Groundnut Rust Disease: Epidemiology and Control

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Abstract

Research on rust disease of groundnut at ICRISAT Center from 1976 to 1984 is briefly reviewed. Spread of the disease in India is documented, and the role of continuous cultivation of groundnut in perpetuating the disease emphasized. Data on yield losses from rust are presented. Methods of screening germplasm and breeding lines for resistance to rust are described, and the identified sources of resistance are listed. Components of resistance to rust and their possible use in greenhouse evaluation of rust resistance are discussed. The results of multilocation testing of rust-resistant germplasm lines are considered. The effects of different agronomic systems on epiphytotics of rust are discussed.

Résumé

Rouille de l'arachide—épidémiologie et lutte : *Les auteurs passent en revue les recherches menées sur la rouille de l'arachide au Centre ICRISAT entre 1976 et 1984. L'étude de la progression de la maladie en Inde souligne le rôle de l'exploitation continue de cette culture dans la propagation de la maladie. Les données sur les pertes de rendement dues à la rouille sont présentées. La description des méthodes de criblage des ressources génétiques et des lignées de sélection pour la résistance est suivie d'une liste de sources de résistance repérées. Les caractères intervenant dans la résistance sont examinés ainsi que leur utilisation éventuelle dans les évaluations en serre de la résistance à la rouille. Les résultats des essais multilocaux du matériel génétique résistant sont présentés. Enfin, les effets des différents systèmes agronomiques sur l'épiphytie de la rouille sont étudiés.*

The rust disease of groundnut (*Arachis hypogaea* L.) caused by *Puccinia arachidis* Spegazzini has increased in importance in recent years. Prior to 1969, the disease was largely confined to South and Central America, with occasional outbreaks occurring in the southernmost groundnut producing areas of the USA. The disease was also recorded in the USSR (Jaczewski 1910), Mauritius (Stockdale 1914), and the People's Republic of China (Tai 1937), but did not become permanently established in these countries (Bromfield 1971). In recent years groundnut rust has spread to, and became established in, many countries in Asia, Australasia, Oceania, and Africa (Hammons 1977, Subrahmanyam et al. 1979, and Subrahmanyam and McDonald 1983) (Fig.1). Rust is now of economic importance in almost all groundnut-growing areas of the world. Yield losses from rust are substantial, damage being particularly severe if the crop is also attacked by the two leaf-spot fungi (*Cercospora arachidicola* Hori and *Phaeoisariopsis personata* (Berk. & Curt.) v. Arx).

Rust epidemics are regular and severe on susceptible groundnut genotypes at ICRISAT Center. This paper briefly reviews research on the disease carried out in the Groundnut Pathology Subprogram from 1976 to the present time.

Biology of Groundnut Rust

The life cycle and taxonomy of *P. arachidis* are described in detail by Hennen et al. (these Proceedings). Investigations were carried out on the biology

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Groundnut rust disease: Proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 405)

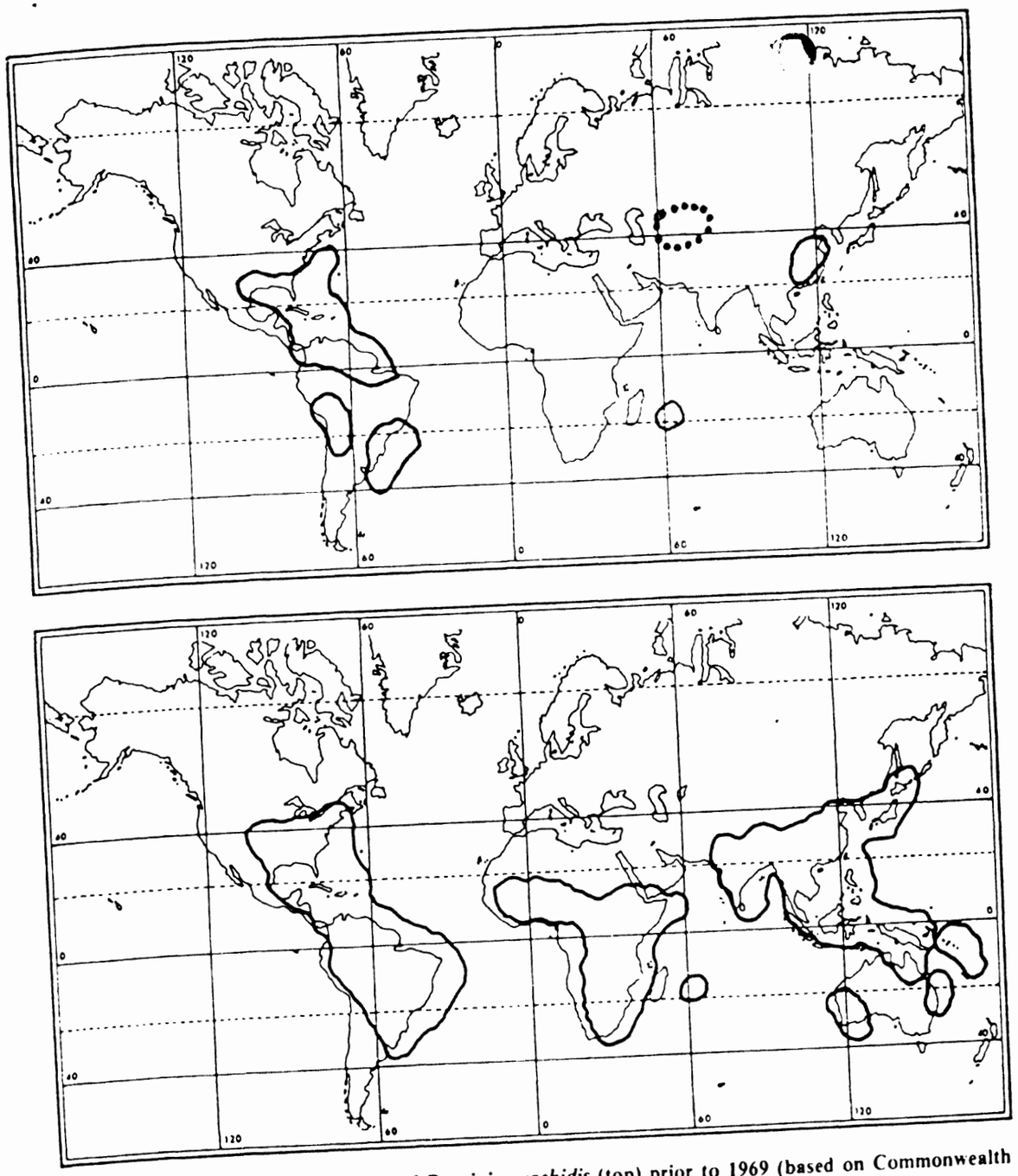

Figure 1. Geographical distribution of *Puccinia arachidis* (top) prior to 1969 (based on Commonwealth Mycological Institute map 16, issued 30 June 1966) and (bottom) in 1983 (based on Commonwealth Mycological Institute map 160, issued 1 Apr 1980).

of *P. arachidis* to determine what factors influenced its perpetuation and spread. Biological data were also needed for the development of resistance-screening methods.

Laboratory experiments showed that urediniospores could be stored for long periods at low temperatures without loss of viability, but that at high temperatures they lost viability within 5 days (Table 1). Temperatures in the range of 20-25° C were optimum for urediniospore germination (Fig.2). Light

Table 1. Effects of storage temperature on viability of urediniospores (from Subrahmanyam and McDonald 1982).

Storage temp. (0°C)	Percentage[1] of urediniospores viable after storage (days)										
	5	13	28	40	48	60	70	78	99	110	120
-16	88	82	89	90	98	88	92	93	92	94	93
6	84	85	82	35	15	4	0	0	-	-	-
25	81	88	80	24	0	0	0	0	0	-	-
40	0	0	0	0	0	0	0	0	0	-	-

1. 1000 spores per sample. Figures to nearest whole number.

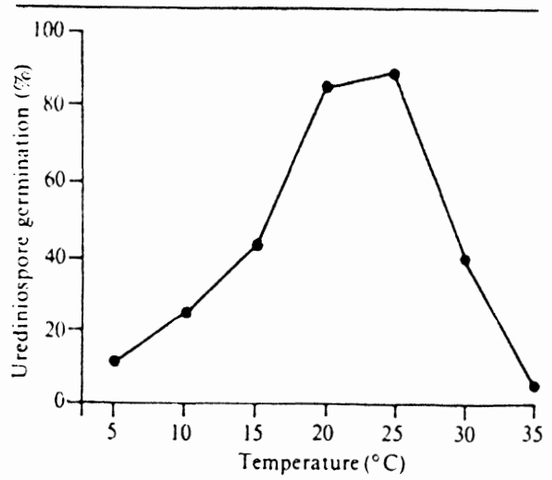

Figure 2. Effect of temperature on urediniospore germination.

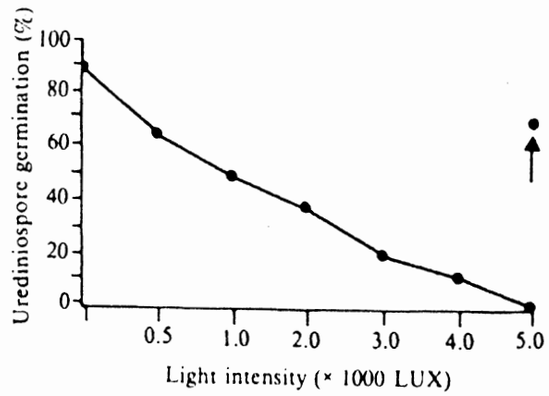

Figure 3. Effect of light intensity on urediniospore germination. Arrow indicates germination percentage of the same spores in dark.

(5000 lux and above) was found to inhibit urediniospore germination (Fig.3). Urediniospores on exposed infected crop debris lost viability within 4 weeks under postharvest conditions at ICRISAT Center (Table 2). Pods and seeds from rust-affected crops are commonly surface-contaminated with urediniospores at harvest. Tests on urediniospores taken from surface-contaminated seeds stored at room temperature showed viability to decrease from an initial 95% to zero after 45 days. Inoculation of two-day-old seedlings of a rust-susceptible cultivar grown in petridishes showed that urediniospores

Table 2. Viability of urediniospores after various periods of exposure to weather on infected crop debris (from Subrahmanyam and McDonald 1982).

Period of exposure (days)	Percentage[1] of urediniospores viable			
	Rainy-season crops		Postrainy-season crops	
	1976	1977	1976-77	1977-78
0	65	90	82	89
6	36	74	9	0
14	1	42	1	1
20	0	26	0	0
22	0	10	0	0
26	0	0	0	0
Period of test	13 Dec 1976 to 7 Jan 1977	7 Nov 1977 to 2 Dec 1977	4 May 1977 to 30 May 1977	2 May 1978 to 28 May 1978
RH% 0714 h	80.7	83.5	60.7	60.7
1414 h	26.0	46.6	26.9	23.9
Temp. (°C) Max.	28.3	28.0	37.6	39.7
Min.	13.4	19.5	24.9	25.6

1. 1000 spores per sample. Figures to nearest whole number.

ould germinate on the surfaces of hypocotyls and otyledons but no infection developed. Plants grown n sterilized soil from seeds heavily contaminated with urediniospores, did not become infected with ust disease (Subrahmanyam and McDonald 1982).

There is no record of the occurrence of any collateral hosts of groundnut rust outside the genus *Arachis*. The possible occurrence of other hosts was considered, and various crop and weed plants growing in or near rust-affected groundnut crops on the ICRISAT farm and in farmers' fields were examined for rust. Some were also inoculated with urediniospores in the glasshouse. No infection was recorded on any of the plant species examined (Subrahmanyam and McDonald 1982).

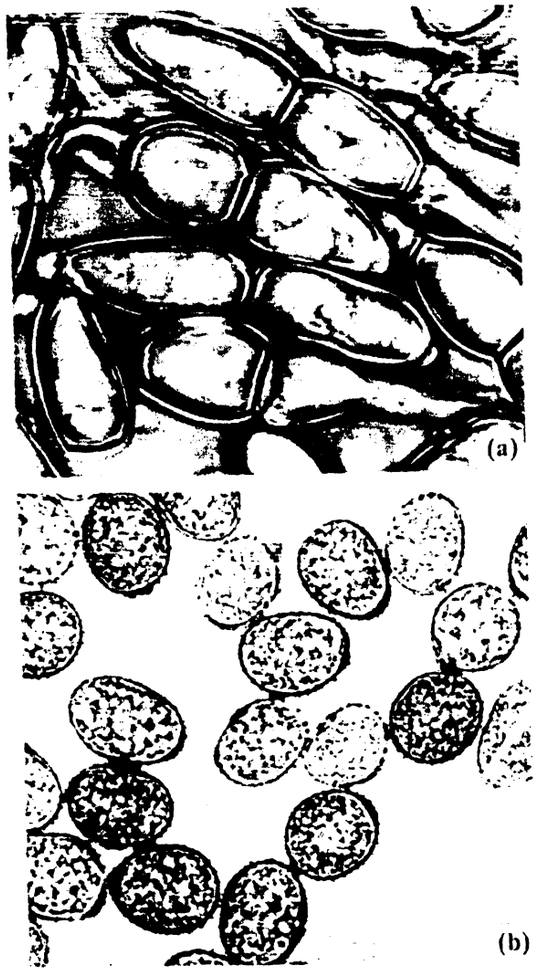

Figure 4. (a) Teliospores (× 800) and (b) Urediniospores (× 800) of *Puccinia arachidis*.

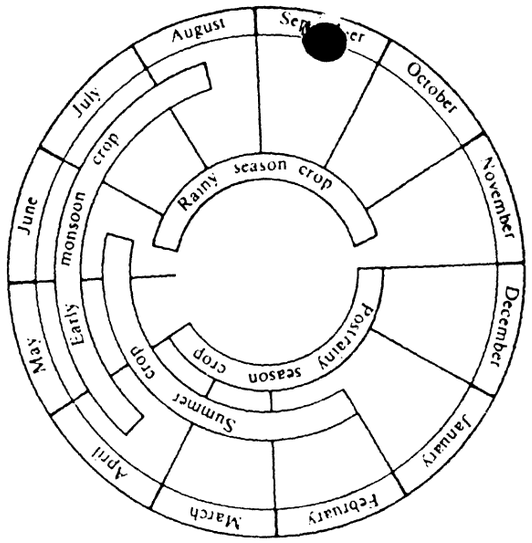

Figure 5. Groundnut cropping seasons in India. Overlapping of these seasons helps to perpetuate rust disease attack.

P. arachidis is known almost exclusively by its uredinial stage. There are a few records of the occurrence of the telial stage on cultivated groundnut (Fig.4(a) and on wild *Arachis* species (Hennen et al.—these Proceedings). Only the uredinial stage (Fig.4(b)) of the rust has been found despite constant examination of many groundnut germplasm lines and wild *Arachis* species at ICRISAT and of rust-infected groundnut plants from various parts of India. Attempts to induce telial formation by modification of environmental factors failed. It was concluded that urediniospores were the main, if not the only, means of rust carry-over and dissemination in India. The practice of continuous cultivation of groundnut in southern India (Fig.5) appears to be an important factor in the perpetuation of groundnut rust in the country (Subrahmanyam and McDonald 1982, 1983).

Survey of groundnut rust in India

From 1971 to 1981 surveys were made in all major groundnut-growing states in India to obtain information on rust and other diseases of groundnut, and to assess their relative importance in different regions. Rust and late leaf spot were the most common and severe diseases in all major groundnut-growing areas of India. Rust was particularly serious in Tamil Nadu, Andhra Pradesh, Karnataka, and Maharashtra States, probably because of extensive and continuous cropping (Subrahmanyam et al. 1979). During the disease survey in Gujarat State in the 1977 rainy season, rust was not observed in the main groundnut-growing tract (Sourashtra region), but a survey in the 1978 rainy season showed rust to be present and causing serious damage to groundnut crops throughout the state. Rust is now a well established and destructive disease of groundnut in all major groundnut-growing states in India.

Assessment of yield losses

Rust and leaf-spot diseases normally occur together and it is difficult to allocate individual responsibility for the resulting losses in crop yield. During the 1979, 1980, and 1981 rainy seasons, yield losses were stimated by applying selective fungicides on a wide ange of susceptible and resistant genotypes; chlorohalonil to control both rust and leaf spots, carbenlazim to control only leaf spots, and tridemorph to ontrol only rust. Loss estimates are presented in Table 3. In general, yield losses were less in the esistant than in the susceptible genotypes (Subrahnanyam et al. 1984).

Resistance to groundnut rust

Screening of germplasm

Screening of the world collection of groundnut germplasm for resistance to rust was started at ICRISAT Center in the 1977 rainy season, and a total of 8000 genotypes were screened in the period 1977-83.

Preliminary screening was done on germplasm multiplication material in the rainy seasons. Genotypes were grown in unreplicated, single-row plots. Rows of the cultivars TMV 2, and Robut 33-1, known to be highly susceptible to groundnut rust, were arranged throughout the germplasm fields with 1 to every 10 test genotypes. One week before harvest each genotype was scored for the development of rust using a 9-point scale in which 1 = no disease, and 9 = 50-100% foliage destroyed. Genotypes with scores of 5 or less were selected for advanced screening.

Advanced screening was done in both rainy and postrainy seasons. Genotypes were grown in replicated plots. Test plots were separated by single infector rows of a mixture of the cultivars TMV 2 and Robut 33-1 sown 14 days before the test material. Cultivars TMV 2 and Robut 33-1 were also sown on test plots to monitor disease spread from infector rows. Due to the dry atmosphere, rust development is not usually high during the postrainy season at ICRISAT Center. Therefore, a field-inoculation technique was developed. Infector rows sown as described above were inoculated with a urediniospore suspension at the time of peak flowering. The suspension (50 000–10 0000 spores ml^{-1}) was made up in tap water to which a small amount of the wetting agent Tween 80 had been added. Inoculation was done in the evening following furrow irrigation. Potted "spreader plants" heavily infested with rust were placed systematically throughout the field to serve as additional sources of inoculum (Fig.6). Following inoculation, the fields were irrigated using overhead sprinklers, on alternate days initially, and then as required by climatic conditions until harvest.

The genotypes were scored for rust development just before harvest using the 9-point scale. Genotypes found resistant to rust at ICRISAT Center are listed in Table 4, together with their mean rust scores on the 9-point scale. Some of these genotypes are also resistant to late leaf spot disease (Subrahmanyam et al. 1980 a, 1980 b, 1982, and 1983 a). It is interesting that most of the rust-resistant genotypes listed in Table 4 originated in Peru, which is believed to be one of the secondary "gene centers" of cultivated groundnut (Gregory et al. 1980, Ramanatha Rao—these Proceedings).

Pod and haulm yields, and shelling percentages of all resistant genotypes were estimated in almost all the seasons; results of the 1982/83 postrainy and 1983 rainy-season trials are presented in Table 5

Table 3. Yield losses from rust and leaf spots, ICRISAT Center, rainy seasons, 1979, 1980, and 1981.

Genotype	Percentage pod-yield loss[1]		
	Rust	Leaf spots	Rust and leaf spots
Robut 33-1[2]	57	55	68
TMV 2[2]	40	37	58
PI 259747[3]	31	27	29
EC 76446(292)[3]	12	10	17
NC Ac 17090[3]	6	13	26

1. Mean of 1979, 1980, and 1981 rainy-season field trials.
2. Standard susceptible cultivars.
3. Resistant genotypes.

Figure 6. Inoculation of infector rows with urediniospores. Note the potted "Spreader plants" placed in infector rows to serve as additional sources of inoculum.

Table 4. Genotypes resistant to rust at ICRISAT Center.

Genotype	ICG No.[1]	Seed color[2]	Country of origin	Rust score[3]
TMV 2[4]	221	Tan	India	9.0
Robut 33-1[4]	791	Tan	India	9.0
NC Ac 17090	1697	Light tan	Peru	2.2
PI 393646	7896	Purple	Peru	2.5
PI 405132[5]	7897	Purple	Venezuela	2.5
PI 414332	7900	Tan	Honduras	2.5
PI 341879[5]	7884	Purple	Peru	2.6
U4-47-7(LB)	-	Purple	-	2.6
PI 390593	7886	Light tan	Peru	2.7
U4-47-7 (MB)	-	Purple	-	2.8
EC 76446(292)[5]	2716	Purple	Uganda	2.9
PI 407454	7898	Tan	Ecuador	2.9
PI 414331	7899	Tan	Honduras	2.9
PI 259747[5]	4747	Purple	Peru	3.0
PI 350680[5]	6340	Purple	Peru	3.0
PI 314817	7882	Light tan	Peru	3.0
PI 315608	7883	Off-white	Israel/ USA	3.0
PI 381622[5]	7885	Purple	Honduras	3.0
PI 393527-B	7892	Red	Peru	3.0
PI 393643	7895	Light tan	Peru	3.0

Continued.

Table 4. *Continued.*

Genotype	ICG No.[1]	Seed color[2]	Country of origin	Rust score[3]
PI 393517	7889	Off-white	Peru	3.1
TMV 63[5]	3527	Purple	USA	3.2
NC Ac 17133-RF[5]	7013	Purple	Peru	3.3
PI 215696[5]	7881	Purple	Peru	3.4
PI 393531	7893	Tan with purple stripes	Peru	3.4
NC Ac 927[5]	6022	Purple	Sudan	3.5
PI 390595[5]	7887	Purple	Peru	3.5
PI 270806[5]	6330	Purple	Zimbabwe	3.7
NC Ac 17132	1707	Purple	Peru	3.9
PI 393641[5]	7894	Light tan with purple stripes	Peru	4.0
NC Ac 17135	1710	Purple	Peru	4.1
PI 393526	7890	Purple	Peru	4.1
NC Ac 17127	1703	Light tan with purple stripes	Peru	4.2
NC Ac 17129	1704	Light tan	Peru	4.2
NC Ac 17130	1705	Tan	Peru	4.2
NC Ac 17124	6280	Tan	Peru	4.2
PI 298115	4746	Off-white	Israel	4.2
PI 393516[5]	7888	White with red blotches	Peru	4.3
Crap.St.16[5]	4790	Purple	Argentina	5.0

1. ICRISAT Groundnut Accession Number.
2. RHS colour chart. The Royal Horticultural Society, London, 1966.
3. Rust scores on a 9-point scale; mean scores of 1977-1983 field trials.
4. Standard susceptible cultivars.
5. Also resistant to late leaf spot (*Phaeoisariopsis personata*) at ICRISAT.

Table 5. Pod and haulm yields and shelling percentages of some groundnut genotypes resistant or susceptible to rust and late leaf spot diseases at ICRISAT Center.

Genotype	1982/83 postrainy season[1]			1983 rainy season[2]		
	Yield (kg ha^{-1})		Shelling (%)	Yield (kg ha^{-1})		Shelling (%)
	Pods	Haulms		Pods	Haulms	
TMV 2[3]	4267	5989	71.7	849	914	66.7
J 11[3]	4177	5657	71.5	1098	914	71.3
Robut 33-1[3]	2989	9978	66.2	1012	1062	70.7
JL 24[3]	-	-	-	1117	1012	69.3
M 13[3]	2519	7164	57.8	-	-	-
PI 314817	5610	7104	66.8	1528	1778	69.7
PI 393643	4826	6923	64.0	1547	2049	66.0
PI 393517	4610	7180	61.1	910	1531	65.7
PI 407454	4459	9050	57.8	1547	2074	68.0
PI 393531	4445	6532	58.2	1453	1432	66.7
PI 393527-B	4436	6317	51.3	1242	2074	65.7
PI 390593	4400	7398	56.9	1404	2296	64.3

Continued.

Table 5. *Continued.*

Genotype	1982/83 postrainy season[1]			1981 rainy season[2]		
	Yield (kg ha^{-1})		Shelling (%)	Yield (kg ha^{-1})		Shelling (%)
	Pods	Haulms		Pods	Haulms	
NC Ac 17142	4299	7475	64.5	1252	1901	68.3
PI 393646	4225	8614	51.3	1722	1803	62.3
PI 259747	4211	8497	57.2	1333	2543	65.3
NC Ac 17506	4184	8632	56.7	1519	1753	62.3
USA 63	4169	7961	60.4	1610	2099	66.7
PI 405132	4087	7880	57.8	1607	2370	67.7
EC 76446(292)	4037	8510	58.2	1573	2642	69.0
NC Ac 17090	4028	8376	59.6	1668	2000	64.7
NC Ac 17132	3995	7280	55.1	1357	1704	61.0
PI 350680	3953	7913	56.6	1420	2939	66.0
PI 341879	3905	8707	59.6	1437	2469	66.0
C.No.45-23	3815	9097	57.1	1116	1358	64.3
NC Ac 17133-RF	3797	8371	55.2	1573	2543	62.7
PI 393526	3777	7916	57.6	607	2296	62.0
PI 393516	3771	8497	56.9	320	2296	53.7
Krap.st.16	3767	9483	55.1	1626	2370	63.7
NC Ac 927	3761	9933	55.5	1778	2469	63.6
RMP 12	3721	8456	61.9	1157	3531	69.7
PI 390595	3712	8329	52.0	1072	1753	62.7
PI 381622	3706	8027	56.0	1746	2840	68.7
RMP 91	3642	7667	61.3	1064	3728	65.7
PI 215696	3542	8825	55.9	1079	2444	65.3
NC Ac 15989	3477	8010	59.7	1382	3210	64.3
PI 414331	3068	10264	57.2	1168	1951	70.4
PI 393641	3054	7084	46.7	1486	1506	63.7
NC Ac 17129	2995	8196	44.3	1364	1333	65.0
NC Ac 17127	2949	7317	43.5	1196	914	64.7
PI 414332	2520	11209	60.0	880	2124	70.3
PI 298115	1982	9120	52.9	1036	1877	65.0
PI 315608	-	-	-	782	1605	66.3
NC Ac 17502	-	-	-	1198	4124	64.7
NC Ac 17135	-	-	-	1888	1975	65.7
PI 270806	-	-	-	1740	2420	64.3
SE	±277.51[4]	±557.20[4]	±1.51[4]	±130.20	±233.12	±1.24
	±279.38[5]		±563.96[5]	±1.54[5]		
CV (%)	9.11[6]	8.50[7]	3.19[8]	17.49	1948	3.26

1. Low disease pressure.
2. High disease pressure.
3. Standard high-yielding check cultivars.
4. Standard error of means for entries appearing in the same block.
5. Standard error of means for entries not appearing in the same block.
6. Efficiency of lattice over RBD is 100.85%.
7. Efficiency of lattice over RBD is 103.53%.
8. Efficiency of lattice over RBD is 112.29%.

Table 6. The FESR (Federal Experiment Research Station Puerto Rico) breeding lines resistant to rust and late leaf spot at ICRISAT Center.

Genotype	Disease scores[1]	
	Rust	Late leaf spot
TMV 2[2]	9.0	9.0
FESR 5-P2-B$_1$	2.0	3.0
FESR 5-P17-B$_1$	2.0	3.0
FESR 7-P13-B$_1$	2.0	3.0
FESR 9-P3-B$_1$	2.0	3.0
FESR 9-P4-B$_1$	2.0	4.3
FESR 9-P7-B$_1$	2.7	3.3
FESR 9-P7-B$_2$	2.7	4.3
FESR 9-P8-B$_2$	2.0	3.0
FESR 9-P12-B$_1$	2.0	2.7
FESR 11-P11-B$_2$	2.3	2.7
FESR 12-P4-B$_1$	2.0	2.0
FESR 12-P5-B$_1$	2.0	2.7
FESR 12-P6-B$_1$	2.7	3.7
FESR 12-P14-B$_1$	2.0	3.3
FESR 13-P12-B$_1$	2.0	2.7

1. On a 9-point scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.
2. Standard susceptible cultivar.

together with yields of four disease-susceptible Indian cultivars for comparison. Several of the resistant genotypes outyielded the established Indian cultivars. In addition to the sources of rust resistance listed in Table 4, several other sources of resistance to both rust and late leaf spot diseases have been found in breeding lines from the Federal Experiment Research Station (FESR), Puerto Rico (Table 6). These lines originated from a natural hybrid selected for resistance to rust in Puerto Rico by USDA scientists. Although these lines have low yield potential and poor agronomic characteristics, they are very good sources of resistance to both rust and late leaf spot, and are being used in the breeding program at ICRISAT Center (Nigam et al. 1980).

Screening of breeding populations

Several of the sources of rust resistance listed in Tables 4 and 6 have been extensively used in the breeding program at ICRISAT Center, and crossed with high-yielding but susceptible cultivars (Nigam et al. 1980, Reddy et al. 1984). The F_1 hybrid plants were normally grown in the greenhouse. Subsequent generations were grown in the field and screened for rust resistance using the "infector-row" method. The populations were classified as resistant (2 and 3 on the 9-point scale), moderately resistant (4,5, and 6 on the 9-point scale), and susceptible (7,8 and 9 on the 9-point scale). Selected lines were advanced by pedigree and bulk pedigree methods on the basis of yield and disease reaction (Subrahmanyam et al. 1985, Reddy et al.—these Proceedings).

Screening of wild *Arachis* species

Sixty-one accessions of wild species, representing five sections of the genus *Arachis*, were evaluated for reaction to rust during the 1980 and 1981 rainy seasons at ICRISAT Center. They were further tested in the laboratory by inoculation of rooted detached leaves (Fig.7). Most of the species were immune, 6 were highly resistant, and 2 were susceptible (Subrahmanyam et al. 1983 d). The reactions of selected wild *Arachis* species to rust disease are presented in Table 7.

Several diploid wild *Arachis* species resistant to rust and/or late leaf spot were crossed with high-yielding but susceptible groundnut cultivars, and the resulting sterile or fertile tetraploids were treated with colchicine to produce fertile hexaploids. Following field evaluation of hexaploids for disease resistance, promising selections were backcrossed with the cultivated groundnut cultivars to produce

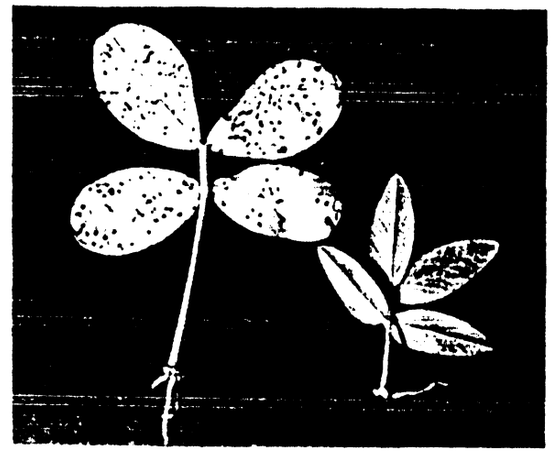

Figure 7. Susceptible groundnut cultivar TMV 2 (left) compared with (right) wild *Arachis* sp with immunity to groundnut rust.

Table 7. Reaction of some wild *Arachis* species to *Puccinia arachidis* (from Subrahmanyam et al. 1983 d).

Section, series and species	USDA plant inventory (PI) number	ICRISAT groundnut accession number (ICG)	Rust reaction
Section: *Arachis*			
Series: *Annuae*			
A. batizocoi	298639	8124	Immune
A. duranensis	219823	8123	Immune
A. spegazzinii	262133	8138	Immune
Series: *Perennes*			
A. correntina	331194	4984	Immune
A. stenosperma	338280	8126	Highly resistant
A. cardenasii	262141	8216	Immune
A. chacoense	276235	4983	Immune
A. villosa	210554	8144	Immune
Section: *Erectoides*			
Series: *Tetrafoliate*			
A. appressipila[1]		8129	Immune
A. paraguariensis[1]		8130	Immune
Section: *Triseminale*			
A. pusilla	338449	8131	Immune
Section: *Extranervosae*			
A. villosulicarpa[1]		8142	Immune
Section: *Rhizomatosae*			
Series: *Eurhizomatosae*			
A. hagenbeckii	338305	8922	Immune
A. glabrata	338261	8149	Immune

1. No PI number allocated because the source was not the USDA.

breeders' lines with 40 chromosomes. These tetraploid, or near-tetraploid, lines were evaluated in field-screening trials for rust and late-leaf spot resistance, using the "infector-row" method, and several lines with rust resistance and high yield were selected (Singh et al.—these Proceedings).

Components of rust resistance

In studies of components of resistance to groundnut rust, it was found that neither the size nor the frequency of stomata were correlated with resistance. Urediniospores germinated on leaf surfaces and the fungus entered through stomata irrespective of whether a genotype was immune, resistant or susceptible to rust. However, in immune genotypes the fungus died shortly after entering the substomatal cavity (Subrahmanyam et al. 1980 b). Differences in resistance were associated with differences in rate and extent of mycelial development within the cavity and within leaf tissues. The rust resistance at present available in the cultivated groundnut is of the "slow rusting" type i.e., resistant genotypes have increased incubation period, decreased infection frequency, and reduced pustule size, spore production (Fig.8), and spore germinability (Table 8) (Subrahmanyam et al. 1983 b, 1983 c).

The possible use of the resistance components in greenhouse screening of germplasm has been studied. All the components were significantly correlated with mean field rust scores. Resistant and susceptible genotypes were readily separated on the basis of resistance components measured in the greenhouse, but classification of moderately resistant genotypes in this way was less effective than by use of field scores (Subrahmanyam et al. 1983b).

The extent of rust damage to foliage is dependent on the physiological age of the plant. Young plants are most susceptible to rust attack and the susceptibility declines with age (Table 9) (Subrahmanyam et al. 1980a).

Stability of rust resistance

The International Groundnut Foliar Diseases Nursery (IGFDN), a cooperative international program, was initiated in 1980. Through the assistance of cooperators in locations throughout the SAT, the

Figure 8. Scanning electron micrographs (× 400) of pustules of *Puccinia arachidis* on (a) the susceptible cultivar TMV 2 and (b) on the resistant genotype NC Ac 17090.

Table 8. Components of resistance to rust in groundnut genotypes (after Subrahmanyam et al. 1983b, 1983c).

Genotype	Rust field score[1]	Incubation period (days)	Infection frequency (lesions cm^{-2})	Pustule diameter (mm)	Pustules ruptured (%)	Spores mm^{-2} pustule area	Urediniospore germination (%)
TMV 2 (Check)	9.0	9.3	13.5	1.12	100.0	855	75.1
NC Ac 17090	2.2	19.3	5.9	0.68	0.5	121	37.2
EC 76446(292)	2.8	17.5	6.2	0.59	13.5	61	48.1
PI 405132	2.4	18.3	8.1	0.63	5.6	127	48.1
PI 407454	2.8	18.5	4.7	0.58	4.7	139	42.6
PI 393643	3.0	14.7	5.5	0.73	9.2	121	43.3

1. Mean rust scores recorded at the ICRISAT Center over the years 1979-82, using a 9-point disease scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.

Table 9. Rust reactions of four groundnut genotypes 30 days after inoculation at three physiological stages of development in the greenhouse (after Subrahmanyam et al. 1980).

	Percent leaf area damaged by rust		
	Plant stage at inoculation		
Genotype	Seedling	Peak flowering	Nearing maturity
TMV 2[1]	100.0	85.5	41.1
NC Ac 17090[2]	4.0	6.5	2.8
NC Ac 17129[2]	26.7	38.1	5.9
PI 259747[2]	50.1	30.8	2.9

1. Cultivar susceptible to rust.
2. Cultivar resistant to rust.

IGFDN aims to check under a range of environments the stability of resistance to rust and late leaf-spot diseases of genotypes identified as resistant to these diseases at ICRISAT Center. A collection of 43 resistant and susceptible genotypes identified and/or assembled at ICRISAT was included in the nursery. At present, the nurseries have been located in 8 countries in Asia, 11 in Africa, and 3 in the Americas. In India, nurseries were established at 14 locations through cooperation with the All India Coordinated Research Project on Oilseeds (AICORPO).

The results obtained so far have not been consistent and it is not yet possible to conclude if the rust resistance identified at ICRISAT is stable or not. In many locations the entries were only evaluated under low disease pressure. However, useful data have been obtained from a few locations. It is interesting that the entry NC Ac 17090, which is highly resistant to rust at ICRISAT Center, was found to be only moderately resistant in the People's Republic of China and susceptible in Taiwan. In contrast, the entry PI 298115, which is only moderately resistant to rust at ICRISAT Center, was highly resistant in the People's Republic of China and in Taiwan. Rust isolates from many parts of the world are being tested for pathogenicity to a range of groundnut genotypes by workers in the United Kingdom.

Biological control of groundnut rust

The fungi, *Verticillium lecani* (Zimmerm.) Viegas (Fig.9) *Penicillium islandicum* Sopp., *Eudarluca caricis* (Fr.) O. Ericks, and *Acremonium persicinum* (Nicot). W. Gams have been found growing on *P. arachidis* and their pathogencity has been confirmed in laboratory inoculation tests. Preliminary investigations on the biological control of rust with *V. lecani* in the laboratory using detached leaves showed considerable reduction in rust development (Table 10).

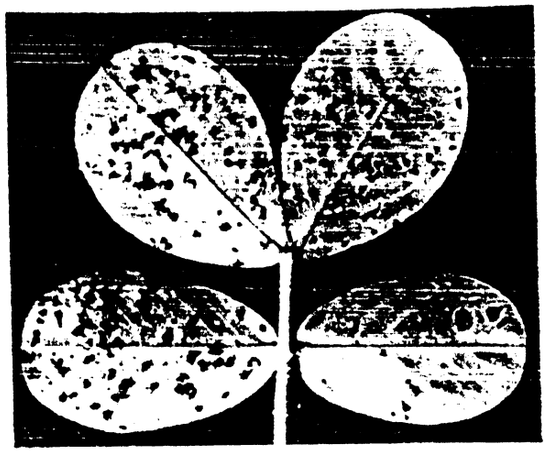

Figure 9. Uredinia of *Puccinia arachidis* parasitized by *Varticillium lecani*.

Table 10. Effect of the hyperparasite *Verticillium lecani* on groundnut rust development on detached leaves.

Inoculation treatment	Rust development assessed by measuring	
	Infection frequency (lesions cm^{-2})	Leaf area damaged (%)
Rust pathogen alone	12.6	19.9
Rust + hyperparasite (mixture)	7.3	8.6
Preinoculation with the hyperparasite	5.3	7.4
SE	±1.27	±1.95
CV (%)	33.7	36.4

Epiphytotics of groundnut rust in different agronomic systems

Many small-scale farmers in the SAT intercrop groundnuts; traditional combinations often involving up to 5 or 6 crops. Although information is available on crop combination, genotype interaction, proportion of each crop in the intercropping system, land equivalent ratio, etc., very little is known of how intercropping affects foliar diseases of groundnut. Trials were carried out at ICRISAT Center during the 1980, 1981, and 1982 rainy seasons to investigate the effect of intercropping groundnut with cereals on the development of rust and leaf-spot diseases. In the 1980 rainy season, there were statistically significant differences in percentage defoliation and percentage leaf area damaged from rust and leaf spots between sole-crop and intercrop systems. Rust and leaf spot severity was higher on groundnut grown as a sole crop than in intercrop situations. Results obtained from the 1981 rainy season were largely in agreement. In the 1982 rainy season there were no significant differences in percentage defoliation or percentage leaf area damaged from leaf spots between sole and intercrop systems, but the percentage leaf area damaged from rust was lower in the intercrop situation.

Investigations on the effects of blending rust and late leaf-spot resistant and susceptible genotypes on the development of these diseases, and on yields were carried out during the 1981-82 postrainy, 1982 rainy, and 1982/83 postrainy seasons. Two trials were conducted in each season, with two sets of resistant and susceptible genotypes physically mixed in different ratios. In general, the resistant genotypes grown in mixed crops showed higher percentage defoliation than those grown as pure crops. There were no significant yield advantages from blending resistant and susceptible genotypes.

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