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Resistance to Rust and Late Leaf Spot of Groundnut at ICRISAT Center: Problems and Progress

P. Subrahmanyam[1], D. McDonald[2], L.J. Reddy[3], S.N. Nigam[4], J.P. Moss[5], A.K. Singh[6], and V. Ramanatha Rao[6]

KGK

Abstract

*Rust (*Puccinia arachidis *Speg) and late leaf spot (*Phaeoisariopsis personata*) are the most important fungal diseases of groundnut (*Arachis hypogaea *L.) worldwide. Simple and effective screening methods for resistance to these diseases have been developed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center, India. Over 12000 germplasm lines from all over the world have been successfully screened for these two diseases from 1977 to 1990 and several sources of resistance to these diseases have been identified. Components of resistance to the two diseases were investigated and the stability of resistance to the diseases established through multi-locational trials. Most of the germplasm lines resistant to these diseases are not agronomically acceptable. Hence, a large-scale hybridization program was initiated and several high-yielding, agronomically superior lines with resistance to the two diseases were bred. Several accessions of wild* Arachis *species were found to be immune or highly resistant to the two diseases. Cytogenetic research incorporating these resistances into cultivated groundnut has been very successful in developing high-yielding, disease-resistant lines. The progress made on these aspects at ICRISAT Center is briefly discussed and future research needs are presented.*

Sumário

Resistência do Amendoim à Ferrugem e Mancha Tardia das Folhas no ICRISAT-Centro: Problemas e Progresso. *A ferrugem (*Puccinia arachidis *Speg) e a mancha tardia das folhas (*Phaeoisariopsis personata*) são as mais importantes doenças do amendoim (*Arachis hypogaea *L.), causadas por fungos, em todo o mundo. Métodos simples e efectivos de avaliação da resistência a estas doenças, foram desenvolvidos no Instituto Internacional de Investigação de Culturas para os Trópicos Semi-Áridos (ICRISAT) Centro, India. Mais de 12000 linhas de germoplasma, vindas de*

1. Senior Plant Pathologist (Legumes Program), ICRISAT Center, Patancheru, A.P. 502324, India.
2. Principal Plant Pathologist and Program Director (Legumes Program) at the above address.
3. Groundnut Breeder (Legumes Program) at the above address.
4. Principal Groundnut Breeder (Legumes Program) at the above address.
5. Principal Cell Biologist (Legumes Program) at the above address.
6. Botanist (Genetic Resources Unit) at the above address. Present address of Dr Rao: Genetic Diversity Officer, IBPGR, 142, via delle Sette Chiese, Rome 00145, Italy.

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todo o mundo, foram avaliadas com sucesso para estas duas doenças, desde 1977 a 1990. Várias fontes de resistência a estas doenças foram identificadas. Através de ensaios multi-locais, os componentes da resistência a estas duas doenças foram investigados e a estabilidade da resistência a estas doenças estabelecida. A maior parte das linhas de germoplasma resistentes a estas doenças não são agronómicamente aceitáveis. Assim, um programa de hibridação de larga escala foi iniciado e várias linhas de alto rendimento, agronómicamente superiores, resistentes a estas duas doenças foram cruzadas. Determinou-se que várias aquisições de espécies selvagens de Arachis *são imunes ou altamente resistentes a estas duas doenças. Investigação citogenética, incorporando estas resistências no amendoim cultivado, tem sido bem sucedida no desenvolvimento de linhas de alto-rendimento, resistentes a doenças. O progresso feito nestes aspectos, no ICRISAT-Centro, é brevemente discutido e as necessidades de investigação futura são apresentadas.*

Introduction

Rust (*Puccinia arachidis* Speg.) and late leaf spot [*Phaeoisariopsis personata* (Berk. & Curt.) v. Arx] are the most serious fungal diseases of groundnut (*Arachis hypogaea* L.) on a worldwide scale (Subrahmanyam et al. 1985b; McDonald et al. 1985). Both diseases are commonly present wherever groundnut is grown, but their incidence and severity vary among localities and seasons. Yield losses are generally substantial when the crop is attacked by both rust and late leaf spot. At ICRISAT Center, India, both diseases normally occur together causing severe damage to foliage and occasioning yield losses as high as 70% (Subrahmanyam et al. 1984). Although rust and late leaf spot can be controlled effectively by certain fungicides (Smith and Littrell 1980), it is not economically feasible for the vast majority of small-scale farmers in the semi-arid tropics (SAT). Hence, developing high-yielding, disease-resistant cultivars and making them available to farmers is one of the best means of reducing the yield losses from these diseases (Gibbons 1980). Recognition of this has stimulated research in many countries to exploit host-plant resistance to rust and late leaf spot.

In this paper, the progress made on breeding for resistance to rust and late leaf spot diseases by a multidisciplinary research team at ICRISAT Center is briefly reviewed, and future research strategies are discussed.

Screening Methods

Effective screening methods have been developed for use in areas where natural disease pressure is high or where such pressure can be artificially created. Genotypes to be screened are sown in replicated plots with infector rows of highly susceptible cultivars on either side. To enhance disease development, plants in infector rows are inoculated with spore suspensions. This is most successful if done in the evening, following irrigation. Additional late leaf spot inoculum is provided by scattering leaf debris collected from the previous season's diseased crops along the infector rows. Potted spreader plants heavily infested with rust or late leaf spot are also placed systematically throughout the field to provide further sources of inoculum. When necessary, to obtain one disease without the other, infector rows are sprayed with carbendazim to control leaf spot or with tridemorph to control rust. Depending on the climatic conditions, fields may be irrigated using overhead sprinklers until harvest. Some 10 days before harvest each genotype is scored for the development of rust and late leaf spot using a 9-point scale (Subrahmanyam et al. 1982a, 1982b).

Screening of germplasm for resistance to rust and late leaf spot can also be done on a limited scale in the greenhouse using potted plants, or in the laboratory using detached leaves, by measuring one or more components of disease resistance such as incubation period, infection frequency, lesion diameter, percentage leaf area damage, defoliation, and sporulation (Subrahmanyam et al. 1982b, 1983a, and 1983b). A greenhouse or laboratory screening method could be useful in areas where rust and late leaf spot epidemics do not occur regularly or where other foliar diseases interfere with field screening. However, these techniques are of limited use in identifying moderate levels of resistance.

Sources of Resistance

At ICRISAT Center, a world collection of over 12 000 germplasm lines has been screened in the field against rust and late leaf spot during the period 1977–89, and 124 rust-resistant, 54 late leaf spot resistant, and 29 rust and late leaf spot resistant germplasm lines were identified (Table 1). These include 14 rust-resistant germplasm lines jointly released by the United States Department of Agriculture and ICRISAT (Subrahmanyam and McDonald 1983). It is interesting that most of the rust and/or late leaf spot resistant genotypes have originated in Peru (Subrahmanyam et al. 1989), which is believed to be one of the secondary gene centers of cultivated groundnut (var. *hypogaea* and var. *fastigiata*) (Gregory et al. 1980). At ICRISAT

Table 1. Sources of resistance to both rust and late leaf spot in groundnut available at ICRISAT Center (in 1989).

ICG No.[1]	Identity	*Arachis* type/variety	Seed color	Origin	Disease score[2] Rust	Late leaf spot
1703	NC Ac 17127	*fastigiata*	Variegated	Peru	4.7	5.0
1707	NC Ac 17132	*fastigiata*	Purple	Peru	4.0	4.0
1710	NC Ac 17135	*fastigiata*	Dark purple	Peru	4.0	4.0
2716	EC 76446 (292)	*fastigiata*	Dark purple	Uganda	3.3	4.7
3527	USA 63	*fastigiata*	Purple	USA	4.7	4.7
4747	PI 259747	*fastigiata*	Purple	Peru	3.7	4.0
4995	NC Ac 17506	*fastigiata*	Purple	Peru	4.3	4.3
6022	NC Ac 927	*fastigiata*	Purple	Sudan	4.0	4.0
6330	PI 270806	*hypogaea*	Tan	Zimbabwe	2.1	3.3
6340	PI 350680	*fastigiata*	Dark purple	Honduras	3.0	4.0
7013	NC Ac 17133-RF	*fastigiata*	Dark purple	India	3.3	4.0
7881	PI 215696	*fastigiata*	Dark purple	Peru	4.3	3.7
7884	PI 341879	*fastigiata*	Purple	Israel	3.0	3.7
7885	PI 381622	*fastigiata*	Purple	Honduras	3.0	4.3
7886	PI 390593	*fastigiata*	Tan	Peru	4.7	3.3
7894	PI 393641	*fastigiata*	Variegated	Peru	4.0	4.7
7897	PI 405132	*fastigiata*	Purple	Peru	2.7	4.0
10010	PI 476143	*fastigiata*	Variegated	Peru	4.0	5.0
10023	PI 476152	*fastigiata*	Tan	Peru	4.3	4.7
10028	PI 476163	*fastigiata*	Purple	Peru	4.7	5.0
10029	PI 476164	*fastigiata*	Tan	Peru	4.3	5.0
10035	PI 476172	*fastigiata*	Purple	Peru	4.0	3.7
10889	PI 476016	*fastigiata*	Red	Peru	3.3	4.3
10915	PI 476148	*fastigiata*	Variegated	Peru	2.3	5.0
10936	PI 476168	*fastigiata*	Dark purple	Peru	4.3	4.0
10940	PI 476173	*fastigiata*	Variegated	Peru	2.3	5.0
10941	PI 476174	*fastigiata*	Light purple	Peru	4.7	4.7
11182	PI 476015	*fastigiata*	Tan	Peru	2.7	5.0
11485		*fastigiata*	Light purple	Peru	5.0	3.7
Susceptible control cultivars						
221	TMV 2	*vulgaris*	Tan	India	8.3	8.0
799	Robut 33–1	*hypogaea*	Tan	India	7.7	7.3

1. ICRISAT groundnut accession number.
2. Scored on a modified 9-point disease scale, where 1 = 0%, 2 = 1 to 5%, 3 = 6 to 10%, 4 = 11 to 20%, 5 = 21 to 30%, 6 = 31 to 40%, 7 = 41 to 60%, 8 = 61 to 80%, and 9 = 81 to 100% foliage destroyed; ICRISAT Center, rainy season 1989.

Center, several accessions of wild *Arachis* spp were also systematically evaluated for their reactions to rust and late leaf spot in the field and in the laboratory. Many of the species were found to be immune/highly resistant to rust and/or late leaf spot (Subrahmanyam et al. 1983c and 1985a).

Components of Resistance

Urediniospores germinate and germ tubes enter through stomata irrespective of whether a genotype is immune, resistant, or susceptible to rust. Rust resistance is not correlated with either the frequency or the size of stomata. Differences in resistance are associated with differences in rate and extent of mycelial development within the substomatal cavity and within leaf tissues. In immune *Arachis* spp the fungus dies shortly after entering the cavity. The rust resistance available at present in the cultivated groundnut is of the "slow-rusting" type, i.e., resistant genotypes have decreased infection frequency, increased incubation periods, and reduced pustule size, spore production, and spore germinability (Subrahmanyam et al. 1983a and 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 (Subrahmanyam et al. 1982a).

Late leaf spot resistance is also not correlated with either the frequency or the size of stomata. Resistance to the late leaf spot pathogen also operates through prolonging incubation and latent periods, and reducing infection frequency, lesion size, sporulation, and defoliation (Subrahmanyam et al. 1982b).

The effects of these components of resistance to rust and late leaf spot are cumulative over the course of a disease epidemic. In general, on resistant genotypes, the disease appears late, builds up only slowly, and does little apparent damage to the foliage, as evidenced by the lower rates of disease development (*r*) and area under the disease progress curve (AUDPC).

Stability of Resistance

Stability of host resistance over space and time is an important breeding objective. Some of the rust and/or late leaf spot resistant genotypes identified at ICRISAT Center are being tested in different locations of the SAT in the International Groundnut Foliar Diseases Nursery. The results obtained indicate that rust and late leaf spot resistances of most genotypes are stable over a wide range of geographic locations but the genotype NC Ac 17090 is highly resistant to rust at ICRISAT, only moderately resistant in the People's Republic of China, and susceptible in Taiwan. In contrast, the genotype PI 298115 is only moderately resistant at ICRISAT, and highly resistant in the People's Republic of China and Taiwan. Although this indicates the possibility of variation in the pathogen, there is no authenticated report of the occurrence of pathotypes.

Utilization of Resistance

Most rust and late leaf spot resistant germplasm lines have undesirable pod and seed characters such as dark testa and heavily reticulated pods. At ICRISAT Center, more than 1000 single, two-way, and three-way crosses were made between lines with good agronomic characters and lines resistant to rust and/or late leaf spot. Large F_2 populations, and subsequent generations, were grown in the field during the rainy season and screened for resistance using the infector row method. Several high-yielding agronomically superior lines with high levels of resistance to rust and moderate levels of resistance to late leaf spot were bred by pedigree and mass pedigree methods (Reddy et al. 1984). Backcrossing was also used in a few instances to improve pod, seed, and plant characters. Several of these resistant lines outyielded released susceptible cultivars when tested in multilocational trials (Table 2), and some are in advanced stages of testing in several countries. For example, the high-yielding varieties ICG (FDRS) 4 and ICG (FDRS) 10 resistant to rust and moderately resistant to late leaf spot will soon be released for cultivation in the peninsular zone of India.

Early generation breeding materials have been freely distributed to scientists in national and international programs to enable them to carry out further selection *in situ* under local agroclimatic conditions. This has resulted in a successful development and release of some rust and late leaf spot resistant groundnut varieties such as Girnar 1, DOR 18–10, and ALR 1 in India.

Cytogenetic research incorporating resistances from wild *Arachis* spp into the cultivated groundnut has also resulted in many resistant lines. The wild *Arachis* spp resistant to rust and/or late leaf spot are diploid, and groundnut cultivars are tetraploid. Tetraploid segregating populations were produced by incorporating genes from wild *Arachis* spp and by screening for resistance. By backcrossing with the cultivated groundnut, and by screening for resistance, several high-yielding lines with resistance to rust and/or late leaf spot were developed (Moss 1985; Singh et al. 1987).

Table 2. Performance of some best groundnut entries in the International Foliar Diseases Resistance Groundnut Varietal Trials conducted in seven countries, 1985–89.

Country	Variety	Pod yield ($t\ ha^{-1}$)
Bangladesh	ICGV 87183	3.62
	Control	
	Dacca 1	1.58
SE		±0.26
CV (%)		24
Myanmar	ICGV 87179	1.73
	Control	
	Japan Kalay	0.14
SE		±0.12
CV (%)		23
India	ICGV 86687	2.30
	Control	
	ICGS 11	0.88
SE		±0.16
CV (%)		20
The Philippines	ICGV 87184	3.06
	Control	
	BPI PN-9	1.45
SE		±0.40
CV (%)		32
Sudan	ICGV 87152	4.84
	Control	
	Kiriz	4.39
SE		±0.37
CV (%)		18
Swaziland	ICGV 87157	2.37
	Control	
	Natal Common	1.63
SE		±0.22
CV (%)		21
Thailand	ICGV 87358	3.92
	Control	
	Tainan 9	2.16
SE		±0.31
CV (%)		20

The level of resistance to late leaf spot in wild species, and in derivatives of crosses between cultivated and wild species, was higher than in *A. hypogaea*. Crosses with *A. cardenasii* have produced many superior derivatives. Line 259–2 was rated 2 on a 1–9 scale for late leaf spot, and withstood a severe infection when most other resistant material were heavily damaged. It also showed some tolerance of early leaf spot (*Cercospora arachidicola* Hori) in a preliminary trial at Pantnagar in northern India.

In addition to resistance to foliar diseases, the derivatives had good pod yields. Many lines yielded over 3 $t\ ha^{-1}$, compared with 1.7 $t\ ha^{-1}$ for Robut 33–1. Yields of over 8 $t\ ha^{-1}$ of dried haulm have also been produced. Forty-four consignments of derivatives have been sent to 21 countries for screening and for use in crossing programs. ICRISAT breeders have used 53 derivatives in 249 cross combinations in groundnut improvement.

In addition to resistance to late leaf spot and to rust, some species in sections *Rhizomatosae* and *Erectoides* are resistant to early leaf spot. Intersectional hybrids between these species and species of section *Arachis* have been established using embryo-rescue techniques. These interspecific hybrids will be particularly useful for early leaf spot resistance breeding programs because of lack of adequate levels of resistance to this disease in the cultivated groundnut.

Genetics of Resistance

Genetic studies of rust resistance were carried out at ICRISAT Center. The F_2 plants segregated in the ratio of 15:1, suggesting that resistance to groundnut rust is governed by duplicate recessive genes. However, quantitative genetic analysis of parents, F_1, F_2, BC_1, and BC_2 generations of rust-resistant × susceptible crosses of the cultivated groundnut using generation mean analysis (Jinks and Jones 1958) indicated that rust resistance is predominantly controlled by additive, additive × additive, and additive × dominance gene effects. Duplicate epistasis was observed both for rust disease scores and for leaf area damage (Reddy et al. 1987). Further studies are required to show conclusively if rust resistance is governed by two or three major genes or by many genes. Wild *Arachis* spp may have mechanisms of rust and/or late leaf spot resistance that differ from those in the cultivated groundnut. In some diploid wild *Arachis* spp, rust resistance appears to be partially dominant (Singh et al. 1984), unlike in the cultivated groundnut (Nigam et al. 1980), indicating that different genes may be involved. Combination of these resistances may result in more stable resistance in the cultivated groundnut.

Resistance to late leaf spot is recessive and quantitatively inherited, and is determined by alleles at five loci.

Future Research Needs

Although many sources of resistance to rust and late leaf spot have been identified from the available germplasm collections, these represent only a narrow genetic base. There is a need to collect more germplasm from the primary and secondary gene centers and to identify genotypes with disease resistance and good agronomic traits for utilization in breeding programs. Utilization of tetraploid or near-tetraploids derived from interspecific crosses should be intensified to accumulate more genetic diversity. The levels of resistance to late leaf spot and the quality of pod and seed characters need to be improved. Existing field screening techniques should be modified to suit various geographic locations. Further research on host genotype, pathogen, and environment interactions is required to determine the stability of resistance to rust and late leaf spot. Identification of pathotypes and their geographical distribution is also necessary for a successful breeding program.

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Discussion

Chigwe: Most of the accessions identified as resistant to rust or late leaf spot are of the *fastigiata*; very few or none from *hypogaea*, *vulgaris*, and *hirsuta*. How extensive has the germplasm collection been in order to identify genotypes from the other varieties/types which are resistant to the diseases? Does ICRISAT have a record of the botanical types of all its collections?

Subrahmanyam: Most (90%) of the rust and/or late leaf spot resistant genotypes available from ICRISAT Center are from South America. We have the records of the botanical types for all germplasm lines but I can't say what the percentages are right now.

Doto: In your slide presentation, differences between susceptible, resistant, and immune genotypes to rust have been attributed to differences in mycelial development. What is the factor responsible for such differences in development (mycelial) in the three different genotypes?

Subrahmanyam: Suberization in immune genotypes takes place immediately when mycelia get in contact with host cells. Five phenolic compounds have also been identified as factors responsible for resistance.

Ndunguru: Do you see any potential for the FDRS lines to be released as pasture material since they produce high yields of haulms?

Subrahmanyam: Some interspecific hybrid derivatives developed at ICRISAT Center may have good potential as pasture material.