RUST INHERITANCE STUDIES IN GROUNDNUT (*ARACHIS HYPOGAEA* L.)

THESIS SUBMITTED TO THE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
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AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE

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CERTIFICATE

This is to certify that the thesis entitled 'RUST INHERITANCE STUDIES IN GROUNDNUT' (*Arachis hypogaea* L.) submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Sri B. Kishore under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been fully acknowledged by him.

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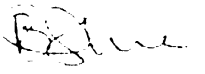

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ABSTRACT

To determine the nature of resistance of cultivated groundnuts (Arachis hypogaea L.) to groundnut rust (Puccinia arachidis Speg.), an experiment was conducted using three rust susceptible and three rust resistant cultivars including their F_2 progeny involving single crosses between them at ICRISAT, India, in kharif, 1980. The plants were scored using 1-9 point scale and then grouped under three categories viz. resistant (scores 1, 2 & 3), intermediate (scores 4-7) and susceptible (scores 8 and 9). However, from the X^2 test conducted on the data, no decisive conclusions could be drawn. However when grouped under two categories viz. resistant (scores 1, 2 & 3) and susceptible (scores 4-9), and X^2 test applied to it, it was observed that digenic inheritance was obtained for the crosses involving EC 76446 (292) as resistant parent and trigenic for the crosses involving PI 259747 and NC Ac 17090 as resistant parents respectively. On an overall basis, trigenic inheritance of resistance to rust was observed. When generation mean analysis was carried out, it was observed that additive dominance model was an adequate representation for the observed data. However, additive effects were more significant as compared to dominance effects indicating the fixable nature of rust resistance. Besides, correlation coefficients were obtained between rust score and plant yield and yield attributing characters for both parents and the crosses.

INTRODUCTION

Groundnut (Arachis hypogaea L.) is one of the most important oil seed crops of the world. In 1978, it was estimated that over 18.92 million hectares were planted and 18.87 million tonnes were harvested at an average yield of 998 kg/ha (FAO Production Year Book, 1978). Asia is the largest producer (10.9 million tonnes) followed by Africa (5.2 million tonnes), North and Central America (1.98 million tonnes) and South America (0.8 million tonnes).

Among the individual countries, India is the largest producer of groundnuts (6.2 million tonnes), followed by China (2.8 million tonnes) and the USA (1.8 million tonnes).

Until the later part of the 19th century, groundnut had relatively few disease problems (Sharief, Y. 1973). However, with the intensive cultivation of the crop due to increased use of groundnuts as a food and a cash crop, devastating diseases like leafspots (Cercosporidium personatum) Beck & Curtis., and Cercospora arachidicola Hori., and rust (Puccinia arachidis) have become very important. These diseases are at present considered to be among the major factors limiting groundnut production (Gibbons, 1980). In India, very few reports are available reporting yield losses due to rust alone. One such report is from Karnataka State where Siddaramaiah et al. (1977) reported a loss of 12.9 and 29 percent during 1975 and 1976 due to rust disease alone by chemically controlling the leafspots. Chemical control of rust, though quite effective, is not economically feasible under rainfed cultivation by peasant farmers. Since

67 percent of the world's total production of groundnuts is produced in seasonally dry, rainfed areas of the semi-arid tropics, it becomes increasingly important to tackle this problem effectively (Gibbons, 1980). The most practical and economically feasible approach to this problem appears to be breeding for resistance to rust. For devising suitable breeding strategies, information on the inheritance of resistance to the rust fungus is needed. In the literature, there is only one preliminary report on inheritance of resistance to the rust fungus (Bromfield, and Baily 1972) which however was not substantiated by further studies at ICRISAT, India, by Nigam et al. (1980). Hence there is a need to study the inheritance of resistance to this fungus, and the present study was undertaken with this objective.

2. REVIEW OF LITERATURE

2.1. Distribution: Groundnut rust, incited by the fungus Puccinia arachidis Speg. was first reported from Paraguay by Spegazzini in 1884. Prior to 1969, rust was largely confined to South America and the Carribean with occasional outbreaks occurring in the groundnut producing areas of the South Eastern United States (Hammons, 1977 and Subrahmanyam, et al. 1979). However, groundnut rust was also recorded in USSR (Jaczewski, 1912), Mauritius (Stockdale, 1914) and mainland of China (Tai, 1937). In recent years, rust has spread to many countries in Asia (Brunei, India, Indonesia, Japan, Korea, Malaysia, Philippines), Australasia and Oceania (Australia, Papua New Guinea and the Solomon islands) and African countries such as Botswana, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Republic of Benin, Republic of South Africa, Somalia, Sudan, Tanzania, Uganda, Zambia and Zimbabwe. Thus, the disease now has a worldwide distribution (Bromfield, 1974; Hammons, 1977; Subrahmanyam et al. 1979; Anon, 1980).

Rust occurrence in India: Chahal and Chohan (1971) first reported finding rust in July 1969 on plants growing in a glasshouse at Punjab Agricultural University, Ludhiana. In subsequent years, a number of reports appeared on the occurrence of groundnut rust from different states of India such as Tamil Nadu (Bhama, 1972), Karnataka (Puranik et al. 1973), Madhya Pradesh (Khosla et al. 1974), Andhra Pradesh (Ramakrishna and Subbayya, 1973), Uttar Pradesh (Yadav et al. 1975), Assam (Goswami, 1974), Maharashtra (Garud et al. 1976), Bihar (Singh, 1977) and Gujarat (Subrahmanyam et al. 1979)

2.2. Symptoms: Rust disease can readily be recognised when the orange coloured pustules (uredosori) appear on the leaves. According to McVey (1965), whitish flecks on the lower surface of the leaf are the first macroscopic evidence of rust infection. Approximately 24 hours later, yellowish green flecks become visible on the upper leaf surface and pustules appear as minute orange spots within the whitish flecks on the lower leaf surface. The immature pustules later enlarge and within another 48 hours rupture the leaf surface and expose the uredospores to the atmosphere. The uredosori are usually circular in shape and range from 0.3 to 1 mm in size and they may be formed on all the aerial parts apart from flowers and pegs.

The uredosori first appear on the abaxial leaf surface, and in highly susceptible cultivars the original pustule may be surrounded by colonies of secondary uredosori (Subrahmanyam et al. 1980). Pustules may later be formed on the adaxial (upper) leaf surface opposite to those on the abaxial (lower) leaf surface. Pustules on the upper surface of the leaflet tend to be smaller than those on the lower surface for a given pustule density. Castellani (1959) counted the number of pustules on both upper and lower surfaces of the leaf and reported the presence of 200-250 pustules/cm^2 on the lower leaf surface and 70-100 pustules/cm^2 on the upper leaf surface on the plants subjected to severe rust attack. In contrast with the rapid defoliation associated with leafspots, leaves infected with rust wither and dry and cling to the plant for several days (Personal Communication by Subrahmanyam, 1981).

2.3. Biology and epidemiology of groundnut rust: Groundnut rust is almost exclusively known by its uredial stage, teliospores having been found on only a few occasions (Subrahmanyam et al. 1979).

Spegazzini (1884) recorded teliospores on A. hypogaea from Paraguay for the first time. He described teliospores as ellipsoid to ovate with a rounded to acute and thickened apex, slightly constricted in the middle, somewhat or gradually alternate at the base, smooth, golden, yellow, 38-42 x 14-16 µ ; pedicel hyaline, thin and 50-60 µ long.

Arthur (1934) noted that teliospores often have 3-4 cells and germination occurs at maturity without dormancy. The wall colour of the teliospores is chestnut brown and the pedicel is colourless and of the same length as the spore.

Chahal and Chohan (1971) also reported finding teliospores on A. hypogaea grown in a glasshouse at Punjab, India but the authors did not give details of spore morphology.

Hennen et al. (1976) reported finding the teliospores of groundnut rust developed within the uredinia on A. hypogaea (cv. Tatu) after artificial inoculation in the greenhouse at Campinas, Brazil. They described the teliospores as two celled, narrowly ellipsoid, more or less rounded, alternate at both ends, constricted at the septum, 34-41 x 15-17 µ, wall 0.7-0.8 µ, thick at sides, 2.5-4 µ thick at top, light yellow but almost hyaline in apical thickening, germpores not seen, pedicel thin walled, usually collapsing laterally, hyaline, upto 35 µ long but usually shorter or detached at spore base. The host that the basidiospores of P. arachidis infect and the fungal structures that follow are unknown. Apparently, it survives in most of its geographic range by uredospores.

Subrahmanyam et al. (1980b), at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), carried out investigations on the biology of the groundnut rust fungus to determine the factors influencing the perpetuation and spread of the disease. A wide range of crop and weed species were checked for possible collateral hosts but none were found outside the genus Arachis. Also, they reported observing only the uredial stage on several germplasm lines, despite several attempts to induce the teliospore formation artificially. Hence they concluded that the uredospores were the main, if not the only means, of rust carry over and dissemination in India. They observed that the uredospores could be stored for long periods at low temperature without loss of viability, but at higher temperatures they rapidly lost viability. They reported that uredospores stored at 40°C lost their viability within 5 days; uredospores on exposed crop debris lost all viability within 5 days; uredospores on exposed crop debris lost all viability within 4 weeks, and those taken from surface contaminated seeds stored at room temperature showed a decrease of viability from 95% to zero after 45 days. They also stated that light inhibits uredospore germination and germtube elongation, and that the presence of liquid water on the leaf surface was necessary for uredospore germination and infection. They indicated that inoculation might be more successful if carried out in the evening rather than through the day.

2.4. Economic importance: South (1912) reported that the groundnut plants infected with the rust fungus die prematurely with a resulting decrease in the quality and quantity of the produce in the West Indies. Ciferri (1926) observed that in the Dominican Republic, an epiphytotic of groundnut rust

practically destroyed the entire harvest. Burger (1920) recorded a 50% loss due to rust in a field at Tory Island, Florida. Arthur (1929) in New York stated that rust does little damage when it occurs towards the end of the season, but with an early attack, especially on wet soil, considerable defoliation, premature ripening of haulms and a large proportion of shrivelled kernels may result. Ken Knight (1941) first recorded the occurrence of groundnut rust in Texas where a field of 20 acres was severely rusted and the leaves exhibited a scorched appearance. Bromfield (1971) stated that the rust disease appeared sporadically at infrequent intervals in widely separated fields in South Texas during 1941 to 1965 but the crops were not severely affected. But in 1965, groundnut rust along with cercospora leafspots became epiphytotic in many fields, and severe losses were caused by the two fungi. Muller (1950) in Central America stated that groundnut crops often fail because of rust especially during the seasons that are unusually dry. Smart (1962) observed that in Virginia, plants in small scattered areas of initial infection were killed and growers harvested their plants prematurely to avoid severe losses. Felix and Ricaud (1977) reported that rust can reduce yield in groundnut to the extent of 70% in Mauritius. Siddaramaiah et al. (1977) from Karnataka, India reported that yield losses due to rust alone were 12.9% during 1975 and 29% during 1976. At ICRISAT, India, yield losses due to rust were estimated to be as high as 52% on the susceptible cultivar, Robut 33-1, during the 1979 rainy season (Subrahmanyam et al. 1980a).

.5. Management of groundnut rust:

Cultural: In the Carribean and Central American production areas,

crop rotation and cultural practices that destroy volunteer groundnut plants or crop debris have obvious value in limiting primary sources of inoculum. Although valuable in delaying the onset of the endemic, these practices are ineffective against wind borne inoculum or in areas where the disease is endemic (Hammons, 1977).

B. Biological: In South India, many sori on rust infected groundnut leaves were found to harbour Darluca filum (Bhama, 1972). This mycoparasite, which was also observed in Texas at several locations (Taber, unpublished, cited by Hammons, 1977) may have value as a means of biological control (Hammons, 1977).

C. Chemical: Ken Knight et al. (1941) stated that applications of sulphur controlled rust disease. This was the first report of fungicidal control of rust. Since then, a number of attempts have been made to control rust with fungicides.

Harrison (1967) documented results obtained in South Central Texas in 1965 and 1966. Several fungicides were tested for effectiveness against both rust and leafspot, and it was concluded that the following had some fungicidal value against both rust and leafspots when applied on a 7-14 day schedule.

Dithane M-45 (Zinc + Maneb)

Chlorothalonil (Tetrachloro isophthalonitrile)

Difolatan (N-1,1,2,2-tetrachloroethyl) sulfenyl), C_i s-4-Cyclohexane-1,2-dicarboximide)

Sprelox S (50% sulphur)

Polyram (mixture of 5.2 parts by weight of amoniates of (ethleneibs (dithiocarbomato)), zinc with one part by weight ethylnebis (dithiocarbanic acid) bimolecular and

and trimolecular cyclic anhydrosulfides and disulfides)

Dusting sulphur (325-mesh)

O'Brien and Davis (1977) mentioned that the fungicides chlorothalonil (Bravo or Daconil) and fentin hydroxide (Duter) are recommended for the control of leafspots and rust in Queensland, Australia. Both chlorothalonil and fentin hydroxide are protectant fungicides and act by killing the leafspot and rust fungi before they enter the leaf. He suggested that the first application be made as soon as either disease is observed, which is generally 4-6 weeks after planting, and subsequent applications at fortnightly intervals until 4-5 weeks before harvesting. Five or six applications in each season would usually be required to give effective control. The systemic fungicides benomyl (Benlate) and carbendazin (Bavistin), which are widely used for leafspot control, are not effective against rust.

Harrison (1973) have observed that chlorothalonil applied at weekly intervals gave the best control of both leafspot and rust fungi.

O'Brien (1974) stated that Mancozeb was effective in controlling rust and can be successfully used in trials in conjunction with benomyl for cercospora control.

Raemaekers and Preston (1977) stated that in Zambia, the results of fungicidal control of leafspot and rust indicate that chlorothalonil and mixtures of Mancozeb with benomyl and Mancozeb, benomyl and fentin hydroxide were the most effective. They observed yield increase between 47 and 102% at Msekera Regional Research Station (MRRS) and 34% at the National Irrigation Research Station (NIRS) by the use of these fungicides. They concluded

that all the fungicides increased the yield by reducing defoliation and necrosis, and thereby increasing the photosynthetic area of the leaves.

Felix and Ricaud (1977) observed that the losses from groundnut rust were considerably reduced through weekly applications of Dithane M-145 (zinc and manganese ethylene bis dithiocarbamate, 80%) or Daconil 2787 (chlorothalonil-tetrachloro isophthalonibile, 75%).

Mayee et al. (1978) observed that, among the 18 chemicals tested, 3 sprays of tridemorph, oxycarboxyn, carboxin and MBC significantly reduced rust intensity.

Mayee et al. (1979), from Marathwada Agricultural University, Parbhani, India stated that Tridemorph (calixin 75 EC) spray at the rate of 0.07% commencing 45 days after planting and continuing at 10 day intervals for a total of three applications, effectively controlled rust of groundnut. This resulted in marked increases in yield.

Siddaramaiah et al. (1977), from Agricultural College, Dharwar, India reported that two sprays of Benodanil (2-Iodo benzanilide), or plantvax at 0.1%, on 40th and 60th day of groundnut crop, or four sprays of Dithane M-45 at 0.2% at 10 days interval from 40th day of the crop, reduced the rust incidence to a great extent and increased the yields significantly.

D. Disease resistance: The use of disease resistant varieties of crop plants is a very practical, economically effective, and widely used method for controlling many plant diseases.

There are very few reports in the literature of research on rust resistance prior to 1965, but with the increasing importance of the disease

in the USA in 1960's and it's rapid spread around the world in the early 1970's, the research effort has been greatly intensified and a number of useful publications on the screening of the groundnut germplasm for rust resistance have now appeared (Hammons, 1977; Subrahmanyam et al. 1980).

Disease resistant lines are obtained by several procedures including: (1) selection of resistant individuals from populations subjected to intensive infection, (2) crossing varieties carrying factors for resistance with varieties possessing other desirable characteristics but lacking resistance, and (3) hybridizing resistant or immune wild Arachis species with susceptible varieties of the cultivated species (Bromfield, 1974).

Mazzani and Hinojosa (1961) in Venezuela observed 254 varieties for reaction to groundnut rust. The test varieties were exposed to natural infection in the field. They classified only one variety, Tarapoto, which was introduced into Venezuela from Peru in 1955, as resistant. Twelve other varieties were reported to have some resistance to groundnut rust but the nature of the resistance was not defined.

Bromfield and Cavario (1970) screened accessions of Arachis hypogaea for reaction to two cultures of groundnut rust, one from Puerto Rico (PR-1-66) and another from Texas (Tex-1-67). Of the 173 A. hypogaea accessions tested, they found only two accessions, PI 314817 and PI 315608, resistant to both the cultures.

Cook (1972) screened cultivars of A. hypogaea both in the greenhouse and in the field for resistance against the Jamaican isolate of groundnut rust and found five accessions PI 259747, PI 298115, PI 314817, PI 341879 and PI 350680 possessed marked resistance. Of the 31 named varieties and

breeding lines tested, she found only one breeding line, NC 13, as markedly resistant although nine others showed some resistance. Cook (1972) used a R0 to R4 scale to score the material where:-

R0 - signified no leaves heavily infected

R1 - less than 25%

R2 - from 25 to 50%

R3 - from 50 to 75%, and

R4 - more than 75% of the leaves heavily infected.

Ravindranath and Indira (1975) from the Regional Research Station (IARI), Rajendranagar, India screened the germplasm maintained at IARI. At maturity each culture (10-20 plants) was evaluated for rust intensity, employing a scale similar to the modified Cobb's scale, where:-

Immune	:	No disease at all on any leaflet of the plant
Moderately resistant	:	5% (1-2 pustules)
Slightly susceptible	:	5-10% of leaflet area damaged
Moderately susceptible	:	10-50% of the leaflet area damaged
Lightly susceptible	:	50% of the leaflet area damaged.

In all, 155 cultures with spreading growth habit (SHG cultures), 56 Virginia bunch type cultures and 13 Spanish cultures were screened. They found among SHB cultures that two varieties, namely B 227 and FCR 583, were immune. Among the Virginia cultures 5 were moderately susceptible, namely, Manfredi 86, Manfredi 96, R7K, US 54, and US 69. Among the Spanish cultures, only one culture, namely, US 50, had moderate resistance to rust. Hence, they concluded that the variegated testa SHB cultures which were immune to rust can supply sources of resistance for any breeding programme.

Subrahmanyam et al. (1980a) screened a germplasm collection of 8,000 groundnut entries at ICRISAT, India. Preliminary field screening was done during the 1977 rainy season when a natural endemic of rust occurred. The cultivars or lines which were rated between 2 and 5 on a 9-point scale during this screening were further tested during 1977/78 dry season employing an infector row system such that every two test rows were alternated with an infector row. High relative humidity was maintained in the field by operating an overhead sprinkler irrigation system. The percentage leaf area damaged on the test material was estimated at 10 day intervals from approximately 90 days after their emergence until harvest. They found that two land races, NC Ac 17090 and EC 76446 (292), to be more resistant than either PI 259747 or PI 298115, which were reported as resistant by other workers. They also reported the following genotypes to be rust resistant at the ICRISAT centre:

Genotype	Genotype
NC Ac 17090	PI 314817
PI 414332	PI 393517
PI 405132	PI 414331
PI 341879	PI 393527-B
PI 393646	NC Ac 927
NC Ac 17133-RF	PI 390595
EC 76446 (292)	PI 393531
PI 259747	NC Ac 17127
PI 350680	PI 393526
PI 350593	NC Ac 17129
PI 381622	NC Ac 17132

Genotype	Genotype
PI 393643	NC Ac 17135
PI 407454	NC Ac 17124
PI 315608	PI 298115
PI 215696	PI 393516
PI 393641	NC Ac 17142

The 9-point scale of Subrahmanyam et al. (1980) was as follows:-

Score	Rust
1	No disease
2	Few, very small pustules on some older leaves
3	Few pustules mainly on older leaves; some ruptured: poor sporulation
4	Pustules small or big, mostly on lower and middle leaves; disease evident
5	Many pustules mostly on lower and middle leaves; yellowing and necrosis of some lower and middle leaves seen; moderately sporulating
6	Like rating 5 but spots heavily sporulating
7	Pustules all over the plant; lower and middle leaves withering
8	Like rating 7 but withering is heavy
9	Plants severely affected; 50-100% leaves withering

Hammons (1977) lists the following lines as having physiological resistance to two or more cultures of rust:

1. Tarapoto (PI's 259747, 341879, 350680, 381622, 405132) originally from Tarapoto, Peru.
2. Israel line 136 (PI's 298115 and 315608), a selection from a USA introduction to Israel.
3. DHT 200 (PI 314817) from San Martin, Peru.

Bromfield and Cevario (1970) reported immunity in five accessions of Arachis glabrata Benth. tested with the rust isolate PR-1-66 from Puerto Rico. The five immune accessions were PI 118457 (Brazil), PI 231318 (Brazil), PI 262141 (Bolivia), PI 262287 (Brazil), and PI 262801 (Argentina).

2.6. Inheritance of resistance: Bromfield and Bailey (1972) during their observations in a plot of the rust resistant cultivar PI 298115, found a single groundnut plant showing a markedly different rust reaction. Since the plant had a red testa in contrast to the white of PI 298115, it was assumed to be an F_1 hybrid obtained from a natural cross between PI 298115 and a pollen donor of a rust susceptible plant of unknown identity. All the seeds from the plant were sown and the resulting plants were checked for rust reaction by inoculating detached leaves with two isolates of rust. They found no differences in reaction to the two isolates from the leaves of individual plants. Of the 108 plants tested, 7 were resistant, 7 were highly susceptible and the others were intermediate in reaction. From these results, they tentatively suggested bigenic control of rust reaction, with resistance being recessive. From this material, 14 F_3 derived rust resistant lines (FESR 1-14) representing 7 F_2 families were developed and released by the USDA and the Virginia, A.E.S., U.S.A. in 1973. These lines were reported to have a level of resistance as high or higher than that of the resistant parent. Nigam et al. (1980) at ICRISAT, India have studied these FESR lines since 1977. They observed that these lines continued to segregate for both morphological characters as well as for reaction to rust at the ICRISAT centre. Resistant single plant selections when progeny rowed in the next generation segregated for their reaction to rust. This material, even after advancement to F_9 generation, was still found to be segregating. From this, they tentatively concluded that

resistance to rust, though recessive, may not be governed by duplicate loci as reported by Bromfield and Baily (1972). Also, they reported the following FESR selections to be resistant to both rust and late leafspot at ICRISAT centre:

FESR 5-P2-B1

FESR 5-P17-B1

FESR 7-P13-B1

FESR 9-P3-B1

FESR 9-P4-B1

FESR 9-P7-B1

FESR 9-P7-B2

FESR 9-P8-B2

FESR 11-P4-B2

FESR 12-P4-B1

FESR 12-P5-B1

FESR 12-P6-B1

FESR 12-P14-B1

FESR 13-P12-B1

2.7. Mechanisms of resistance: Subrahmanyam et al. (1980b) reported that there was no correlation between the size and frequency of stomata and resistance to Puccinia arachidis and that, irrespective of whether the genotypes were immune, resistant or susceptible, uredospores germinated on the leaf surface and germtubes entered the leaf via stomata. Further, they found that the infection frequency was lower and incubation period longer in resistant genotypes as compared to the susceptible ones, and that the differences in resistance resulted due to differences in growth rate of the mycelium in the substomatal cavities and invasion of leaf tissue

Nevill (1980) observed that in immune wild species, Puccinia arachidis was able to penetrate through stomata, but it's development ceased after the formation of a single hypha out of the substomatal vesicle.

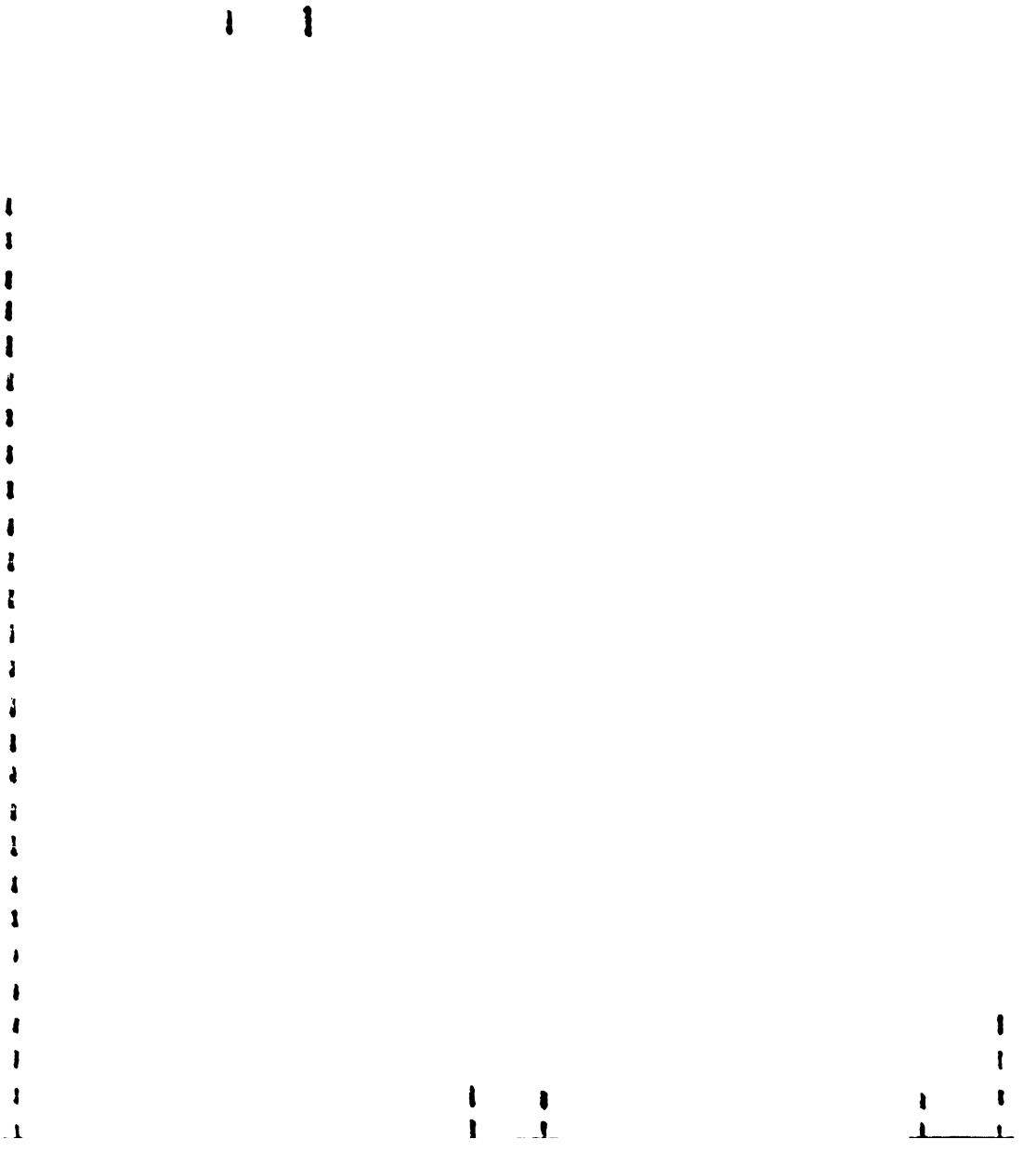
3. MATERIAL AND METHODS

Three rust susceptible and three rust resistant cultivars, together with their nine F_2 generations derived from single crosses, were selected for the present study. The susceptible cultivars represented three botanical varieties of the cultivated groundnut. All the resistant parents belonged to one botanical variety. Detailed information on the parental cultivars is presented in Table 1.

All the cultivars, and the F_2 populations, were sown at the ICRISAT centre, Patancheru, Hyderabad, on 23rd June 1980 in rows 9 m long. Spacing was 75 cms between the rows and 15 cms between the plants. The parents were planted in single rows but all the available F_2 seeds were sown, and hence its row numbers were variable for the hybrid progenies. The parents and the F_2 generation of each cross were grown together in adjacent rows. For each two rows of the test material, an infector row comprising a mixture of the rust susceptible cultivars Robut 33-1 (medium duration) and TMV 2 (short duration) was planted. The purpose of the infector row was to supply rust inoculum over a prolonged period to the test material. The sowing pattern adopted is shown in figure 1.

The first furrow irrigation was given on June 27th and subsequent irrigations were given as and when required, since the crop was raised during the rainy season. All other intercultural operations, such as weeding, were done as and when required. Although the disease development was quite uniform in the infector rows, the whole set of material including the infector rows, were artificially inoculated at the flowering stage with uredospores during the evening hours to further ensure uniform disease build up. The concentration of the inoculum used in the spray was ca. 100,00 uredospores/ml.

FIGURE 1 : SOWING PATTERN ADOPTED



Infector row

Test row

LENGTH OF EACH ROW : 9 meters

SPACING : 75 x 15 cm

OBSERVATIONS RECORDED

a) Rust scoring:

All parental and hybrid plants that were free from bud necrosis infection were selected for recording rust reactions. Although sufficient number of plants were planted, very few plants of both parents and crosses were free from bud necrosis disease, despite weekly application of insecticides to control the disease. The plants were scored twice, once at 90 days and again at 100 days after planting. The scoring was done on a 1-9 point scale as described by Subrahmanyam et al. (1980) at ICRISAT (Figure 2). The plants were then grouped under three categories viz. resistant (scores 1, 2 & 3), intermediate (scores 4, 5, 6 & 7) and susceptible (scores 8 and 9) in the first instance and then under two categories, resistant (scores 1, 2 & 3) and susceptible (scores 4-9) in the next instance.

b) Post harvest observations:

The following observations were recorded on the individually selected plants:

1. Plant height in cm (length of the main axis): The length was measured from the base of the main axis to the top most unfurled leaf.
2. Number of primary branches.
3. Number of secondary branches.
4. Total number of pods.
5. Number of mature pods.
6. Number of immature pods.

FIGURE 2 : RATING SCALE ADOPTED (1-9 POINT SCALE)

FIGURE 2.1 : SCORE 1

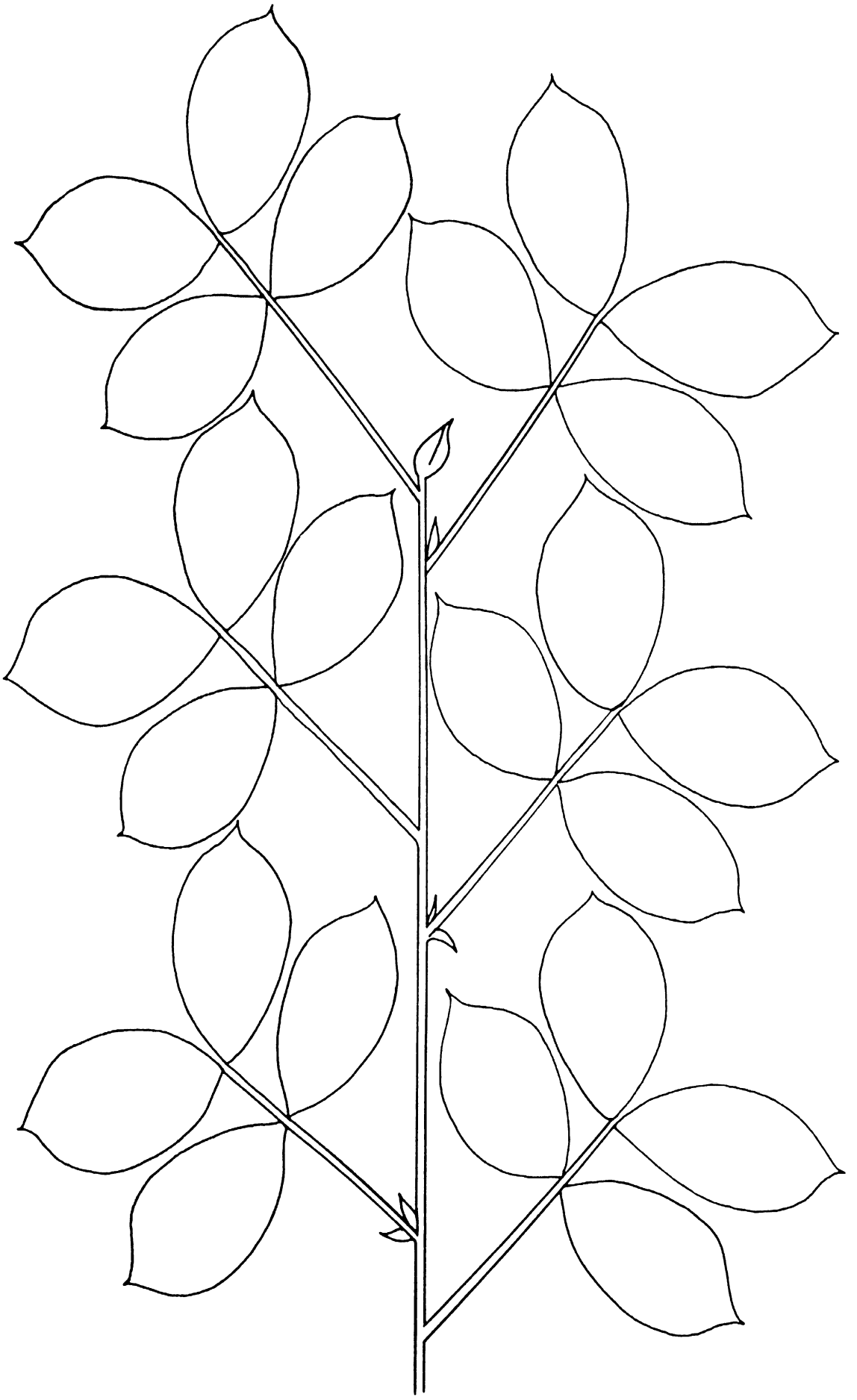


FIGURE 2.1 · SCOR

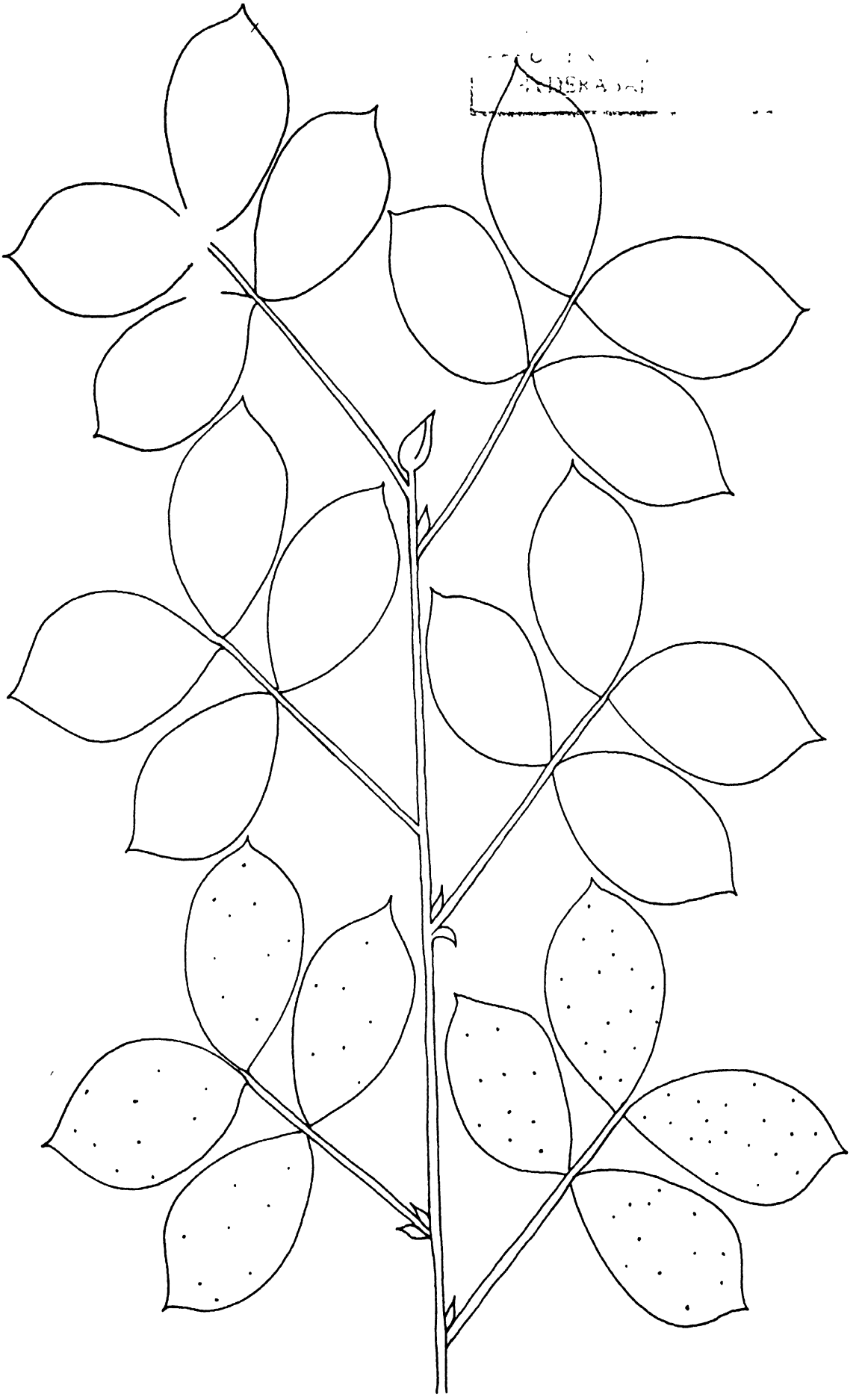


FIGURE 2.3 : GUOFU 3

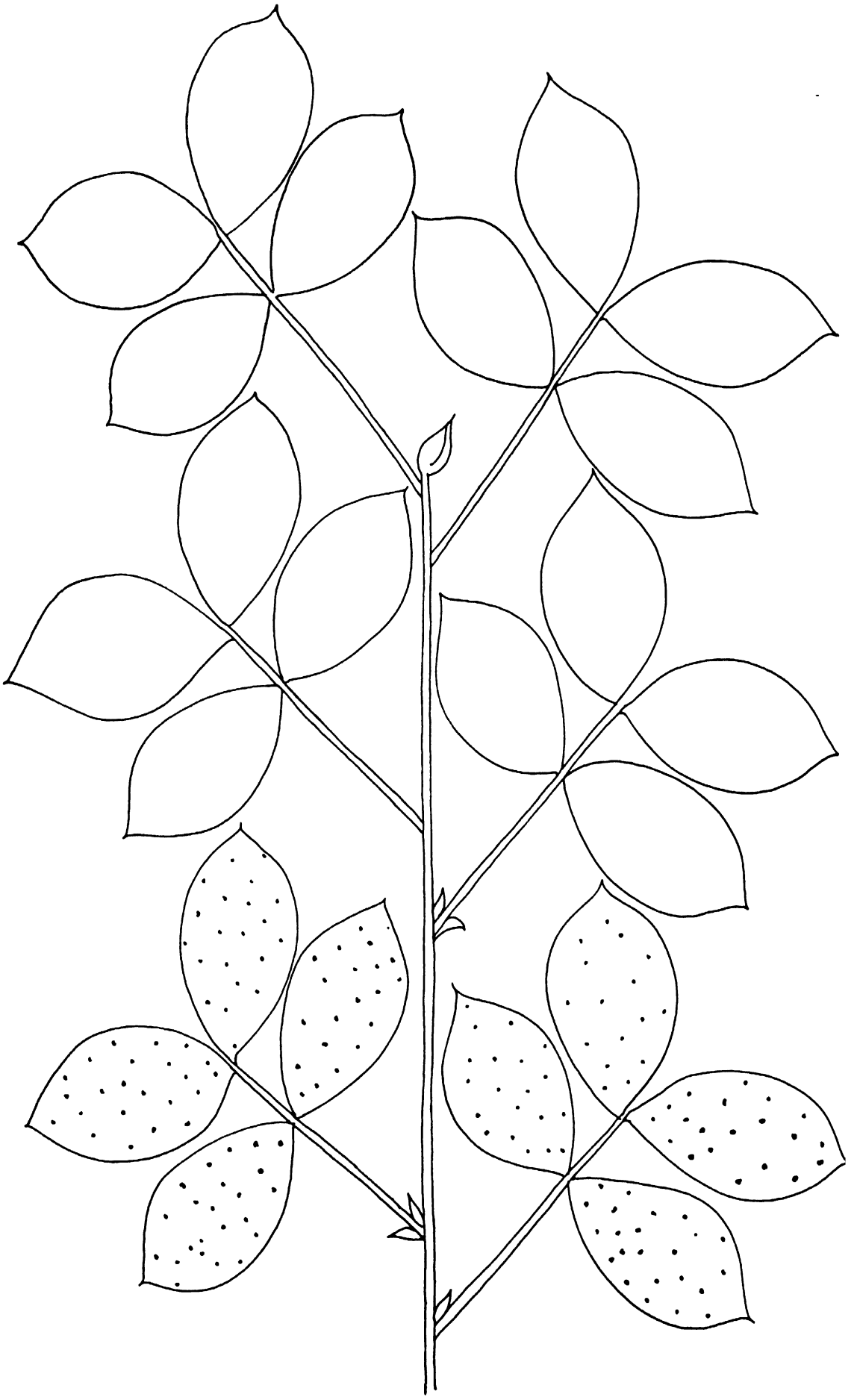


FIGURE 2.4 ; SCORE 4

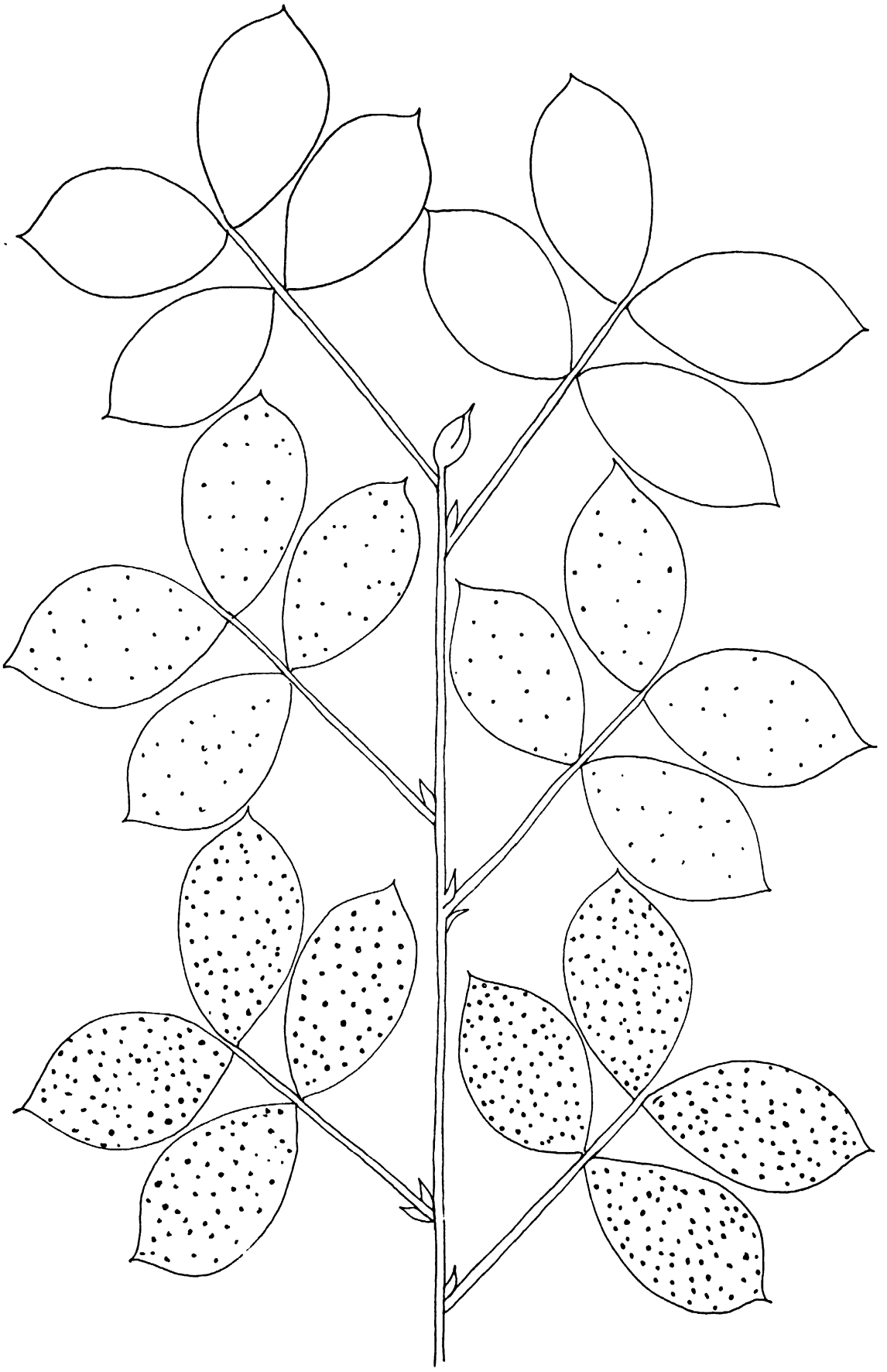


FIGURE 2.5 : SCORE 5

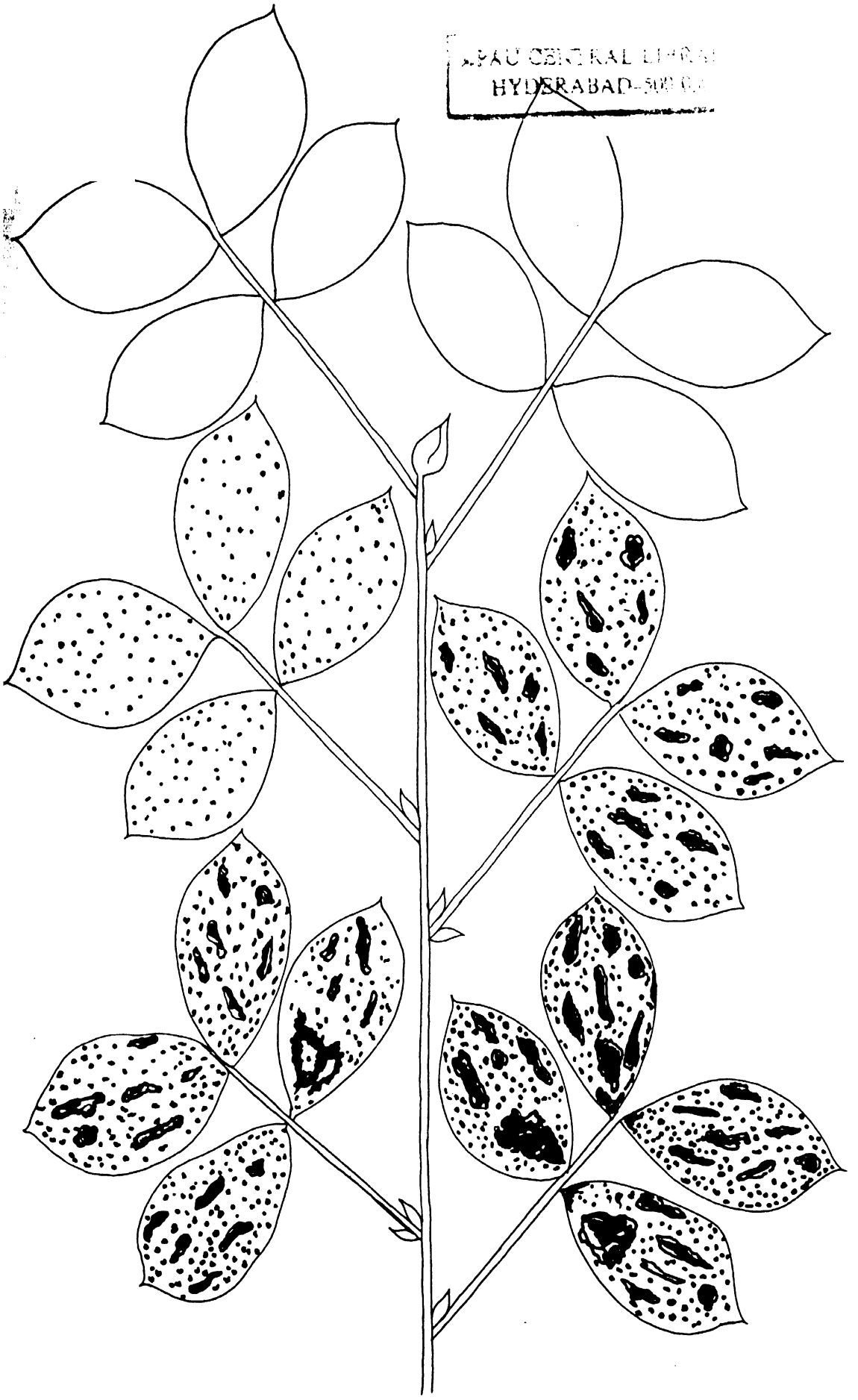


FIGURE 2.6: SCORE 6

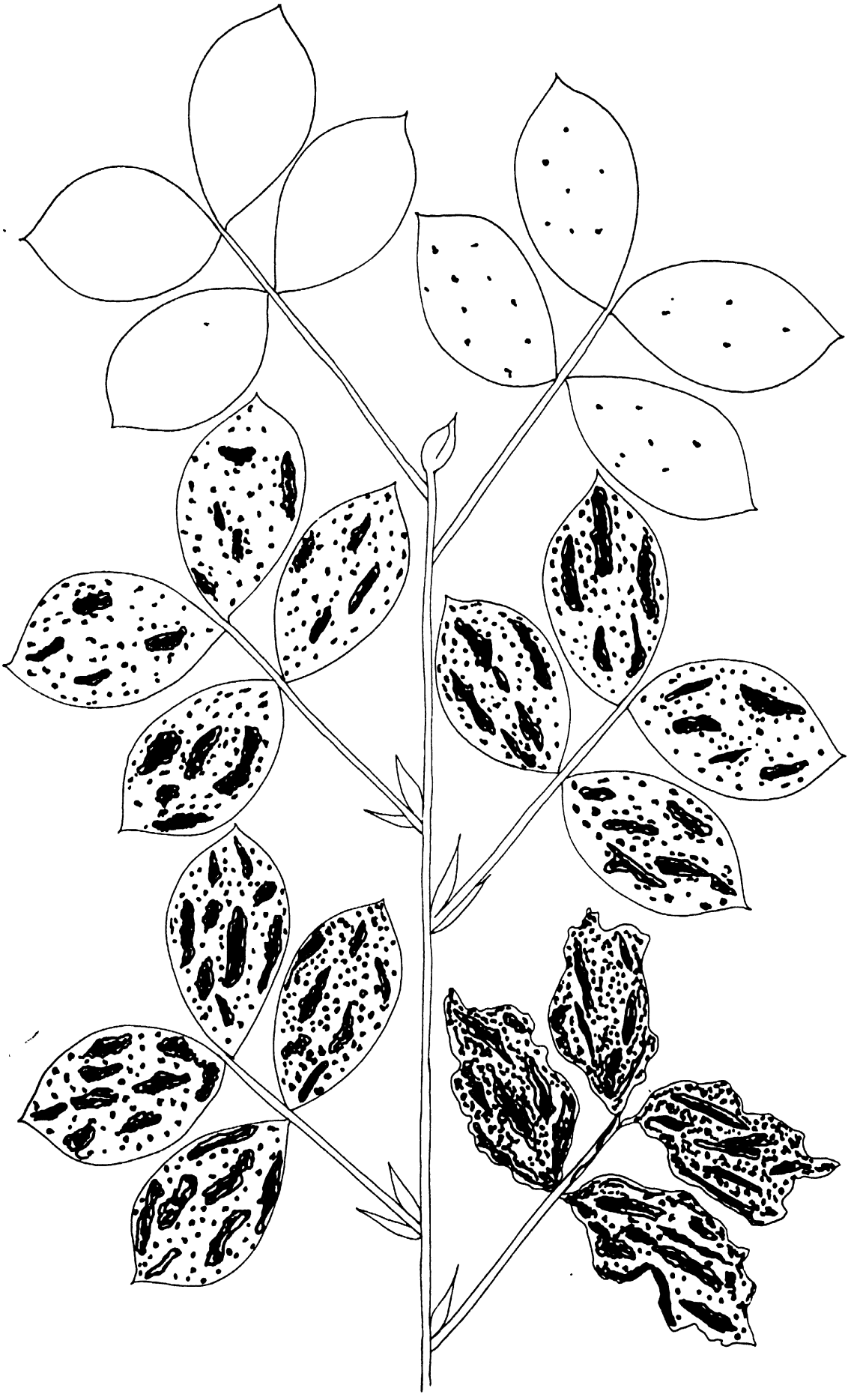


FIGURE 2.7 : SCORE 7

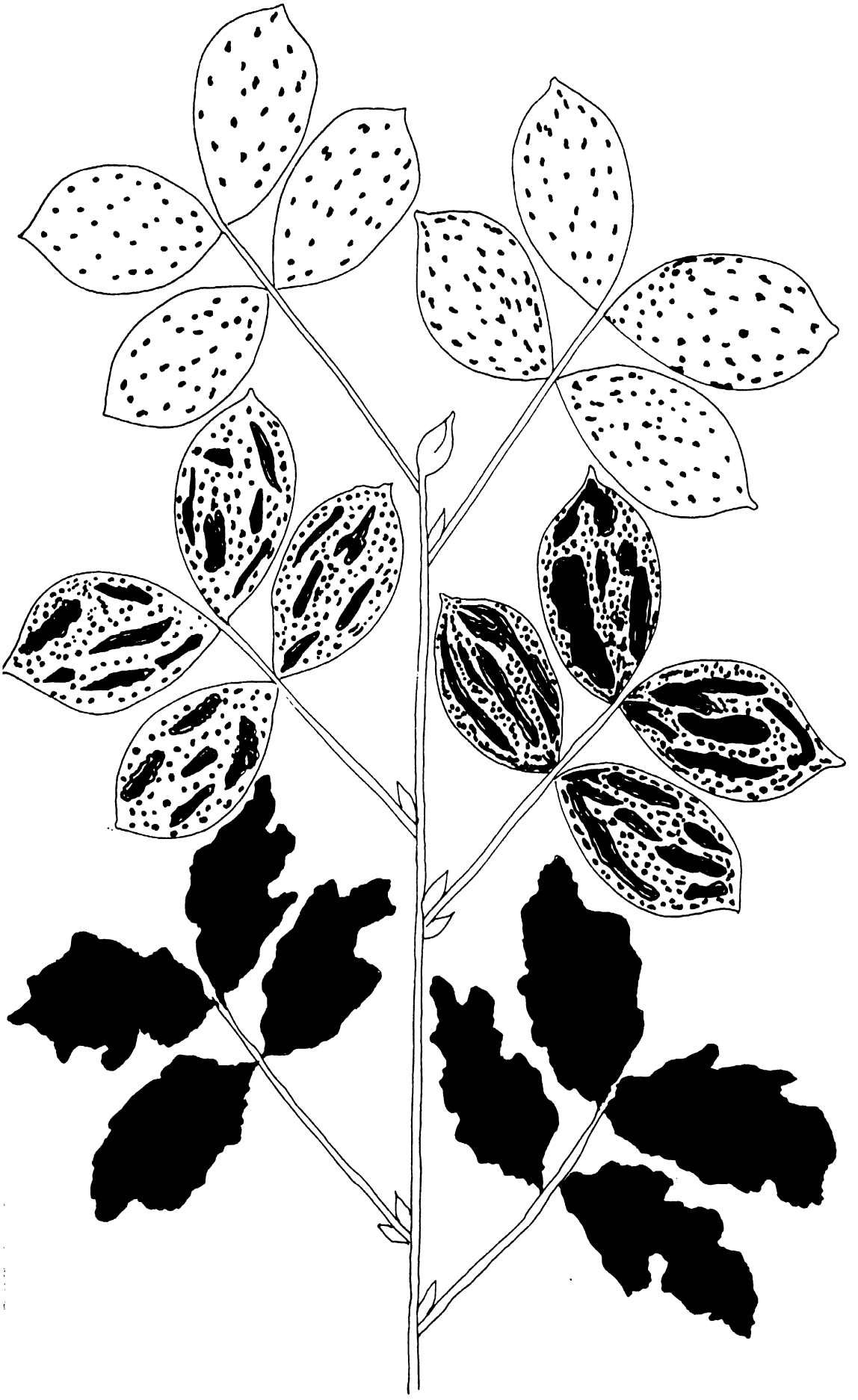


FIGURE 2.8 : SCORE 8

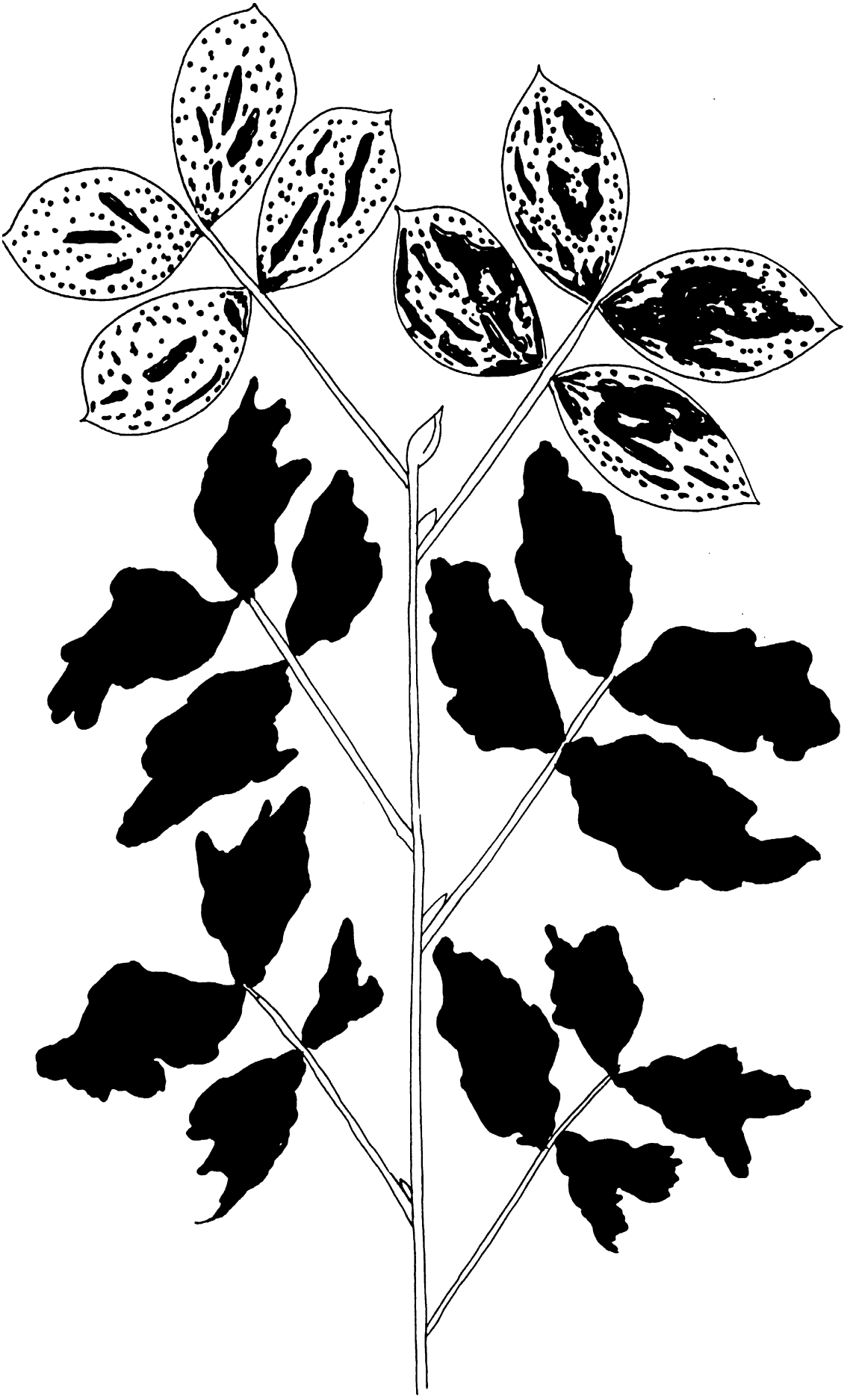


FIGURE 2.9 : SCORE 9

7. Pod yield: The pods obtained from each selected plant were thoroughly cleaned, air dried and then weighed in gm/plant.
8. Total number of kernels.
9. Number of mature kernels: All fully developed kernels were counted separately as mature kernels.
10. Number of immature kernels.
11. Kernel yield: The kernels obtained from each selected plant were weighed separately in gm/plant.

STATISTICAL ANALYSIS

a) Chi square (X^2) test:

To determine the number of genes governing the resistance to the rust pathogen, the X^2 test was conducted on the F_2 plants scored on 1-9 scale. The formula generally used is as follows:-

$X^2 = \varepsilon \frac{(O-E)^2}{E}$ where O is the observed frequency and E is the expected frequency (Bailey, 1965).

Since the correction for continuity is applied, the formula used was:

$$X^2 = \varepsilon \frac{[\{(O-E)-\frac{1}{2}\}]^2}{E}$$

b) Generation mean analysis:

To determine the genetics of the response to infection by the rust fungus, Puccinia arachidis Speg., the generation mean analysis described by Mather and Jinks (1971) was used. The means and variances of the parental and F_2 generations were calculated for both the rust scorings.

These values were then utilized to estimate the parameters m, (d), (h) and e where m is the mid point between the two parents, (d) is the deviation of the susceptible parent and reflects fixable or additive genetic effects, (h) reflects the dominance genetic effects and e is the environmental effect. The estimation of these parameters was done by weighted least squares, taking as weights the reciprocals of the squared standard errors of the mean. Later, expected means of these generations were derived utilizing these parameters and a comparison was made between the observed and expected means using the X^2 test with four degrees of freedom less than the total number of family means used (four less because four parameters were fitted). In all, six equations were available, since the observations were recorded twice on the three generations (parent 1, parent 2 and their F_2 generation) for estimating these four parameters. The six equations and their weights were combined to give three equations yielding weighted least square estimates of the three parameters as follows. Each of the equations is multiplied through by the coefficient of m which it contains, and by its weight, and the six are then summed. The remaining three equations were found in the same way using the coefficients of (d), (h) and e in turn and the weights as multipliers. Then matrix inversion was done to estimate these four parameters using the programmable calculator. The following table shows the coefficients of the four parameters over two rust scorings of the three generation means (Mather & Jinks, 1971).

Means	m	(d)	(h)	e
P1	1	1	0	1
P2	1	-1	0	1
F2	1	0	½	1
P1	1	1	0	-1
P2	1	-1	0	-1
F2	1	0	½	-1

The expected generation means were obtained using these parameters as follows:

$\bar{P}1 = m + (d) + e$

$\bar{P}2 = m - (d) + e$

$\bar{F}2 = m + \frac{1}{2}(h) + e$

$\bar{P}1 = m + (d) - e$

$\bar{P}2 = m - (d) - e$

$\bar{F}2 = m + \frac{1}{2}(h) - e$

The goodness of fit between the observed and expected means was obtained by the X^2 test at (6-4) d.f. and conclusions were drawn accordingly (Tables 8 to 17). The average degree of dominance of each cross was determined by the formula (h)/(d).

Correlations:

All the post harvest observations recorded on the selected plants were correlated with their rust scores on an individual plant basis separately for parents and F_2 crosses (Tables 18 and 19).

The correlation coefficients (r) were calculated between rust disease and all other yield attributing characters using the formula:

$$\frac{\text{Covariance } XY}{\sqrt{\text{Variance x X variance Y}}}$$

$$= \frac{\varepsilon XY - \frac{\varepsilon X\, \varepsilon Y}{n}}{\sqrt{\left[\varepsilon X^2 - \frac{(\varepsilon X)^2}{n}\right]\left[\varepsilon Y^2 - \frac{(\varepsilon Y)^2}{n}\right]}}$$

Snedecor and Cochran (1967).

Table 1. Description of the parental cultivars used in the study*

Cultivar	Origin	Sub species and botanical variety	Reaction to rust	Remarks
M 13	India	Sub sp. hypogaea var. hypogaea	Susceptible	Released cultivar in India
J 11	India	Sub sp. fastigiata var. vulgaris	Susceptible	Released cultivar in India
Gangapuri	India	Sub sp. fastigiata var. fastigiata	Susceptible	Grown in Madhya Pradesh
EC 76446 (292)	Uganda	Sub sp. fastigiata var. fastigiata	Resistant	Land race
PI 259747	Peru	Sub sp. fastigiata var. fastigiata	Resistant	Land race
NC Ac 17090	Peru	Sub sp. fastigiata var. fastigiata	Resistant	Land race

Personal communication, Dr. S.N. Nigam, Groundnut Breeder, ICRISAT

RESULTS

a) Frequency distribution

The infector rows consisting of susceptible cultivars, TNV 2 and Robut 33-1 developed uniform, severe rust infection. Rust symptoms appeared 25 days after emergence. Figure 3 shows the typical rust symptoms on a susceptible cultivar, and Figure 5 shows the comparison between rust susceptible (TNV 2) and rust resistant (PI 259747) cultivars. Among the susceptible cultivars on both first and second scorings, J 11 was the most susceptible followed by H 13 and Gangapuri. Mean rust score increased during the second scoring. On the first scoring, susceptible parents ranged from 7.46 to 8 on the 1-9 point scale. On second scoring, the range was 7.92 to 8.5. Similarly, the mean rust score for resistant parents ranged from 2.25 to 2.45 in the first scoring. In the second observation, the range was 2.91 to 2.93. On frequency distribution, score of the individual plants in susceptible varieties varied from 6-9 in the first scoring and 7-9 in the second scoring. For resistant cultivars, individual plants scored either '2' or '3' during both the scorings. None of the plants scored '1' in the resistant varieties (Tables 4 & 5). Mean rust score for the crosses ranged from 5.58 to 6.15 in the first scoring whereas it was 5.73 to 6.73 in the second or final scoring. In the final scoring, highest variance (2.504) was recorded in the cross Gangapuri x EC 76446 (292) and its mean rust score was the lowest (5.73). In all other crosses, there was not much variation in mean rust score or variance (Tables 6 & 7). On an overall basis, for one resistant parent i.e. considering the three crosses involving the same resistant parent together, the mean score for rust varied from 5.60 to 6 in the first and 6.32 to 6.53 in the second scorings respectively. Crosses involving parent EC 76446 (292)

FIGURE 3 : SYMPTOMS OF GROUNDNUT RUST

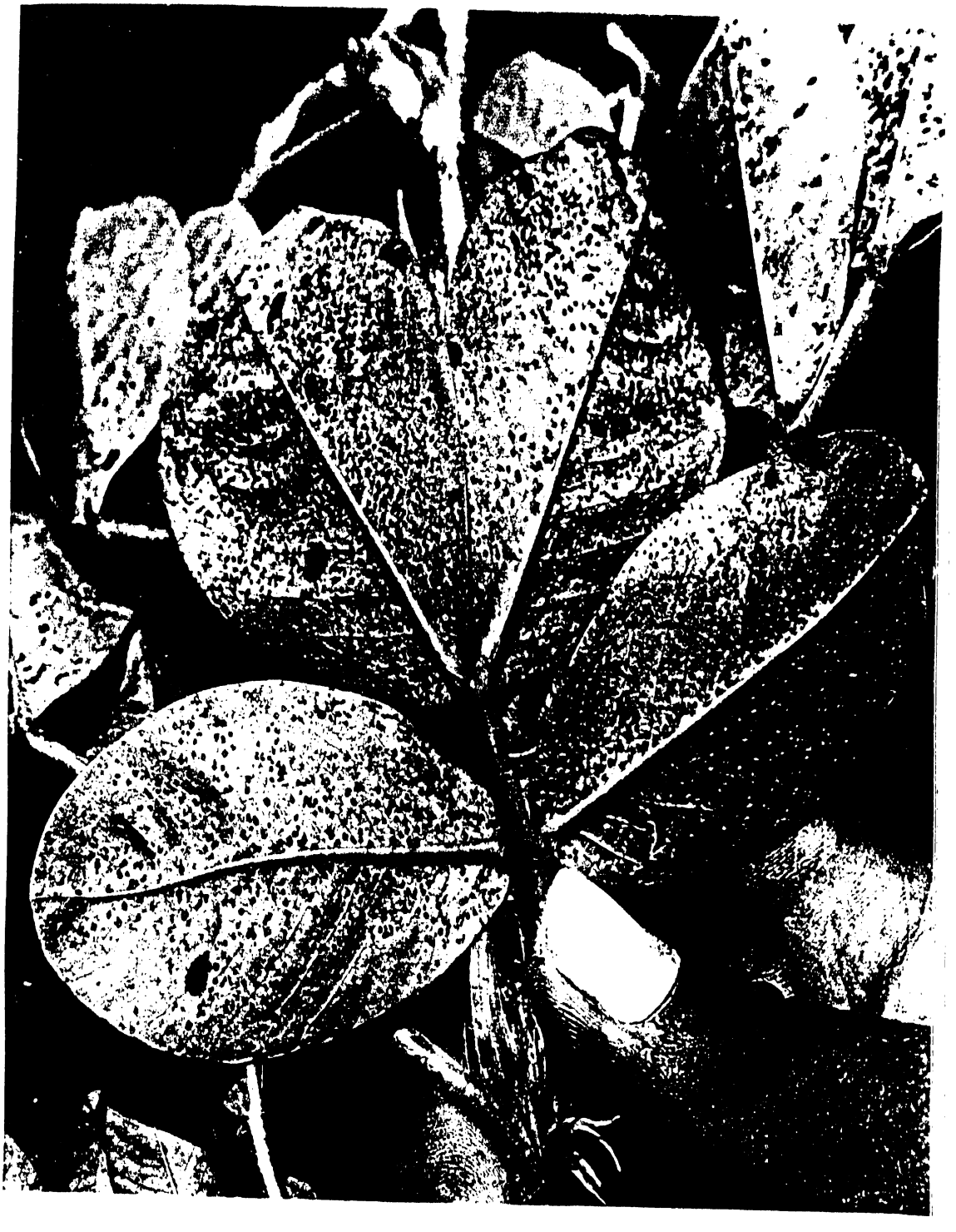


FIGURE 4 : F_2 FREQUENCY DISTRIBUTION FOR RUS REACTION IN THE CROSSES

4.1 F_2 Frequency Distribution for Rust Reaction in the Cross M-13xEC76446(292)

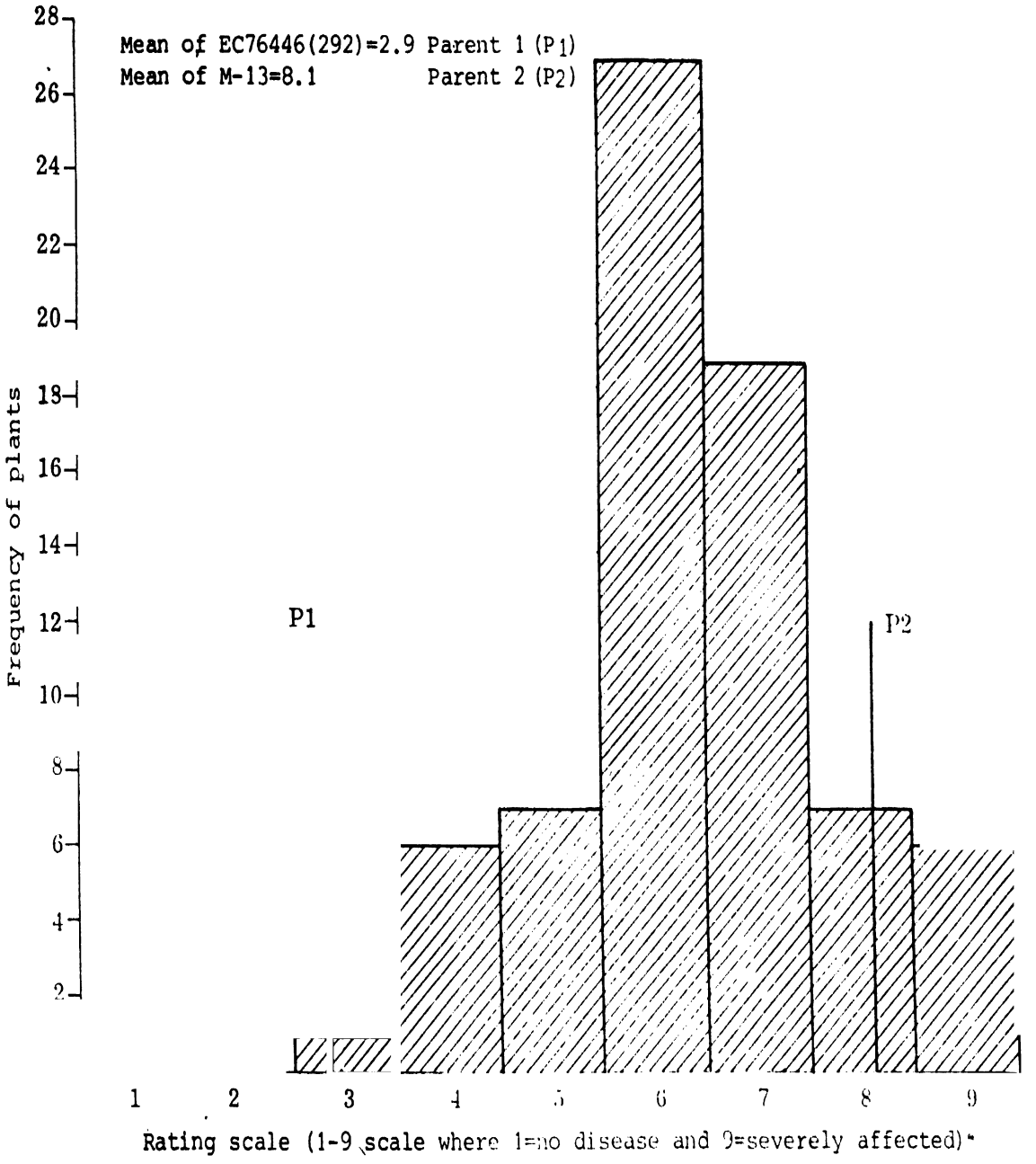
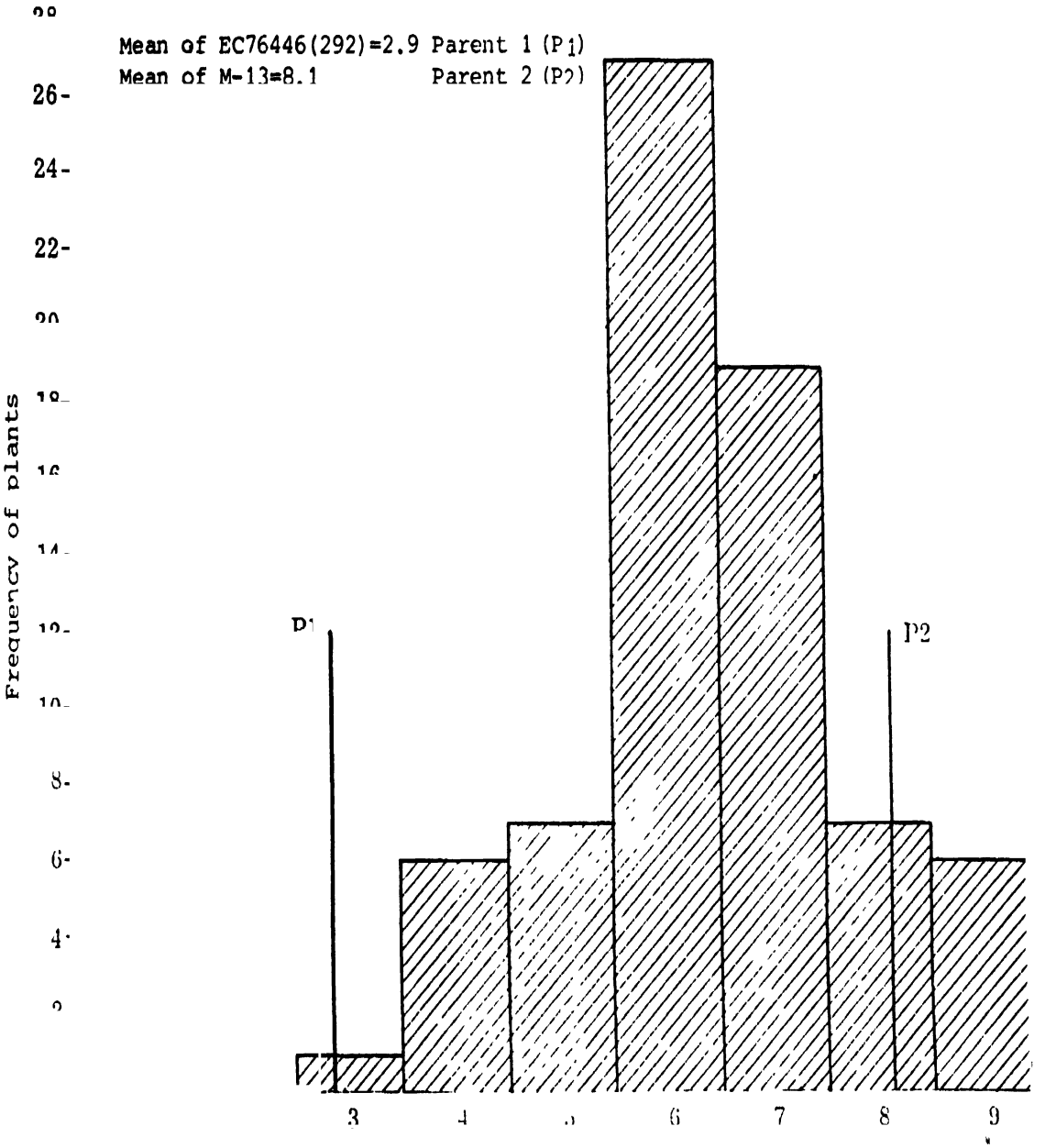
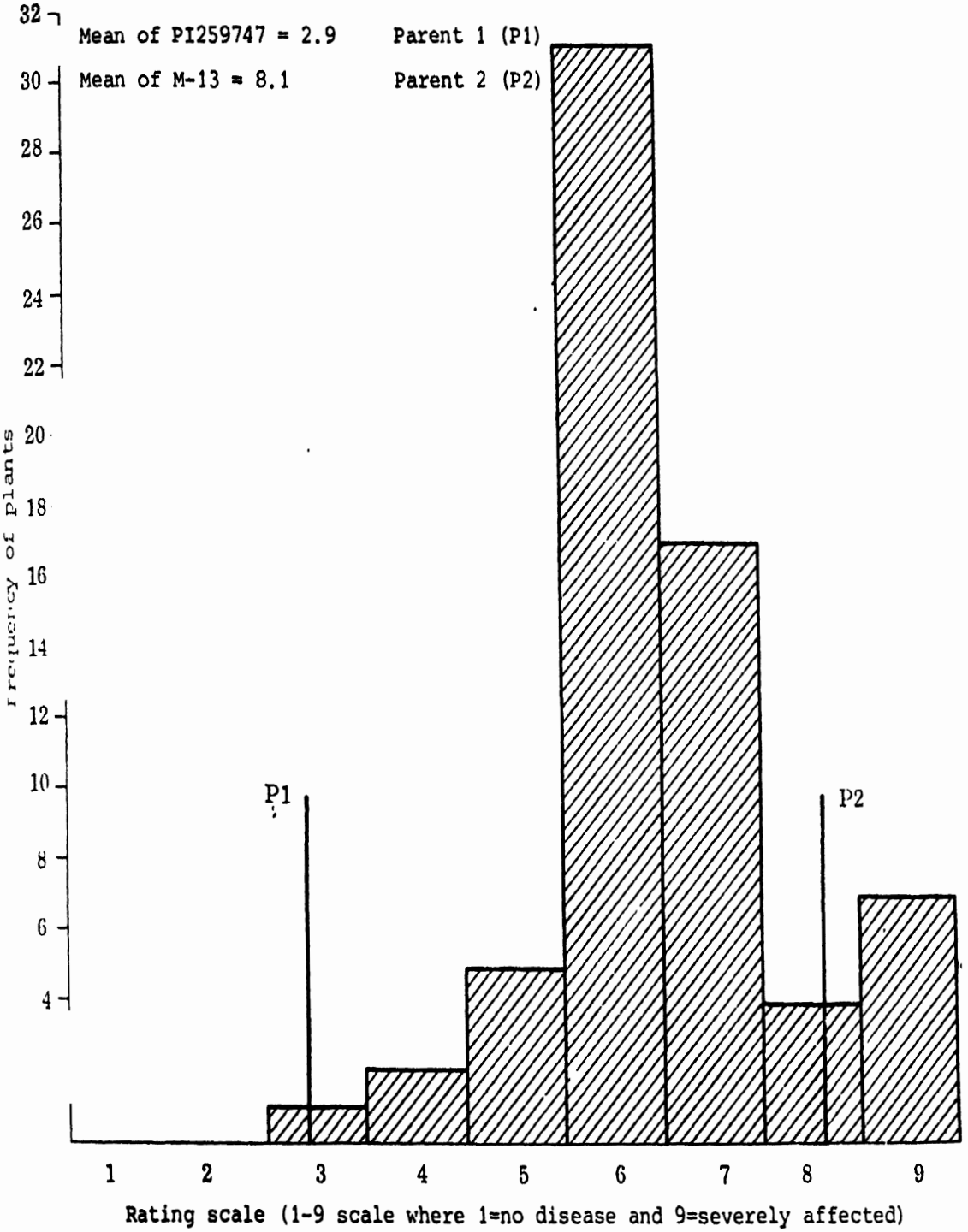


FIGURE 4 : F_2 FREQUENCY DISTRIBUTION FOR RUST REACTION IN THE CROSSES

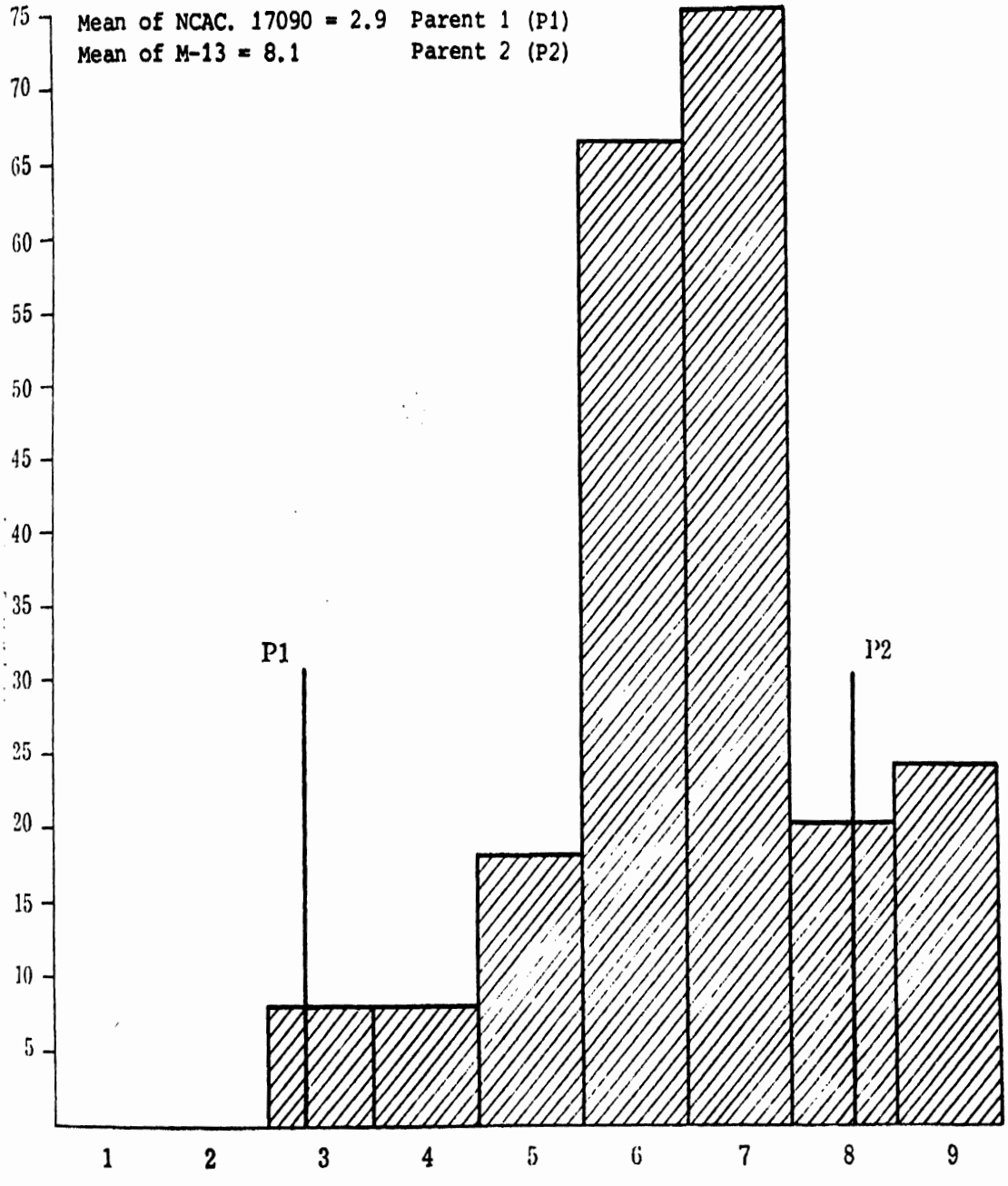
4.1. F_2 Frequency Distribution for Rust Reaction in the Cross M-13xEC76446(292)



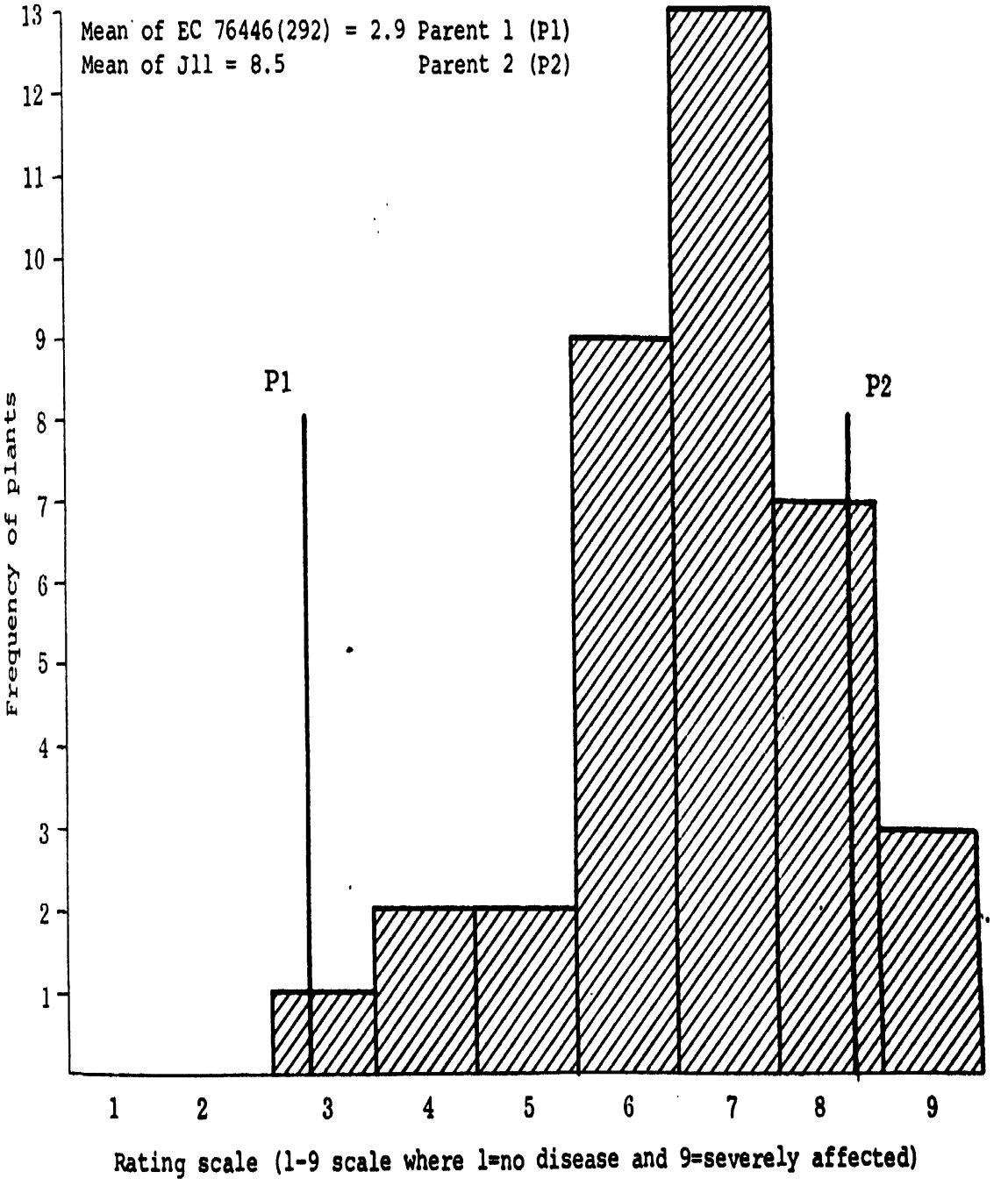
4.2 F_2 Frequency Distribution for Rust Reaction in the Cross M-13 x PI259747



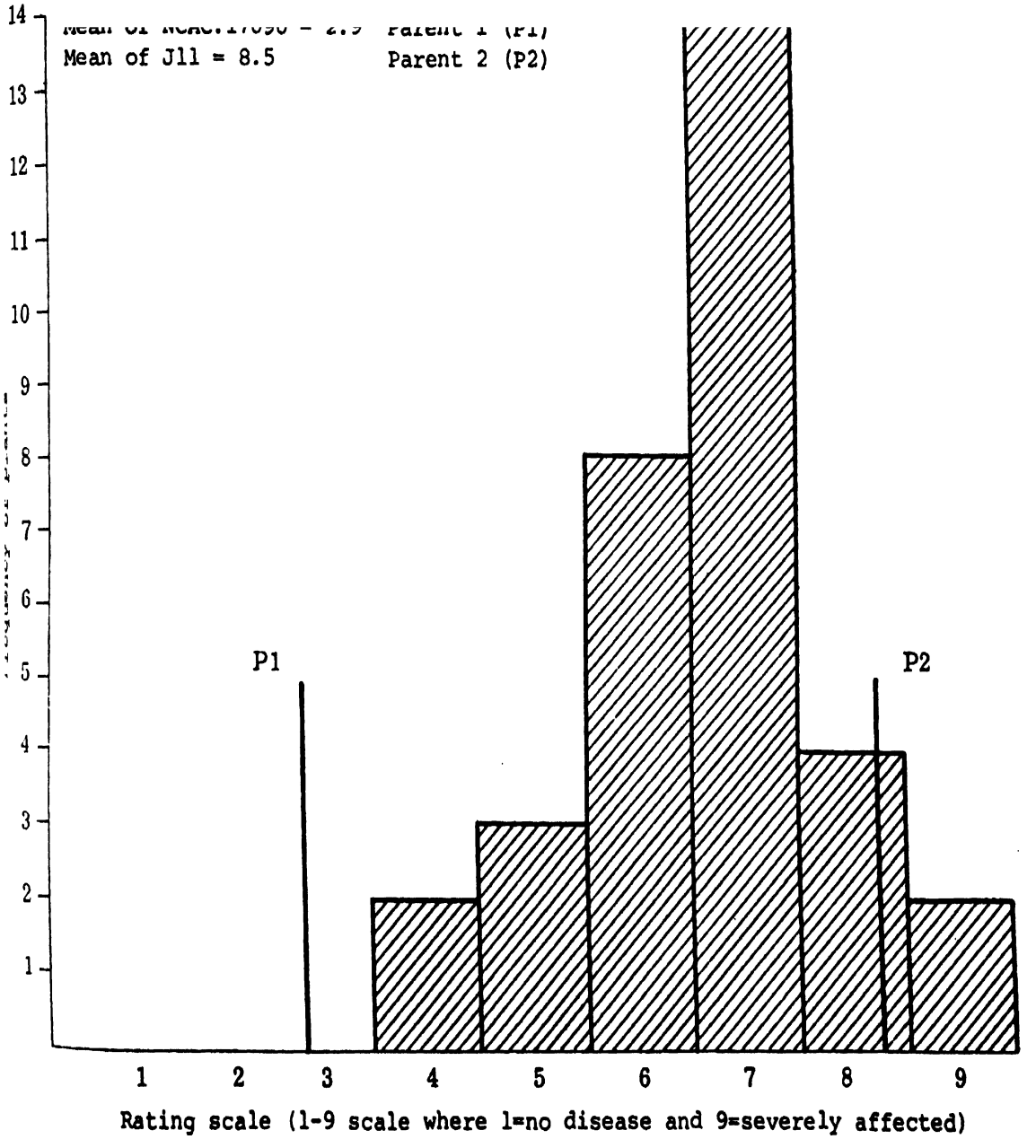
4.3. F_2 Frequency Distribution for Rust Reaction in the Cross M-13 x NCAC. 17090



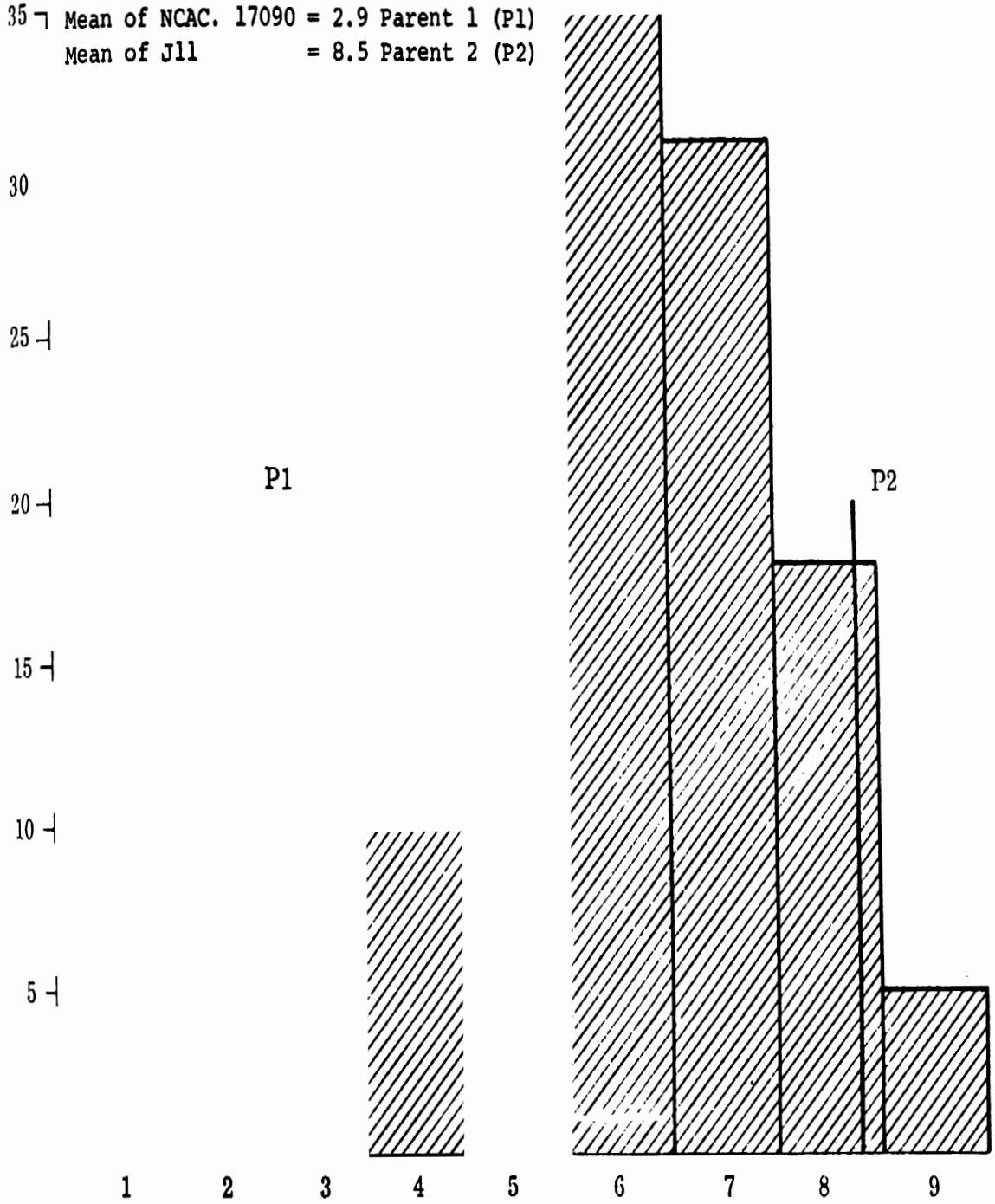
4.4. F_2 Frequency Distribution for Rust Reaction in the Cross J 11 x EC 76446 (292)



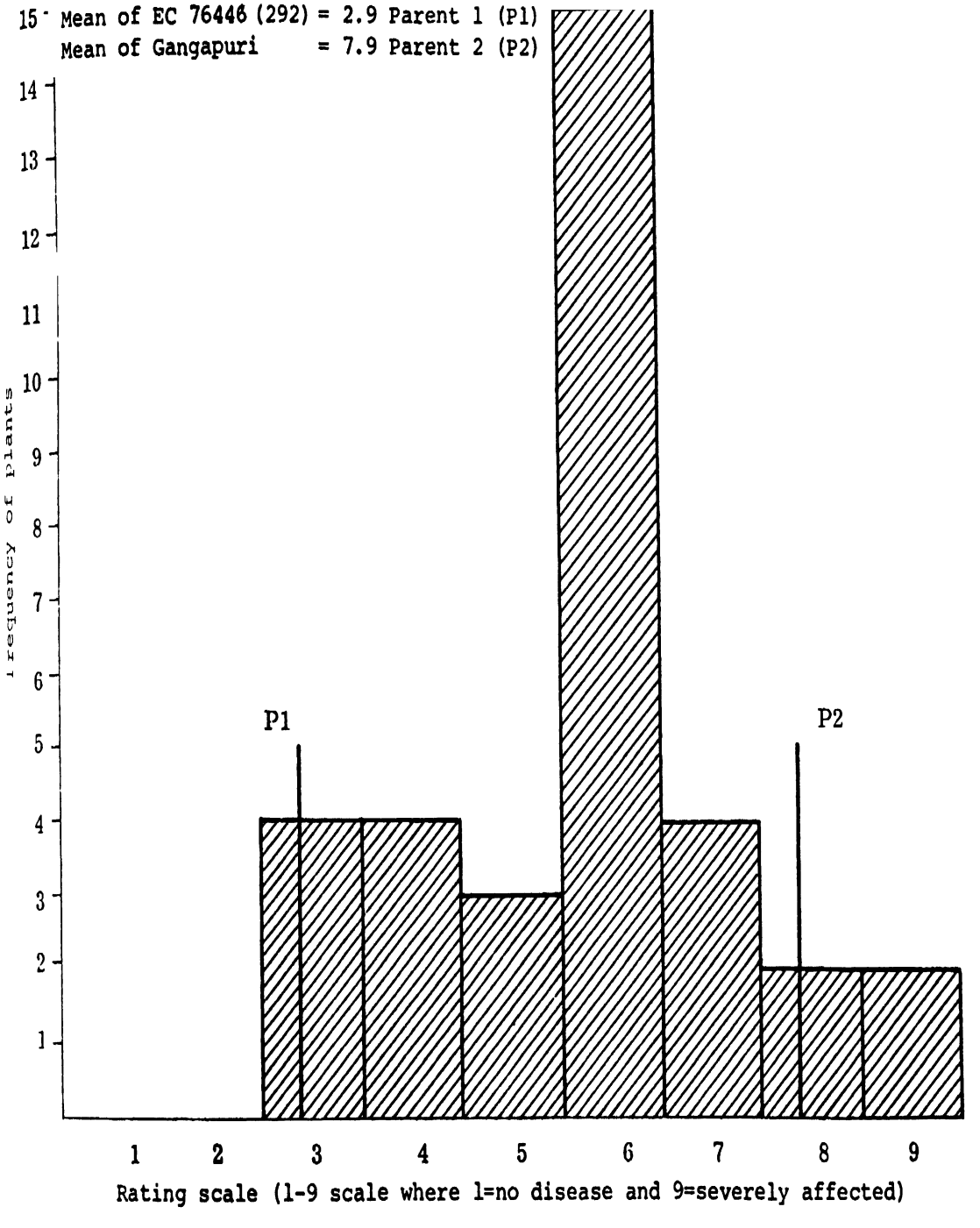
4.5. F_2 Frequency Distributions for Rust Reaction in the Cross J 11 x PI 259747



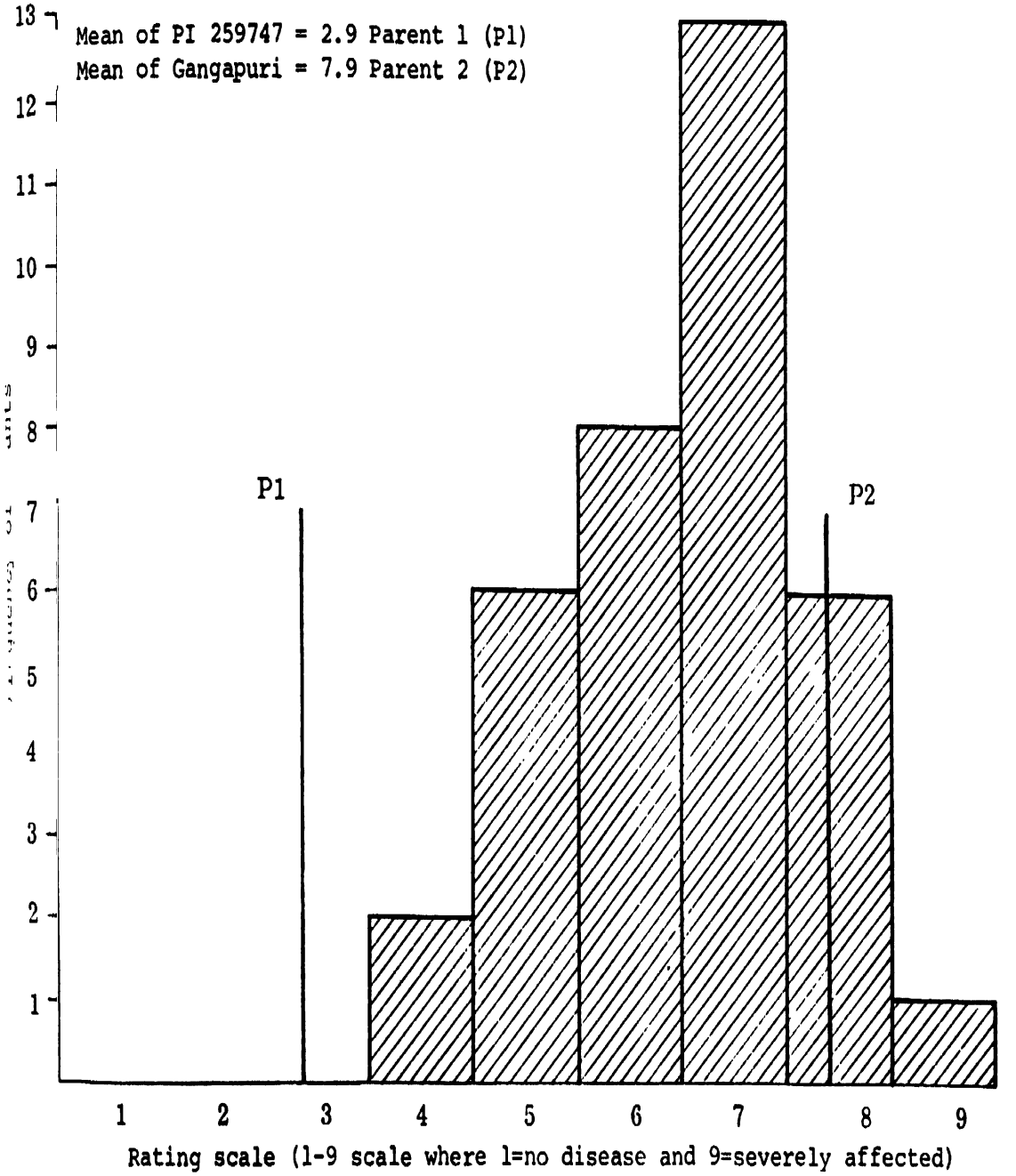
4.6. F_2 Frequency Distribution for Rust Reaction in the Cross J 11 x NCAC. 17090



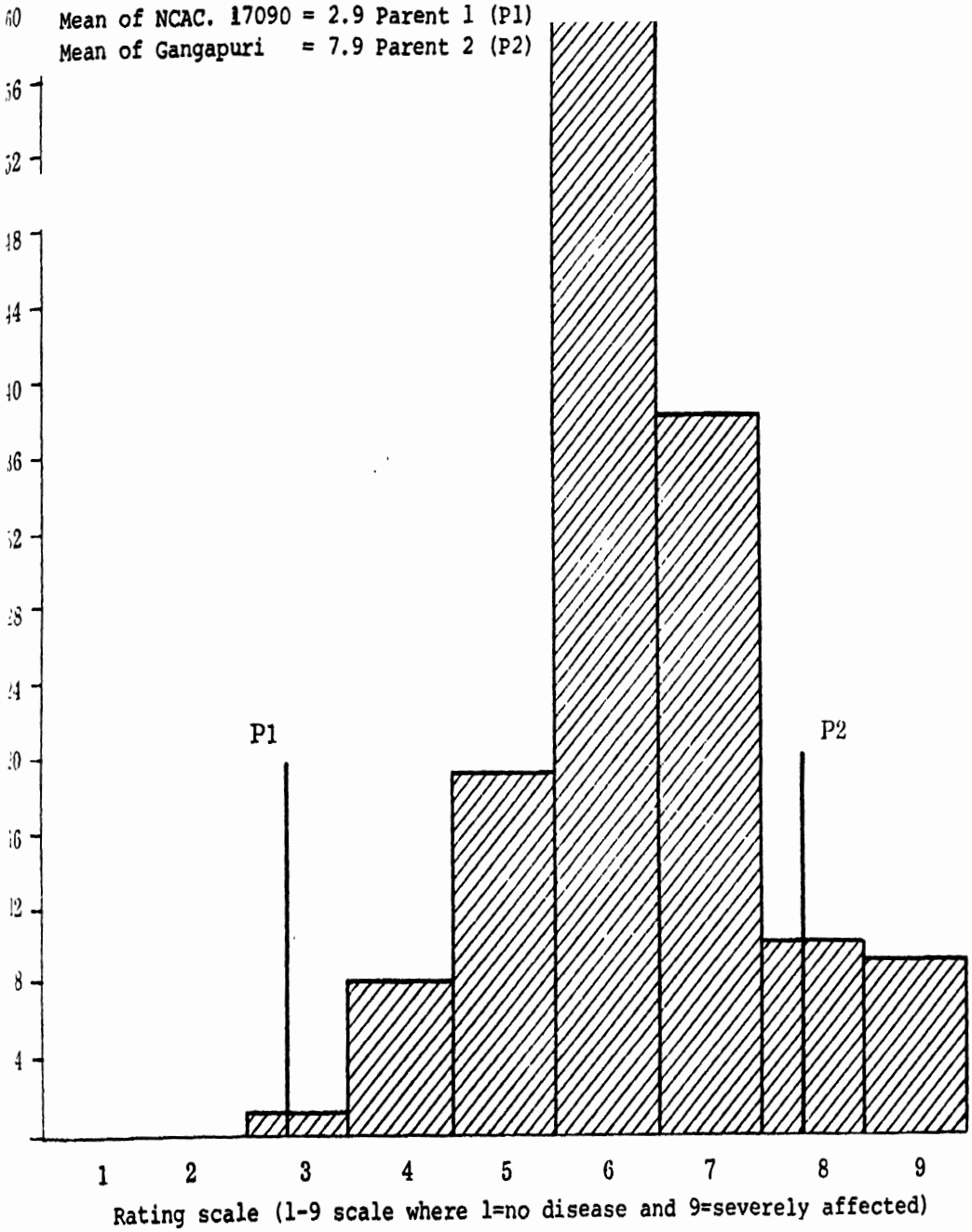
4.7. F_2 Frequency Distribution for Rust Reaction in the Cross Gangapuri x EC 76446 (292)



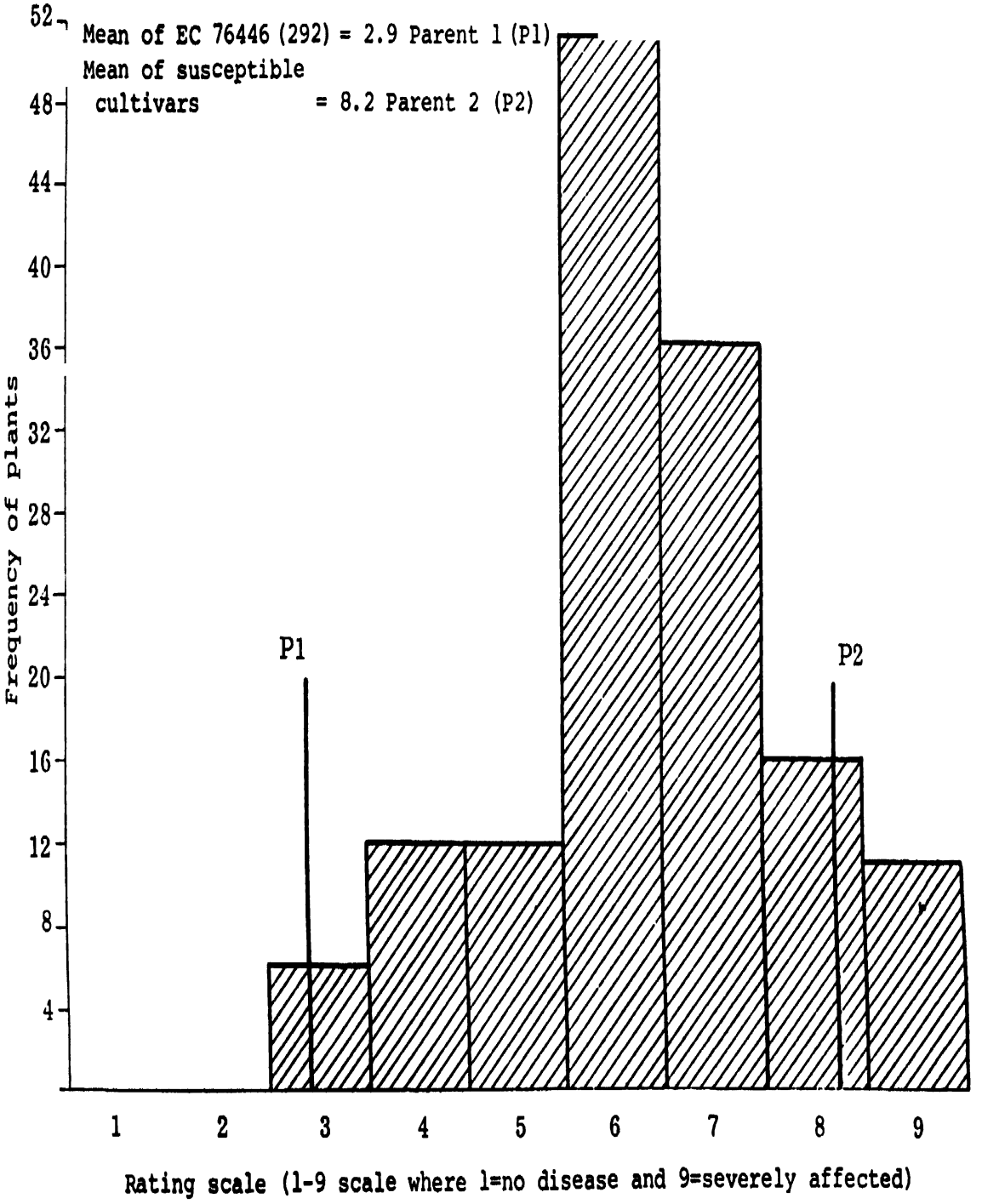
4.8. F_2 Frequency Distribution for Rust Reaction in the Cross Gangapuri x PI259747



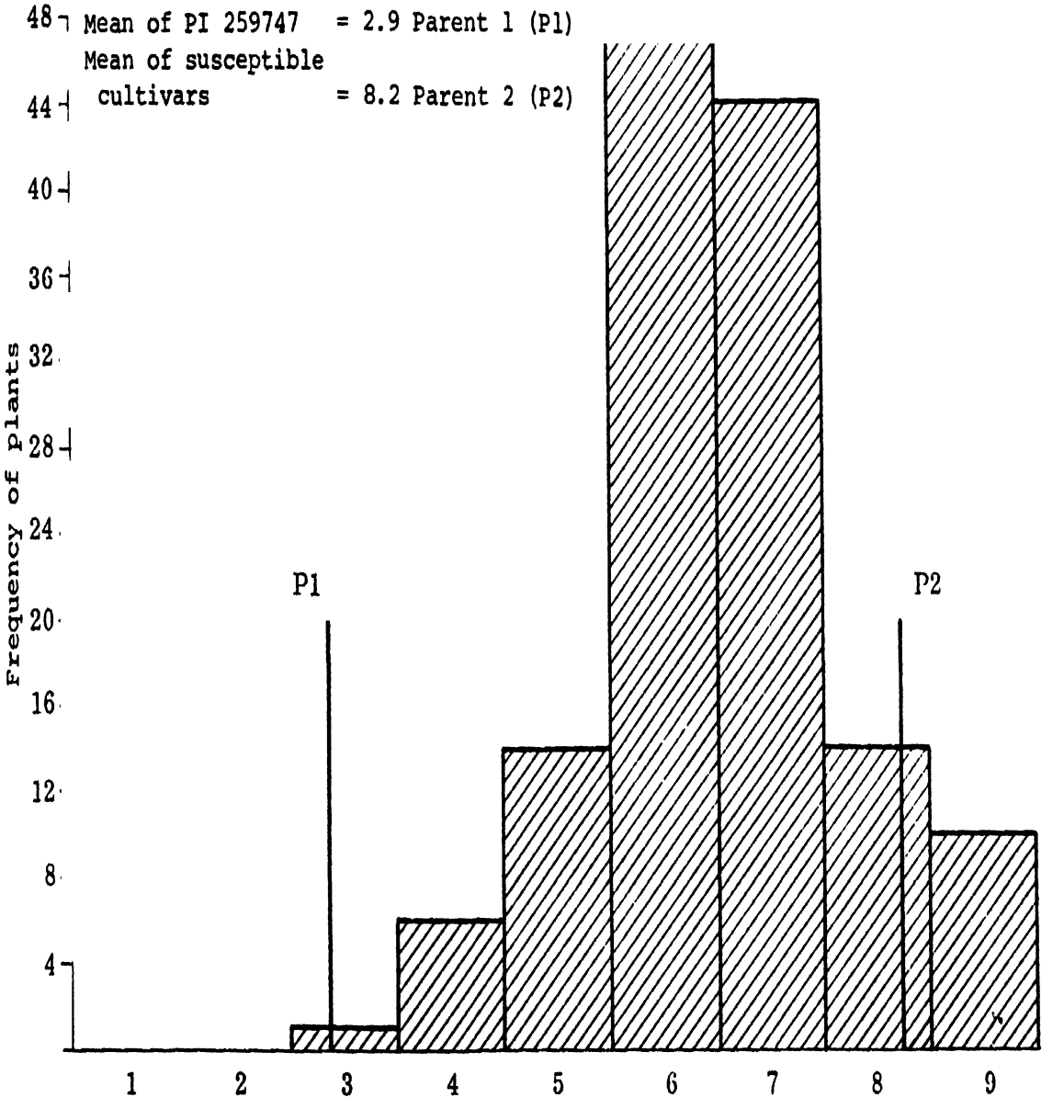
4.9. F_2 Frequency Distribution for Rust Reaction in the Cross Gangapuri x NCAC. 17090



4.10. F_2 Frequency Distribution for Rust Reaction in the Cross Between Susceptible Cultivars x EC 76446 (292)



4.11. F_2 Frequency Distribution for Rust Reaction in the Cross Between Susceptible Cultivars x PI259747



4.12. F_2 Frequency Distribution for Rust Reaction in the Cross Between Susceptible Cultivars x NCAC. 17090

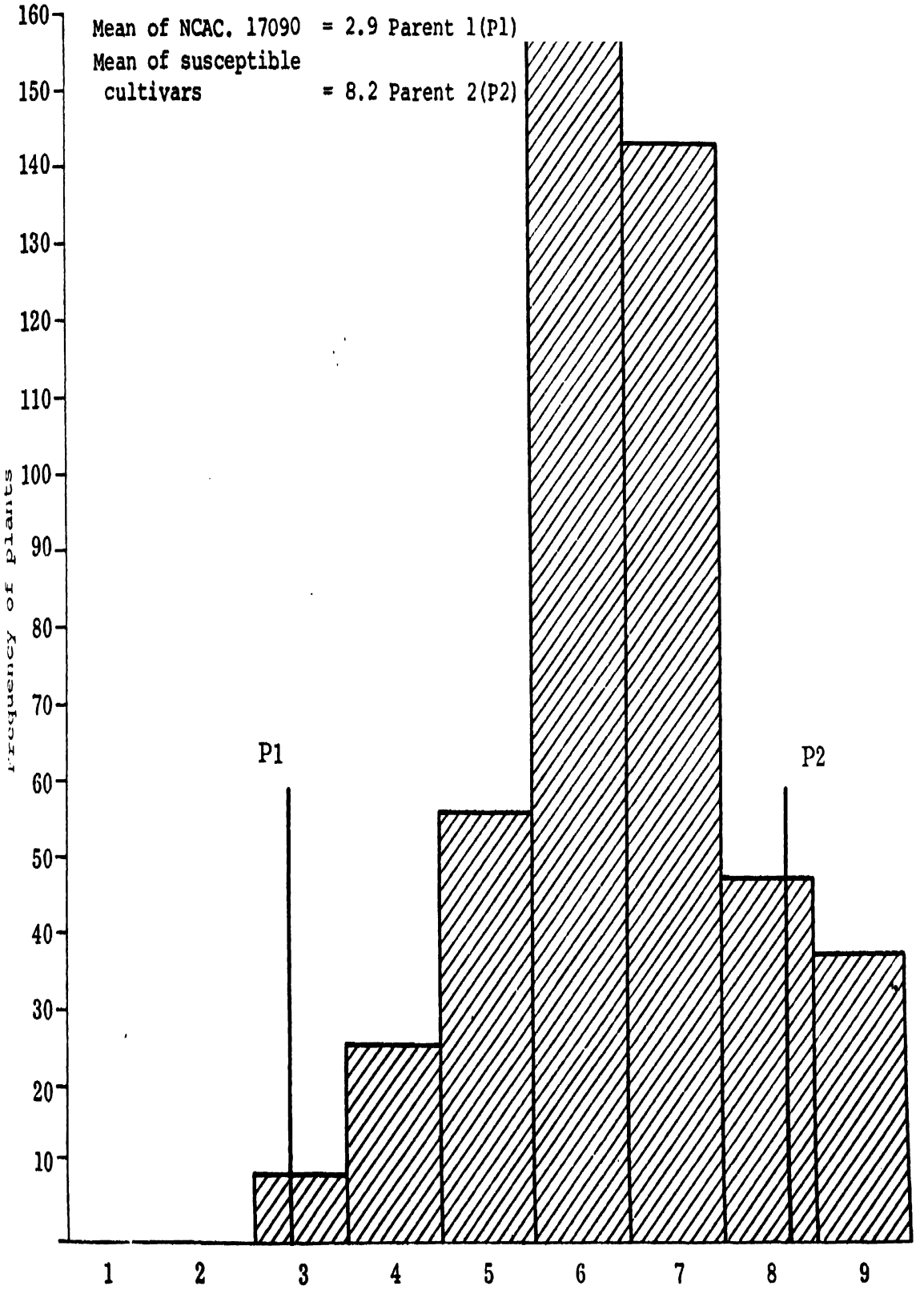


FIGURE 5 : COMPARISON BETWEEN RUST RESISTANT (PI 250747) AND RUST SUSCEPTIBLE (TMV-2) CULTIVARS.

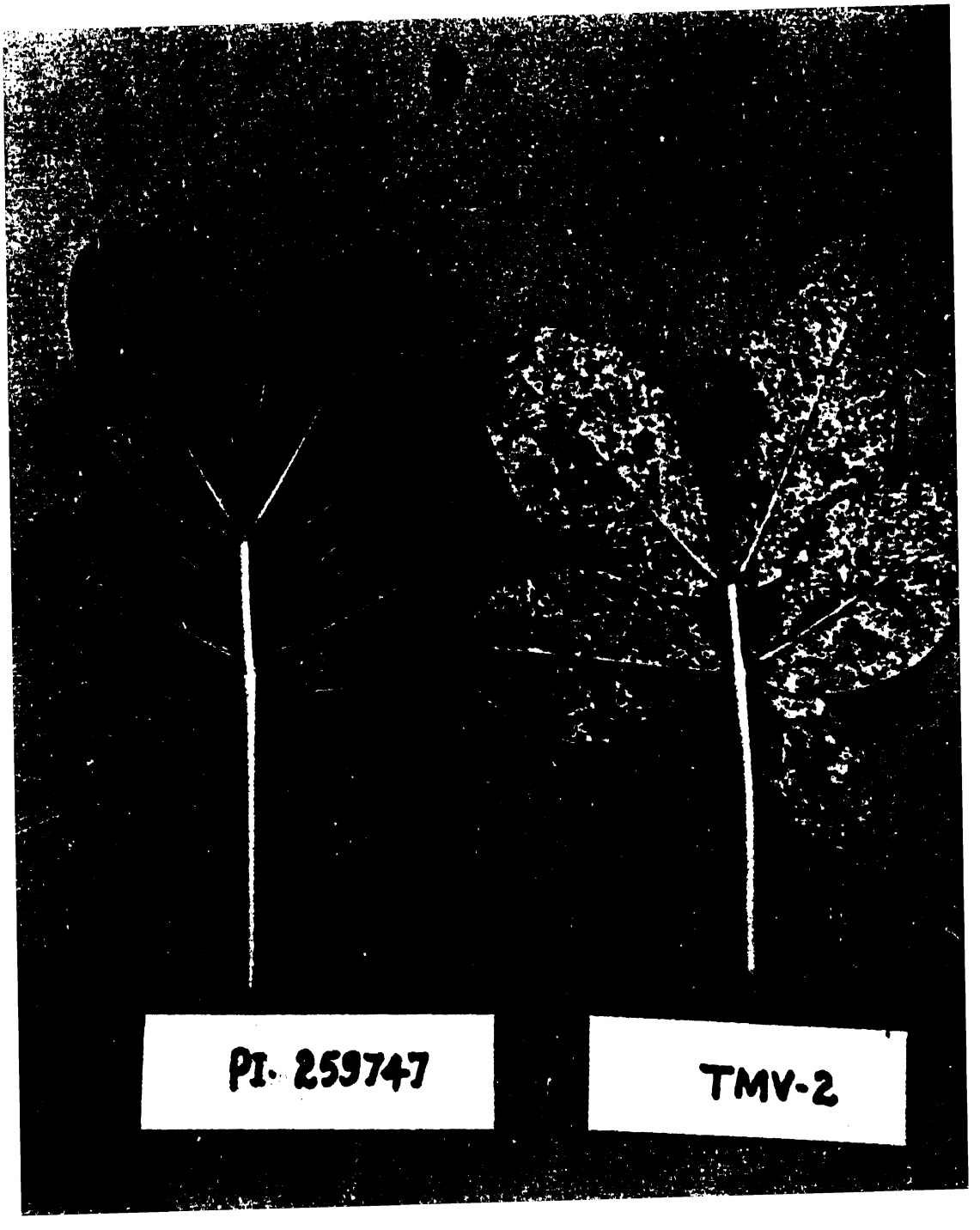

PI. 259747
TMV-2

Table 2. Proportion of resistant, intermediate and susceptible plants in the crosses for the final rust scoring

	Total No. of plants		Resistant	Inter-mediate	Suscep-tible	Expected ratios	X^2 value
Cross A	144	Observed	6	111	27		
		Expected	9	54	81	9:6:1	95.146
		Expected	9	27	108	12:3:1	318.928
		Expected	2	81	61	27:36:1	35.266
Cross B	136	Observed	1	111	24		
		Expected	8.5	51	76.5	9:6:1	110.527
		Expected	8.5	25.5	102	12:3:1	347.983
		Expected	2.1	76.5	57.4	27:36:1	34.139
Cross C	481	Observed	9	386	86		
		Expected	30	180	271	9:6:1	374.230
		Expected	30	90	361	12:3:1	1192.959
		Expected	7.5	270.5	203	27:36:1	115.882
Total	761	Observed	16	608	137		
		Expected	47.5	285.4	428.1	9:6:1	581.014
		Expected	47.5	142.5	571	12:3:1	1866.710
		Expected	12	428	321	27:36:1	181.199

where A = crosses involving EC 76446 (292) as resistant parent.
B = crosses involving PI 259747 as resistant parent.
C = crosses involving NC Ac 17090 as resistant parent.

had the highest variance (2.082) and lowest mean rust score (6.33) in the final rust scoring. The spread of the F2 plants in frequency distribution was between scores '3' and '9'. None of the plants in the crosses scored '1' or '2'. Very few plants had the score of '3'. In general, the F2 distribution was skewed towards the susceptible parents. Considering scores '1', '2' and '3' as resistant and scores '4', '5', '6' and '7' as intermediate and '8' and '9' as susceptible, the following proportions were obtained for the crosses in the final rust scoring (Table 2).

However, the data did not fit into digenic and trigenic ratios.

Considering scores '1', '2' and '3' as resistant and remaining as susceptible, the following proportions were obtained for the crosses in the final rust scoring (Table 3).

Table 3. Proportion of resistant and susceptible plants in the crosses for final rust scoring

Cross	Total # of plants	Resistant	Susceptible	Expected ratio	X^2 value at 1 d.f.
A	144	Observed: 6	138		
		Expected: 9	135	1:15	0.741
B	136	Observed: 1	135		
		Expected: 2.1	133.9	1:63	0.174
C	481	Observed: 9	472		
		Expected: 7.5	473.5	1:63	0.135
Total	761	Observed: 16	745		
		Expected: 12	749	1:63	1.037

A = crosses involving EC 76446 (292) as resistant parent
B = crosses involving PI 259747 as resistant parent
C = crosses involving NC Ac 17090 as resistant parent

Thus, for the crosses involving EC 76446 (292) as resistant parent, there was a digenic resistance to rust whereas for the other two crosses which involved PI 259747 and NC Ac 17090 respectively, the resistance to rust was governed by three genes. On an overall basis, the resistance to rust was governed by three genes.

B. Generation mean analysis

The means and variances of the parental and F2 generations for the first and second scorings and the joint scaling tests are presented in

Tables 6-14. For all the crosses, the X^2 value was non-significant. This indicated the goodness of fit for an additive dominance model.

Estimates of additive and dominance genetic components for the nine crosses are presented in Table 15. In all the crosses, additive and dominance gene effects were highly significant except in the cross Gangapuri x EC 76446 (292) where dominance effects were insignificant. Additive gene effects were more pronounced as compared to dominance gene effects for all the crosses. In all the crosses, the environmental component was negative indicating that the rust susceptibility increased with plant age. Among the crosses, M 13 x PI 259747 recorded the highest degree of dominance (0.79) and Gangapuri x EC 76446 (292), the lowest (0.20).

c) Correlations

The correlation coefficients between the rust score and plant morphological characters and yield components for the parents are presented in Table 16. Plant height was significantly and negatively correlated with rust score. The characters which were highly significantly and positively correlated with rust score were number of primary branches, number of secondary branches, total number of pods, number of mature and immature pods, pod yield and total number of kernels. The magnitude of correlation coefficient for total number of kernels with rust score was, though highly significant, very low. However, there was no significant correlation between mature, immature kernels and kernel yield with rust score.

In crosses except plant height which was positively and highly significantly correlated with rust score, all other characters had highly significant, negative correlation with rust score. The magnitude of correlation coefficients for the number of primary branches, number of

immature pods and number of immature kernels with rust score was though highly significant, very low (Table 19).

able 4. Frequency distribution, means ($\bar{X}$) and variances (σ^2) for the rust scoring data on 1-9 point scale for the parent cultivars - First scoring

Identity	Total No. of plants	1	2	3	4	5	6	7	8	9	$\bar{X}$	σ^2
13	49	0	0	0	0	0	0	25	19	5	7.59	0.455
J 11	8	0	0	0	0	0	1	0	5	2	8.00	0.857
angapuri	13	0	0	0	0	0	0	7	6	0	7.46	0.269
C 76446 (292)	30	0	21	9	0	0	0	0	0	0	2.30	0.217
PI 259747	24	0	13	11	0	0	0	0	0	0	2.45	0.259
NC Ac 17090	59	0	44	15	0	0	0	0	0	0	2.25	0.193

Table 5. Frequency distribution, means ($\bar{X}$) and variances (σ^2) for the rust scoring data on 1-9 point scale for the parent cultivars - Second scoring

Identity	Total No. of plants	1	2	3	4	5	6	7	8	9	$\bar{X}$	σ^2
3	49	0	0	0	0	0	0	0	43	6	8.12	0.110
1	8	0	0	0	0	0	0	0	4	4	8.50	0.286
gapuri	13	0	0	0	0	0	0	1	12	0	7.92	0.080
76446 (292)	29	0	2	27	0	0	0	0	0	0	2.93	0.066
259747	24	0	2	22	0	0	0	0	0	0	2.91	0.080
Ac 17090	59	0	4	55	0	0	0	0	0	0	2.93	0.064

Table 6. Frequency distribution, means ($\bar{X}$) and variances (σ^2) for the F2 rust scoring data on 1-9 point scale

First scoring

Identity	Total No.of plants (n)	1	2	3	4	5	6	7	8	9	$\bar{X}$	σ^2
M 13 x EC 76446 (292)	73	0	0	2	8	24	23	16	0	0	5.58	1.079
J 11 x EC 76446 (292)	37	0	0	1	5	6	10	9	3	3	6.13	2.287
Gangapuri x EC 76446 (292)	34	0	0	4	5	16	7	0	0	2	5.05	1.794
Total	144	0	0	7	18	46	40	25	3	5	5.60	1.681
M 13 x PI 259747	67	0	0	1	2	15	35	7	0	7	6.09	1.537
J 11 x PI 259747	33	0	0	0	3	8	8	11	1	2	6.15	1.633
Gangapuri x PI 259747	36	0	0	0	4	7	22	2	1	0	5.69	0.733
Total	136	0	0	1	9	30	65	20	2	9	6.00	1.363
M 13 x NC Ac 17090	219	0	0	13	20	56	88	20	6	16	5.74	1.960
J 11 x NC Ac 17090	118	0	0	0	20	16	46	24	10	2	5.94	1.519
Gangapuri x NC Ac 17090	144	0	0	3	15	28	69	23	2	4	5.80	1.235
Total	481	0	0	16	55	100	203	67	18	22	5.81	1.634

Table 7. Frequency distribution, means ($\bar{X}$) and variances (σ^2) for the F2 rust scoring data on 1-9 point scale - Second scoring

Identity	Total No.of plants	1	2	3	4	5	6	7	8	9	$\bar{X}$	σ^2
M 13 x EC 76446 (292)	73	0	0	1	6	7	27	19	7	6	6.39	1.798
J 11 x EC 76446 (292)	37	0	0	1	2	2	9	13	7	3	6.73	1.869
Gangapuri x EC 76446 (292)	34	0	0	4	4	3	15	4	2	2	5.73	2.504
Total	144	0	0	6	12	12	51	36	16	11	6.32	2.082
M 13 x PI 259747	67	0	0	1	2	5	31	17	4	7	6.50	1.526
J 11 x PI 259747	33	0	0	0	2	3	8	14	4	2	6.63	1.426
Gangapuri x PI 259747	36	0	0	0	2	6	8	13	6	1	6.50	1.457
Total	136	0	0	1	6	14	47	44	14	10	6.53	1.465
M 13 x NC Ac 17090	219	0	0	8	8	18	66	75	20	24	6.58	1.913
J 11 x NC Ac 17090	118	0	0	0	10	19	35	31	18	5	6.36	1.635
Gangapuri x NC Ac 17090	144	0	0	1	8	19	59	38	10	9	6.32	1.424
Total	481	0	0	9	26	56	160	144	48	38	6.45	1.707

Table 8. Joint scaling test for rust data on the cross M 13 x EC 76446 (292)

Identity	Generation	Total No. of plants	σ^2	$\bar{V}\bar{X}$	Weight $(1/\bar{V}\bar{X})$	Observed mean	Expected mean	X^2 at 2 df
M 13	P1	49	0.455	.009	111.11	7.59	7.53	0.399
EC 76446 (292)	P2	30	0.217	.007	142.86	2.30	2.32	0.057
M 13 x EC 76446 (292)	F2	41	1.079	.026	38.46	5.58	5.66	0.246
M 13	P1	49	0.110	.002	500.00	8.12	8.13	0.050
EC 76446 (292)	P2	29	0.066	.002	500.00	2.93	2.92	0.050
M 13 x EC 76446 (292)	F2	41	1.798	.044	22.73	6.39	6.26	0.384
								1.186

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2-\frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{V}\bar{X}$ is the variance of sample mean = variance/n

Table 9. Joint scaling test for rust data on the cross M 13 x PI 259747

Identity	Generation	Total No. of plants	σ^2	$\bar{\bar{V}}\bar{X}$	Weight $(1/\bar{\bar{V}}\bar{X})$	Observed mean	Expected mean	X^2 at 2 df
M 13	P1	49	.455	.009	111.11	7.59	7.62	0.099
PI 259747	P2	24	.259	.011	90.91	2.45	2.43	0.036
M 13 x PI 259747	F2	67	1.537	.022	45.45	6.09	6.05	0.073
M 13	P1	49	.110	.002	500.00	8.12	8.11	0.050
PI 259747	P2	24	.080	.003	333.33	2.91	2.92	0.033
M 13 x PI 259747	F2	67	1.526	.023	43.48	6.50	6.54	0.069
								0.360

σ^2 is the variance $= \frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{\bar{V}}\bar{X}$ is the variance of sample mean = variance/n

Table 49 Joint scaling test for rust data on the cross M 13 x NC Ac 17090

Identity	Genera-tion	Total No. of plants	σ^2	$\bar{\bar{V}}\bar{X}$	Weight $(1/\bar{\bar{V}}\bar{X})$	Observed mean	Expected mean	X^2 at 2 df
M 13	P1	49	.455	.009	111.11	7.59	7.480	1.344
NC Ac 17090	P2	59	.193	.003	333.33	2.25	2.260	0.033
M 13 x NC Ac 17090	F2	219	1.960	.009	111.11	5.74	5.83	0.899
M 13	P1	49	.110	.002	500.00	8.12	8.14	0.200
NC Ac 17090	P2	59	.064	.001	1000.00	2.93	2.92	0.100
M 13 x NC Ac 17090	F2	219	1.913	.009	111.11	6.58	6.50	0.711
								3.287

σ^2 is the variance $= \frac{1}{n-1}\left[\epsilon Xi^2 - \frac{(\epsilon Xi)^2}{n}\right]$

$\bar{\bar{V}}\bar{X}$ is the variance of sample mean = variance/n

Table 11. Joint scaling test for rust data on the cross J 11 x EC 76446 (292)

Identity	Generation	Total No. of plants (n)	σ^2	$V\bar{X}$	Weight $(1/V\bar{X})$	Observed mean	Expected mean	χ^2 at 2 df
J 11	P1	8	.857	.107	9.35	8.00	7.91	0.075
EC 76446 (292)	P2	30	.217	.007	142.86	2.30	2.31	0.014
J 11 x EC 76446(292)	F2	37	2.287	.062	16.13	6.13	6.12	0.001
J 11	P1	8	.286	.036	27.78	8.50	8.54	0.044
EC 76446 (292)	P2	29	.066	.002	500.00	2.93	2.93	0
J 11 x EC 76446(292)	F2	37	1.869	.051	19.61	6.73	6.74	0.002
								0.136

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$V\bar{X}$ is the variance of sample mean = variance/n

Table 12. Joint scaling test for rust data on the cross J 11 x PI 259747

Identity	Generation	Total No. of plants (n)	σ^2	$\bar{VX}$	Weight (1/$\bar{VX}$)	Observed mean	Expected mean	X^2 at 2 df
J 11	P1	8	.857	.107	9.35	8.00	8.03	0.008
PI 259747	P2	24	.259	.011	90.91	2.45	2.45	0
J 11 x PI 259747	F2	33	1.633	.049	20.41	6.15	6.16	0.002
J 11	P1	8	.286	.036	27.78	8.50	8.49	0.003
PI 259747	P2	24	.080	.003	333.33	2.91	2.92	0.033
J 11 x PI 259747	F2	33	1.426	.043	23.26	6.63	6.63	0
								0.046

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

VX is the variance of the sample mean = variance/n

Table 13. Joint scaling test for rust data on the cross J 11 x NC Ac 17090

Identity	Generation	Total No. of plants (n)	σ^2	$\bar{V}\bar{X}$	Weight $(1/\bar{V}\bar{X})$	Observed mean	Expected mean	X^2 at 2 df
J 11	P1	8	.857	.107	9.35	8.00	7.89	0.113
NC Ac 17090	P2	59	.193	.003	333.33	2.25	2.28	0.299
J 11 x NC Ac 17090	F2	118	1.519	.013	76.92	5.94	5.84	0.769
J 11	P1	8	.286	.036	27.78	8.50	8.53	0.025
NC Ac 17090	P2	59	.064	.001	1000.00	2.93	2.92	0.100
J 11 x NC Ac 17090	F2	118	1.635	.014	71.43	6.36	6.48	1.028
								2.334

σ^2 is the variance $= \frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{V}\bar{X}$ is the variance of sample mean = variance/n

Table 14. Joint scaling test for rust data on the cross Gangapuri x EC 76446 (292)

Identity	Genera-tion	Total No. of plants (n)	σ^2	$\bar{V}\bar{X}$	Weight (1/$\bar{V}\bar{X}$)	Observed mean	Expected mean	X^2 at 2 df
Gangapuri	P1	13	.269	.021	47.62	7.46	7.36	0.476
EC 76446 (292)	P2	30	.217	.007	142.86	2.30	2.33	0.128
Gangapuri x EC 76446 (292)	F2	34	1.794	.052	19.23	5.05	5.09	0.031
Gangapuri	P1	13	.080	.006	166.67	7.92	7.95	0.150
EC 76447 (292)	P2	29	.066	.002	500.00	2.93	2.92	0.05
Gangapuri x EC 76446 (292)	F2	34	2.504	.074	13.51	5.73	5.69	0.021
								0.856

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{V}\bar{X}$ is the variance of sample mean = variance/n

Table 15. Joint scaling test for the rust data on the cross Gangapuri x PI 259747

Identity	Generation	Total No. of plants (n)	σ^2	$\bar{V}\bar{X}$	Weight (1/$\bar{V}\bar{X}$)	Observed mean	Expected mean	X^2 at 2 df
Gangapuri	P1	13	0.269	.021	47.62	7.46	7.43	0.043
PI 259747	P2	24	0.259	.011	90.91	2.45	2.42	0.082
Gangapuri x PI 259747	F2	36	0.733	.020	50.00	5.69	5.79	0.500
Gangapuri	P1	13	0.080	.006	166.67	7.92	7.93	0.017
PI 259747	P2	24	0.080	.003	333.33	2.91	2.93	0.133
Gangapuri x PI 259747	F2	36	1.457	.040	25.00	6.50	6.30	1.000
								1.775

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{V}\bar{X}$ is the variance of sample mean = variance/n

Table 16. Joint scaling test for rust data on the cross Gangapuri x NC Ac 17090

Identity	Genera-tion	Total No. of plants (n)	σ^2	$\bar{V}\bar{X}$	Weight (1/$\bar{V}\bar{X}$)	Observed mean	Expected mean	X^2 at 2.df
Gangapuri	P1	13	.269	.021	47.62	7.46	7.33	0.805
NC Ac 17090	P2	59	.193	.003	333.33	2.25	2.29	0.533
Gangapuri x NC Ac 17090	F2	144	1.235	.009	111.11	5.80	5.75	0.278
Gangapuri	P1	13	.080	.006	166.67	7.92	7.96	0.267
NC Ac 17090	P2	59	.064	.001	1000.00	2.93	2.92	0.100
Gangapuri x NC Ac 17090	F2	144	1.424	.010	100.00	6.32	6.38	0.360
								2.343

σ^2 is the variance = $\frac{1}{n-1}\left[\varepsilon Xi^2 - \frac{(\varepsilon Xi)^2}{n}\right]$

$\bar{V}\bar{X}$ is the variance of sample mean = variance/n

Table 17. Showing m, (d), (h) and e for all the crosses

Identity	m	(d)	(h)	e	X^2	Degree of dominance (Mather & Jinks, 1971)
M 13 x EC 76446 (292)	5.2291±.035	2.6052±.028 **	1.4744±.268**	-.3003±.034	1.165	.566
M 13 x PI 259747	5.274 ±.038	2.5959±.0316**	2.0506±.226**	-.2445±.0368	0.361	.790
M 13 x NC Ac 17090	5.2044±.028	2.6087±.024**	1.929 ±.146**	-.3335±.0251	3.375	.739
J 11 x EC 76446 (292)	5.419 ±.088	2.8009±.084**	2.0242±.377**	-.3106±.044	0.129	.723
J 11 x PI 259747	5.472 ±.090	2.7868±.086**	1.8453±.351**	-.2322±.053	0.015	.662
J 11 x NC Ac 17090	5.4087±.084	2.8064±.083**	1.5039±.236**	-.3203±.029	2.371	.536
Gangapuri x EC 76446(292)	5.1408±.045	2.5148±.039**	.4981±.363	-.2966±.040	0.841	.198
Gangapuri x PI 259747	5.1767±.049	2.5032±.042**	1.7405±.258**	-.2528±.045	1.729	.695
Gangapuri x NC Ac 17090	5.125±.040	2.5202±.037**	1.8874±.159**	-.3150±.027	2.257	.749

m = mid point between the two parents
(d) = additive genetic component
(h) = dominance genetic component
e = environmental effects

Table 18. Correlations between different yield attributing characters and rust among the parent cultivars

Character	Rust score
Plant height (length of main axis in cms)	-.778**
Number of primary branches	.734**
Number of secondary branches	.751**
Total number of pods	.455**
Number of mature pods	.316**
Number of immature pods	.486**
Pod yield	.315**
Total number of kernels	.199**
Number of mature kernels	.187
Number of immature kernels	.163
Kernel yield	.163

* - Significant at 5% level

** - Significant at 1% level

Table 19 Correlations between different yield attributing characters and rust among the crosses

Character	Rust score
Plant height (length of main axis in cm)	.473**
Number of primary branches	-.239**
Number of secondary branches	-.560**
Total number of pods	-.731**
Number of mature pods	-.756**
Number of immature pods	-.259**
Pod yield	-.809**
Total number of kernels	-.747**
Number of mature kernels	-.789**
Number of immature kernels	-.215**
Kernel yield	-.814**

* - Significant at 5% level

** - Significant at 1% level

DISCUSSION

Groundnut rust, caused by the fungus, Puccinia arachidis Speg. has become a serious problem in all the major groundnut growing countries in the world. In India, groundnut rust was reported for the first time in 1969 on the plants growing in a glasshouse at Punjab Agricultural University, Ludhiana (Chahal & Chohan, 1971). Since then, it has spread to all the groundnut growing states in India causing considerable yield losses. The problem is more serious in the southern states due to continuous cropping and overlapping of groundnut growing seasons (Subrahmanyam et al. 1979). Yield losses due to rust as high as 52% have been observed in the cultivar Robut 33-1 which has been released on a state basis in 1979 kharif at ICRISAT centre (Subrahmanyam et al., unpublished data). From several other countries equally high or higher, yield losses caused by rust have been reported (Burger, 1920; Ciferri, 1926; Müller 1950). Rust, besides causing direct yield loss, also affects kernel quality, reduces the seed size (Arthur, 1929 and South 1912) and the oil content (Castellani, 1959).

Several approaches are available to manage groundnut rust. The cultural approach, consisting of crop rotation and destroying volunteer groundnut plants or crop debris, is of limited value because of the windborne nature of inoculum (Hammons, 1977). The biological approach of utilizing mycoparasites to control rust is yet to be fully investigated as a possible economic control measure. Several effective chemical control measures are available to control rust in groundnuts. However, as a high proportion of the crop is grown under rainfed conditions in developing countries with a low average production (998 kg/ha), the use of chemicals is not a very viable proposition because of lack of finance for the purchase

of sprayers and fungicides. Often chemicals, efficient sprayers and even water for spraying the crop are unavailable to peasant farmers (Personal Communication by Gibbons, 1981). Under these circumstances, the most effective and practical approach would be the development of rust resistant cultivars. Good sources of resistance to rust have been reported by several workers (Hammons 1977, Subrahmanyam et al. 1980). Most of the resistant cultivars are however relatively low yielding or of poor quality. However as these sources are in the cultivated species i.e. Arachis hypogaea L., it may be relatively simple to transfer this resistance to the high yielding but susceptible cultivars. Before starting an effective breeding program however the information on the inheritance of the character is necessary to formulate appropriate breeding strategies. There is very little information available in the literature on the inheritance of resistance to rust in groundnuts. Bromfield and Cevario (1972) indicated bigenic control of rust reaction with resistance being recessive. However, Nigam et al. (1980) confirmed the recessive nature of resistance but suggested that more than two genes may be involved in the control of rust reaction.

The present study was undertaken with a view to obtain more information on the inheritance of resistance to rust. The experimental material in the present study, consisted of three rust resistant cultivars (EC 76446 (292), PI 259747 and NC Ac 17090) and three rust susceptible cultivars (M 13, J 11 and Gangapuri) and their F2 progenies. The material was planted in the field under infector row system in kharif, 1980. The plants were scored individually on the 1-9 scale at two plant stages.

All the resistant cultivars scored between 2.91 to 2.93 on a mean basis. Individual plants in resistant cultivars either had a score of

'2' or '3'. The mean rust score for susceptible parents ranged from 7.92 to 8.50 with individual plants scoring either '7', '8' or '9' (Table 5). In all the F2 crosses, the distribution of plants was skewed towards susceptible parents indicating the recessive nature of rust resistance (Table 7). This confirmed the earlier observation by Bromfield and ~~Covarib~~ Bailey (1972) and Nigam et al. (1980). Among the crosses, Gangapuri x EC 76446 (292) showed promise from a breeding point of view because it had the lowest mean rust score and the highest variance (Table 7). The mean rust score for all other crosses ranged from 6.32 to 6.73. Similarly, the variance ranged from 1.424 to 1.913. Considering the crosses involving the same rust resistant cultivar together, the cultivar EC 76446 (292) resulted in the lowest overall mean rust score (6.32) and the highest variance (2.082). This indicated that EC 76446 (292) may be more resistant than PI 259747 and NC Ac 17090 and could be more profitably utilised in a breeding program.

The F2 data was subjected to X^2-test in two ways for testing the hypothesis of whether 2 or 3 genes governed the expression of the character. In the first case, scores '1', '2' and '3' were considered as resistant, '4', '5', '6' and '7' as intermediate and '8' and '9' as susceptible categories. However, the X^2 fit was not good for either 2 or 3 genes (Table 2). In the second case, scores '1', '2' and '3' were considered as resistant and the rest as susceptible category (Table 3). In the case of crosses involving EC 76446 (292), the fit was good for a 2 gene hypothesis. In crosses involving PI 259747 and NC Ac 17090 as resistant parents, the fit was good for 3 gene hypothesis. When considered on an overall basis, the fit was good for a three gene hypothesis. As in this case all the plants having score between '4' and '9' have been grouped together, the

goodness of fit gives an indication of number of genes involved in governing the expression of the character. Individual scores in 1-9 scale have definite meaning and grouping the plants having a score between '4' and '9' together is not appropriate. It appears that there has been a lot of overlapping while scoring the plants in the field. Nonetheless, the data gives an indication of the number of genes involved as three. For crosses of category 'A', involving EC 76446 (292) as a rust resistant parent, two genes appear to be involved in the resistance which is similar to the observations made by Bromfield and Bailey (1972). Even with three genes involved in the expression of the character, it should be possible to isolate stable rust resistant lines in early generations. The observation of Nigam et al. (1980) has been contrary to this, as the selected resistant plants segregated in the next generation. In FESR group of material, which originated from a cross between PI 298115 and an unknown pollen donor, the resistant plants kept on segregating in advanced generations (Nigam et al. unpublished). It appears that the inheritance of resistance to rust may be more complex, at least in the FESR material which involves another rust resistant genotype, PI 298115. However, this can only be confirmed by advancing the F2 plants to further generations.

To study the nature of the reaction involved in the expression of rust resistance, the data on parental and the F2 generations were subjected to generation mean analysis as suggested by Mather and Jinks (1971). The fitting of genetic models to this data indicated that an additive-dominance model was an adequate representation for the data (Tables 8-17). The X^2 tests that examined the goodness of fit of the model were not significant, which indicated that these combinations of genetic parameters were adequate representation of the data. Both additive and dominance effects were

important in the expression of the character with the exception of the cross Gangapuri x EC 76446 (292) where only additive gene effects were significant. However, additive gene effects were more pronounced as compared to dominance gene effects. In all the crosses, the environmental component was negative, which indicated that the resistance decreased with the increase in the plant age. This is also indicated by the frequency distribution data of the parents and crosses (Tables 4-7). With a view to understanding the nature of the relationship between rust score and other yield attributing characters, correlation coefficients were calculated. The correlation coefficients between rust score and number of primary branches, number of secondary branches, total number of pods, number of mature and immature pods, pod yield and total number of kernels were positive and highly significant with the exception of plant height which was negative for the parents (Table 18). There was no significant correlation between rust score and number of mature and immature kernels and kernel yield. All the resistant plants involved in the study are old land races with low yield potential, belonging to the Valencia group (Arachis hypogaea sub sp. fastigiata). The susceptible parents involved are the high yielding varieties belonging to Spanish Arachis hypogaea sub sp. fastigiata (J 11), Valencia - Arachis hypogaea sub sp. fastigiata (Gangapuri) and Virginia runner - Arachis hypogaea sub sp. hypogaea (M 13).

All these botanical types have been described as follows (Gibbons, 1972):

Virginia: Bunch and runner forms occur, branching alternate; inflorescence simple and never borne on main axis directly; pods 1-2 seeded, beaks present, but small, pods moderately or slightly constricted, pod large 15-20 mm

diameter, testa colour brown but red, white and purple forms occur.

Valencia: Habit erect, branching sequential, inflorescence always present on the main axis, typically only 4 branches on the main stem, pods 2-3-4 seeded, beaks absent, not or very little constricted, size medium or small, testa colour commonly red but brown, white and purple forms are recorded, pod medium and diameter 10-15 mm.

Spanish: Habit erect, branching sequential, inflorescences always present on main axis, strictly two seeded and pods constricted.

Cultivar clusters: (a) Large Spanish - pods medium 10-15 mm diameter

(b) Spanish - pods small 10 mm diameter

In case of F2 crosses, the nature of association between these characters was completely reversed (Table 19). The remaining three characters, number of mature kernels, number of immature kernels and kernel yield also was negative and highly significantly associated with the rust score. The possible explanation for the reverse trend in the association could be given on the basis of the large population and increased variability for plant characters and growth habit observed in the F2 population. Since resistant phenotypes are very few in the F2 generation, it is unlikely that disease resistant plants which have a high yield potential can be selected unless a very large F2 population is grown. Since it is the objective of any breeding programme to incorporat disease resistance into an agronomically acceptable variety, the selection of resistant plants in the F2 generation as part of a pedigree selection method may not be an efficient procedure because of very few resistant F2 plants observed in the study. It would be advantageous in early generations

to retain high yielding disease susceptible plants in the bulk from which resistant phenotypes may be selected in later generations (Nigam et al. 1980)

Another useful approach as indicated by Nevill, 1980, could be the selection of resistant segregants in the early generation and intermating their progenies. From them high yielding populations with resistance could be selected and recurrent selection methods could be employed so that resistant lines with improved agronomic performance could be crossed again and further selected. This may improve the chances of producing high yielding rust resistant cultivars.

SUMMARY AND CONCLUSIONS

In order to determine the inheritance of resistance to rust, an experiment involving three rust susceptible and three rust resistant cultivars (PI 13, J 11 and Gangapuri) and three rust resistant cultivars (EC 76446 (292), PI 259747 and NC Ac 17090) including their F2 progenies consisting of single crosses between them, was conducted at ICRISAT, Hyderabad, India in kharif, 1980. The rust scoring was done on all the plants free from bud necrosis disease at two plant ages on the 1-9 point scale followed at ICRISAT, India. When the data weregrouped under three categories, resistant, intermediate and susceptible, no conclusions could be drawn. However, on grouping the data into two categories, resistant and susceptible and subjecting it to X^2 test for determining the number of genes involved in the expression of the character, the data proved adequate for digenic (15:1) fit in the crosses involving EC 76446 (292) as resistant parent and trigenic fit in the crosses involving PI 259747 and NC Ac 17090 as resistant parents respectively. On an overall basis also, trigenic fit was observed for the crosses.

When the generation mean analysis was conducted on the F2 generation, it was found that the data was fitting into additive-dominance model. However, additive or fixable effects were more pronounced as compared to the dominance effects indicating that the fixable nature of rust resistance. The degree of dominance for different crosses was also indicated.

Besides, an attempt was made to correlate yield and yield attributing characters with rust score for both parents and crosses. It was observed that the correlation trends between parents and crosses were completely

reversed. Since very few resistant F2 plants were available in the study, it was indicated that selection of resistant plants in F2 generation may not be an efficient procedure. Another useful approach of intermating the resistant segregants and selection of high yielding resistant plants from them was discussed as a possible means of producing high yielding rust resistant cultivars.

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