Bacterial Wilt Disease in Asia and the South Pacific

Proceedings of an international workshop held at PCARRD, Los Baños, Philippines 8–10 October 1985

Editor: G. J. Persley

Workshop Steering Committee:
Ponciano A. Batugal, SAPPRAD
Dely P. Gapasin, PCARRD
Leonarda G. Nallana, ACIAR/PCARRD
Gabrielle J. Persley, ACIAR
Peter Vander Zaag, CIP

Co-sponsors:
Philippine Council for Agriculture and Resources Research and Development (PCARRD)
International Potato Centre (CIP)
Southeast Asian Program for Potato Research and Development (SAPPRAD)
Australian Centre for International Agricultural Research (ACIAR)

Bacterial Wilt of Groundnut: Control with Emphasis on Host Plant Resistance

V. K. Mehan, D. McDonald and P. Subrahmanyam*

BACTERIAL wilt caused by *Pseudomonas solanacearum* is the only important bacterial disease of groundnut. It is a serious problem in major groundnut-producing areas of Indonesia (Schwarz and Hartley 1927; Machmud, these Proceedings), in southern China (Darong et al. 1981), and in restricted areas of Africa (Simbwa-Bunnya 1972). The disease is a potential threat to groundnut production in several other parts of the world, especially in warm humid areas. Effective control measures are to use suitable crop rotations and to grow wilt-resistant groundnut cultivars (Schwarz and Hartley 1950; Porter et al. 1982). Breeders have produced bacterial wilt-resistant groundnut cultivars in several parts of the world (Schwarz and Hartley 1926; Darong et al. 1981). Several screening/inoculation techniques have been used to identify sources of resistance (Darong et al. 1981; Winstead and Kelman 1952), but the wide range of variability in the pathogen populations complicates wilt resistance breeding.

This paper reviews the disease situation in groundnut and recent advances in identifying sources of resistance. Strategies for incorporating genetic resistance to bacterial wilt and to some other important diseases of groundnut into high yielding cultivars are also discussed.

Distribution and Economic Importance

Bacterial wilt caused by *Pseudomonas solanacearum* is common on many crops throughout the tropics and subtropics, but the disease occurs in a relatively isolated fashion on groundnuts. For instance, bacterial wilt of tobacco, tomato, and egg plant is common in India, the Philippines, and in West Africa, but there are no reports of the disease on groundnut in these areas. Bacterial wilt, also called slime disease, of groundnut was first observed in 1905 in Indonesia (Van Breda de Haan 1906) where it was later reported to cause an estimated loss of at least 25% of the crop (Palm 1922). In the United States the disease was first reported in 1912 from Granville County, North Carolina (Fulton and Winston 1914), and was later reported to occur in all groundnut-growing counties of Georgia (Miller 1931; Miller and Harvey 1932). However, bacterial wilt is not at present regarded as an important disease of groundnut in the United States. The disease on groundnut has also been reported from Mauritius (Shepherd 1924; Edwards 1928), South Africa (McClean 1930), Libya (Petri 1931), Somalia (Curzi 1934), Ethiopia (Castellani 1939), Madagascar (Bouriquet 1934), and Japan (Fujioka 1952), but little is known about its present status in these countries.

Bacterial wilt of groundnut is currently known to cause serious damage to the crop in Indonesia (Machmud, these Proceedings), in the south of the People's Republic of China (Darong et al. 1981), and in restricted areas of Uganda (Simbwa-Bunnya 1972). The disease is particularly severe on crops grown in wet soils where incidence commonly reaches 10%. Losses of up to 30% of the crop are experienced in seasons favouring severe disease development (Darong et al. 1981; Simbwa-Bunnya 1972).

Races and Strains of *P. solanacearum*

The existence of strains of *P. solanacearum* varying in virulence and host specificity is well documented. Van der Goot (1924) suggested that the strain of *P. solanacearum* attacking potatoes in Java was distinct from the strain affecting groundnut, and this viewpoint was supported by

* Pathologist, Principal Pathologist, and Pathologist, Groundnut Improvement Program, International Crops Research Institute for the Semi-Arid Tropics, Patancheru P. O., Andhra Pradesh 502324, India.

Submitted as Conference Paper No. 230 by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Schwarz (1926). She carried out extensive rotation experiments with groundnut, tobacco, potato, tomato, and eggplant and interpreted differing wilt disease incidences as evidence for strain differences. She considered that the strain of *P. solanacearum* which attacked groundnut, tomato and tobacco at Buitenzorg, Indonesia, was different from the strain attacking potato and eggplant.

In South Africa tobacco is rarely attacked by *P. solanacearum*, although bacterial wilt is often serious on other solanaceous crops and on groundnut (Wager 1944). Experimental evidence that the strain in South Africa is avirulent or weakly pathogenic to tobacco was given by McClean (1930). Two strains of the pathogen have also been reported from southern Rhodesia (Hopkins 1947). One strain cannot attack tobacco but affects potato, groundnut, sunflower and tomato (Dowson 1949). In extensive cross-inoculation tests in the United States, Kelman and Person (1961) identified strains differing widely in pathogenicity to tobacco and groundnut. Certain isolates that were avirulent on tobacco were highly virulent on groundnut, while the reverse was true for other isolates. The reported existence of pathogenic strains of *P. solanacearum* was based mainly on: (i) the apparent immunity or high resistance of plants in a given area that were hosts elsewhere, and (ii) the failure to produce wilt in known host plants by inoculations with pure cultures of the bacterium isolated from the same host plants elsewhere.

Three races of *P. solanacearum* were described by Buddenhagen and Kelman (1964). Four biovars, based on differences in physiological characters, have been described by Hayward (1984). The three races are:

Race 1: affecting solanaceous and other plants including plants in the Leguminosae;

Race 2: affecting triploid bananas and heliconias; and

Race 3: affecting potato.

Recently, He et al. (1983) designated the strains from mulberry in China as race 4 biotype V. The strains from mulberry that they tested were unusual because they were weakly virulent on eggplant and potato and not virulent on tomato, pepper, groundnut, or tobacco. Physiologically, the strains were also unusual in their ability to oxidise lactose, maltose, cellobiose, and mannitol, a combination of traits not found in biovars described previously by Hayward (1964).

Within each of these races there are numerous pathotypes that may be associated with particular geographical locations (Buddenhagen and Kelman 1964; Harris 1972). Several pathotypes, some pathogenic and some non-pathogenic to groundnut, have been described from Uganda (Simbwa-Bunnya 1972). Little effort has been made to describe pathotypes of the bacterium pathogenic on groundnut in areas where bacterial wilt of this crop is a serious problem.

There is a critical need to understand the distribution of distinct pathotypes in nature in relation to ecology and etiology of bacterial wilt of groundnut. We need to have answers to the following questions: (1) whether groundnut in a given area is infected by a uniform and stable population of *P. solanacearum*; (2) whether this population can, under natural conditions, cause disease of crops rotated with groundnut; (3) whether there are other strains present which cannot be detected because the crop cultivar grown is not susceptible to these strains; (4) whether the strain affecting a given host is the one attacking it in other regions. Answers to these questions would enable more realistic inferences to be drawn on questions of origin, relationship, and biology of populations pathogenic to groundnuts.

Disease Cycle and Epidemiology

Bacterial wilt of groundnut is most prevalent and severe in heavy clay soils (Van Breda de Haan 1906; Palm 1922; McClean 1930; Darong et al. 1981) although the disease has also been recorded in red lateritic and light sandy loam soils (Van Hall 1924; Palm 1926, Miller and Harvey 1932). The disease is most severe on groundnut grown in wet soils, and where the crop is grown continuously (Palm 1922; Kelman 1953; Darong et al. 1981). High rainfall, high water tables, and inadequate drainage predispose groundnuts to infection by *P. solanacearum*. Young succulent plants develop critical wilt symptoms much more rapidly than older plants (Palm 1922; McClean 1930; Miller and Harvey 1932). High soil temperatures prevailing early in the growing season favour the development of bacterial wilt in young groundnut plants (Miller and Harvey 1932; Darong et al. 1981). Wilt symptoms appear rapidly if the diseased plants are subjected to a spell of dry weather. The infected plants collapse and die quickly. If the weather remains continuously wet the disease develops and spreads, but symptoms of severe wilt may not appear for some time. Later infected plants may not develop severe wilt symptoms except when subjected to hot, dry weather late in the season.

No thorough studies have been made of penetration of groundnut roots by *P. solanacearum*, but

it is believed that roots may become infected through insect and nematode wounds, lenticels, or rifts in the root cortex made by secondary roots (Kelman 1953). Under field conditions infection of susceptible host plants usually occurs through the root system, and a wound is generally considered essential for entrance of the pathogen (Palm 1922; Kelman 1953).

Many investigators have recognised the importance of rootknot (*Meloidogyne* spp.) and other nematodes in providing wounds for entry of the pathogen into roots. On the basis of histopathological studies of groundnut roots it was concluded that infection occurred in part through insect wounds (Miller and Harvey 1932). However, Miller and Harvey (1932) reported that wounding of roots was not always required for bacterial infection. Two Japanese workers have made similar observations (Nakata 1927; Vong 1937). In their studies this phenomenon of bacterial infection through undamaged roots occurred only when highly virulent cultures were used.

The relationship between host and pathogen from time of entry of the bacterium into the susceptible host plant and the appearance of wilt symptoms has been described in detail by Buddenhagen and Kelman (1964). The xylem trachae of infected plants become filled with bacteria that eventually return to the soil following death and breakdown of plant tissues.

There is no definite evidence of *P. solanacearum* being transmitted through groundnut seed. Palm (1922) isolated the bacterium from groundnut shells and found that it could penetrate the funiculus and sometimes the integuments of the seed. But no bacteria were isolated from embryos. The possibility of the bacterium remaining viable on the outside of dry seed appears to be remote. Further research is needed to determine whether or not *P. solanacearum* can be seed transmitted in groundnut.

Control

Cultural Measures

Rotation of groundnut with crops that are immune or highly resistant to *P. solanacearum* such as corn, soybean, sugarcane and rice has been reported to be an effective means of control of bacterial wilt of groundnut (Schwarz 1926; Kelman 1953; Darong et al. 1981). In Guangdong Province of the People's Republic of China, rotation of groundnut with sugarcane for 2-3 years has been found to reduce bacterial wilt incidence from 60% to below 10%, while rotation with rice could reduce incidence to below 1% (Liang-Gao Zhou, personal communication with D. McDonald 1980). Although crop rotations for shorter periods with immune crops have proved effective in containing the disease, a gap of at least 4-5 years between groundnut crops would probably be most effective for control of the disease on soils that are heavily infested with the pathogen. Little is known as to how these cropping systems affect soil microorganisms in general and the perpetuation survival of the bacterial wilt pathogen in particular.

In areas where groundnut is grown with irrigation in the dry season, it should be possible to control or greatly reduce levels of the disease by dry season fallowing since the bacterium is highly susceptible to desiccation. The effects of the dry season fallow can be enhanced by cultivation to improve drying out of soil and to reduce weed growth.

A few attempts have been made with limited success to minimise crop losses from bacterial wilt in groundnut by altering dates of planting (Palm 1922) to avoid periods of high temperatures or heavy rainfall that favour bacterial infection and disease development.

Crop sanitation (e.g. burning of crop residues and removal of solanaceous weeds, and cleaning of tools and machinery after operations in infested fields) should help reduce disease levels.

Chemical Control

Soil treatment with sulfur, lime and several other chemicals has not proved useful in controlling bacterial wilt of groundnut (Poole 1936; Kelman 1953).

Plant Quarantine

Since the bacterium is potentially seed-borne, strict control of seed movement should be enforced to avoid the spread of the pathogen on pods or seeds to disease-free areas.

Use of Resistant Cultivars

An effective and practical way of controlling bacterial wilt is to grow groundnut cultivars resistant to *P. solanacearum*.

The first successful attempt to breed groundnut cultivars resistant to bacterial wilt was made in Indonesia. Extensive field trials were conducted in 1921 to evaluate possible sources of resistance in groundnut genotypes from Africa, South America, North America and Indonesia (Hartley 1925). All of these gentotypes, especially the Jumbo and Valencia types, were more susceptible than the best Javanese cultivars, Tjina, Brol and Holle. Among the latter, Tjina was most resistant to bacterial wilt. Van Hall (1924, 1925) reported that Hybrid No. 3, Katjan Toeban, and Pure Line 21 showed relatively

high levels of resistance. However, these cultivars were not immune and showed high mortality of plants under severe disease pressure (Palm 1926). Later, from an extensive breeding program in Java (Indonesia), a highly resistant cultivar, Schwarz 21, was developed by selection from a wilt-resistant groundnut line of doubtful origin (Schwarz and Hartley 1950). However, on the basis of relative resistance and character of the gynophore, it was thought that Schwarz 21 probably originated from the Plumbon seed collection No. 16. This seed population and lot No. 15 from Madjalenkga were the two collections from which the lines with highest resistance were obtained in the original selection work by Schwarz at the Institute voor Plantenziekten. It is of interest that both of these collections were obtained from the Cheribon region of Java where the disease was especially severe. The history of the development of the wilt resistant cultivar Schwarz 21 has been discussed in detail by Schwarz and Hartley (1950). This cultivar has also shown a high level of resistance when inoculated with several isolates of *P. solanacearum* in greenhouse tests (Winstead and Kelman 1952; Jenkins et al. 1966).

Several groundnut cultivars resistant to local strains of the pathogen have been reported from the United States, South Africa, Uganda and the People's Republic of China. In South Africa, the small, two-seeded Natal Common types were found to be more resistant than the Virginia Bunch types (Sellschop 1947). In Mauritius, a local cultivar known as Cabri was observed to be highly resistant to bacterial wilt (Orian 1949). Simbwa-Bunnya (1972) reported three germplasm accessions, PI 341884, PI 341885, and PI 341886 immune to biotypes III and IV of *P. solanacearum* in Uganda.

In extensive inoculation tests of 17 groundnut cultivars in Georgia, USA, using three isolates of *P. solanacearum*, Jenkins et al. (1966) found a high level of resistance to bacterial wilt in Ga.119-20. However, when tested in Hubei Province of China, this cultivar did not show any resistance to bacterial wilt (Darong et al. 1981). This difference in reaction could be due to variation in pathogen and/or host-pathogen-environment interactions.

Many sources of resistance have been reported from the People's Republic of China where an active program of breeding and selection for wilt resistance has been operating since 1972. In the early 1970s two wilt-resistant cultivars, Suei tian and Yui io 589, were bred and released for cultivation in South China (Darong et al. 1981). Over the past 10 years, considerable research effort has been made in China to identify further sources of stable resistance to bacterial wilt of groundnut. From an extensive screening of germplasm accessions and breeding lines under high disease pressure in the field, Darong et al. (1981) reported five cultivars that showed relatively high levels of resistance to the disease. These cultivars were Xie kong chung, Suei tian, Yui io 589, Teishan sanliyue, and Huongzhuan zhili. Of these cultivars, Xie kong chung had the highest level of resistance. The cultivars that gave less than 10% mortality of plants were regarded as highly resistant. Recently, several additional wilt-resistant genotypes have been identified in China (Yeh Wei-Lin 1982 and Guang Rou zheng 1984, both personal communications with D. McDonald).

Genotypes from all sources reported resistant to bacterial wilt are listed in Table 1. Some of these genotypes have also been reported to have resistance to late leafspot and rust in India (Subrahmanyam et al. 1980) and in China (Yeh Wei-Lin 1982 – personal communication with D. McDonald). Wilt-resistant genotypes that have been found resistant to other diseases of groundnut are listed in Table 2.

Chinese workers have made some interesting speculations on the origins of wilt-resistant genotypes. They noted a definite relationship between environmental conditions and resistance to bacterial wilt, with most of the resistant genotypes being developed in lower latitudes (Darong et al. 1981). Wilt-resistant cultivars seem to have been bred in areas where the disease occurs in severe form, especially in hot and humid areas, and such environments are most common in low latitudes. However, care should be taken to discover the primary origin when trying to relate wilt resistance in genotypes to where they have been grown. These findings indicate a need for extensive evaluation of germplasm from low latitude areas for sources of resistance to bacterial wilt.

Although it has been suggested that the stability and durability of genetic resistance to bacterial wilt may be suspect due to the possible genetic variability of the pathogen, this is not borne out by the continued resistance of cultivars such as Schwarz 21 that were bred about 55 years ago. However, this consideration is complicated by the absence of critical information on the distribution of the wilt pathogen in farmers' fields and on the genetic composition of local cultivars. There is critical need to determine the distribution of possible different strains of the pathogen in areas where the disease is a serious problem. The inheritance of wilt resistance is not yet well understood. Resistance is nor-

Table 1. Genotypes reported resistant to bacterial wilt.

Genotype/ identity	Country of origin	Criteria* code for resistance	Test locations	References
Schwarz 21	Indonesia	1	Cheribon Buitenzorg (Indonesia)	Schwarz and Hartley (1950)
		2	North Carolina (USA)	Winstead and Kelman (1952)
		2	Georgia (USA)	Jenkins et al (1966)
PI 267771 (Manjan)	Indonesia	2	Georgia (USA)	
PI 341884	?	2	Uganda	Simbwa-Bumya (1972)
PI 341885	?	2	Uganda	
PI 341886	?	2	Uganda	
Xie Kong Chung	China	1, 2	Huong An County (China)	Darong et al (1981)
Suei tian	China	1, 2	Huong An County (China)	
Huongzhuan zhih	China	1, 2	Huong An County (China)	
Yuei to 589	China	1, 2	Huong An County (China)	
Ieishan sanliyue	China	1, 2	Huong An County (China)	
PI 393531 (ICG 7893)	Peru	1, 2	Guangdong (China)	Yeh Wei-Lin (1982)[a]
NC Ac 17130 (ICG 1705)	Peru	1, 2	Guangdong (China)	
NC Ac 17129 (ICG 1704)	Peru	1, 2	Guangdong (China)	
NC Ac 17127 (ICG 1703)	Peru	1, 2	Guangdong (China)	
PI 393641 (ICG 7894)	Peru	1, 2	Guangdong (China)	
PI 414332 (ICG 7900)	Honduras	1, 2	Guangdong (China)	
Hai-hua 1(HPS) PI 476825	China	?	?	Hammons and Porter (1982)[b]
Yie-You 22 (HP-23) PI 476842	China	-	-	
Yue-you 589 (HP-15) PI 476834	China	-	-	
320-14 (HP-4) PI 476824	China	-	-	
Dingzixli	China	-	-	Guang Rou Zheng (1984)[a]
Jinake	China	-	-	
Yuebeizhong	China	-	-	
Shuikouyazai	China	-	-	
Baimizai	China	-	-	
Bayuehao	China	-	-	
Dunduzai	China	-	-	
Liamzhou	China	-	-	
Yangtang pudizhan	China	-	-	
Qujiangdazhiaou	China	-	-	

* 1 = field evaluation at disease hot spots and by artificial inoculation
2 = greenhouse evaluation under artificial inoculation conditions

[a] Personal Communication to D. McDonald

[b] Collected on their visit to People's Republic of China as being resistant to bacterial wilt (cited by Mixon et al. 1983).

nally expressed in terms of high percentage of surviving plants, but this can be influenced by such factors as soil type, soil moisture and temperature, condition of the root system of the host, inoculum thresholds, and virulence of the pathogen.

Late leafspot and rust diseases are recognised as serious problems in countries where bacterial wilt occurs. As pointed out earlier, some bacterial wilt-resistant genotypes have been found to possess high levels of resistance to both late leafspot and rust. However, these genotypes are low yielding and have undesirable pod and seed characters. Emphasis should be placed on incorporating resistances to rust, leafspots and bacterial wilt into high yielding cultivars with agronomic and quality characters adapted to specific environments. At ICRISAT we are collecting a wide range of germplasm resistant to bacterial wilt. Such germplasm could be crossed with sources of resistance to major groundnut diseases and pests, and with high yielding cultivars suited to different environments. Segregating populations from such crosses could be made available for selection in areas where bacterial wilt is a problem.

Research Needs

Bacterial wilt of groundnut has received little attention except in those few regions of the world where it causes obvious economic damage. However, there is no guarantee that the disease will not become important in other regions, and priority should be given to determining the full extent of the distribution of the strains of *P. solanacearum* that attack groundnut. This work could well be done in cooperation with scientists working on bacterial wilt diseases of other tropical and subtropical crops. Little is known of the occurrence of bacterial wilt on groundnut and on wild *Arachis* species in the regions of South America where the genus *Arachis* originated, although such information could be valuable in many ways (e.g. it may be possible to study factors limiting the spread and severity of bacterial wilt in natural populations of wild *Arachis* species).

Surprisingly little is known about the infection process although this is of obvious importance in relation to inoculation methods and study of components of resistance. Research on this process could include investigation of the possible roles of nematodes and pathogenic soil fungi in rendering groundnut plants more susceptible to infection. For such studies it would be useful to have highly specific antisera (preferably monoclonal) to permit the identification of individual strains of the bacterium in soil, in the rhizosphere, and in root and pod tissues. Initially, standard methods of antiserum production such as those used successfully to type strains of *Rhizobium* (Nambiar and Anjaiah 1985) may be used, but if these prove ineffective it should be possible to produce monoclonal antibodies. Antisera could also be used in field surveys as modifications to the ELISA technique to permit antibody plates and buffer solutions to be carried to different locations.

More information is needed on the effects of different cropping systems and rotations on survival of *P. solanacearum* and on the mechanisms involved in decreasing or increasing populations of the pathogen.

Resistance screening of groundnut germplasm and breeding lines should be organised on an international basis. ICRISAT is responsible for collection and maintenance of a world collection of

Table 2. Bacterial wilt-resistant genotypes reported resistant to other groundnut diseases.

Genotype	Reaction to: Bacterial wilt	Late leafspot	Rust	Pythium pod rot	Verticillium wilt
NC Ac 17127	R[a]	R[a,b]	R[a,b]	?	?
NC Ac 17129	R[a]	R[a,b]	R[a,b]	?	?
NC Ac 17130	R[a]	R[a,b]	R[a,b]	?	?
PI 393531	R[a]	R[a,b]	R[a,b]	?	?
PI 393641	R[a]	R[a,b]	R[a,b]	?	?
PI 414332	R[a]	S[a,b]	R[a,b]	?	?
Schwarz 21	R[d]	S[a,b]	S[a,b]	R[c]	R[c]

[a] Yeh Wei-Lin, personal communication with D. McDonald 1982.
[b] Subrahmanyam et al. 1980.
[c] Frank and Krikun 1968, 1969.
[d] Schwarz and Hartley 1950; Jenkins et al. 1966.
R = Resistant; S = Susceptible; ? = reaction not known.

groundnut germplasm and this currently consists of 11 500 groundnut accessions and 57 accessions of wild *Arachis* species. These could be made available to research workers in countries where bacterial wilt 'hot spots' occur that can be used for field resistance screening. Lines found resistant or tolerant in one region should be retested in other regions because of the possible differences in geographic distribution of pathogenic strains of the bacterium. It may also be possible to organise a project in a country where groundnut is not grown and where *P. solanacearum* is not a problem, to test selected resistant lines for their reaction to inoculation with strains of the pathogen from different regions of the world. Such tests, preferably in conjunction with international disease nurseries would be useful in determining stability of resistance of cultivars to bacterial wilt.

The overall aim should be to combine stable resistance to bacterial wilt with resistance to other economically important diseases and pests that occur in the same regions.

References

Ashby, S. F. 1926. A bacterial wilt disease of bananas in Trinidad caused by *Bacterium solanacearum* E. F. Smith. Tropical Agriculture, 3, 127-129, (Trinidad).

Bouriquet, M. G. 1934. Madagascar: list of the parasites and diseases of cultivated plants. International Bulletin of Plant Protection, 8, 99-100.

Buddenhagen, I., and Kelman, A. 1964. Biological and physiological aspects of bacterial wilt caused by *Pseudomonas solanacearum*. Annual Review of Phytopathology, 2, 203-230.

Buddenhagen, I., Sequeira, L., and Kelman, A. 1962. Designation of races in *Pseudomonas solanacearum*. (Abstract). Phytopathology 52, 726.

Castellani, E. 1939. Considerazioni fitopathologiche sull' Africa Orientale Italiana. Agri. Colon. 33, 486-492, (Italy).

Curzi, M. 1934. De fungis et morbis Africanis II. De *Pseudomonas* plantarum parasitis Somaliae. Roma R. Staz. Patol. Veg. Bol., N.S., 14, 179-183, (English summary).

Darong Sun, Chen Chuenrung, and Wang Yuring. 1981. Resistance evaluation of bacterial wilt (*Pseudomonas solanacearum* E. F. Sm.) of peanut (*Arachis hypogaea* L.) in the People's Republic of China. Proceedings of American Peanut Research and Education Society, Inc., 13, 21-28.

Dowson, W. J. 1949. Manual of bacterial plant diseases. London, Adam and Charles Black, 183 p.

Edwards, W. H. 1928. Botanical Division, Department of Agriculture, Mauritius, Annual Report 1927, 17-19.

Frank, Z. R., and Krikun, J. 1968. Verticillium wilt of groundnut in Israel. Screening for varietal resistance. Israel Journal of Agricultural Research, 18, 83-85.

1969. Evaluation of peanut (*Arachis hypogaea*) varieties for verticillium wilt resistance. Plant Disease Reporter, 53, 744-746.

Fujioka, Y. 1952. List of crop diseases in Japan. 2 vol. Gen. Hq. Supreme Command Allied Powers, Economic and Scientific Section, Nat. Resources Preliminary Study 73, 212 p.

Fulton, H. R., and Winston, J. R. 1914. A disease of peanut plants caused by *Bacterium solanacearum* (Abstract). Phytopathology, 3, 72-73.

Harris, D. C. 1972. Intra-specific variation in *Pseudomonas solanacearum*. In: H. P. Maas Geesteranus, ed. Proceedings of the third international conference on plant pathogenic bacteria. Wageningen, Netherlands, 289-292.

Hartley, C. 1925. Varietal tests of peanut (*Arachis hypogaea*) for wilt resistance. Abstract. Phytopathology, 15, 55.

Hayward, A. C. 1964. Characteristics of *Pseudomonas solanacearum*. Journal of Applied Bacteriology, 27, 265-277.

He, L. Y., Sequeira, L., and Kelman A. 1983. Characteristics of strains of *Pseudomonas solanacearum* from China. Plant Disease, 67, 1357-1361.

Hopkins, J. C. F. 1947. Annual Report Branch of Botany and Plant Pathology for year ending December 31, 1946. South Rhodesia Department of Agriculture and Lands, 13 p.

Jenkins, S. F., Hammons, R. O., and Dukes, P. D. 1966. Disease reaction and symptom expression of seventeen peanut cultivars to bacterial wilt. Plant Disease Reporter, 50, 520-523.

Kelman, A. 1953. The bacterial wilt caused by *Pseudomonas solanacearum*. Raleigh, N.C., North Carolina Agricultural Experiment Station, Technical Bulletin, 99, 194 p.

Kelman, A., and Person, L. H. 1961. Strains of *Pseudomonas solanacearum* differing in pathogenicity to tobacco and peanut. Phytopathology, 51, 158-161.

McClean, A. P. D. 1930. The bacterial wilt disease of peanuts. South Africa, Department of Agriculture Science Bulletin, 87, 14 p.

Miller, J. H. 1931. A plant disease survey of peanuts in Georgia. Plant Disease Reporter, 15, 167-170.

Miller, J. H., and Harvey, H. W. 1932. Peanut wilt in Georgia. Phytopathology, 22, 371-383.

Mixon, A. C., Hammons, R. O., and Branch, W. D. 1983. Germplasm for use in genetic enhancement of peanut genotypes. In: Proceedings of American Peanut Research and Education Society, Inc., 15, 15-38.

Nakata, K. 1927. Concerning the vitality and pathogenicity of *Bacterium solanacearum* E. F. S., a cause of tobacco wilt (In Japanese). Science Agriculture Society Journal, 296, 283-304. (Japan, English summary).

Nambiar, P. T. C., and Anjaiah, V. 1985. Enumeration of rhizobia by enzyme-linked immunosorbent assay (ELISA). Journal of Applied Bacteriology, 58, 187-193.

Orian, G. 1949. Division of Plant Pathology, Department of Agriculture, Mauritius, Annual Report 1948, 69-74.

Palm, B. T. 1922. Aanteekeningen over slijmziekte in *Arachis hypogaea* (Katjang tanah). Inst. V. Plantenziekten (Dutch East Indies), Meded., 52, 41 p. (English summary).

1926. Verslag van het Deli Proefstation over 1 Januari 1925 31 December 1925. Deli Proefsta. te Medan, Meded., Ser. 2, 42, 35 p.

Petri, L. 1931. Rassegna dei casi fitopatologici osservati nel 1930. Roma R. Staz. di Patol. Veg., Bol., N. S. 11, 1-50.

Poole, R. T. 1936. Studies on the control of Granville wilt. North Carolina Agricultural Experiment Station Annual Report 58 (1935), 29-30.

Porter, D. M., Smith, D. H., and Rodriguez-Kabana, Rodrigo. 1982. Peanut plant diseases. In Pattee, H.E., and Young, C. T. ed., Peanut Science and Technology. Yoakum, Texas, USA, American Peanut Research and Education Society, Inc., 326–410.

Schwarz, Marie B. 1926. De invloed van de voorvrucht op het optreden van slijmziekte (*Bacterium solanacearum*) in *Arachis hypogaea* en eenige andere gewassen. Inst. v. Plankenziekten (Dutch East Indies), Meded. 71, 37 p. (English summary).

Schwarz, Marie B., and Hartley, C. 1927. *Bacterium solanacearum* sur l'arachide et quelques autres plantes a Java. Rev. de Bot. Appl. et d'Agr. Colon, 7, 355.

1950. De selectie van Schwarz 21, een tegen slijmziekte resistente lijn van *Arachis hypogaea*. Landbouw (Bogor), 22, 223-244. (English summary).

Sellschop, J. 1947. Groundnuts. Farming in South Africa, 22, 705-712.

Shepherd, E. F. S. 1924. Botanical division, Mauritius, Department of Agriculture Annual Report for 1923, 9-11.

Simbwa-Bunnya, M. 1972. Resistance of groundnut varieties to bacterial wilt (*Pseudomonas solanacearum*) in Uganda. East African Agriculture and Forestry Journal, 37, 341-343.

Subrahmanyam, P., Mehan, V. K., Nevill, D. J., and McDonald, D. 1980. Research on fungal diseases of groundnut at ICRISAT. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) In. Proceedings of the international workshop on groundnuts, 13-17 October, 1980. Patancheru, A. P., India, 193-198.

Van Breda de Haan, J. 1906. Rapport over ziekte in den aanplant van *Arachis hypogaea* (Katjangholle) in de Afdeelingen Koeningen en cheribon der Residentie Cheribon, Teysmannia, 17, 52-63.

Van der Goot, P. 1924. Overzicht der voornaamste ziekten von het aardappelgewas op Java. Inst. V. Plantenziekten (Dutch East Indies), Bulletin 18, 37-39.

Van Hall, C. J. J. 1924. Ziekten en plagen der cultuurgewassen in Nederlandsch-Indie' in 1923. Inst. V. Plantenziekten (Dutch East Indies), Meded., 64, 47 p.

1925. Ziekten en plagen der cultuurgewassen in Nederlandsch-Indie' in 1924. Inst. V. Plantenziekten (Dutch East Indies), Meded. 67, 53 p.

Vong, W. G. 1937. The entrance and migration of *Bacterium solanacearum* Smith in tobacco plants. (In Japanese). Phytopathology Society of Japan, Ann. 7, 14-23 (Abstract, Rev. Appl. Mycol. 17, 76, 1938).

Wager, V. A. 1944. Bacterial wilt of eggplant. Farming in South Africa, 19, 661-664.

Winstead, N. N., and Kelman A. 1952. Inoculation techniques for evaluating resistance to *Pseudomonas solanacearum*. Phytopathology, 42, 628-634.