6.2	5.7
4 x 6	44.6	40.6b-d	63.7ab	11.8	12.3gh	11.8d-f	6.6	6.4	4.3	6.6	6.4	4.3
5 x 6	66.3	31.8d	65.0ab	11.9	12.4h	11.2cd	5.6	7.1	6.0	5.6	7.1	6.0
Average		54.2	59.4		11.6	11.5		5.8	5.4		5.8	5.4
C.V.%		42.7	41.0		4.7	4.9		49.3	53.5		49.3	53.5

^ψ Mid-parental values.[†] Coefficient of velocity of emergence.[‡] Coefficient of velocity of post-emergence damping-off.[§] Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 15. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade			Root grade		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	3.6	5.0bc ^s	4.6a-c	3.3	3.9a-c	4.0a-c
1 x 3	4.8	4.2a-c	5.7c	3.8	3.8a-c	5.0c
1 x 4	4.8	3.8ab	4.6a-c	3.9	3.2ab	3.2ab
1 x 5	3.7	5.0bc	4.3a-c	3.0	4.4bc	3.5a-c
1 x 6	3.9	4.4a-c	4.4a-c	3.1	4.0a-c	4.3bc
2 x 3	4.5	4.2a-c	3.8ab	3.9	3.2ab	3.0ab
2 x 4	4.6	3.2a	4.3a-c	4.1	2.6a	3.3ab
2 x 5	3.5	4.1ab	3.4ab	3.1	3.6a-c	3.0ab
2 x 6	3.6	4.3a-c	4.0ab	3.2	3.5ab	3.1ab
3 x 4	5.8	4.0ab	3.2a	4.6	3.3ab	2.6a
3 x 5	4.7	3.9ab	3.9ab	3.6	3.4ab	3.2ab
3 x 6	4.8	5.0bc	3.1a	3.7	4.0a-c	2.4a
4 x 5	4.7	4.0ab	4.9bc	3.8	3.3ab	4.0a-c
4 x 6	4.9	5.6c	3.9ab	3.8	3.7a-c	3.0ab
5 x 6	3.7	5.5c	3.8ab	2.9	5.2c	3.3ab
Average		4.4	4.1		3.7	3.4
C.V. %		26.9	31.8		38.0	39.9

 ^{ψ} Mid-parental values.^s Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

parents, indicating dominance deviation to be more in the direction of increased final stand, suggesting overdominance for these crosses.

Nine F_1 's and eight F_2 's emerged slower than their mid-parents. Dominance deviation is more in the direction of slower rates of emergence (C.V.E). No significant differences were observed for rate of post-emergence damping-off (C.V.D).

Hypocotyl grades were lower for six F_1 's and eight F_2 's than their mid-parents. Hypocotyl grades ranged from 3.2 to 5.6 in the F_1 and from 3.1 to 5.7 in the F_2 . Root grade of five F_1 's and nine F_2 's were lower than their mid-parents. This suggests that dominance deviation is in both directions of low and high root grades. One F_1 and two F_2 's had root grade lower than the lowest mid-parent.

Pythium ultimum

Experimental Run 1

Significant differences among the parental lines were obtained for emergence, pre-emergence damping-off, final stand, and C.V.E when inoculated with P. ultimum at an inoculum density of 50 propagules per 1.0g of soil (Table 16). In Table 17, the parental averages for the eight traits are presented. Tamcot CAMD-E gave the highest seedling emergence of 68.7%, followed by Dixie King III (67.5%), Tamcot SP 37 (61.2%), and Lankart 57 (57.5%).

Table 16. Mean squares for eight seedling traits for parental lines inoculated with 50.0 propagules of *P. ultimum* per 1.0 g of soil, run 1.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replications	2	62.15	62.15	214.14	180.56	2.32	4.40	1.12
Entry	5	473.54**	473.54**	265.52	529.17*	2.50*	14.93	1.01
Error	15	69.65	69.65	360.64	179.72	0.89	14.23	0.95
Total	23	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

‡ Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 17. Averages for eight seedling traits for parental lines inoculated with 50.0 propagules of *P. ultimum* per 1.0 g of soil, run 1.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [‡]	Hypocotyl grade	Root grade
1. Dixie King III	67.5a§	32.5a	22.1	52.5ab	12.2a	4.8	4.4	3.9
2. Acala SJ-5	42.5c	57.5c	13.6	32.2bc	13.2ab	6.1	3.8	3.6
3. Lankart 57	57.5ab	42.5ab	19.8	42.5a-c	14.6b	3.7	4.3	3.9
4. Tamcot SP37	61.2a	38.7a	12.6	53.7ab	13.8ab	7.1	4.0	4.1
5. Tamcot CAMD-E	68.7a	31.2a	14.5	60.0a	13.3ab	3.6	3.5	3.4
6. TX-LEBO-3-80	46.2bc	53.7bc	33.9	30.0c	13.9b	8.4	4.9	4.6
Average	57.2	42.7	19.4	45.8	13.5	5.6	4.1	3.9
C.V.%	14.5	19.5	97.5	29.2	6.9	66.5	23.3	25.7

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Acala SJ-5 and TX-LEBO-3-80 gave the lowest emergence of 42.5% and 46.2%, respectively, which were significantly lower than the emergence of the other four parental lines. The rate of seedling emergence (C.V.E), ranged from 12.2 to 14.6. The slowest rate was for Dixie King III (12.2), followed by Acala SJ-5 and Tamcot CAMD-E. Lankart 57 and TX-LEBO-3-80 had the fastest rates of 14.6 and 13.9, respectively, which were significantly faster than that of Dixie King III.

Differences among the parental lines in pre-emergence damping-off induced by *P. ultimum* were significant. Tamcot CAMD-E gave the lowest pre-emergence damping-off (31.2%) but was not significantly different from those of Dixie King III (32.5%), and Tamcot SP 37 (38.7%) or Lankart 57 (42.5%), (Table 17). Acala SJ-5 and TX-LEBO-3-80 had the highest significant pre-emergence damping-off of 57.5% and 53.7%, respectively. TX-LEBO-3-80 had the highest post-emergence damping-off (33.9%), and Acala SJ-5 the lowest (13.6%). Differences among the parental lines for post-emergence damping-off were not significant. The fastest rate of post-emergence damping-off (C.V.D) was that of TX-LEBO-3-80 (8.4), while Tamcot CAMD-E had the slowest rate (3.6).

Final stand ranged from 30.0% to 60.0%. Significant differences among the parents for final stand is indicative of their levels of resistance to the combined effects

of pre- and post-emergence damping-off. Tamcot CAMD-E gave the highest stand (60.0%), followed by Tamcot SP 37 (53.7%) and Dixie King III (52.5%), respectively. TX-LEBO-3-80 and Acala SJ-5 had the lowest final stand of 30.0% and 32.2%, respectively, which were significantly lower than the stand of Tamcot CAMD-E, Tamcot SP 37 and Dixie King III. The highest severity of hypocotyl and root rot was for TX-LEBO-3-80, while the lowest was for Tamcot CAMD-E.

Analysis of variance for F_1 generation (Table 18) shows that significant differences were obtained for post-emergence damping-off, final stand, C.V.E, hypocotyl grade, and root grade. In the F_2 generation, only emergence, pre-emergence damping-off and C.V.E gave significant differences (Table 19).

Averages for traits of the F_1 and F_2 generations are presented in Table 20. On the average, the F_2 's gave higher emergence than the F_1 's. Eleven F_1 's and twelve F_2 's had higher emergence than their mid-parents. Dominance deviation was more towards higher emergence. Emergence ranged from 48.7% to 82.5% for the F_1 's and from 48.7% to 86.2% for the F_2 's. Pre-emergence-damping-off for the F_1 's ranged from 17.5% to 51.2%, and from 13.7% to 51.2% for the F_2 's. Twelve F_1 's and fourteen F_2 's had lower pre-emergence damping-off than their mid-parents. Dominance deviation was in both directions, but more

Table 18. Mean squares for eight seedling traits for F_1 generations inoculated with 50.0 propagules of *P. ultimum* per 1.0 g of soil, run 1.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replication	3	110.42	110.42	263.53	470.00	0.72	7.68	1.05
Entry	14	291.49	291.49	824.04**	697.92*	2.56**	17.03	2.17**
Error	42	197.92	197.92	315.69	314.34	1.07	14.75	1.02
Total	59	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

† Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 19. Mean squares for eight seedling traits for F_2 generation inoculated with 50.0 propagules of *P. ultimum* per 1.0 g of soil, run 1.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final Stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
Replication	3	111.67	111.67	1659.196**	489.44	0.95	22.23	4.19**
Entry	14	409.64**	409.64**	262.06	409.52	4.96**	9.58	0.92
Error	42	138.45	138.45	367.19	398.63	0.47	14.24	0.83
Total	59	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence

‡ Coefficient of velocity of post-emergence damping-off

*,** Significant at the 0.05 and 0.01 levels of probability, respectively

Root Grade

Table 20. Averages for eight seedling traits of mid-parents, F₁ and F₂ generations inoculated with 50.0 propagules of *P. ultimum* per 1.0 g of soil, run 1. (a) Emergence, Pre-emergence damping-off, Post-emergence damping off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	55.0	48.7	75.0ab ^s	45.0	51.2	25.0ab	17.9	38.3cd	17.7
1 x 3	62.5	76.2	60.0bc	37.5	23.7	40.0bc	20.9	13.0a-c	33.5
1 x 4	64.4	71.2	80.0a	35.6	28.7	20.0a	17.4	23.9a-d	29.9
1 x 5	68.1	66.2	72.5ab	31.9	33.7	27.5ab	18.3	34.1b-d	29.2
1 x 6	56.9	70.0	70.0ab	43.1	30.0	30.0ab	28.0	4.1ab	9.1
2 x 3	50.0	77.5	75.0ab	50.0	22.5	25.0ab	16.7	33.0a-d	21.1
2 x 4	51.9	66.2	71.2ab	48.1	33.7	28.7ab	13.1	12.5a-c	17.2
2 x 5	55.6	71.2	76.2ab	44.4	28.7	23.7ab	14.1	5.5ab	11.8
2 x 6	44.4	73.7	48.7c	55.6	26.2	51.2c	23.8	8.9a-c	12.5
3 x 4	59.4	66.2	76.2ab	40.6	33.7	23.7ab	16.2	25.2a-d	31.1
3 x 5	63.1	57.5	81.2a	36.9	42.5	18.7a	17.2	7.6ab	18.7
3 x 6	83.4	67.5	67.5ab	48.1	32.5	32.5ab	26.9	40.0d	32.6
4 x 5	64.9	82.5	86.2a	34.9	17.5	13.7a	13.6	3.5a	15.2
4 x 6	53.7	58.7	58.7bc	46.2	41.2	41.2bc	23.3	24.8a-d	17.6
5 x 6	57.5	72.5	58.7bc	42.5	27.5	41.2bc	24.2	5.0ab	19.5
Average		68.4	70.5		31.5	29.5		19.2	21.1
C.V.%		20.5	16.6		44.5	39.8		92.4	90.5

ψ Mid-parental values.

^s Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 20. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)		C.V.E. ⁺		C.V.D. [†]	
	MPV	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	42.4	32.5c §	63.7	12.7	13.4a-c	14.5ef
1 x 3	47.5	66.2ab	40.0	13.4	12.2ab	12.7b-d
1 x 4	53.1	56.2a-c	55.0	13.0	12.8a-c	13.5c-e
1 x 5	56.3	45.0bc	52.5	12.8	13.9bc	13.7de
1 x 6	41.3	67.5ab	63.7	13.1	14.3c	14.6f
2 x 3	37.4	53.7a-c	58.7	13.9	11.7a	11.9b
2 x 4	42.9	57.5a-c	58.7	13.5	13.9bc	13.5c-e
2 x 5	46.1	67.5ab	67.5	13.3	13.2a-c	12.3b
2 x 6	31.1	67.5ab	41.2	13.6	14.3c	14.0ef
3 x 4	48.1	52.5a-c	52.5	14.2	13.1a-c	10.6a
3 x 5	51.3	53.7a-c	67.5	13.9	14.0c	12.7b-d
3 x 6	36.3	36.2c	46.2	14.3	13.9bc	12.5b-d
4 x 5	56.8	80.0a	73.7	13.6	13.0a-c	12.1b
4 x 6	41.9	45.0bc	48.7	13.9	14.4c	13.9ef
5 x 6	30.0	68.7ab	47.5	13.6	14.2c	14.2ef
Average		56.6	55.8		13.5	13.1
C.V.%		31.2	35.4		7.6	5.1

ψ Mid-parental values.

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 20. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade				Root grade	
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	4.1	4.8bc §	3.7	3.8	4.5de	d.6
1 x 3	4.4	3.8ab	4.9	3.9	3.3a-d	4.4
1 x 4	4.2	4.0a-c	4.4	4.0	3.6a-e	3.8
1 x 5	3.9	4.6bc	4.7	3.7	4.0a-e	4.1
1 x 6	4.7	3.3ab	4.0	4.3	2.7ab	3.7
2 x 3	4.1	4.8bc	3.8	3.8	4.2c-e	3.7
2 x 4	3.9	3.4ab	4.6	3.9	3.3a-d	4.1
2 x 5	3.7	3.7ab	4.1	3.5	3.4a-d	3.8
2 x 6	4.4	4.1a-c	4.4	4.1	4.3c-e	4.7
3 x 4	4.2	4.3a-c	3.9	4.0	4.1a-e	4.0
3 x 5	3.9	3.2ab	3.9	3.7	2.8a-c	3.8
3 x 6	4.6	5.5c	5.0	4.3	5.1e	4.6
4 x 5	3.8	2.8a	3.3	3.8	2.5a	3.2
4 x 6	4.5	4.5bc	4.1	4.4	4.4c-e	3.8
5 x 6	4.2	3.9a-c	4.3	4.0	3.6a-e	4.0
Average		4.0	4.2		3.7	3.9
C.V. %		24.6	21.4		25.8	25.4

 ψ Mid-parental values.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

towards lower pre-emergence damping-off. Post-emergence damping-off averaged 19.2% for the F_1 's, and 21.1% for the F_2 's. Dominance deviation was in both directions.

Final stand of twelve F_1 's and twelve F_2 's were higher than their mid-parents. Dominance deviation was more towards increased final stand, suggesting overdominance and probably epistasis. Final stand ranged from 36.2% to 80.0% for the F_1 's and from 40.0% to 73.7% for the F_2 's.

The rate of emergence (C.V.E) averaged 13.5 for the F_1 's, and 13.1 for the F_2 's. Segregation in the F_2 's was more towards slower emergence (low C.V.E). Dominance deviation in both generations was in both directions. There was no significant differences among the F_1 and F_2 entries (crosses) for C.V.D. Average rate of post-emergence damping-off of the F_1 was 6.6, and of the F_2 , 6.3.

Hypocotyl grades were lower for eight F_1 's and six F_2 's than their mid-parents. Dominance deviation was in both directions. Hypocotyl grades ranged from 2.8 to 5.5 in the F_1 and from 3.3 to 5.0 in the F_2 . Similar trend of results were obtained for root grades.

Experimental Run 2

The analysis of variance for parental lines inoculated with P. ultimum at an inoculum density of 52 propa-

gules per 1.0g of soil, indicates lack of significant differences for all the seedling traits (Table 21).

The parental averages are presented in Table 22). Average emergence ranged from 58.7% for TX-LEBO-3-80 to 77.5% for Tamcot CAMD-E. The result, though not significant, agrees with the established trend for run 1. The rate of emergence (C.V.E) ranged from 12.3 to 13.4 Tamcot CAMD-E had the lowest pre-emergence damping-off (22.5%), and TX-LEBO-3-80 the highest (41.2%). Post-emergence damping-off ranged from 6.5% for Acala SJ-5 to 22.0% for TX-LEBO-3-80. The rate of post-emergence damping-off ranged from 1.7 for Acala SJ-5 to 8.7 for TX-LEBO-3-80.

Tamcot CAMD-E gave the highest final stand (67.5%), and Lankart 57, the lowest (45.0%). Hypocotyl rot was more severe on Lankart 57, with a hypocotyl grade of 4.3. The lowest grade was for Acala SJ-5 (3.5). Similar trends were obtained for root grade.

Analysis of variance for F_1 generations showed significant differences for emergence, pre-emergence damping-off, final stand and C.V.E (Table 23). Only C.V.E indicated significant differences for the F_2 generations (Table 24).

Averages for traits of the F_1 and F_2 are presented in Table 25. Seven F_1 's and fourteen F_2 's had higher emergence than their mid-parents. Dominance deviation was more towards higher emergence, suggesting overdominance

and epistasis. Similar trends towards lower pre-emergence damping-off were obtained in the F_2 's. Pre-emergence damping-off for F_1 's ranged from 21.2% to 46.2% and from 15.0% to 33.7% for the F_2 's. Dominance deviation was more towards lower pre-emergence damping-off. No significant differences for post-emergence damping-off were obtained in the F_1 and F_2 generations. Post-emergence damping-off ranged from 1.5% to 32.0% for the F_1 's, and from 3.1% to 22.1% for the F_2 's.

Significant differences were obtained for stands of the F_1 and not of the F_2 entries. Final stand ranged from 46.2% to 75.0% for the F_1 , and from 58.7% to 81.2% for the F_2 's. Nine F_1 's and fourteen F_2 's had stand higher than the highest mid-parent. This suggests overdominance and/or epistasis. Dominance deviation towards fast and slow rates of emergence (C.V.E) was obtained in both the F_1 and F_2 generations. F_1 's ranged from 11.5 to 14.1, and F_2 's from 10.7 to 14.1.

Significant differences among the F_1 's and F_2 's were not obtained for rates of post-emergence damping-off (C.V.D), hypocotyl grade, and root grades. Rates of post-emergence damping-off ranged from 1.9 to 8.5 for the F_1 and from 1.5 to 5.9 for the F_2 . Hypocotyl grades ranged from 3.1 to 4.4 for the F_1 , and from 2.4 to 3.8 for the F_2 , indicating segregation towards lower hypocotyl rot. A similar trend for root grade was obtained.

Table 21. Mean squares for eight seedling traits for parental lines inoculated with 52.0 propagules of *P. ultimum* per 1.0 g of soil, run 2.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. ⁺	C.V.D. [†]	Hypocotyl grade
Replication	3	70.49	70.49	363.59	245.83	2.27	7.40	1.21
Entry	5	196.04	196.04	295.41	346.67	0.78	27.08	0.38
Error	15	195.49	195.49	231.99	271.67	0.81	10.91	0.63
Total	23	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

* Significant at the 0.05 level of probability, respectively.

Table 23. Mean squares for eight seedling traits for F_1 generations inoculated with 52.0 propagules of *P. ultimum* per 1.0 g of soil, run 2.

		Mean Squares							
Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade	Root grade
Replication	3	1049.44**	1049.44**	139.63	1157.78**	6.21**	7.36	0.55	0.32
Entry	14	221.13*	221.13*	246.14	370.95*	2.52**	20.35	0.62	0.65
Error	42	95.57	95.57	164.83	161.35	0.46	14.13	0.54	0.53
Total	59	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 24. Mean squares for eight seedling traits for P_2 generations inoculated with 52.0 propagules of *P. ultimum* per 1.0 g of soil, run 2.

Mean Squares									
Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade	Root grade
Replication	3	581.53*	581.53*	41.52	588.89	8.92**	13.79	0.06	0.19
Entry	14	146.43	146.43	132.60	159.70	5.24**	7.19	0.49	0.64
Error	42	186.59	186.59	188.51	343.35	0.74	17.29	0.72	0.69
Total	59	-	-	-	-	-	-	-	-

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 25. Averages for eight seedling traits of mid-parents, F_1 and F_2 generations inoculated with 52.0 propagules of *P. ultimum* per 1.0 g of soil, run 2. (a) Emergence, Pre-emergence damping-off, Post-emergence damping-off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP ψ	F_1	F_2	MP	F_1	F_2	MP	F_1	F_2
1 x 2	70.0	70.0a-c $\S$	85.0	30.0	30.0ab	15.0	9.7	9.9	10.7
1 x 3	65.0	60.0bc	77.5	35.0	40.0bc	22.5	22.0	18.7	10.4
1 x 4	70.0	67.5a-c	82.5	30.0	32.5a-c	17.5	16.3	23.6	17.7
1 x 5	72.5	73.7ab	80.0	27.5	26.2ab	20.0	13.3	32.0	8.4
1 x 6	63.1	77.5a	66.2	36.9	22.5a	33.7	17.4	3.2	9.8
2 x 3	67.5	78.7a	76.2	32.5	21.2a	23.7	18.9	11.4	4.2
2 x 4	72.5	62.5a-c	70.0	27.5	37.5a-c	30.0	13.2	13.6	15.3
2 x 5	75.0	68.7a-c	85.0	25.0	31.2ab	15.0	10.2	1.5	16.1
2 x 6	65.6	60.0ab	68.7	34.4	40.0bc	31.2	14.3	18.3	3.1
3 x 4	67.5	76.2ab	82.5	32.5	23.7ab	17.5	25.5	12.9	22.1
3 x 5	70.0	76.2ab	81.2	30.0	23.7ab	18.7	22.5	5.8	4.1
3 x 6	60.6	67.5a-c	83.7	39.4	32.5a-c	16.2	26.6	13.5	3.1
4 x 5	75.0	75.0ab	81.2	25.0	25.0ab	18.7	16.8	13.3	10.6
4 x 6	65.6	70.0a-c	83.7	34.4	30.0ab	16.2	20.9	7.7	13.1
5 x 6	68.1	53.7c	77.5	31.9	46.2c	22.5	17.9	10.9	15.1
Average		69.1	78.7		30.8	21.2		13.1	10.9
C.V.%		14.1	17.3		31.7	64.2		97.8	124.9

ψ Mid-parental values.

$\S$ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 25. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)			C.V.E. ⁺			C.V.D. [‡]		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	62.5	63.7a-d§	77.5	13.3	12.4ab	13.8e	4.2	4.4	3.9
1 x 3	51.9	50.0cd	71.2	12.9	12.3ab	12.9c-e	5.9	8.0	4.5
1 x 4	58.1	51.2b-d	68.7	12.9	12.3ab	12.7c-e	7.6	8.4	5.9
1 x 5	63.1	50.0cd	73.7	12.9	12.8bc	13.8e	5.9	7.3	3.7
1 x 6	53.1	75.0a	61.2	13.2	14.1e	14.1e	7.7	4.5	5.2
2 x 3	55.6	71.2a-c	72.5	12.7	11.5a	12.3b-d	3.5	4.0	1.5
2 x 4	61.9	53.7a-d	58.7	12.7	12.5ab	13.7e	5.1	4.1	5.7
2 x 5	66.9	67.5a-d	71.2	12.8	12.7b	11.1ab	3.4	2.0	6.1
2 x 6	56.9	48.7d	66.2	13.0	13.3b-e	13.3de	5.2	8.1	5.0
3 x 4	51.3	66.2a-d	65.0	12.3	12.3ab	10.7a	6.9	6.5	5.0
3 x 5	56.3	72.5ab	77.5	12.4	12.9bc	11.8a-c	5.2	4.2	3.5
3 x 6	46.3	58.7a-d	81.2	12.6	13.8c-e	10.9ab	7.0	8.5	2.2
4 x 5	62.5	65.0a-d	72.5	12.4	12.4ab	11.5a-c	6.8	1.9	4.2
4 x 6	52.5	65.0a-d	76.2	12.6	13.9de	13.2de	8.6	3.7	4.0
5 x 6	57.5	46.2d	66.2	12.7	14.1e	12.0a-c	6.9	6.0	5.7
Average		60.3	70.6		12.9	12.5		5.4	4.4
C.V.%		21.0	26.22		5.2	6.8		68.4	93.3

 ψ Mid-parental values.

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 25. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade			Root grade		
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	3.8	4.8	3.8	3.7	4.0	3.8
1 x 3	4.2	4.2	3.4	3.8	3.9	3.4
1 x 4	3.9	4.4	3.8	3.8	4.1	3.8
1 x 5	3.9	4.2	3.3	3.7	4.1	3.3
1 x 6	4.1	3.3	3.8	3.8	3.1	3.8
2 x 3	3.9	3.3	2.7	3.7	3.2	2.7
2 x 4	3.7	3.4	3.5	3.7	3.5	3.5
2 x 5	3.6	3.3	3.2	3.5	3.8	3.2
2 x 6	3.8	4.0	3.4	3.6	4.1	3.4
3 x 4	4.1	3.8	3.5	3.8	3.3	3.5
3 x 5	4.0	3.1	2.9	3.7	3.2	2.9
3 x 6	4.2	4.0	2.4	3.8	3.6	2.4
4 x 5	3.8	3.7	2.8	3.7	3.5	2.8
4 x 6	4.0	3.5	2.8	3.8	3.2	2.8
5 x 6	3.9	3.8	3.1	3.6	3.3	3.1
Average		3.7	3.4		3.5	3.2
C.V. %		19.5	24.9		20.3	25.9

 ψ Mid-parental values.

Combined Analysis Over Run 1 and Run 2

As indicated for R. solani, a combined analysis over runs is the average performance of the parental lines and their offsprings over the two runs. Significant differences among parental lines for emergence, pre-emergence damping-off, final stand, and C.V.D were obtained when the data were combined over runs 1 and 2. (Table 26). Averages for the parental lines, are presented in Table 27. Tamcot CAMD-E had the highest seedling emergence of 73.1%, followed by Dixie King III (67.5%), and Tamcot SP 37 (66.8%). Emergence for these three cultivars were not significantly different. Emergence of Lankart 57 and Acala SJ-5 were intermediate. The lowest emergence of 52.5% was that of TX-LEBO-3-80.

Pre-emergence damping-off ranged from a low of 26.8% for Tamcot CAMD-E, 32.5% for Dixie King III, and 33.1% for Tamcot SP 37, to a high of 47.5% for TX-LEBO-3-80, and 42.5% for Acala SJ-5. Tamcot CAMD-E, Dixie King III, and Tamcot SP 37 had much less pre-emergence damping-off than TX-LEBO-3-80. Post-emergence damping-off ranged from 10.1% to 27.9%, however, the differences among cultivars were not significant.

Average final stand over runs was 51.4%. The differential response in pre-emergence damping-off and to a lesser extent post-emergence damping-off among cultivars was reflected in final stand. Tamcot CAMD-E had the

Table 26. Mean squares for eight seedling traits for parental lines inoculated with *P. ultimum*, combined over runs.

Mean Squares									
Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D. [†]	Hypocotyl grade	Root grade
Replication	3	126.38	126.38	476.94	403.47	3.03*	9.63	2.26*	2.38*
Entry (E)	5	459.58**	459.58*	374.84	650.83*	0.55	30.68*	1.16	0.59
Run (R)	1	1518.75**	1518.75**	35.71	1518.75**	6.23*	1.64	0.61	0.80
E * R	5	210.00	210.00	177.08	225.00	2.27*	11.32	0.24	0.28
Error	33	121.08	121.08	278.54	207.26	0.91	11.62	0.72	0.70
Total	47	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 27. Averages for eight seedling traits for parental lines inoculated with *P. ultimum*, combined over runs.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. ⁺	C.V.D. [†]	Hypocotyl grade	Root grade
1. Dixie King III	67.5ab [§]	32.5ab	17.4	55.6ab	12.8	5.7a-c	4.2	3.8
2. Acala SJ-5	57.5bc	42.5bc	10.1	51.2a-c	13.2	3.9a	3.6	3.6
3. Lankart 57	60.0bc	40.0bc	25.5	43.7bc	13.5	4.5ab	4.3	3.8
4. Tamcot SP37	66.8ab	33.1ab	16.2	55.6ab	13.0	7.8bc	3.9	4.0
5. Tamcot CAMD-E	73.1a	26.8a	14.2	63.7a	12.9	4.3ab	3.6	3.4
6. TX-LEBO-3-80	52.5c	47.5c	27.9	38.7c	13.4	8.6c	4.5	4.1
Average	62.9	37.0	18.6	51.4	13.1	5.8	4.0	3.8
C.V.%	17.4	29.6	89.6	27.9	7.2	58.2	20.8	21.8

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

§ Averages within columns followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

highest stand of 63.7%; however it was not significantly different from Dixie King III (55.6%), Tamcot SP 37 (55.6%), and Acala SJ-5 (51.2%). The lowest stand of 38.7% was for TX-LEBO-3-80, which was significantly lower than the other three parental lines, except Lankart 57. The rate of emergence (C.V.E) ranged from 12.8 to 13.5; however, the differences were not significant.

Significant differences among the parental lines was obtained for the rate of post-emergence damping-off (C.V.D). Acala SJ-5 gave the lowest C.V.D of 3.9. This reflects its low post-emergence damping-off. The highest rate of damping-off of 8.6 was for TX-LEBO-3-80.

Differences among the parental lines were not significant for hypocotyl and root grades. Hypocotyl grades ranged from 3.6 for both Tamcot CAMD-E and Acala SJ-5 to 4.5 for TX-LEBO-3-80. The same trend was obtained for root grade.

Combined over runs, the analysis of variance for the F_1 generations showed significant mean squares for post-emergence damping-off, final stand, C.V.E, hypocotyl grade and root grade (Table 28). However, significant differences between the F_2 's generations was indicated for emergence, pre-emergence damping-off, and C.V.E (Table 29). Replication effects were significant for some traits, both analyses, and for some entry X run interactions.

Table 28. Mean squares for eight seedling traits for F_1 generations inoculated with P. ultimum, combined over runs.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [†]	C.V.D. [‡]	Hypocotyl grade
Replication	3	811.32**	811.32**	166.33	1161.67**	5.27**	12.14	0.89
Entry (E)	14	222.53	222.53	693.86**	498.13*	4.67**	23.69	1.83**
Run (R)	1	16.87	16.87	1113.33*	483.33	10.26**	37.17	3.10*
E * R	14	290.08*	290.08*	376.32	570.74**	0.40	13.68	0.96
Error	87	153.70	153.70	240.14	245.72	0.79	14.03	0.77
Total	119	-	-	-	-	-	-	-

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

0.56

1.84**

1.08

1.02

0.74

Table 29. Mean squares for eight seedling traits for F_2 generations inoculated with P. ultimum, combined over runs.

Source	d.f.	Mean Squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. ⁺	C.V.D. [†]	Root grade
Replication	3	575.76*	575.76*	691.86	28.28	4.42**	12.73	1.74
Entry (E)	14	378.04**	378.04*	218.75	293.39	9.18**	7.98	0.89
Run (R)	1	2041.07**	2041.07**	3106.85**	6600.83**	10.13**	101.38**	21.00**
E * R	14	178.04	178.04	175.91	275.83	1.03	8.79	0.52
Error	87	160.96	160.96	303.09	390.82	0.77	16.04	0.84
Total	119	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Averages for the F_1 and F_2 generations for each trait, combined over runs, are presented in Table 30. Average emergence of the F_1 's was 68.7% and of the F_2 's, 74.6%. Twelve F_1 's and all the fifteen F_2 's had higher emergence than their mid-parents. Dominance deviation was in the direction for increased emergence.

Segregation in the F_2 's lead to lower pre-emergence damping-off; being reduced from an average of 31.2% for the F_1 's to 25.3% for the F_2 's. Twelve F_1 's and all the fifteen F_2 's had lower pre-emergence damping-off than their mid-parents. Dominance deviation was in the direction of reduced pre-emergence damping-off. Averages of post-emergence damping-off for the F_1 's and F_2 's were apparently the same; however, F_1 's ranged from 3.5% to 33.1%, while the F_2 's ranged from 7.8% to 23.8%. Dominance deviations was in both directions.

Final stand for twelve F_1 's and all F_2 's were higher than their mid-parents. Dominance deviation was more in the direction of higher stand. Overdominance and epistasis was indicated. The F_1 's averaged 58.5%, while the F_2 's averaged 63.2%. Significant differences among the F_1 's and F_2 's was obtained for C.V.E. Six F_1 's and seven F_2 's had lower C.V.E values than their mid-parents. Dominance deviation was in both directions. No significant differences for the F_1 's and F_2 's were obtained for C.V.D. The rates of post-emergence damping-off (C.V.D) ranged

Table 30. Averages for eight seedling traits of mid-parents, F_1 and F_2 generations inoculated with *P. ultimum*, combined over runs. (a) Emergence, Pre-emergence damping-off, Post-emergence damping-off

Cross	Emergence (%)			Pre-emergence damping-off (%)			Post-emergence damping-off (%)		
	MP ψ	F_1	F_2	MP	F_1	F_2	MP	F_1	F_2
1 x 2	62.5	59.3	80.0ab [§]	37.5	40.6	20.0ab	13.8	24.1b-d	14.2
1 x 3	63.8	68.1	68.7a-c	36.3	31.8	31.2a-c	21.6	15.9a-d	21.9
1 x 4	67.2	69.3	81.2ab	32.8	30.6	18.7ab	16.9	23.8b-d	23.8
1 x 5	70.3	70.0	76.2ab	29.7	30.0	23.7ab	15.9	33.1d	8.8
1 x 6	60.0	73.7	68.1bc	40.0	26.2	31.8bc	22.7	3.6a	9.4
2 x 3	58.8	78.1	75.6ab	41.2	21.8	24.3ab	17.9	22.2a-c	12.7
2 x 4	62.2	64.3	70.6a-c	37.8	35.6	29.3a-c	13.2	13.1a-c	16.2
2 x 5	65.3	70.0	80.6ab	34.7	30.0	19.3ab	12.2	3.5a	14.0
2 x 6	55.0	66.8	58.7c	45.0	33.1	41.2c	19.0	13.6a-c	7.8
3 x 4	63.5	71.2	79.3ab	36.6	28.7	20.6ab	20.9	19.1a-d	26.6
3 x 5	66.6	66.8	81.2ab	33.5	33.1	18.7ab	19.9	6.7ab	11.4
3 x 6	56.3	67.5	75.6ab	43.8	32.5	24.3ab	26.8	30.7cd	17.8
4 x 5	70.0	78.7	83.7a	30.0	21.2	16.2a	15.3	8.4ab	12.9
4 x 6	59.7	64.3	71.2a-c	40.3	35.6	28.7a-c	22.1	16.2a-d	15.3
5 x 6	62.8	63.1	68.1bc	37.2	36.8	31.8bc	21.1	7.9ab	17.5
Average		68.7	74.6		31.2	25.3		16.1	16.0
C.V.%		18.0	17.0		39.7	49.9		95.8	103.3

ψ Mid-parental value.

[§]Averages within columns followed by the same letter are not significantly different according to Duncan's multiple range test at the 5% level of probability.

Table 30. (b) Final stand, C.V.E., C.V.D.

Cross	Final stand (%)				C.V.E. ⁺				C.V.D. [‡]			
	MP ψ	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂	MP	F ₁	F ₂
1 x 2	53.5	48.1c§	70.6	13.0	12.9b-d	14.1f	4.8	5.5	5.1	4.8	5.5	5.1
1 x 3	49.7	58.1a-c	55.6	13.2	12.2ab	12.8c-e	5.2	8.4	5.5	5.2	8.4	5.5
1 x 4	55.6	53.7bc	61.8	12.9	12.5bc	13.1de	6.8	6.4	7.1	6.8	6.4	7.1
1 x 5	59.7	47.5c	63.1	12.9	13.3c-e	13.7ef	5.1	7.7	4.6	5.1	7.7	4.6
1 x 6	47.2	71.2ab	62.5	13.1	14.2e	14.4f	7.2	4.3	4.7	7.2	4.3	4.7
2 x 3	47.5	62.5a-c	65.6	13.4	11.6a	12.1bc	4.3	5.9	4.8	4.3	5.9	4.8
2 x 4	53.5	55.6a-c	58.7	13.2	13.2b-e	13.6ef	5.9	6.5	6.4	5.9	6.5	6.4
2 x 5	57.5	67.5ab	69.3	13.1	12.9b-d	11.7b	4.2	2.9	7.0	4.2	2.9	7.0
2 x 6	45.0	58.1a-c	53.7	13.3	13.8de	13.6ef	6.3	7.4	4.8	6.3	7.4	4.8
3 x 4	49.7	59.3a-c	58.7	13.3	12.7bc	10.6a	6.3	5.9	5.0	6.3	5.9	5.0
3 x 5	53.7	63.1a-c	72.5	13.2	13.5c-e	12.2bc	4.5	4.3	3.0	4.5	4.3	3.0
3 x 6	41.2	47.5c	63.7	13.5	13.8de	11.7b	6.6	8.7	5.1	6.6	8.7	5.1
4 x 5	59.7	72.5	73.1	13.0	12.7bc	11.8b	6.2	3.3	5.1	6.2	3.3	5.1
4 x 6	47.2	55.0a-c	62.5	13.3	14.1e	13.6ef	8.3	6.8	5.3	8.3	6.8	5.3
5 x 6	51.2	57.5a-c	56.8	13.2	14.1e	13.1d-f	6.5	6.1	6.2	6.5	6.1	6.2
Average		58.5	63.2		13.2	12.8		6.0	5.3		6.0	5.3
C.V.%		26.7	31.2		6.7	6.8		61.9	74.5		61.9	74.5

 ψ Mid-parental value.⁺ Coefficient of velocity of emergence.[‡] Coefficient of velocity of post-emergence damping-off.[§] Averages within columns followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Table 30. (c) Hypocotyl grade, Root grade.

Cross	Hypocotyl grade			MP	Root grade	
	MP ψ	F ₁	F ₂		F ₁	F ₂
1 x 2	4.0	4.4bc ⁵	3.5	3.7	4.2C	3.3
1 x 3	4.4	4.0a-c	4.2	3.8	3.6a-c	3.9
1 x 4	4.1	4.2a-c	4.2	3.9	3.9a-c	3.8
1 x 5	3.9	4.4bc	4.1	3.6	4.1bc	3.7
1 x 6	4.5	3.3a	3.9	3.9	2.9a	3.7
2 x 3	4.1	4.0a-c	3.3	3.7	3.7a-c	3.2
2 x 4	3.8	3.4ab	4.0	3.8	3.4a-c	3.8
2 x 5	3.7	3.5ab	3.7	3.5	3.2ab	3.5
2 x 6	4.2	4.0a-c	4.0	3.9	4.2C	4.0
3 x 4	4.2	4.1a-c	3.7	3.9	3.7a-c	3.7
3 x 5	4.0	3.2a	3.5	3.6	3.0a	3.4
3 x 6	4.5	4.8c	3.9	3.9	4.4C	3.5
4 x 5	3.8	3.2a	3.1	3.7	3.0a	3.0
4 x 6	4.3	4.0a-c	3.6	4.1	3.8a-c	3.3
5 x 6	4.1	3.9a-c	3.9	3.8	3.5a-c	3.5
Average		3.9	3.8		3.6	3.6
C.V.%		22.4	23.9		23.4	26.8

 ψ Mid-parental values.⁵ Averages within columns followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

from 3.3 to 8.4 for the F_1 's and from 3.0 to 7.0 for the F_2 's. Dominance deviation for hypocotyl grade appears to operate in both directions. The F_1 's averaged 3.9 and the F_2 's 3.8. Ten F_1 's and ten F_2 's had hypocotyl grades lower than their mid-parents. Similar trends was obtained for root grade as was for hypocotyl grade. Both F_1 's and F_2 's averaged 3.6.

The Diallel Analyses

The diallel analysis and its genetic interpretations will be based on the combined analysis over the two runs for each of R. solani and P. ultimum. Comparative references of results with the two runs for each fungal pathogen will be made where necessary.

Validity of Assumptions

The methods of testing the diallel assumptions upon which Hayman (34) and Jinks (40) based their biometrical genetic model, as well as information that help to verify the validity of some of such assumptions, follow.

Diploid Segregation

Brown (19), Kimber (43) and Endrizzi (29) presented evidence from cytological studies that tetraploid cotton segregates in a diploid-like manner. However, duplicate

was for C.V.E with a significant parent X run interaction (Table 26). In the F_1 , significant interaction term was obtained for emergence, pre-emergence damping-off and final stand (Table 28).

No Epistasis and Multiple Allelism and Uncorrelated Gene Distribution

The validity of the assumptions can be tested using parental and F_1 generations data. If the assumptions are valid, the value $(W_r - V_r)$, i.e. the covariance between parents and the means of their offspring minus, the variance of offspring arrays having common parents, should be constant (33,40). A significant array effect indicates that one or more of the three assumptions was not met. Presented in Tables 31 and 32 are the mean squares for the $(W_r - V_r)$ analysis for R. solani and P. ultimum, respectively. The results indicate that the arrays were homogeneous, and that the assumptions of the diallel analysis were met for all traits for both R. solani and P. ultimum.

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Hayman's (35) extension of the diallel analysis to the F_2 generation provided sensitive procedures for detecting epistatic effects, multiple allelism, and uncorrelated gene distribution which may not be detected using $(W_r - V_r)$ analysis. Epistasis was tested by chi-square.

The chi-square tests for epistasis for traits associated with resistance to R. solani are presented in Table

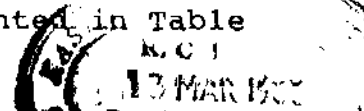


Table 31. Mean squares of (Wt-Vr) for eight seedling traits associated with resistance to R. solani, combined over runs.

Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. ⁺	C.V.D. [‡]	Hypocotyl grade	Root grade
Replication	3	2018.17	2018.19	205078.67	70603.67	0.19**	59.28**	0.59	0.88
Array	5	2401.18	2401.19	91016.75	27822.39	0.07	14.28	0.39	0.42
Error	15	1716.11	1716.12	85615.50	52687.59	0.04	9.69	0.29	1.01
Total	23	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 32. Mean squares of (Wt-Vr) for eight seedling traits for P. ultimum, combined over runs.

Source	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade	Root grade
Replication	3	26754.12*	26754.08*	13549.50	25009.75*	0.49	27.39	0.22	0.26
Array	5	6103.27	6103.28	17471.62	51255.68	0.12	17.39	0.02	0.02
Error	15	4507.38	4507.38	13797.07	5892.61	0.16	25.82	0.07	0.08
Total	23	-	-	-	-	-	-	-	-

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

* Significant at the 0.05 level of probability.

33. Sum of all and pooled chi-square values were significant for all the traits. Heterogeneity chi-square values were also significant for each trait; however, the magnitude was higher than for the pooled chi-squares except for C.V.E. A similar result is indicated for P. ultimum (Table 34). The results suggest that the assumption of independent action of non-allelic genes, that is, no epistasis are not valid for all the traits for both R. solani and P. ultimum. Also, the significant heterogeneity chi-squares suggests that epistasis in the F_2 's was not uniform or unidirectional in all crosses.

A detailed analysis of variance of the second degree statistics was performed to test for no multiple allelism and uncorrelated gene distributions for the eight traits associated with resistance to R. solani and P. ultimum. The deviation of observed statistics from expected were calculated after fitting the estimated genetic components, to each replication and totals over replications (36). The results of this test for R. solani showed components and interaction - multiple allelism to be significant for all the traits (Table 35). Similar results were obtained for P. ultimum (Table 36). In no case was the interaction, multiple allelism, parental heterozygosity and gene correlation component significant. It may, therefore, be concluded that the significance of the interaction and multiple allelism component was due to epistasis

Table 33. Chi-square test for epistasis for eight traits associated with resistance to *R. solani*, combined over runs.

Chi-square	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
Sum of all Chi-squares	60	289.54**	289.56**	433.39**	445.34**	478.81**	295.70**	569.15**	335.54**
Pooled Chi-squares	15	81.64**	81.64**	166.19**	155.14**	342.29**	94.03**	223.09**	109.87**
Heterogeneity Chi-square	45	207.90**	207.92**	267.21**	290.19**	136.51**	201.67**	346.05**	225.68**

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 34. Chi-square test for epistasis for eight traits associated with resistance to *P. ultimum*, combined over runs.

Chi-square	d.f.	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
Sum of all Chi-squares	60	340.91**	340.91**	226.92**	353.24**	603.05**	245.86**	230.87**	276.03**
Pooled Chi-squares	15	199.29*	199.30**	41.56**	126.90**	465.12**	64.80**	66.81**	67.99**
Heterogeneity Chi-square	45	141.61**	141.61**	185.35**	226.33**	137.93**	181.05**	164.06**	208.03**

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 35. Detailed analysis of variance of second degree statistics from the parental, F_1 and F_2 diallel data for *R. solani*, combined over runs.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade
Components	14	5339.03**	5338.89**	350157.69**	215867.69**	0.489**	25.59**	1.936**
Interaction and multiple allelism	35	1645.48**	1645.54**	165908.87**	122983.31**	0.098**	9.02**	1.009**
Interact., multiple allelism, heterozygosity and gene correlation	5	252.46	252.46	3330.39	2232.00	0.010	1.46	0.011
Replication X components	42	1385.53	1385.54	42023.19	26607.76	0.037	4.45	0.184
Replication X i and m.a.	105	747.94	747.94	31076.49	20241.44	0.022	3.62	0.175
Replication X i., m.a., p.h., and g.c.	15	139.61	139.59	9097.33	5766.66	0.004	1.01	0.033
								0.079

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 36. Detailed analysis of variance of second degree statistics from the parental, F_1 and F_2 diallel data for *P. ultimum*, combined over runs.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade
Components	14	25636.68**	25635.88**	51097.38**	76375.56**	1.69**	101.29	0.4759**
Interaction and multiple allelism	35	6192.27**	6192.31**	8370.34*	13691.06**	0.56**	21.51	0.0484*
Interact., multiple allelism, heterozygosity and gene correlation	5	443.19	443.14	1477.45	769.29	0.01	1.73	0.0023
Replication X components	42	5475.03	5474.99	7500.25	10004.90	0.13	11.14	0.0656
Replication X i and m.a.	105	1603.44	1603.45	4764.13	3075.81	0.11	10.03	0.0287
Replication X i, m.a., p.h., and g.c.	15	422.99	422.98	1525.77	639.14	0.02	2.65	0.0069
								0.0087

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

since the chi-square tests, were significant. The results strongly indicate that only the assumption of independent action of non-allelic genes (epistasis) was not met for both R. solani and P. ultimum.

Estimates of the genetic components for traits having a partial failure of the assumptions are still possible (35); however, the estimators are less reliable than when all the assumptions are fulfilled. Hayman (35) theoretically showed that a complementary type of gene interaction distorts the (Wr,Vr) graph, inflates H_1/D (which estimates the average degree of dominance), depresses h^2/H_2 (which estimates the minimum number of group of genes), but has little effect on $H_2/4H_1$ (which estimates the average frequency of positive versus negative alleles in the parents). Types of epistasis that are similar to duplicate gene interaction have little effect on H_1/D , $H_2/4H_1$, and the (Vr,Wr) graph, but depresses h^2/H_2 . The effect of significant epistasis for all the traits studied and some of the genetic estimators will be discussed in the next section.

The Genetic System

Analysis of the genetic system was carried out, as stated previously, by the methods of Hayman (33,34,35) and Jinks (40) using FORTRAN programs developed by K.M. El-Zik and B.L. Lisenbe (unpublished) for the parental and F_1

data, and for the parental, F_1 and F_2 data, commonly referred as the F_2 diallel analysis. Estimation of the genetic components of variation was obtained from the two diallel analyses for R. solani and P. ultimum.

Rhizoctonia solani

It was implied from the analysis of variance for the parental lines, that significance for any trait indicates genotypic differences. From the combined analysis of variance, significant differences were obtained for post-emergence damping-off, final stand, C.V.E, hypocotyl grade, and root grade.

The F_1 diallel analysis for the combined runs (Table 37) shows that additive genetic component (D) was significant for post-emergence damping-off, final stand, and hypocotyl grade. The dominance components (H_1 and H_2) were significant for all traits. The magnitude of H_1 and H_2 are much larger than D. The non-significance of component h^2 for all the traits, confirms that dominance is bidirectional.

The parameter F was significantly different from zero and positive for post-emergence damping-off, final stand and hypocotyl grade. The positive sign of F for the three traits indicates an excess of dominant alleles, or of dominant genetic effects in the parents. The same pattern of results was obtained for run 1 (Appendix Table 1). The

Table 37. Genetic components and their standard errors and environmental variances from F_1 diallel data, for traits associated with resistance to *R. solani*, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [†]	C.V.D. [‡]	Hypocotyl grade	Root grade
D	-6.1357	-6.1357	333.1435**	225.5515**	0.2634	-0.8176	1.0210**	0.0550
S.E.	10.5558	10.5558	59.0893	79.9833	0.1786	0.3399	0.2125	0.3362
F	-2.9728	-2.9728	731.1875*	563.9299*	0.5445	-2.1303	1.9914*	1.0177
S.E.	27.3378	27.3378	230.4241	220.8598	0.2717	1.7571	0.4901	0.7421
H_1	127.4056*	127.4047*	1521.1590**	1272.8060**	1.3804*	6.5549	3.6495**	3.3857*
S.E.	40.3424	40.3426	40.6503	258.6142	0.3732	6.0556	0.6755	0.9415
H_2	118.1409*	118.1735*	980.8798*	847.3212**	0.7979	6.0118	2.3829**	2.1929**
S.E.	36.7831	36.7782	236.3760	114.5418	0.2306	4.0677	0.3593	0.4637
h^2	7.7043	7.7043	15.7024	30.4423	0.0346	-1.2426	-0.1633	0.0889
S.E.	17.6889	17.6889	118.2079	137.2666	0.0192	0.4162	0.0547	0.1651
E	49.2088	49.2088	290.5510	249.1880	0.1833	4.0955	0.5616	0.8325

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

results for run 2 are presented in Appendix Table 2. It shows the same trend for the dominance components (H_1 and H_2); however, none of the D components were significant.

Comparable results were obtained from the F_2 diallel analysis, utilizing parental, F_1 , and F_2 data (Table 38). Additive gene action was indicated for emergence, pre-emergence damping-off, post-emergence damping-off, final stand, hypocotyl and root grade. It should be recalled that the additive component was not significant for emergence and pre-emergence damping-off utilizing the parental and F_1 analysis. Dominance components (H_1 and H_2) were significant for all traits and of larger magnitude than the additive component. This agrees with the results from the parental and F_1 analysis. The F component was significant and positive for all traits except for C.V.E and C.V.D. The results from the combined data agrees with those of run 1 (Appendix Table 3) and run 2 (Appendix Table 4).

The ratios of genetic components, phenotypic and dominance order of parents, and the correlation of parental phenotypic means ($\bar{y}$) and ($W_r + V_r$), from the parent and F_1 diallel analysis for the combined runs are presented in Table 39. The average degree of dominance, $(H_1/D)^{1/2}$, was greater than one for post-emergence damping-off, final stand, and hypocotyl grade indicating overdominance or epistasis for these traits. The values of $H_2/4H_1$ for

Table 38. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to *R. solani*, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	55.4860*	55.4860*	691.1006**	598.9683**	0.1806	1.1955	1.3996*	1.2583*
S.E.	15.0459	15.0459	143.8636	106.1775	0.1343	1.0435	0.3105	0.3886
F	97.2699*	97.2725*	1327.1104*	1201.3486*	0.2515	0.5728	2.5306*	3.0115*
S.E.	40.0116	40.0116	419.9766	290.4907	0.4605	3.0717	0.9154	1.0139
H ₁	226.4374**	226.4423**	2151.6387**	1884.6748**	1.5846*	11.3316	4.6439**	5.1625**
S.E.	42.2531	42.2534	458.5862	301.7044	0.4575	6.1363	0.7615	1.0726
H ₂	174.0883**	174.1118**	1410.7734**	1218.2900**	1.2421**	10.3222*	3.3707**	3.1374**
S.E.	29.9194	29.9192	224.6230	181.7863	0.1631	3.9254	0.4142	0.4099
E ₀	7.9302	7.9297	49.4782	45.8114	0.0685	0.6015	0.1246	0.0795
E ₁	13.5349	13.5342	79.5894	66.6543	0.0406	1.2119	0.1520	0.2515
E ₂	11.9336	11.9329	70.9861	60.6992	0.0486	1.0375	0.1442	0.2024

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

emergence and pre-emergence damping-off were not significantly different from 0.25, indicating that for these traits the proportion of positive and negative alleles of genes (at loci exhibiting dominance) were equally distributed among the parents (Table 39). The ratio of dominant to recessive genes, K_D/K_R , was more than one for all traits. This is further evidence of an excess of dominant genes in the parents.

The number of effective factors, h^2/H_2 , that control the traits and exhibit dominance to some degree, were all below the value of one. This quantity is underestimated when gene effects are not equal. This result is confirmed by values of $H^2/4H_1$ discussed earlier. As Hayman (35) showed, it is probable that the epistatic effects indicated for all the traits may have depressed the values of h^2/H_2 .

Estimates of heritability in the narrow sense were calculated by the method suggested by Crumpacker and Allard (23). The method estimates the additive and/or additive X additive epistatic variance to the total phenotypic variance. The values ranged from -1.91% for emergence to 20.7% for hypocotyl grade. Values were relatively high for post-emergence damping-off, final stand, hypocotyl grade and C.V.E. It may be recalled that a major part of the total phenotypic variance is due to dominance and overdominance. Utilizing a breeding and

Table 39. Ratio of genetic components, phenotypic and dominance order of parents, and correlation of $\bar{y}$ and $Wt+Vt$ from F_1 diallel data, for eight traits associated with resistance to *R. solani*, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D ⁺	Hypocotyl grade	Root grade
$(H_1/D)^{1/2}$	-1.5470	-1.5470	2.0923**	2.5891**	-2.2252	-2.5728	1.9248**	0.1099
S.E.	1.4826	1.4825	0.1948	0.3009	2.5134	1.1905	0.1919	1.5124
$H_2/4H_1$	0.2230	0.2232	0.1682**	0.1801**	0.1437**	-0.0618**	0.1689**	0.1761**
S.E.	0.0326	0.0325	0.0145	0.0231	0.0061	0.1921	0.0142	0.0234
K_D/K_R	2.5737*	2.5738*	3.1957*	3.2787*	2.0969*	2.9525	3.1569**	3.0896*
S.E.	0.8523	0.8524	0.7789	0.9282	0.7711	3.3140	0.5152	1.0697
h^2/H_2	-0.3048	-0.3035	-0.0408	-0.0097	0.0407	-0.7169	-0.0628	0.0809
S.E.	0.4415	0.4402	0.1886	0.1507	0.0184	0.4935	0.0199	0.0922
Heritability	-1.91	-1.91	14.58	11.68	14.37	-4.21	20.73	0.97
Order of parents:								
Dominance order	465231	465231	215364	213564	615423	153624	125364	213564
Phenotypic order	516432	516432	526134	516234	145623	256134	251634	561234
Correlations of $\bar{y}$ and $Wt+Vt$	0.399	-0.399	0.628	-0.475	0.731	-0.025	0.690	0.238

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

selection procedure, like the one being used for the MAR program (14), whereby the frequency of favorable alleles (whether dominant or recessive) are increased will lead to an increase of the frequency of resistant plants in the target population.

Dominance and phenotypic orders of the parents for the eight traits showed little similarities for all the traits, suggesting that dominance was not unidirectional (Table 39). This agrees with the significant values of both H_1 and H_2 . Tamcot SP 37 possessed the most dominant genes for emergence, followed by TX-LEBO-3-80 and Tamcot CAMD-E. The parental line with the most recessive genes for emergence was Dixie King III. Resistance in Dixie King III to pre-emergence damping-off is conditioned by recessive genes. Tamcot SP 37 has the highest frequency of recessive alleles for susceptibility to post-emergence damping-off, hypocotyl and root grades and final stand establishment. The dominance and phenotypic orders agree perfectly. Dixie King III generally tended to possess more dominant alleles than Tamcot CAMD-E and TX-LEBO-3-80.

Hayman (34) reported that the parental mean ($\bar{y}$) is closely correlated with the number of positive alleles in the parents, while (W_r+V_r) bears the same relation to the number of recessive alleles in the common parent of an array. If the genes are unequal in their effects, then the correlation between $(\bar{y})$ and (W_r+V_r) is weighted in

favor of genes with large effects. When such a correlation is near unity, most of the dominant alleles are operating in one direction and most of the recessive alleles in the opposite direction. When the correlation is near +1, the dominant genes in the parents are operating mostly in the negative direction (in this study, towards lower pre- and post-emergence damping-off, hypocotyl and root grades or resistance to the seedling pathogens), and the recessive alleles mostly in the positive direction (towards susceptibility). When the correlation is near -1, the dominant alleles are mostly positive and the recessive alleles negative in direction. If the correlation is small, about equal proportions of the dominant genes will be positive (increase in the resistance expression of the character) and negative (decrease the expression), the same being true for the recessive genes. The correlation coefficients of $(\bar{y})$ and (W_r+V_r) for all the traits were not significantly different from zero, indicating that almost equal proportions of the genes showed dominance in a positive direction (increase the expression of the trait), while others acted in the negative direction (decrease the expression), the same being true for recessive genes.

Pythium ultimum

The F_1 diallel analysis for the combined runs (Table 40), shows that additive genetic component (D) was not significant for any trait, except for the rate of post-emergence damping-off (C.V.D). The dominance components (H_1 and H_2) were significant for post-emergence damping-off, final stand, C.V.D., hypocotyl and root grades (Table 40). The dominance components were of larger magnitude than the additive component. The non-significance of component h^2 for all the traits, except for root grade, indicates that dominance was bidirectional. The parameter F was not significantly different from zero for any trait. Generally, similar trends were established for run 1 (Appendix Table 5) and run 2 (Appendix Table 6).

Comparable and additional results were obtained when the diallel analysis was extended to the F_2 (Table 41). The additive component of variation was significant for all the traits, except C.V.E. Dominance components (H_1 and H_2) were significant for all the traits, thus confirming results from the F_1 diallel analysis. The magnitudes for H_1 and H_2 were also larger than for the D components.

Recall that the F values were not significant in the F_1 analysis; however, the F component was significant for all traits, except C.V.E and C.V.D, from the F_2 analysis. All F values were positive, thus indicating excess domi-

Table 40. Genetic components and their standard errors and environmental variances from F_1 diallel data, for traits associated with resistance to P. ultimum, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	29.5713	29.5713	41.9746	33.7308	-0.0031	3.9035*	0.0356	-0.0171
S.E.	34.0806	34.0806	57.7206	53.5989	1.1122	1.5869	0.1756	0.0956
F	31.2336	31.2336	40.9279	34.7657	-0.1005	1.1108	-0.0578	-0.0878
S.E.	50.8924	50.8924	70.5099	102.3379	0.1934	2.0367	0.2644	0.1279
H ₁	192.9882	192.9789	378.4660**	354.7746*	1.7129*	10.4527	0.9462*	1.0815*
S.E.	138.8200	138.8198	76.0082	135.9261	0.6028	4.7766	0.2418	0.3370
H ₂	159.8040	159.8264	329.7580**	308.3850*	1.1496*	8.8696*	0.8593*	0.9863*
S.E.	104.5947	104.6025	67.9324	101.4585	0.3900	2.4729	0.1993	0.2759
h ²	147.4370	147.4372	75.4783	317.5522	0.1994	0.0365	0.4238	0.4113*
S.E.	138.2503	138.2503	48.2723	213.6537	0.2759	0.8266	0.1811	0.1276
E	83.8666	83.8666	134.9550	137.2070	0.3982	6.3247	0.4190	0.3247

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant of the 0.05 level and 0.01 levels of probability, respectively

Table 41. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to P. ultimum, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [‡]	C.V.D. [‡]	Hypocotyl grade	Root grade
D	188.9808**	188.9796**	134.4269*	218.2286**	0.6580	9.8718*	0.3008**	0.2497**
S.E.	38.4634	38.4634	47.3333	43.1614	0.3195	1.2422	0.0440	0.0021
F	268.0078*	268.0088*	187.5645*	294.0527**	0.7515	11.6204	0.3284*	0.3181*
S.E.	97.2554	97.2559	43.4586	61.8644	0.5082	8.4081	0.0917	0.1011
H ₁	437.8362*	437.8398*	588.3643**	694.7935**	3.0185**	22.3185*	1.6143**	1.5865*
S.E.	159.5043	159.5042	86.6665	113.3711	0.4657	6.5588	0.3153	0.3928
H ₂	298.8437*	298.8643*	465.6042**	545.1873*	2.1703*	16.2271**	1.3765**	1.3208**
S.E.	118.7340	118.7366	84.8861	144.7788	0.5388	2.9276	0.1682	0.2277
E ₀	18.6635	18.6633	43.3577	29.8612	0.1085	2.1309	0.1032	0.0779
E ₁	19.6815	19.6813	27.7929	28.9330	0.0878	1.3711	0.0909	0.0874
E ₂	19.3906	19.3904	32.2399	29.1982	0.0937	1.5882	0.0944	0.0847

* Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 level and 0.01 levels of probability, respectively.

nant alleles for emergence, pre- and post-emergence damping-off, final stand, hypocotyl and root grades. Generally, similar trends in the results were obtained for run 1 (Appendix Table 7 and run 2 (Appendix Table 8).

These results point out the need and importance of extending the analysis to the F_2 generation to obtain reliable information on the genetic system controlling resistance. Indeed, the analysis of the genetic basis for resistance to P. ultimum would be misleading if only the F_1 analysis was employed. Significant additive components (D) of variation and of F values were evident in the F_2 analysis. Evaluation of the genetic system for resistance to this pathogen, especially for emergence and pre-emergence damping-off, would require the use of the F_2 .

The ratio of genetic components, phenotypic and dominance order of parents, and the correlation of parental phenotypic means ($\bar{y}$) and (W_r+V_r) from the parental and F_1 diallel analysis, for the combined data over runs, are presented in Table 42. The values for average degree of dominance, $(H_1/D)^{1/2}$, were not significantly different from zero, but greater than one for emergence, pre-emergence damping-off, and C.V.E. This suggests overdominance for these traits. Partial dominance (0 to 1.0) was indicated for post-emergence damping-off, final stand, C.V.D. and hypocotyl and root grades (Table 42).

Table 42. Ratio of genetic components, phenotypic and dominance order of parents, and correlation of $\bar{y}$ and $Wt+Vr$ from F_1 diallel data, for eight traits associated with resistance to P.ultimatus, combined over runs.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
$(H_1/D)^{1/2}$	3.5749	3.5749	-0.9019	-0.7591	2.6029	0.4471	-0.4085	-0.5486
S.E.	2.8502	2.8502	1.7838	1.2357	1.7036	0.9916	1.0760	1.4025
$H_2/4H_1$	0.1237*	0.1236*	0.2189	0.2474	0.1711**	0.3287	0.2482	0.2549
S.E.	0.0492	0.0493	0.0109	0.0269	0.0036	0.0986	0.0306	0.0356
K_D/K_R	-2.5272	-2.5272	2.0324*	1.8106	1.4021*	4.2955	2.6464**	1.5813**
S.E.	3.6012	3.6012	0.6240	0.7829	0.4433	3.0132	0.4589	0.2954
h^2/H_2	-15.7718	-15.4421	0.3246	1.1539	0.1196	-0.0331	0.5246*	0.4759**
S.E.	16.8840	16.5544	0.1732	0.5109	0.1742	0.1313	0.1542	0.1003
Heritability	5.61	5.61	4.56	3.74	-0.09	10.18	1.31	-0.69
Order of parents:								
Dominance order	135426	135426	524316	215463	654213	641532	154263	154263
Phenotypic order	514326	514326	254136	514236	362451	253146	524136	521346
Correlations of ($\bar{y}$) and $Wt+Vr$	-0.753	0.754	0.831*	-0.775	0.007	-0.989**	0.578	0.511

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and the 0.01 levels of probability, respectively.

The values of $H_2/4H_1$ for post-emergence damping-off, final stand, C.V.D., hypocotyl and root grades were not significantly different from 0.25, indicating that for these traits the proportion of positive and negative alleles of genes (at loci exhibiting dominance) were equally distributed among the parents (Table 42).

The ratio of dominance to recessive genes, K_D/K_R , was more than one only for post-emergence damping-off, final stand, C.V.E, C.V.D, hypocotyl and root grades. For these traits, there is an excess of dominant genes in the parents.

The values for the number of effector factors or genes, h^2/H_2 , that control the traits and exhibit dominance to some degree, were all below one, except for final stand. The significant epistatic effects demonstrated for all the traits indicates that the values of h^2/H_2 were indeed depressed (35). The estimates are, therefore, unreliable.

Estimates of heritability in the narrow sense ranged from -0.09% for C.V.E. to 10.2% for C.V.D (Table 42). Since the major component of the total phenotypic variance for all the traits is due to dominance, effective phenotypic selection for resistance would be difficult. The utilization of breeding and selection procedures that increases the frequency of favorable alleles will lead to an increase in the frequency of resistant plants (14).

Dominance and phenotypic orders of the parents showed little similarities for all the traits, further suggesting that dominance was not unidirectional. For emergence, Dixie King III, has more of the dominant genes, while TX-LEBBO-3-80 has a preponderance of recessive alleles. This pattern was indicated for pre-emergence damping-off. This means that resistance in Dixie King III to P. ultimum is conditioned by dominant genes. In the case of R. solani, it was shown that resistance in Dixie King III was due to recessive genes. TX-LEBO-3-80 had the highest frequency of recessive alleles for pre-emergence damping-off. Thus, resistance is conditioned by recessive genes. Tamcot CAMD-E tended to have the same proportions of dominant and recessives alleles. TX-LEBO-3-80 had the highest frequency of recessive alleles for post-emergence damping-off. This may be true for hypocotyl and root grades.

The correlation coefficients of ($\bar{y}$) and (W_r+V_r) were not significantly different from zero for emergence, pre-emergence damping-off, final stand, C.V.E, C.V.D, hypocotyl and root grades. The correlation was positive and near unity (significantly different from zero but not from unity) for post-emergence damping-off ($r = 0.83$). This shows that most of the dominant genes in the parents were acting in one direction, that of resistance or low incidence of post-emergence damping-off. On the other hand, the rate of post-emergence damping-off (C.V.D) was nega-

tive (-0.99) and significantly different from zero, but not from -1. This indicates that recessive alleles were acting in the positive direction (higher rate of damping-off).

Combining Ability Analysis

Rhizoctonia solani

The combining ability analysis for the combined data over runs, is presented in Table 43. Mean squares for general combining ability effects were significant for post-emergence damping-off, final stand, C.V.E, hypocotyl and root grades. Significant specific combining ability (SCA) effect was indicated for hypocotyl grade. The results for run 1 (Appendix Table 9) agrees with that of the combined analysis; however, significant SCA effect were indicated for post-emergence damping-off and for final stand. The magnitudes for the GCA effects were greater than the SCA effects. For run 2, significance for GCA effect was indicated only for C.V.E (Appendix Table 10).

A further analysis of the GCA effects of the parents and the specific combining ability effects for the fifteen cross combinations is contingent on the significant differences between the F_1 means for each trait as revealed by the Analysis of variance (Table 13). Significant differences were indicated for post-emergence damping-off, final stand, C.V.E, hypocotyl and root grades. Estimates

Table 43. Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects of cotton genotypes for eight traits associated with resistance to *R. solani*, combined over runs.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade
GCA	5	62.29	62.29	1070.19**	888.85*	2.78**	4.17	2.46**
SCA	9	86.74	86.74	557.65	476.98	0.29	5.40	1.43*
Error	42	54.14	54.14	318.36	266.62	0.16	4.84	0.61
								0.58
								1.01

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

of the GCA effects for the parental lines, combined over runs are presented in Table 44. A positive effect is to be desired for emergence and final stand, while a negative effect is to be desired for pre-and post-emergence damping-off, hypocotyl grade, root grade and C.V.D. If a slow rate of emergence is desired, than a negative value for GCA effect is favored.

The GCA effects for emergence and pre-emergence damping-off were not significant. The highest average performance of the parental lines for emergence as evidenced by the high estimate of GCA effect of 2.45 was obtained for Tamcot SP 37. This means that favorable combinations and interactions for emergence were more frequent between the gametic arrays of other parents and those of Tamcot SP 37. The highest emergence of 85.6% was obtained from the cross between Lankart 57 and Tamcot SP 37 (3 x 4). The parent with the least GCA effect of -3.33 is TX-LEBO-3-80. The lowest emergence of 71.2% was obtained between Tamcot CAMD-E and TX-LEBO-3-80 (5 x 6). Interactions between the gametes of these resistant parents leads to reduced emergence. Similar results were obtained for pre-emergence damping-off. Again, Tamcot SP 37 had the best GCA effect of -2.45. This was followed by Tamcot CAMD-E with a value of -0.89. The lowest F_1 mean value for pre-emergence damping-off was for the cross between Lankart 57 and Tamcot SP-37 with a value of 14.3%.

Table 44. Estimates of general combining ability effects for parental lines for eight traits associated with resistance to *R. solani*, combined over runs.

Parent	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade	Root grade
1. Dixie King III	-0.99	0.99	5.43	-4.74	-0.19	10.96	0.07	-0.59
2. Acala SJ-5	0.73	-0.73	-8.26	6.04	-0.20	-0.97	-0.33	-1.22
3. Lankart 57	0.26	-0.26	-4.33	3.39	-0.52	0.09	-0.17	-1.04
4. Tamcot SP37	2.45	-2.45	-7.87	8.39	0.07	-0.09	-0.38	-1.41
5. Tamcot CMD-E	0.89	-0.89	2.87	-1.46	0.15	0.20	0.12	-0.49
6. TX-LEEO-3-80	-3.33	3.33	12.15	-11.61	0.70	0.31	0.68	0.36
S.E. ($\hat{g}_i - \hat{g}_j$) =	5.20	5.22	12.62	11.55	0.28	1.56	0.55	0.71

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

This was followed by the cross between Lankart 57 and Tamcot CAMD-E, with a value of 15.6%.

The best GCA effect value for post-emergence damping-off was by Acala SJ-5 (-8.26), followed by Tamcot SP 37 (-7.87). The highest and unfavorable value of 12.15 belonged to TX-LEBO-3-80. The lowest post-emergence value of 10.5% was for the F_1 cross combination between Acala SJ-5 and Tamcot SP 37 (2 x 4). The highest GCA effect for final stand was recorded by Tamcot SP 37, with a value of 8.39. This was followed by Acala SJ-5. Among the resistant lines, Tamcot CAMD-E was the best with a value of -1.46. The cross between Acala SJ-5 and Tamcot SP 37 (2 x 4) had the highest F_1 mean final stand of 73.7%. The slowest rate of emergence (C.V.E) GCA effect of -0.52 was for Lankart 57, while the fastest value of 0.7 was for TX-LEBO-3-80. Acala SJ-5 had the best GCA effect (-0.97) for C.V.D while Dixie King III gave the highest and less favorable value of 10.96.

The best average performance leading to the lowest incidence of hypocotyl rot was for parent Tamcot SP 37 with a GCA effect of -0.38 for hypocotyl grade. The lowest F_1 mean value for hypocotyl grade was for the cross between Acala SJ-5 and Tamcot SP 37 (2 x 4) with a value of 3.2. Among the resistant line, Dixie King III gave the best GCA effect of 0.07. This was followed by Tamcot

CAMD-E with a value of 0.12. The same trend of results was obtained for root grade.

Significant differences among the F_1 means for specific combining ability effects was obtained for hypocotyl grade only. The SCA effects for all the F_1 cross combinations for each trait is presented Table 45. The resistant parents have an array of gametes that generally favored more of a specific combining ability effects than a general combining ability effect. For example, the best SCA effects for emergence were for those crosses involving Tamcot CAMD-E. The cross Dixie King III and Tamcot CAMD-E (1 x 5) and the cross Lankart 57 and Tamcot CAMD-E (3 x 5) gave the same SCA effect of 4.31. Emergence for these crosses ranged from 83.1% to 85.6%. Specific combining ability effects for pre-emergence damping-off ranged from 5.84 for the cross between Lankart 57 and TX-LEBO-3-80 (3 x 6) to -5.56 for Acala SJ-5 and TX-LEBO-3-80 (2 x 6). SCA effects for post-emergence damping-off ranged from the best and favorable value (-14.28) for the cross Dixie King III and TX-LEBO-3-80 (1 x 6) to 18.26 the unfavorable value for the cross Dixie King III and Acala SJ-5 (1 x 2).

The best and favorable final stand SCA effect of 13.94 was for the cross between Dixie King III and TX-LEBO-3-80 (1 x 6). The lowest and unfavorable values (low stand) were for the cross combinations of Tamcot SP 37 and TX-LEBO-3-80 (4 x 6) and Tamcot CAMD-E and TX-LEBO-3-80 (5

Table 45. Estimates of specific combining ability effects for 15 F_1 generations for eight traits associated with resistance to *R. solani*, combined over runs.

Cross	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D ⁺	Hypocotyl grade	Root grade
1 x 2	-1.16	1.16	18.26	-16.22	0.45	1.35	0.84	0.36
1 x 3	-1.31	1.31	0.74	-1.06	-0.37	0.00	-0.08	0.09
1 x 4	-4.75	4.75	-9.07	4.57	-0.02	-0.63	-0.34	-0.11
1 x 5	4.31	-4.31	4.35	-1.22	0.16	0.46	0.36	0.12
1 x 6	2.91	-2.91	-14.28	13.94	-0.21	-1.18	-0.78	-0.46
2 x 3	-1.16	1.16	1.51	-1.84	-0.10	0.07	0.28	0.09
2 x 4	-0.84	0.84	-5.94	5.03	-0.09	-1.35	-0.51	-0.14
2 x 5	-2.41	2.41	-1.07	-0.75	-0.26	0.38	-0.10	-0.03
2 x 6	5.56	-5.56	-12.77	13.78	0.00	-0.45	-0.50	-0.29
3 x 4	4.00	-4.00	3.00	0.19	0.06	1.32	0.14	0.33
3 x 5	4.31	-4.31	-9.92	10.82	0.06	-1.85	-0.46	-0.52
3 x 6	-5.84	5.84	3.87	-7.94	0.35	0.46	0.12	0.00
4 x 5	-1.00	1.00	-2.67	0.66	0.12	0.25	-0.13	-0.19
4 x 6	2.59	-2.59	13.87	-10.44	-0.07	0.41	0.84	0.12
5 x 6	-5.22	5.22	9.31	-9.34	-0.07	0.76	0.32	0.63
S.E. ($\hat{s}_{ij}-\hat{s}_{ij}^*$)=	9.01	9.01	21.85	19.99	0.49	2.69	0.96	1.23
S.E. ($\hat{s}_{ij}-\hat{s}_{kl}^*$)=	7.36	7.36	17.04	16.33	0.40	2.20	0.78	1.00

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

x 6). These cultivars represent the various hybrid pools of the MAR program. The results indicate that they may have non-complementary genes for seedling disease resistance which upon interaction in their progenies leads to reduced resistance expression. The SCA effect values for C.V.E ranged from 0.45 to -0.21, while C.V.D. values ranged from -1.85 to 1.35.

Differences among the F_1 mean for SCA effect for hypocotyl grade was significant. Values ranged from -0.78 for the cross Dixie King III x TX-LEBO-3-80 (1 x 6) to 0.84 for the cross Dixie King III x Acala SJ-5 (1 x 2) and Tamcot SP 37 x TX-LEBO-3-80 (4 x 6). Similar trends were generally obtained for root grade as for hypocotyl grade.

The results of the genetic system, the combining ability analysis and the survey of the F_1 and F_2 means and those of their mid-parents, suggest that the gene action involved in the case of GCA may be due to additive and epistasis and for SCA dominance and overdominance. A phenotypic recurrent selection would enhance the accumulation of favorable alleles in which overdominance, partial dominance and additive gene action is involved in GCA and SCA. A delayed convergent breeding program as practiced in the MAR program would also enhance the levels of favorable alleles in the desired population (14).

Pythium ultimum

Mean squares for the combining ability analysis, combined over runs are presented in Table 46. Significant mean squares for SCA were indicated for post-emergence damping-off, final stand, C.V.D, hypocotyl and root grades. General combining ability was significant only for C.V.E. The results were in agreement with that of run 1 (Appendix Table 11) where in addition, SCA mean squares were significant for emergence and pre-emergence damping-off. For run 2 (Appendix Table 12), significant mean squares for SCA were obtained for emergence, pre-emergence damping-off and final stand. Significant mean square for GCA was indicated for C.V.E.

Estimates of the GCA effects for the parental lines, combined over runs are presented in Table 47. Differences among the parents for GCA effects were not significant, except for C.V.E. However, Tamcot CAMD-E was shown to be the best parental line for average performance, associated with resistance to P. ultimum. The highest emergence of 78.7% was obtained for the F₁ cross between Tamcot SP 37 and Tamcot CAMD-E (4 x 5). Tamcot CAMD-E gave the highest and best GCA effect (3.91) for final stand, reflecting its average performance for pre- and post-emergence damping-off, hypocotyl and root grades. GCA effects for C.V.E. ranged from -0.51 for Lankart 57 to 1.05 for TX-LEBO-3-80.

Presented in Table 48 are the SCA effects for all the fifteen F_1 cross combinations. Significant differences among the F_1 means were indicated for post-emergence damping-off, C.V.D., hypocotyl and root grades. The best and favorable SCA effect (-15.3) for post-emergence damping-off was for the cross between Dixie King III and TX-LEBO-3-80 (1 x 6) and the unfavorable SCA effect (17.26) was for the cross between Dixie King III and Tamcot CAMD-E (1 x 5).

The cross combination with the best and favorable SCA effects for pre-emergence damping-off (-7.88), post-emergence damping-off (-15.31), hypocotyl grade (-0.93) and root grade (-1.02) resulting in the highest and best SCA effect for final stand (16.97) was for Dixie King III and TX-LEBO-3-80 (1 x 6). Dixie King III was shown to be resistance to P. ultimum. The F_1 cross with second best SCA effect (9.16) for final stand was for Tamcot SP 37 and Tamcot CAMD-E (4 x 5).

Specific combining ability effect for C.V.E. ranged from -0.51 for the cross between Tamcot SP 37 and Tamcot CAMD-E (4 x 5) to 0.68 for the cross between Acala SJ-5 and Lankart 57 (2 x 3). This suggest that the F_1 cross, 4 x 5, emerged much slower than the cross, 2 x 3. Generally, similar trends were obtained for the rate of post-emergence damping-off (C.V.D) as that of post-emergence damping-off.

Table 46. Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects of cotton genotypes for eight traits associated with resistance to *P. ultimum*, combined over runs.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade
GCA	5	42.14	42.14	223.23	92.19	5.10**	12.62	0.67
SCA	9	149.67	149.67	415.65**	336.22**	0.79	11.42*	1.05**
Error	42	78.73	78.73	111.17	115.73	0.35	5.48	0.36
								0.35

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 47. Estimates of general combining ability effects for parental lines for eight traits associated with resistance to *P. ultimum*, combined over runs.

Parents	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D ⁺	Hypocotyl grade	Root grade
1. Dixie King III	-0.83	0.83	4.95	-3.44	-0.17	0.57	0.22	0.12
2. Acala SJ-5	-1.30	1.30	-1.05	-0.16	-0.38	-0.47	-0.02	0.15
3. Lankart 57	1.98	-1.98	3.48	-0.47	-0.51	0.78	0.14	0.06
4. Tamcot SP37	1.04	-1.04	-0.56	0.94	-0.17	-0.29	-0.14	-0.10
5. Tamcot CAMD-E	1.19	-1.19	-5.25	3.91	0.17	-0.42	-0.33	-0.36
6. TX-LEBO-3-80	-2.08	2.08	-2.11	-0.78	1.05	0.81	0.13	0.14
S.E. ($\hat{g}_i - \hat{g}_j$) =	6.11	6.11	9.31	7.73	0.46	2.06	0.45	0.39

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

Table 48. Estimates of specific combining ability effects for 15 F_1 generations for eight traits inoculated with P. ultimum, combined over runs.

Cross	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade	Root grade
1 x 2	-7.28	7.28	4.05	-6.78	0.25	-0.59	0.31	0.35
1 x 3	-1.81	1.81	-8.69	3.53	-0.26	1.07	-0.26	-0.22
1 x 4	0.38	-0.38	2.70	-2.25	-0.28	0.08	0.24	0.22
1 x 5	0.85	-0.85	17.26	-11.47	0.15	2.50	0.63	0.67
1 x 6	7.88	-7.88	-15.31	16.97	0.14	-3.09	-0.93	-1.02
2 x 3	8.66	-8.66	3.66	4.63	-0.68	-0.46	0.02	-0.12
2 x 4	-4.15	4.15	-2.00	-3.66	0.55	1.21	-0.32	-0.28
2 x 5	1.32	-1.32	-6.34	5.25	-0.04	-1.21	-0.07	-0.50
2 x 6	1.47	-1.47	0.65	0.56	-0.08	1.04	0.05	0.29
3 x 4	-0.56	0.56	-0.52	0.41	0.18	-0.63	0.18	0.10
3 x 5	-5.09	5.09	-7.66	1.19	0.64	-1.05	-0.54	-0.31
3 x 6	-1.18	1.18	13.22	-9.75	0.12	1.06	0.59	0.55
4 x 5	7.72	-7.72	-2.43	9.16	-0.51	-0.97	-0.21	-0.17
4 x 6	-3.37	3.37	2.26	-3.59	0.06	0.29	0.09	0.13
5 x 6	-4.78	4.78	-0.81	-4.13	-0.24	0.72	0.17	0.05
S.E. ($\hat{s}_{ij}-\hat{s}_{ij}$)=	10.58	10.58	16.13	13.39	0.80	3.57	0.78	0.68
S.E. ($\hat{s}_{ij}-\hat{s}_{kl}$)=	8.64	8.64	13.17	10.93	0.66	2.92	0.64	0.56

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

The results of the combining ability analysis indicates favorable general combining ability between the gametic arrays of some of the six-parents involved in the fifteen F_1 cross combinations to be important in resistance expression to R. solani, while specific combining ability between the gametes involving specific cross combinations were favorable for accumulating genes for resistance to P. ultimum. The results of the genetic system, the combining ability analysis and the survey of the F_1 and F_2 means and those of their mid-parents, suggests that the gene action involved in the case of GCA may be due to additive and epistasis and for SCA dominance and overdominance. A phenotypic recurrent reciprocal selection would enhance the accumulation of favorable alleles in which overdominance, partial dominance and additive gene action is involved in GCA and SCA. A delayed convergent breeding program as practiced in the MAR program would enhance the levels of favorable alleles in the target population (14).

Interrelationships Among Traits and Measurements

One of the objectives of this investigation was to determine the traits and measurements that best measures resistance to both R. solani and P. ultimum. Selection procedures for the genetic improvement of cotton in the MAR program has been based on the direction (positive and negative) and magnitude of associations between seed and

seedling traits under controlled laboratory conditions and those under field conditions (14).

In order to identify traits that best describe resistance to seedling diseases pathogens, the term resistance has to be defined in its useful and/or economic terms. Under the conditions of this experiment, resistance to both R. solani and P. ultimum, should translate to high final stand establishment. To identify these traits that adversely affect stand establishment, correlations and multiple regression variable selection (maximum R^2) analyses were performed on the data combined over runs for the parental lines for both R. solani and P. ultimum.

Rhizoctonia solani

Presented in Table 49 are the simple correlation coefficients for the combined data between the traits for the parental lines. The strongest negative correlation ($r = -1.0$) was between emergence and pre-emergence damping-off. The lower the incidence of pre-emergence damping-off, the higher the emergence. This was followed by post-emergence damping-off and final stand with a negative correlation ($r = -0.96$). This was the strongest association between any of the traits and final stand. The next strongest association are between hypocotyl grade and/or root grade and final stand. The lower the incidence of post-emergence damping-off, hypocotyl and root grades, the

Table 49. Correlation coefficients between seedling traits for parental lines inoculated with *R. solani*, combined over runs.

	C.V.E ⁺	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	Hypocotyl grade	Root grade	C.V.D [‡]
C.V.E ⁺	---	0.269	-0.269	-0.205	0.235	-0.067	-0.244	-0.205
Emergence (%)		---	-1.000**	-0.305	0.534**	-0.111	-0.443	-0.162
Pre-emergence damping-off (%)			---	0.305	-0.534**	0.111	0.443*	0.162
Post-emergence damping-off (%)				---	-0.961**	0.935**	0.851**	0.591**
Final Stand (%)					---	-0.868**	-0.845**	-0.597**
Hypocotyl grade						---	0.778**	0.587**
Root grade							---	0.323
C.V.D [‡]								---

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

higher the final stand. Post-emergence damping-off appears to be the most important trait in stand establishment, followed by hypocotyl and root grades. Post-emergence damping-off seemed to be explained by hypocotyl and root grades with significant positive correlations of 0.95 and 0.85, respectively. Thus, a severe hypocotyl rot and root rot leads to a high incidence of post-emergence damping-off and hence reduced final stand. A significantly positive correlation between percent emergence and final stand was obtained ($r = 0.53$). High emergence tends to suggest a probability for high stand establishment; however, if the incidence of post-emergence damping-off is high, the effect of high emergence on final stand may not be significant.

Multiple regression is useful for determining which traits have the greatest potential for predicting a particular response, in this study, final stand. Multiple regression variable selection analysis (maximum R^2) was performed on the combined data to determine which of the traits was important in explaining variability in final stand (dependent variable) and hence to confirm the significance of the direct associations obtained from the correlation analysis. Traits with the highest R^2 value were chosen as the best for explaining variability in final stand. The sign of the partial regression coefficient indicates the direction of influence.

The single best model for predicting final stand in the temperature controlled tank consisted of four traits (Tables 50 and 51). Because emergence and pre-emergence gave a significantly negative correlation of one, the two were not included in the model at the same time. The four traits are post-emergence damping-off, hypocotyl grade, emergence and pre-emergence damping-off, explaining 99% of the variability in final stand. The signs of their influence were the same as those of the correlation coefficients. The results confirm and agrees with those obtained for the analysis of variance (Table 11). Significant differences among the parental lines were obtained for post-emergence damping-off, final stand, hypocotyl and root grades.

Pythium ultimum

The simple correlation coefficients for the combined data are presented in Table 52. The strongest and negative association of unity was between emergence and pre-emergence damping-off. This agrees with the observation for R. solani. For final stand, the highest positive association was with emergence ($r = 0.79$), while the strongest negative association was with pre-emergence damping-off ($r = -0.79$). Thus, the higher the incidence of pre-emergence damping-off, the lower the emergence and hence the lower the final stand. The results tend to

Table 50. The influence of other traits (independent variables) for explaining variability in final stand (dependent variable) in the temperature tank using maximum R^2 stepwise multiple regression variable selection, for R. solani.

Final Stand	Sign of the partial regression coefficient for the independent variables					
	Number of independent variables in model	R^2	Post-emergence damping-off	Emergence	Hypocotyl grade	Root grade
1		0.92	---			
2		0.98	---	+		
3		0.99	---	+	---	
4		0.99	---	+	---	+
5		0.99	---	+	---	+
6		0.99	---	+	---	+

+ Coefficient of velocity of emergence.

* Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 51. The influence of other traits (independent variables) for explaining variability in final stand (dependent variable) in the temperature tank using maximum R^2 . Stepwise multiple regression variable selection, for R. solani.

Final Stand	Sign of the partial regression coefficient for the independent variables					
Number of independent variables in model	R^2	Post-emergence damping-off	Pre-emergence damping-off	Hypocotyl grade	Root grade	C.V.D. [†] C.V.E. [†]
1	0.92	---	---			
2	0.98	---	---			
3	0.99	---	---	---		
4	0.99	---	---	---	+	
5	0.99	---	---	---	+	---
6	0.99	---	---	---	+	---

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

suggest that pre-emergence damping-off is more important for final stand establishment in the presence of Pythium ultimum than for R. solani. Thus conditions favorable for seed rot is also favorable for P. ultimum. This agrees with similar observations made by DeVay et al. (25). The next strong negative association was between final stand and post-emergence damping-off. This indicates the influence of post-emergence damping-off in determining final stand establishment for both R. solani and P. ultimum. Strong and positive associations were obtained between post-emergence damping-off and hypocotyl and root grades. A strong association was also obtained between hypocotyl and root grades. An early invasion of the hypocotyl tissue will eventually lead to the progressive infection of the hypocotyl - root transition zone and ultimately the root system, thus enhancing the severity of root grade due to primary infection of the root systems. The reverse is true if early infections occurred in the root tissues. This is applicable for both R. solani and P. ultimum.

The single best model for predicting final stand in the temperature tank consists of four traits (Table 53,54). As with R. solani, emergence and pre-emergence damping-off with negative correlation of unity were not included simultaneously in the model. Emergence and pre-emergence damping-off, each explained 62% of the variability in final stand. The signs of these influences are

Table 52. Correlation coefficients between seedling traits for parental lines inoculated with *P. ultimum*, combined over runs.

	C.V.E ⁺	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	Hypocotyl grade	Root grade	C.V.D [†]
C.V.E ⁺	---	-0.277	0.277	0.209	-0.273	0.245	0.341	-0.109
Emergence (%)		---	-1.000**	-0.209	0.788**	-0.342	0.209	-0.055
Pre-emergence damping-off (%)			---	0.209	-0.788**	0.342	0.209	0.055
Post-emergence damping-off (%)				---	-0.748**	0.828**	0.818**	0.569**
Final Stand (%)					---	-0.732**	-0.629**	-0.390*
Hypocotyl grade						---	0.919**	0.343
Root grade							---	0.443*
C.V.D [†]								---

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 53. The influence of other traits (independent variables) for explaining variability in final stand (dependent variable) in the temperature tank using maximum R^2 stepwise multiple regression variable selection, for $P_{ultimum}$.

Final Stand	Sign of the partial regression coefficient for the independent variables					
	Number of independent variables in model	R^2	Emergence	Post-emergence damping-off	C.V.E [†]	Hypocotyl grade Root grade C.V.D [‡]
1	1	0.62	+++			
2	2	0.97	+++	---		
3	3	0.98	+++	---	+	
4	4	0.98	+++	---	+	
5	5	0.98	+++	---	+	+
6	6	0.98	+++	---	+	+

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Table 54. The influence of other traits (independent variables) for explaining variability in final stand (dependent variable) in the temperature tank using maximum R^2 stepwise multiple regression variable selection, for P . ultimum.

Final Stand	Sign of the partial regression coefficient for the independent variables					
Number of independent variables in model	R^2	Pre-emergence damping-off	Post-emergence damping-off	C.V.G ⁺	Hypocotyl grade	Root grade C.V.D. [†]
1	0.62	---	---			
2	0.97	---	---			
3	0.98	---	---	+		
4	0.98	---	---	+	---	
5	0.98	---	---	+	---	+
6	0.98	---	---	+	---	+

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

opposite, but similar to those obtained with the correlation coefficients. When post-emergence damping-off was added to the model, 97% of the variability was explained. Addition of the rate of emergence (C.V.E) to the model gave the best model for predicting final stand, with a R^2 value of 0.98 (98% variability explained). The sign for C.V.E was positive, but not significant. This means that a higher rate of emergence may indeed lead to a higher final stand establishment. However, other studies (56,58) have indicated a favorable association between final stand and slower rate of emergence (C.V.E). The MAR parental line, Tamcot CAMD-E, was resistant to P. ultimum. Because of the inherent cold-resistance and mold-resistance levels of MAR cultivars, a slower rate of initial emergence under disease conditions may not enhance a high rate of pre-emergence damping-off. Significant differences among the parental lines were obtained for emergence, pre-emergence damping-off and final stand (Table 26).

For R. solani, the most important traits and measurements that are associated with the expression of resistance are post-emergence damping-off, hypocotyl grade, emergence, pre-emergence damping-off and final stand. In the case of P. ultimum, the most important traits are pre-emergence damping off, post-emergence damping-off, and final stand. A low incidence of pre- and post-emergence damping-off, hypocotyl rot, and an ability for high emer-

gence under cold conditions are characters that a resistant cotton strain should possess.

DISCUSSION AND CONCLUSION

The results of the study confirms the complex nature of the seedling disease of cotton. The interaction of host and pathogen(s), and the subsequent manifestations of the disease complex can be influenced by many variables. The important variables known to influence the severity of the disease complex are quality and quantity of beneficial micro-organisms in the rhizosphere-rhizoplane, pathogen(s) and combinations of pathogens present, inoculum density and potential of pathogens, soil temperature and moisture levels, and seed quality.

Resistance to seedling disease pathogens in agronomically acceptable cotton cultivars is relatively new. The potential range in host reaction from highly susceptible to highly resistant has not been clearly defined nor are there known sources representing these extremes. This difficulty, as revealed in this study, is further confounded by the lack of consistent expression of resistance or susceptibility among cotton cultivars to all the different phases of the disease complex. A perusal of literature shows that the presently known sources of resistance are not high and do not even approach immunity; similarly, it is not known with certainty if the sources of susceptibility are indeed highly susceptible or not (15). The parental lines chosen for this study were reported to differ in levels of resistance and susceptibility to R.

solani and P. ultimum (15,21,30,38,41,47,57). Differences among the parental lines were verified in preliminary tests conducted to ascertain the most favorable inoculum densities to use in distinguishing between resistance and susceptibility. The parental lines and their offsprings were used to obtain information on gene action and the inheritance of resistance to R. solani and P. ultimum, and to determine which traits and measurements are the best for ascertaining the inheritance of resistance to cotton seedling disease pathogens.

In planning for field experiments it was anticipated they would fail unless the natural soil temperatures and moisture levels were favorable for seedling disease development. It turned out that conditions in both years (1984 and 1985) of the test were unfavorable (high temperatures and low moisture). This probably lead to reduced inoculum potential and consequently the lack of significant differences among the parental lines and their offsprings. Under these conditions and given the genetic levels of resistance and susceptibility of the parents, it was not possible to partition phenotypic variances for most traits into true genetic and environmental components. The tests in the controlled temperature water bath tanks were planned to supplement the data from the field tests. The data obtained under these conditions of controlled temperature and moisture levels, and of inoculum densities pro-

vided realistic measurements that were used in determining the genetic systems controlling the expression of resistance to R. solani and P. ultimum.

Differences Among Parents and Progenies

For the purposes of discussion, a summary showing levels of significance among parents, and among F₁ and F₂ generation populations for each trait and for each pathogen was prepared (Table 55). The important traits for measuring the resistance and susceptibility to the seedling disease pathogens are pre- and post-emergence damping-off, final stand, and hypocotyl and root grades. Definite differences among parents and among the filial generations were found for three of the important traits (post-emergence damping-off, final stand, and hypocotyl grade) and among parents and among F₂ generation populations for the fourth trait (root grade) in the presence of R. solani. Rate of seedling emergence (C.V.E.) is a trait that reflects a degree of predisposition to damage by seedling pathogens. Populations with higher C.V.E. values often have more disease damage (56,58). Differences among parents and among progenies were significant for C.V.E. in the presence of R. solani. This suggests that data for parents, F₁'s and F₂'s for five of the eight traits measured should be adequate for use in ascertaining how resistance of cotton seedlings to R. solani is inherited.

Table 55. A summary showing levels of significance for parents, F_1 and F_2 for the measured traits in the presence of *R. solani* and *P. ultimum*.

Traits	<i>R. solani</i>			<i>P. ultimum</i>		
	Parents	F_1	F_2	Parents	F_1	F_2
C.V.E ⁺	**	**	**	NS	**	**
Emergence(%)	NS	NS	NS	**	NS	**
Pre-emergence damping-off (%)	NS	NS	NS	**	NS	*
Post-emergence damping-off (%)	**	**	**	NS	**	NS
C.V.D [†]	NS	NS	NS	*	NS	NS
Final Stand (%)	**	**	*	*	*	NS
Hypocotyl grade	**	**	*	NS	**	NS
Root grade	**	NS	*	NS	**	NS

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

NS Not significant

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Differences among parents and among progenies for most traits associated with resistance to P. ultimum are not as definitive as was the case for R. solani (Table 55). Of the five key traits the parents differed for pre-emergence damping-off and final stand. However, differences among F_1 populations were obtained for four of the five important traits, and C.V.E. Only C.V.E. had significant differences among the F_1 and F_2 populations. It is possible to obtain some genetic information when significant differences between parents and either or both F_1 and F_2 populations occurred (emergence, pre-emergence damping-off, and final stand). It is also conceivable that some genetic information may be obtained when significant differences did not occur between parents but did occur among either or both the F_1 and F_2 generations (C.V.E., post-emergence damping-off, and hypocotyl and root grades).

In comparing differences between R. solani and P. ultimum, and for traits which indicated significant differences within the various populations, it is apparent that host response was different for each pathogen. It is also evident that, as expected, P. ultimum had a greater impact in the seed rot, pre-emergence and emergence phase of stand establishment than R. solani. The observed performances for the pathogens on one hand and the host populations on the other conforms to expectations relative to investigations by other researchers (24,25). It is

logical to infer that data for traits important and associated with the expression of resistance for each of R. solani and P. ultimum should provide reliable information on the genetic system conditioning resistance to the pathogens.

Interrelationships Among Traits

It has been established that R. solani exerts more of its adverse pathogenic effect at the post-emergence phase of seedling development. Variation among the parental lines in hypocotyl rot is an indication of differences in hypocotyl tissue resistance and hence to post-emergence damping-off and final stand. This is in agreement with the results of the correlation and multiple regression variable selection analyses. Hypocotyl grade was positively correlated ($r=0.94$) with post-emergence damping-off. Post-emergence damping-off was negatively correlated ($r=-0.96$) with final stand. Post-emergence damping-off explained 92% of the variability ($R^2=0.92$) in final stand in the presence of R. solani. A combined effect of pre- and post-emergence damping-off and hypocotyl rot explained 99% of the variability in final stand.

In contrast to R. solani, P. ultimum tends to exert its pathogenic effect at the pre-emergence phase of seedling development. This would reflect variation among parental lines for seed cold resistance, seed rot (seed

coat resistance), and resistance of young radicles (combination of cotyledon and young hypocotyl tissues). The combined effect of resistance for these tissues reflects the total pre-emergence damping-off manifested. The differences in resistance expression and the magnitude of the individual effects of these tissues on pre-emergence damping-off could not be partitioned in this study due to the nature of the experiments. The correlation analysis for P. ultimum revealed a highly negative and significant association ($r=-0.79$) between pre-emergence damping-off and final stand. A similar association was obtained between post-emergence damping-off and final stand ($r=-0.75$). This suggests that pre- and post-emergence damping-off due to P. ultimum have the same magnitude of influence on final stand. However, the stepwise multiple regression analysis showed that 62% of the variability in final stand was due to pre-emergence damping-off. Pre- and post-emergence damping-off explained 97% of the variability, indicating that post-emergence damping-off singularly explained 35% of the variability in final stand.

The sign for the partial regression coefficients for hypocotyl and root grades in their influence on final stand for both R. solani and P. ultimum was negative and positive, respectively. The negative sign for hypocotyl grade agrees with that of the correlation analysis, but not for root grade. This is probably a further suggestion

of the differences in these tissues as it relates to resistance expression to both R. solani and P. ultimum. The confounding effect of post-emergence damping-off with both hypocotyl and root grades may be reflected in the signs of the partial regression coefficients. The effects of post-emergence damping-off on hypocotyl and root grades can be avoided by not including grades that describe dead seedlings in severity scales when assessing the severities of hypocotyl and root lesions.

Gene Action and Inheritance of Traits

Measures of gene action and interactions, and the inheritance of the traits that were earlier identified to be important and associated with resistance to R. solani and P. ultimum were obtained from the F_1 and F_2 diallel genetic analyses according to methods of Hayman (33,34), Jinks (40), and Griffing (32).

Validity of Diallel Assumptions

A summary of the test of the validity of the diallel genetic analyses for all traits measured for both R. solani and P. ultimum is presented in Table 56. The validity of the diallel assumptions of parental homozygosity, no multiple allelism, and independent distribution of genes between the parents for each trait for both R. solani and P. ultimum were met. Diploid segregation was

Table 56. A summary of the validity of the diallel genetic analysis for traits associated with resistance to R. solani and P. ultimum.

Traits	Diallel Assumptions				Independent gene distribution
	Parental homozygosity	Diploid segregation	No epistasis	No multiple allelism	
C.V.E. ⁺	V	V	NV	V	V
Emergence (%)	V	V	NV	V	V
Pre-emergence damping-off (%)	V	V	NV	V	V
Post-emergence damping-off (%)	V	V	NV	V	V
C.V.D. [‡]	V	V	NV	V	V
Final Stand	V	V	NV	V	V
Hypocotyl grade	V	V	NV	V	V
Root grade	V	V	NV	V	V

V, NV Valid and not valid, respectively.

⁺ Coefficient of velocity of emergence.

[‡] Coefficient of velocity of post-emergence damping-off.

assumed for the fact that allotetraploid cotton which is amphidiploid in nature has been shown to segregate in a diploid-like manner (19,29,43). However, duplicate genes from the two genomes can influence the expression of traits.

The assumption of independent action of non-allelic genes, that is, no epistasis was not met for all traits for both R. solani and P. ultimum. Baker (9) suggested that the assumption of no epistasis and independent distribution of genes among the parents for quantitative traits is unrealistic because gene action and interactions cannot be avoided at the biochemical level. The reasoning being that a structural gene(s) codes for a fixed amount of its product which upon interaction with products of other gene(s), leads in the ultimate expression of resistance and susceptibility at the phenotypic level. This may indeed be the logical explanation for the apparent manifestation of overdominance effects of genes for some of the traits for each of R. solani and P. ultimum.

Hayman (34) indicated that estimates of the genetic components of variation for traits that exhibit a partial failure of the assumptions of the biometrical genetic model are still possible, although the estimates are less reliable than when all the assumptions are fulfilled. The fact that epistatic effects of genes were exhibited for all traits for each of R. solani and P. ultimum, does

confirm earlier expectations of the genetic control of traits that are important and associated with resistance to each of R. solani and P. ultimum. These traits may indeed be heritable.

The Genetic System

The F_1 diallel analyses indicated significant additive gene effects for resistance to R. solani for post-emergence damping-off, final stand, and hypocotyl grade (Table 57). It was for these traits that significant and consistent differences between parents, F_1 and F_2 generations were indicated for R. solani. Therefore, the results of the genetic analysis for these traits are considered highly reliable. For these traits, the significant and positive (F) component indicated that dominant genes were predominant relative to their recessive counterparts in the expression of resistance to R. solani. In the presence of R. solani, significant dominance components (H_1 and H_2) were indicated for emergence, pre- and post-emergence damping-off, final stand, hypocotyl and root grade (Table 57). Dominance deviation was unidirectional for C.V.E.

In contrast to R. solani, the F_1 diallel analysis revealed no significant additive effects of genes for any of the key traits associated with resistance to P. ultimum, except C.V.D (Table 57). This suggests that the parents

Table 57. A summary showing levels of significance for genetic components from the F_1 diallel analysis for traits associated with resistance to R. solani and P. ultimum.

Traits	<u>R. solani</u>					<u>P. ultimum</u>				
	D	F	H ₁	H ₂	h ²	D	F	H ₁	H ₂	h ²
C.V.E ⁺	NS	NS	*	NS	NS	NS	NS	*	*	NS
Emergence(%)	NS	NS	*	*	NS	NS	NS	NS	NS	NS
Pre-emergence damping-off (%)	NS	NS	*	*	NS	NS	NS	NS	NS	NS
Post-emergence damping-off (%)	**	*	**	*	NS	NS	NS	**	**	NS
C.V.D [‡]	NS	NS	NS	NS	NS	NS	NS	*	*	NS
Final Stand (%)	**	*	**	**	NS	NS	NS	*	*	NS
Hypocotyl grade	**	*	**	**	NS	NS	NS	*	*	NS
Root grade	NS	NS	*	**	NS	NS	NS	*	*	*

⁺ Coefficient of velocity of emergence.

[‡] Coefficient of velocity of post-emergence damping-off.

NS Not significant

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

and F_1 populations could not detect additive gene action in the expression of resistance to P. ultimum. A further confirmation of this observation is indicated in the lack of significant F component for any of the traits (Table 57). In the presence of P. ultimum, significant dominance components (H_1 and H_2) were obtained for C.V.E., post-emergence damping-off, final stand, hypocotyl and root grades. Dominance effects of genes could not be detected in the parents and F_1 populations for emergence and pre-emergence damping-off due to P. ultimum.

For both R. solani and P. ultimum, the F_1 diallel analyses revealed no significant additive effects of genes for root grade. Dominance deviation for post-emergence damping-off, final stand, hypocotyl and root grades was bidirectional for each of R. solani and P. ultimum. For these traits and for both pathogens, dominance acted in the directions of both resistance and susceptibility. It is interesting to note that dominance components (H_1 and H_2) were not significant for emergence and pre-emergence damping-off in the presence of P. ultimum. This is further evidence of the differences in gene action for these traits (emergence and pre-emergence damping-off) between R. solani and P. ultimum. However, similarity in the dominance effects of genes (significant H_1 and H_2) for both R. solani and P. ultimum were indicated for post-emergence damping-off, final stand, hypocotyl and root

grades. The low average dominance over loci component, h^2 , relative to the dominance components, H_1 and H_2 , for all the traits for each pathogen, except root grade in the case of P. ultimum, was indicative of two-directional dominance. This is in agreement with similar findings of Bourland and Bird (18) relative to the rate of seedling emergence (C.V.E.).

Extension of the genetic analysis to the F_2 provided a more reliable information on the genetic system conditioning resistance to both R. solani and P. ultimum (Table 58). In the presence of R. solani, the F_2 analysis revealed additive gene action for emergence, pre- and post-emergence damping-off, final stand, hypocotyl and root grades. The F_2 populations confirmed the results of the F_1 populations for post-emergence damping-off, final stand, and hypocotyl grades. These were the key traits for the expression of resistance to R. solani. Therefore, they are the most important for inheritance studies of resistance to R. solani. In addition the F_2 populations detected additive gene action for emergence and pre-emergence damping-off. Significant dominance components (H_1 and H_2) were indicated for all traits; further, confirming the results of the F_1 analysis. Significant F component of the F_1 for post-emergence damping-off, final stand, and hypocotyl grade was also indicated for the F_2 analysis. In addition, however, the F_2 indicated signifi-

Table 58. A summary showing levels of significance for genetic components from the F_2 diallel analysis for traits associated with resistance to R. solani and P. ultimum.

Traits	<u>R. solani</u>				<u>P. ultimum</u>			
	D	F	H ₁	H ₂	D	F	H ₁	H ₂
C.V.E ⁺	NS	NS	*	**	NS	NS	**	*
Emergence(%)	*	*	**	**	**	*	*	*
Pre-emergence damping-off (%)	*	*	**	**	**	*	*	*
Post-emergence damping-off (%)	**	*	**	**	*	*	**	**
C.V.D [†]	NS	NS	NS	**	*	NS	*	**
Final Stand (%)	**	*	**	**	**	**	**	*
Hypocotyl grade	*	*	**	**	**	*	**	**
Root grade	*	*	**	**	**	*	*	**

⁺ Coefficient of velocity of emergence.

[†] Coefficient of velocity of post-emergence damping-off.

NS Not significant

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

cant F component for emergence, pre-emergence damping-off, and root grade.

In the presence of P. ultimum, no significant additive effects of genes were indicated for emergence and pre-emergence damping-off for the F_1 analysis, however, the F_2 analysis indicated significant additive gene action for these traits. Similarly, the F_1 analysis did not detect significant dominance effects of genes for emergence and pre-emergence damping-off; however, the F_2 detected significant dominance effects for all traits. Also, significant F component for all traits except C.V.E and C.V.D was indicated, as against none for the F_1 analysis. For those traits that are important and associated with resistance to P. ultimum, the F_2 populations provided evidence of gene action and inheritance.

Additive gene action for the expression of resistance to both R. solani and P. ultimum was detected in the F_2 populations for emergence, pre-emergence damping-off, and root grade. Because the F_1 analysis could not detect additive gene action for these traits, it is conceivable to assume that the range of genetic variability of the F_1 populations for these traits were limited. While the F_1 analysis detected significant dominance effects of genes for emergence and pre-emergence damping-off in the presence of R. solani, it was in the F_2 populations dominance effects of genes was detected for these traits in the

presence of P. ultimum. The F_2 diallel analysis also revealed significant epistatic effects of genes for all traits associated with resistance to both R. solani and P. ultimum. The significant heterogeneity chi-squares suggest that epistasis in the F_2 's was not uniform or unidirectional in all crosses for both pathogens. A survey of the F_2 crosses for each of the pathogens suggested a lack of consistent gene interaction for some of the cross combinations. This type of gene interaction (complementary and duplicate) as proposed by Hayman (35) is probably different for some crosses for both R. solani and P. ultimum.

From the foregoing, it can be concluded that the evaluation of the genetic system conditioning resistance to P. ultimum would have been misleading if only the parents and F_1 populations were employed. This is because the parental lines and their F_1 's represented in this study could not adequately differentiate gene actions that condition resistance to P. ultimum. For adequate genetic information, the range of variability among the parents in resistance to P. ultimum should be widened; more so, that there is evidence of increased levels of resistance to the seedling disease pathogens within the advanced MAR hybrid pool strains.

In this study, the F_1 diallel analysis was inadequate for the investigation of the inheritance of resistance to

both pathogens but extension of the analysis to the F_2 generation provided reliable information on the genetic system. El-Zik (27) indicated that adequate information about the genetic system controlling resistance to races of Xanthomonas campestris pv malvacearum (Smith) Dye in cotton can be obtained utilizing the parental and F_1 diallel analysis. The expression of resistance and susceptibility in cotton to X. campestris pv malvacearum is controlled by major genes and a complex of minor and modifier genes. Also, the effect of environmental variations on resistance expression in cotton to X. campestris pv malvacearum is much less than on the seedling disease complex of cotton.

Average degree of dominance for traits associated with resistance to R. solani and P. ultimum ranged from partial to overdominance (Table 59). The probable role of epistasis in the apparent expression of overdominance was discussed earlier. Partial dominance effects of genes for R. solani was indicated for C.V.E., emergence, pre-emergence damping-off, C.V.D. and root grade, while overdominance was indicated for post-emergence damping-off, final stand, and hypocotyl grade. In contrast, partial dominance effects of genes for P. ultimum was obtained for post-emergence damping-off, C.V.D, final stand, hypocotyl and root grades, while for emergence, pre-emergence damping-off, and C.V.E., overdominance was indicated.

Table 59. A summary of partial dominance and overdominance for traits associated with resistance to R. solani and P. ultimum.

Traits	Partial Dominance		Overdominance	
	<u>R. solani</u>	<u>P. ultimum</u>	<u>R. solani</u>	<u>P. ultimum</u>
C.V.E [†]	P	N	N	P
Emergence(%)	P	N	N	P
Pre-emergence damping-off (%)	P	N	N	P
Post-emergence damping-off (%)	N	P	P	N
C.V.D [‡]	P	P	N	N
Final Stand (%)	N	P	P	N
Hypocotyl grade	N	P	P	N
Root grade	P	P	N	N

P,N Positive and negative, respectively.

[†] Coefficient of velocity of emergence.

[‡] Coefficient of velocity of post-emergence damping-off.

This is an agreement with the results of El-Zik and Bird (28) which showed that emergence and final stand were controlled by genes exhibiting overdominance and epistasis.

Conclusions are drawn from the results of the average degree of dominance, although the role of epistasis in the phenotypic expression of overdominance effects of genes may confound these interpretations, are as follows: 1) genes that condition partial dominance effects in the presence of R. solani, may or may not condition overdominance effects in the presence of P. ultimum for C.V.E., emergence and pre-emergence damping-off. 2) genes that condition partial dominance effects in the presence of P. ultimum, may or may not condition overdominance effects in the presence of R. solani for post-emergence damping-off, final stand and hypocotyl grade. 3) genes that condition partial dominance for the expression of resistance to root rot (grade) to both R. solani and P. ultimum, may be common, but do not condition overdominance effects.

Since direct selection to P. ultimum was not employed in the MAR program, it means that the resistance of Tamcot CAMD-E to both R. solani and P. ultimum was accomplished by the MAR procedure. Therefore, MAR cultivars probably possess genes that condition resistance to two or more pathogens. This would be in agreement with the working hypothesis of the MAR genetic improvement program (14).

Minton and Garber (47) showed that MAR cultivars gave higher seedling survival than a Mississippi and Acala cultivars in a California field known to be infested with R. solani, P. ultimum and T. basicola. Dixie King III was also shown to be resistant to both R. solani and P. ultimum. Is the resistance of Tamcot CAMD-E and Dixie King III conditioned by genes with similar gene action? The answer to this question would require chromosome mapping of genes. While the dominance and phenotypic parental orders were not similar for all traits and for both pathogens, some inferences can be made. For example, resistance of Dixie King III to pre-emergence damping-off due to R. solani and P. ultimum is conditioned by recessive and dominant genes, respectively. This trend was not clearly established for resistance of Tamcot CAMD-E to both pathogens. Dominance deviation seem to be operating in the direction of resistance and susceptibility. This may be due to the MAR procedure, which relies heavily on both direct and indirect selection pressure, and to the introgression of interspecific genes. Dixie King III possesses more dominant genes for final stand than Tamcot CAMD-E in the presence of both R. solani and P. ultimum. The same being the case for hypocotyl and root grades.

For both pathogens, the number of genes, or effective factors, that control the expression of the traits and exhibit dominance to some degree were all below the value

• of one. This indicates that the expression of each of the eight traits contributing to resistance to R. solani and P. ultimum was conditioned by polygenes with minor effects. Major genes are probably not involved in the genetic system. This would be in agreement with findings of Abd-Alla (1), which indicated that most seed and seedling disease escape traits were polygenically inherited. El-Zik and Bird (28) indicated that the number of genes controlling post-emergence damping-off could not be determined.

Heritabilities in the narrow sense were low, ranging from 0.0% to 20.7% for R. solani and from 0.0% to 10.2% for P. ultimum. This is a reflection of the large dominance component relative to the additive component of variation. Heritability estimates for traits associated with resistance to R. solani were higher than those for P. ultimum. For example, heritability for post-emergence damping-off due to R. solani was 14.5% compared to 4.6% for P. ultimum. Heritability of final stand in the presence of R. solani was 11.7%, and 3.7% in the presence of P. ultimum. These results suggest that selection for these traits will be more efficient in the presence of R. solani than for P. ultimum.

General and specific combining ability effects of the parental lines and their F_1 cross combinations, for both R. solani and P. ultimum, showed Tamcot SP 37 to be a good

general combiner, while Tamcot CAMD-E and Dixie King III were good specific combiners. However, interactions between the gametic arrays of Tamcot CAMD-E and TX-LEBO-3-80 in the F_1 and F_2 progenies resulted in reduced expression of resistance to both pathogens.

The results of the combining ability analysis indicated favorable general combining ability between the gametic arrays of the parental lines in the F_1 cross combinations to be important for the expression of resistance to R. solani. Specific combining ability between the gametes of parental lines involved in specific F_1 cross combinations appeared to be favorable for accumulating genes for resistance to P. ultimum.

The selection of parents for crosses should be based on good combining ability for high emergence percentage and consistency of expression of resistance to different phases of the seedling disease syndrome so as to result in high final stand establishment. With respect to R. solani, the cross between Lankart 57 and Tamcot CAMD-E (3 x 5) gave emergences of 84.3% and 82.5% for the F_1 and F_2 , respectively, and a final stand of 66.8% for the F_1 and 65.0% for the F_2 . The cross between Tamcot SP 37 and Tamcot CAMD-E (4 x 5) was the overall best performer in the presence of P. ultimum, with 78.7% emergence for the F_1 and 83.7% for the F_2 . Final stand was 72.5% and 73.1% for the F_1 and F_2 , respectively. It is logical to infer

that selection utilizing these crosses would have the highest probability for the accumulation of favorable effects of minor gene complexes.

Implications for Breeding

The results of this study indicate that resistance to both R. solani and P. ultimum is polygenically inherited and under the control of minor genes, with gene actions of additive effects, overdominance, partial dominance and epistasis. It would be difficult to select directly for the desired expression of traits conditioned by genes with such actions. Therefore, a phenotypic recurrent selection would enhance the accumulation of favorable genes. Direct selection procedures of the MAR program for traits such as seed coat resistance to mold and resistance to cold, known to have indirect effects on the expression of resistance to both R. solani and P. ultimum (14,15), facilitates the pyramiding of favorable genes in the target population. In addition, an adequate selection pressure for both pathogens would help in the identification of resistant seedlings.

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APPENDIX

Appendix Table 1. Genetic components and their standard errors, and environmental variances from F_1 diallel data, for traits associated with resistance to *R. solani*, run 1.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [‡]	C.V.D. [‡]	Hypocotyl grade	Root grade
D	-38.6208*	-38.6208*	703.7382**	427.1433*	0.1409	1.7385	2.0986**	0.4159
S.E.	10.7394	10.7394	104.7170	176.2704	0.1087	1.4903	0.3145	1.2887
F	-31.2172	-31.2172	1512.6830*	1053.1340*	0.5745	0.9787	3.9870*	2.6656
S.E.	14.3828	14.3828	509.6037	399.9919	0.3926	1.8682	1.3492	2.8243
H ₁	226.8721**	226.8721**	4110.9840**	3502.2370**	2.4548*	19.5222	1.0529	9.3479*
S.E.	23.4574	23.4574	543.4997	414.9006	0.8908	10.1103	0.6372	2.4241
H ₂	200.5314**	200.5314**	2852.3090**	2553.5740**	1.6507*	18.1935	7.6453**	6.1855**
S.E.	16.9952	16.9952	137.2782	139.8990	0.5947	8.5126	0.7009	1.1977
h ²	45.7121	45.7121	-26.6744	100.1490	0.0056	-2.8555	0.2939	-0.4001
S.E.	69.2018	69.2018	223.2229	317.9838	0.1125	1.1403	0.4277	0.2603
E	83.2044	83.2044	744.2370	648.2736	0.3789	8.5891	1.9014	2.0341

+ Coefficient of velocity of emergence.

‡ Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 level and 0.01 levels of probability, respectively.

Appendix Table 2. Genetic components and their standard errors, and environmental variances from F_1 diallel data, for traits associated with resistance to *R. solani*, run 2.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	-6.5374	-6.5374	13.8975	-38.8588	0.4913	-0.3246	0.0571	0.1531
S.E.	44.9375	44.9375	109.3802	78.0295	0.5374	2.7616	0.1999	0.3145
F	7.6718	7.6718	63.4129	33.1876	0.6649	0.8367	0.1539	0.8929
S.E.	75.5885	75.5885	220.5693	192.3816	0.7109	6.0561	0.3707	0.7460
H ₁	317.9143*	317.9143*	748.0561*	645.3339*	0.9815*	13.3975	2.2522*	3.0526**
S.E.	111.3643	111.3643	215.8307	264.2214	0.3845	10.4711	0.6416	0.5727
H ₂	303.3039*	303.3039*	590.5812*	526.2650*	0.5151*	10.2091	1.9251**	2.1838**
S.E.	122.9203	122.9203	167.4190	206.1607	0.1674	6.6118	0.2717	0.1677
h ²	-24.9091	-24.9091	-55.5851	-93.9455	-0.0142	-0.0139	0.3743*	-0.0353
S.E.	20.4986	20.4986	67.9223	22.0927	0.0652	1.1037	0.1571	0.2188
E	117.9960	117.9960	400.2648	331.9841	0.2999	6.8689	0.7096	0.9136

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 3. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to *R. solani*, run 1.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	103.8958**	103.8961**	1603.8252*	1330.0052**	0.1989	1.2950	3.4130*	3.1850*
S.E.	10.3693	10.3693	400.4724	216.7237	0.2576	0.9398	0.9284	1.0171
F	208.6498**	208.6534**	3100.7793*	2660.7705*	0.3974	-2.3254	6.3393	7.5289*
S.E.	31.8322	31.8319	1158.2720	785.9016	0.7137	5.2549	2.8339	1.9742
H ₁	446.0852**	446.0894**	5674.4727**	4962.9922**	2.9149*	24.8776*	13.5744**	13.2999*
S.E.	36.6991	36.6989	989.0413	706.9868	0.9038	9.0095	1.7364	2.8620
H ₂	324.6841**	324.7175**	3849.5889**	3392.3887**	2.3267*	26.0769**	10.0935**	8.2765*
S.E.	38.4716	38.4703	286.1282	211.9591	0.6127	5.3308	1.0648	1.8751
E ₀	9.4458	9.4445	150.9476	117.8479	0.0675	2.4659	0.4075	0.2900
E ₁	23.0112	23.0109	197.6812	172.8723	0.1097	2.0153	0.5129	0.5969
E ₂	19.1353	19.1348	184.3286	157.1509	0.0960	2.1441	0.4828	0.5092

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 4. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to *R. solani*, run 2.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [†]	C.V.D. [†]	Hypocotyl grade	Root grade
D	174.9072*	106.0044**	305.3093*	368.4492**	0.6133	0.5030*	0.7935**	0.9648**
S.E.	52.1517	20.2469	103.0898	52.4960	0.2624	2.5913	0.1665	0.1531
F	316.0391*	109.0879**	446.5720	659.6243**	0.7283	13.8536	1.1643*	1.8764*
S.E.	103.9877	36.2616	267.5183	144.5213	0.5146	6.8458	0.4512	0.4941
H_1	585.5171**	507.9526**	1403.6787**	1337.5117**	1.6343**	28.3203*	3.4083**	4.1828**
S.E.	74.0247	97.2422	307.1045	263.8908	0.2314	11.1986	0.4395	0.7049
H_2	426.3501**	409.0435**	1140.3252**	971.6326*	1.2271**	20.3011*	2.8806**	3.0394**
S.E.	75.3506	86.1726	187.0809	237.8506	0.2134	6.3336	0.3427	0.4145
E_0	24.1489	24.1493	84.9743	61.7198	0.1811	0.9654	0.1367	0.1900
E_1	32.1525	32.1528	106.4778	93.3288	0.0400	2.0068	0.1904	0.2372
E_2	29.0658	29.0661	100.3338	84.2977	0.0803	1.7093	0.1751	0.2238

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and the 0.01 levels of probability, respectively.

Appendix Table 5. Genetic components and their standard errors, and environmental variances from F_1 diallel data, for traits associated with resistance to *P. ultimum*, run 1.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	7.9874	7.9874	12.8261	-17.6775	0.2315	0.3641	-0.0271	0.0153
S.E.	26.7194	26.7194	77.0439	62.4394	0.5863	2.3793	0.1872	0.2284
F	2.5938	2.5938	19.9069	-71.9035	0.3629	-8.3899	-0.3555	-0.1031
S.E.	96.9539	96.9539	86.3862	103.6423	1.0988	2.9620	0.2129	0.2913
H ₁	516.3686*	516.3686*	939.2636**	861.6101*	3.0049	14.5791	2.1776*	2.3182*
S.E.	149.2561	149.2561	136.9646	207.6950	1.3378	12.3443	0.6396	0.9497
H ₂	439.1193*	439.1193*	821.4699**	756.9931*	2.1205*	16.3597	2.0308*	1.9608
S.E.	120.1969	120.1969	174.0749	176.0257	0.6504	9.7579	0.5677	0.8575
h ²	318.4223	318.4223	-75.1684	360.2019	0.2759	-3.8619	-0.0873	-0.1130
S.E.	180.0508	180.0508	59.7169	324.5314	0.4832	2.1262	0.1731	0.1434
E	162.6380	162.6380	321.7800	284.7609	1.0615	14.0396	0.9959	0.9587

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 6. Genetic components and their standard errors and environmental variances from F_1 diallel data, for traits associated with resistance to *P. ultimum*, run 2.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D ⁺	Hypocotyl grade	Root grade
D	61.1313	61.1313	56.2287	72.2568	0.2152	1.6833	-0.0523	-0.2015
S.E.	55.7963	55.7963	91.1126	73.5732	0.2828	1.4079	0.1739	0.1208
F	158.7298	158.7298	64.3855	174.3924	0.0211	-0.8576	0.0816	-0.1657
S.E.	76.7073	76.7073	105.4765	170.8134	0.2557	7.6721	0.2744	0.2421
H ₁	393.9189*	393.9184*	365.0505	610.8688	1.6602**	26.4883*	1.0724*	0.9756
S.E.	98.4249	98.4249	237.0903	301.3857	0.3068	10.6374	0.3867	0.5019
H ₂	302.9057*	302.9348*	311.4833	513.5207	0.9408**	23.1935*	0.8370*	0.8555
S.E.	95.8738	95.8729	177.4432	215.1274	0.0656	7.9685	0.2776	0.4177
h ²	108.3636	108.3634	130.1916	270.8115	0.2708	-0.2386	0.5741*	0.6035
S.E.	103.3679	103.3677	86.1049	152.7007	0.2297	2.8282	0.2134	0.3626
E	134.4940	134.4940	191.6159	218.1640	0.5849	13.2698	0.6203	0.5792

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and the 0.01 levels of probability, respectively.

Appendix Table 7. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to P. ultimum, run 1.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [†]	Hypocotyl grade	Root grade
D	294.0305*	294.0303*	354.4797*	368.8594**	0.1804	12.2179**	0.7986**	0.9471**
S.E.	91.3042	91.3046	140.0353	80.4964	0.3872	1.8295	0.1108	0.1883
F	465.0205*	465.0217*	575.0157*	612.7949*	-0.5519	10.6090	0.9156*	1.3668*
S.E.	194.2749	194.2749	215.6739	174.2213	0.7677	8.5026	0.2567	0.4181
H ₁	922.7759**	922.7771**	1523.4131**	1645.9658**	4.2086**	37.8106*	3.6978**	3.9833**
S.E.	117.1480	117.1480	177.6143	261.8044	0.6576	13.1071	0.6192	0.6983
H ₂	640.2366**	640.2559**	1125.4473**	1270.1455*	4.1015*	32.3507**	2.9204**	2.9015*
S.E.	128.6969	128.6976	227.1499	337.2678	0.9823	5.8915	0.5692	0.8500
E ₀	17.4135	17.4133	90.1585	44.9306	0.2259	3.5573	0.2385	0.2611
E ₁	49.4792	49.4792	78.9226	106.3645	0.2675	3.6979	0.2545	0.2376
E ₂	40.3175	40.3175	82.1329	88.8119	0.2547	3.6506	0.2499	0.2443

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 8. Genetic components and their standard errors and environmental variances from F_1 and F_2 diallel data, for eight traits associated with resistance to *P. ultimum*, run 2.

Components	Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E. [†]	C.V.D. [†]	Hypocotyl grade	Root grade
D	215.9611**	215.9599**	144.0060	267.8033	2.2791	14.3249*	0.6289**	0.5131**
S.E.	35.1001	35.1003	83.4908	117.2006	0.5519	5.7138	0.0866	0.0985
F	381.0552**	381.0562**	182.1271	418.5657	3.7989*	19.6109	1.1000*	0.9030*
S.E.	76.8080	76.8078**	244.3407	242.0189	0.9399	18.5606	0.2704	0.2148
H ₁	717.3098**	717.3120	632.0894*	1089.7432*	4.5195**	50.4956*	2.4075**	2.2763*
S.E.	141.3792	141.3792	244.2113	310.3559	0.7195	12.2598	0.3575	0.5410
H ₂	523.8144**	523.8379**	537.9548*	903.7571*	2.0768**	40.0645**	1.7422**	1.6917*
S.E.	103.3614	103.3594	195.9439	294.5371	0.3282	7.4612	0.3701	0.4682
E ₀	48.8718	48.8716	57.9974	67.9166	0.2018	2.7281	0.1575	0.1698
E ₁	23.8939	23.8939	41.2073	40.3378	0.1158	3.5336	0.1355	0.1327
E ₂	31.0305	31.0303	46.0044	48.2174	0.1404	3.3035	0.1418	0.1282

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 9. Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects for of cotton genotypes for eight traits associated with resistance to *R. solani*, run 1.

Source	d.f.	Mean squares							
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E [†]	C.V.D [‡]	Hypocotyl grade	Root grade
GCA	5	176.04	176.04	3201.91**	2587.29**	3.61**	11.69	6.72*	7.96*
SCA	9	153.40	153.40	2328.15**	2169.37**	0.95	15.34	6.04**	2.57
Error	42	92.04	92.04	790.73	691.49	0.44	8.57	2.05	2.39

* Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Appendix Table 10. Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects of cotton genotypes for eight traits associated with resistance to *R. solani*, run 2.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade
GCA	5	92.29	92.29	407.79	355.00	2.08**	5.42	0.63
SCA	9	239.65	239.65	382.09	208.06	0.12	5.02	1.58
Error	42	128.61	128.61	425.91	373.31	0.17	8.03	0.76
								0.95

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

** Significant at the 0.01 level of probability.

Appendix Table 11. Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects for cotton genotypes for eight traits associated with resistance to P. ultimum, run 1.

Source	d.f.	Mean squares						
		Emergence (%)	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Final stand (%)	C.V.E ⁺	C.V.D [†]	Hypocotyl grade
GCA	5	38.54	38.54	588.71	354.79	4.30**	9.34	1.89
SCA	9	432.01*	432.01*	954.79*	888.54*	1.59	21.30	2.33*
Error	42	197.92	197.92	315.69	314.35	1.07	14.75	1.02
								0.95

+ Coefficient of velocity of emergence.

† Coefficient of velocity of post-emergence damping-off.

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

VITA

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