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Management of Bacterial Wilt of Groundnut Using Genetic Resistance and Cultural Practices

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Abstract

The use of bacterial wilt-resistant groundnut cultivars is an effective and practical way of reducing yield losses from the disease. Many sources of resistance have been reported from the People's Republic of China, Indonesia, and Uganda where bacterial wilt is a serious problem. Much progress has been made in the development of several wilt-resistant cultivars in China and Indonesia. Several of these cultivars are now widely grown in various parts of Indonesia (e.g. Gajah, Pelanduk, Tupai) and south and central China (e.g. El Hua 5, Lu Hua 3, Yue You 92, Guiyou 28, Zhong Hua 2), and have had much impact in reducing yield losses in wilt-affected areas. The wilt-resistance in Indonesian cultivars Schwarz 21 and Gajah continues to be useful even after several decades of their cultivation. However, recent studies in China have highlighted the existence of strains/pathotypes in the wilt pathogen, *Pseudomonas solanacearum*. This necessitates more critical genetic evaluation of wilt-resistance to elucidate host-pathogen interactions. Future research into stability and durability of wilt-resistance, as well as incorporation of resistance to other yield reducing diseases, are indicated. Crop rotation with feasible non-host crops (e.g. rice and maize) is also a useful means of reducing the disease levels in humid tropical areas. An integrated approach to disease management, involving wilt-resistant cultivars, crop rotation, intercropping, and crop sanitation, is emphasised.

BACTERIAL wilt (BW) of groundnut (*Arachis hypogaea* L.) occurs in several countries of southern Asia, Southeast Asia, Africa, and North America, but it is economically important in only the People's Republic of China, Indonesia and Uganda (Hayward 1990; He 1990; Machmud 1986; Mehan et al. 1986; Simbwa-Bunnya 1972). The disease has recently been reported as severe in some groundnut-producing areas, of Vietnam (Mehan et al. 1991). In the People's Republic of China, the disease is most severe in central and southern groundnut-producing areas where more than 0.2 million hectares are infested with the wilt pathogen, *Pseudomonas solanacearum* E.F. Smith, and yield losses of 10–30% are common (Liao et al. 1990). However, within any region there are variations in disease incidence and severity attributable to soil type, pathogen populations, cropping patterns, climatic factors and groundnut cultivars. The persistence of the pathogen in soil, and its wide host range, often limit the effectiveness of cultural and chemical control practices. Although rotation with non-host crops provides effective disease management, control of BW of groundnut has been achieved mainly with resistant cultivars. In this review paper we provide information on sources of resistance to the disease and examine how these sources are being utilised in the breeding of resistant cultivars. Resistant cultivars and cultural control measures are considered for use in integrated disease management systems.

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Host Plant Resistance

Sources of resistance

Attempts to select wilt-resistant groundnut cultivars were first made in Indonesia in the 1920s. Most of the cultivars selected as BW-resistant, such as Hybrid No. 3, Katjan Toeban, and Pure Line 21, later showed high mortality of plants under severe disease pressure (Palm 1926). Subsequently, from an extensive wilt resistance breeding program in Java, a highly resistant cultivar, Schwarz 21, was developed by selection from a wilt-resistant groundnut line of unknown origin (Schwarz and Hartley 1950). Resistance in this cultivar was confirmed in several field and greenhouse screening tests (Jenkins et al. 1966; Machmud and Lasimin 1987; Machmud and Middleton 1988; Yeh 1990). From extensive screening of several hundred germplasm and breeding lines in wilt-sick plots in Indonesia, several lines with varying levels of resistance to BW were identified (Machmud and Middleton 1988, 1990; Sharma and Soekarno 1992).

Various lines/cultivars resistant to *P. solanacearum* have also been reported from Mauritius, South Africa, Uganda, the United States, the Philippines and Sri Lanka (Orian 1949; Sellschop 1947; Jenkins et al. 1966; Simbwa-Bunnya 1972; Natural et al. 1988; Jayasena and Rajapaksa 1990). However, some of these were susceptible in China (Sun et al. 1981).

Many sources of resistance have been reported from the People's Republic of China where a selection and breeding program for wilt resistance was begun in the late 1950s. Of over 500 germplasm lines screened in Guangdong Province in the early 1960s, 30 wilt-resistant lines were identified (Zhou and Liu 1962; OCRI 1976). From extensive screening of over 4000 germplasm accessions and breeding lines in the 1970s and 1980s, many additional sources of resistance were identified (OCRI 1977; Xu et al. 1980; Wang et al. 1983; Tan and Liao 1990; Duan and Li 1987; Duan et al. 1991). These included Xiekangqing, Taishan Sanlirou, Lukangking 1, Yue io 589, Huangchuan Zhili, Tianjing Dou, Taishan Zhengzhu, and many lines of 'Chinese Dragon' type. Some of these (Taishan Zhengzhu, Yue io 589) were later shown to be susceptible (Sun et al. 1981). In the next decade, several other cultivars (Xiekongchung, Sueitian, Teishan Sanliyue, and Huongzhuanzhili) were reported resistant (Sun et al. 1981).

Recently, several wilt-resistant cultivars with high yield and quality were released in China (Yeh 1990; Liao et al. 1990). These cultivars are Lu Hua 3, El Hua 5, Zhong Hua 2, Yue You 92, Yue You 256, Guiyou 28, and Jinyou 3121. The cultivars El Hua 5, Zhong Hua 2 and Yue You 92 have shown stable wilt resistance in multilocation tests carried out in Hubei Province, China (Liao et al. 1990). These wilt-resistant lines/cultivars have approximately 90% plant survival compared with below 10% survival in susceptible cultivars in infested fields.

Differential disease reactions of some lines/cultivars have been noted in different locations. For instance, the lines PI 414332 and NC Ac 17130, found resistant in China (Yeh 1990), were susceptible in Indonesia (Machmud and Middleton 1988, 1990). Some cultivars (Gajah, Kidang, Macan, Banteng) reported resistant in Indonesia were moderately resistant in China (Yeh 1990). Likely causes of variations in wilt reactions of these lines include inoculum pressure, pathogen virulence, environmental factors and genetic background of the lines. Many of the reported sources of resistance have only field resistance to BW: they show substantial wilt incidence in glasshouse screening tests. Only a few lines have been found resistant to BW in both field and glasshouse tests (Machmud and Middleton 1990).

Field screening under high disease pressure is useful for identifying sources of resistance. In most cases, glasshouse tests and disease ratings in the field do not correlate well. In general, certain inoculation techniques (e.g. hypodermic syringe inoculation) used in the glasshouse give high levels of wilt in most genotypes (Machmud and Middleton 1990). It is noteworthy that several accessions of Schwarz 21 (ICG 1609, ICG 5313, and ICG 8666) glasshouse tested in Bogor, Indonesia, showed susceptibility (over 60% wilt incidence) with this technique, while this cultivar has shown consistent resistance in many field and glasshouse tests. These genotypic variations in reactions to BW (in field and glasshouse tests) can be attributed to pathogen virulence, inoculum pressure, and inoculation techniques. Stem-inoculation techniques often give higher disease levels than root-inoculation techniques. It is important to employ inoculation techniques (in glasshouse screening tests) that simulate natural field conditions, especially in terms of infection route. Some studies have shown higher levels of wilt-resistance in selected progenies of Gajah and several other wilt-resistant lines than in unselected bulk of Gajah and other lines (Sharma and Soekarno 1992). This emphasises the need for maintaining a high level of resistance in cultivars by proper selection and maintenance of breeder seed through plant progeny evaluation, particularly under high disease pressure.

Lines/cultivars resistant to BW are listed in Table 1. A majority of resistance sources belong to *Arachis hypogaea* subsp. *fastigiata*. However, there are some sources, such as Tianjin Dou, that belong to subsp. *hypogaea*.

High levels of resistance to BW have also been reported in several wild *Arachis* species (Yeh 1990). These species are *A. duranensis*, *A. spegazzini*, *A. correntina*, *A. stenosperma*, *A. cardenasii*, *A. chacoense*, *A. villosa*, *A. appressipila*, *A. pusilla* and *A. glabrata*. These species also have high levels of resistance or immunity to rust, late leaf spot and early leaf spot pathogens. Some of the wilt-resistant lines/cultivars possess resistance to two or more major groundnut diseases. For instance, some Peruvian accessions (PI 393641, PI 393531, NC Ac 17127, NC Ac 17129) have resistance to rust and late leaf spot (Subrahmanyam et al. 1980; Mehan et al. 1986; Yeh 1990). Some interspecific hybrid derivatives such as CS 7 and CS 30 possess resistance to bacterial wilt and rust and late leaf spot

Table 1. Groundnut lines/cultivars resistant to bacterial wilt.

Lines/cultivars	Other identity[a]	Country of origin	Reference
Schwarz 21	–[b]	Indonesia	Schwarz and Hartley (1950) Winstead and Kelman (1952)
PI 267771	Matjan	Surinam	Jenkins et al. (1966)
PI 341884	–	Israel	Jenkins et al. (1966), Simbwa-Bunnya (1972)
PI 341885	–	Israel	Simbwa-Bunnya (1972)
PI 341886	–	Israel	
Rusa, Anoa	–	Indonesia	Anon. (1983, 1984),
Tupai, Gaja	–	Indonesia	Machmud (1986),
Kidang, Banteng, Pelanduk	–	Indonesia	Wakman (1988)
ICGS(E)-61	–	India	Machmud and Lasimin (1987)
F4 924/1014	–	Indonesia	
F4 726/1014	–	Indonesia	
Holland St. Runner	–	USA	Machmud and Middleton (1990)
Bulundi	ICG 7502	Uganda	
ICGV 87206	–	India	
ICGV 86606	–	India	
EGPN 11	–	–	
GH 32/NC Ac 17090-4B-10	–	India	
ICGV-87160-BWR-1B	–	India	Sharma and Soekarno (1992)
ICGV-88275-BWR-B	–	India	
ICGV-88278-BWR-B	–	India	
Ah3 × NCAc 17090-BWR-2	–	India	
Altika-BWR-2B	–	–	
Taishan Sanlirou	–	China	Zhou and Liu (1962)
Tianjing Dou	–	China	Xu et al. (1980)
Xiekangqing	–	China	Wang et al. (1983)
Huangchuan Zhigan	–	China	
Xiekongchung	–	China	Sun et al. (1981)
Teishan Sanliyue	–	China	
Sueitian	–	China	
Yue You 22	PI 476842	China	Hammons and Porter (1982)[c]
Yue You 589	PI 476834	China	
Yue You 320-14	PI 476824	China	
Hai Hua	PI 476825	China	
Lok-wou	PI 445925	China	Mixon et al. (1983)
Sui-man-tai-zong	PI 445926	China	
Dingzixili	ICG 11506	China	Guang Rou Zheng (1984)[c]
Jinake	ICG 11508	China	
Dunduzai	–	China	
Liamzhou	–	China	
Bairizai	ICG 11505	China	
Bayuchao	–	China	
Yuebeizhong	ICG 11516	China	
Shuikouyazai	ICG 11512	China	
Qujiangdazhiaou	ICG 11650	China	
Yangjiangpudizhan	–	China	
Yue You 92	–	China	Liao et al. (1990)

Table 1. (cont'd.) Groundnut lines/cultivars resistant to bacterial wilt.

Lines/cultivars	Other identity[a]	Country of origin	Reference
Yue You 256	–	China	Yeh (1990)
NC Ac 17124	WCG 168(ICG 1702)	Peru	
NC Ac 17127	WCG 173(ICG 1703)	Peru	
NC Ac 17129	ICG 1704	Peru	
NC Ac 17130	WCG 182(ICG 1705)	Peru	
PI 393531	Tingo Maria (ICG 7893)	Peru	
PI 393641	ICG 7894	Peru	
PI 393528-B	–	Peru	
PI 414332	Resistente Largo (ICG 7900)	Honduras	
ICG 1073	Rasteiro	USA	
ICG 5346	Rasteiro	Brazil	
7343, 8632, 8647	–	Indonesia	
CS 7, CS 30	–	India	
Lu Hua 3	–	China	Liao et al. (1990)
El Hua 5	–	China	
Jin You 3121	–	China	
Guiyou 28	–	China	GAAS (1987), Liao et al. (1990)
Zhong Hua 2	–	China	Wang et al. (1990), Liao et al. (1990)
IPB PN 82-68-16	–	Philippines	Natural et al. (1988)
IPB PN 82-68-174	–	Philippines	
IPB PN 82-70-67	–	Philippines	
IPB PN 82-70-27	–	Philippines	
IPB PN 87-71-27	–	Philippines	
ICG (FDRS) 21, 28, 29, 30, 31	India		Jayasena and Rajapaksa (1990)

[a]ICG = ICRISAT Groundnut Number.
[b]– = Not known.
[c]D. McDonald (pers. comm).

(Yeh 1990). Schwarz 21 has resistance to BW, verticillium wilt and pythium pod rot (Frank and Krikun 1969; Jenkins et al. 1966).

Breeding for resistance to bacterial wilt

Breeding for wilt-resistance was first initiated in Indonesia, where bacterial wilt was the most important groundnut disease. A highly resistant cultivar, Schwarz 21, was selected from a local population of groundnut in the early 1920s. This cultivar was derived from wilt-resistant populations obtained from the Cheribon region of Java, where the disease was especially severe. Schwarz 21 and its derivatives are grown predominantly in Java, and have made groundnut cultivation possible in areas where other cultivars previously suffered heavy yield losses. In the 1950s, crosses between Schwarz 21 and other introductions from Japan, Israel and the USA led to the development of several wilt-resistant cultivars, viz. Gajah, Kidang, Banteng, and Macan. These four wilt-resistant cultivars were released in Indonesia in 1952. Several other crosses between Gajah and Kidang and introductions from Honduras and the USA led to the development of wilt-resistant cultivars Rusa, Anoa, Pelanduk, Tupai and Tapir, and these were released in 1982–83 (Anon. 1983, 1984). Resistance in these cultivars has been verified in several field and greenhouse tests in Indonesia (Machmud 1986; Wakman 1988). Recently, hybridisation of the improved BW-resistant Indonesian cultivars with other accessions has been achieved, with particular emphasis on incorporation of resistance to rust and leaf spots. Emphasis on maintenance of wilt resistance has been a high priority objective throughout the history of crop improvement in Indonesia. Genetic resistance to bacterial wilt is essential, and selections are made in wilt-sick plots. It is noteworthy that resistance can be enhanced by selection under severe bacterial wilt pressure in wilt-sick plots (Sharma and Soekarno 1992).

In the People's Republic of China, breeding efforts in the 1960s led to the development of two moderately resistant cultivars, Yue You 589 and Sueitien. Later an exotic source of wilt resistance was crossed with a local cultivar and several wilt-resistant cultivars, including Yue You 92 and Yue You 256, were developed. During the past 15 years, much attention was given to breeding groundnuts for resistance to BW in China. High yielding wilt-resistant cultivars have been released and have an important role in disease control and increased groundnut production in areas infested with BW. These include Jinyou Guiyou 28, Lu Hua 3, El Hua 5, and Zhong Hua 2 (GAAS 1987; Liao et al. 1990; Wang et al. 1990). Of these, Lu Hua 3 is the highest yielder in infested areas of southern China (He 1990).

Several wilt-resistant germplasm lines and cultivars have been used as resistant parents (Teishan Sanliyue, Teishan Zhenzhu, Xiekongchung, Tianjin Dou, Taishan Sanlirou, Xiekangqing and Schwarz 21) in several wilt-resistance breeding programs in China. Two wilt-resistant lines with good general combining ability, Xiekangqing and Taishan Sanlirou, have been used extensively as resistance donors in wilt-resistance breeding programs (Liao et al. 1990). In recent years, breeding emphasis has been placed on combining BW-resistance with resistances to rust and leaf spot diseases. In breeding for resistance to BW, some parents with rust and late leaf spot resistance have been used, and some breeding lines (Yue You 202, Yue You 266) with resistance to rust and BW have been developed (Liao et al. 1990).

Wilt-resistant groundnut cultivars released in Indonesia and China are given in Table 2. Most of these belong to the Spanish group.

Wilt-resistant cultivars have been developed in lower latitudes, where selection pressures are greatest. This demonstrates a need for extensive evaluation of germplasm in low-latitude areas for sources of bacterial wilt resistance. However, the primary origin of BW-resistant genotypes should be determined.

Genetics and mechanisms of resistance

Although the results from limited inheritance studies (Liao et al. 1986) involving Spanish groundnuts are suggestive of partial dominance of resistance and the involvement of three pairs of major genes and some minor genes, they are not conclusive. More detailed studies with different botanical types and strains or pathotypes in controlled environments are required to elucidate the nature of inheritance of BW resistance in groundnut.

Little is known about the mechanism(s) of resistance to BW. Resistance is probably manifested mainly through host defence to disease development, though there might be differences among cultivars in their ability to resist invasion by *P. solanacearum*.

Table 2. Bacterial wilt-resistant groundnut cultivars released in Indonesia and China.

Cultivar	Pedigree	Year of release
Schwarz 21	Selection from a wilt-resistant line from the Cheribon region of Java (Indonesia)	1925
Gajah	Schwarz 21 × Spanish 18-38	1952
Banteng	Schwarz 21 × Spanish 18-38	1952
Kidang	Schwarz 21 × Small Japan	1952
Macan	Schwarz 21 × Spanish 18-38 Eye 3	1952
Anoa	Gajah × AH 223 (PI350680)	1982
Rusa	Gajah × AH 223 (PI 350680)	1982
Pelanduk	Gajah × Virginia Bunch Improved	1983
Tapir	Kidang × Virginia Bunch Improved	1983
Tupai	US 26 × Kidang	1983
Yue You 92	(Yue You 116 × Xiekangqing) × Yue You 116	--
Yue You 256	(Yue You 116 × Xiekangqing) × Yue You 116	--
Lu Hua 3	Xuzhou 68-4 × Xiekangqing	1982
Jin You 3121	(Dalian × Linyu 1) × Kiekangqing	1984
Guiyou 28	Taishan Sanlirou × Yue You 551	1986
El Hua 5	Xiekangqing × Yue you 589	1985
Zhong Hua 2	El Hua 4 × Taishan Sanlirou	1990

Some infected plants do not display wilting symptoms, and partial wilting symptoms can be observed in resistant genotypes (Liao et al. 1990). The expression of resistance may be influenced by the genetic background of the host plant, inoculum level, virulence of the pathogen and environmental factors.

Stability and durability of resistance

Although it has been suggested that the stability and durability of genetic resistance to BW may be questionable because of the possible genetic variability of the wilt pathogen (Lum 1990), this is not borne out by the continued resistance of cultivars such as Schwarz 21 and Gajah that are extensively grown in Indonesia. These cultivars were released to farmers in 1925 and 1952, respectively. It is noteworthy that in one of the wilt sick plots in the Hubei Province, China a resistant cultivar was successfully grown continuously for nine years without losing its resistance.

There is little information on the distribution and variability of the wilt pathogen in farmers' fields or on the genetic composition of local cultivars. Some studies e.g. Tan et al. 1991 have demonstrated the existence of highly virulent strains or pathotypes (Table 3) and, in the light of these findings, it is important to study stability of resistance through collaborative trials at different disease 'hot spots' and in areas where different strains or pathotypes are suspected. A set of

Table 3. Reactions of groundnut isolates of *Pseudomonas solanacearum* on some diagnostic groundnut cultivars[a].

Cultivars	Pathotypes of *P. solanacearum*[b]						
	1	2	3	4	5	6	7
Xiekangqing	R	R	R	M	M	M	S
Taishan Sanlirou	R	R	M	R	M	M	S
Huangchuan Zhigan	R	M	M	M	M	M	S
Lukangqing	R	M	M	M	M	M	S
Fuhuasheng	S	S	S	S	S	M	S
Ehua 1	S	S	S	S	S	M	S

a. Data from Tan et al. (1991): R = Highly resistant (< 10% wilt incidence); M = Moderately resistant (10-50% wilt incidence); and S = Susceptible (> 50% wilt incidence)

b. Thirty-six isolates from various parts of China were divided into seven pathotypes based on their virulence to six cultivars with different levels of BW-resistance.

differentials should be included in these trials. Some description of the strains of the pathogen to which these lines/cultivars are subjected is obviously important.

Durability of wilt-resistance should be ensured by adopting appropriate breeding strategies and by bringing in new resistance genes from diverse sources and wild species.

Impact of wilt-resistant cultivars

Releases of wilt-resistant cultivars in Indonesia have significantly reduced yield losses in various parts of the country where disease was a serious problem. Two early bred resistant cultivars, Schwarz 21 and Gajah, are widely grown in Java where the disease previously caused heavy yield losses (25–45%) in susceptible cultivars. Some wilt-resistant cultivars (Pelanduk, Tupai) developed in the 1980s are now becoming popular with farmers. The disease in farmers' fields is now sporadic because of the cultivation of improved Indonesian cultivars resistant to BW. Wilt-resistant, high-yielding cultivars play an important role in disease control and increased groundnut production in several provinces of China where BW is a production constraint. El Hua 5 is grown in most of the bacterial-wilt-affected areas, covering over 10000 ha, in central China (Liao et al. 1990). Zhong Hua 2, an early maturing wilt-resistant cultivar with wide adaptation, is becoming popular with farmers in southern China. Yue You 92, Lu Hua 3, Jinyou 3121 and Guiyou 28 are grown extensively in Guangdong, Guangxi, Fujian and Shandong provinces. Some recently developed cultivars have multiple resistances to BW and rust and are awaiting release in the near future. They are expected to further increase groundnut production in areas where both BW and foliar fungal diseases are serious.

Cultural Measures

Rotation of groundnuts with non-host crops such as rice, sugarcane, maize and wheat is an effective means of controlling BW of groundnut (Sun et al. 1981; He 1990). It is possible to minimise and even achieve near complete control of BW following rotation of groundnuts with paddy rice for 3–5 years (Wang et al. 1983; He 1990). Several groundnut-rice rotation systems are widely adopted in irrigated areas of Guangdong, Fujian, Hubei and Shandong provinces of China where the disease is a production constraint. In Guangdong Province of China, rotation of groundnut with sugarcane for 2–3 years has been found effective in reducing BW incidence from 60% to below 10% (OCRI 1977). In the Hubei Province, rotation of groundnuts with wheat is helpful in reducing wilt incidence in uplands. In drylands, rotation of groundnuts with maize, sorghum and sugarcane for longer periods (4–5 years) is useful in containing the disease. In such areas intercropping of groundnuts and maize can also be used as a means of reducing wilt incidence. Intercropping experiments in the Philippines showed that maize was the most effective of several intercrops in reducing BW disease incidence in potatoes (Kloos et al. 1987). Little is known as to how these cropping systems affect the perpetuation and survival of the BW pathogen.

Flooding of groundnut fields for 15–30 days before planting effectively reduces BW incidence (OCRI 1977; Li et al. 1981).

Some soil amendments such as S-H mixture, urea and mineral ash can be useful in reducing BW incidence (Chang and Hsu 1988, Sun and Huang 1985). The S-H mixture is very rich in calcium and silicon, and calcium is likely to enhance host resistance to wilt. Other components of S-H mixture may stimulate soil microbial activity against the wilt pathogen. Further research is required to elucidate mechanisms of BW control following soil amendments.

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

Concluding Remarks

The cultivation of wilt-resistant groundnut cultivars is highly useful in effective management of bacterial wilt. Over 60 germplasm lines have been identified as resistant to BW, and 20 wilt-resistant cultivars have been developed, mainly in China and Indonesia. It is imperative to broaden the genetic base of wilt-resistance by using different parents with high levels of stable resistance, including highly resistant wild *Arachis* species. International 'bacterial wilt nurseries' should be established to test stability of resistance and pathogen variability. Since rust and leaf spot diseases are severe in many areas where BW is a production constraint, priority should be given to incorporating resistances to bacterial wilt, rust and leaf spots into high-yielding cultivars adapted to specific environments. Further genetic evaluation of BW-resistance, involving several strains or pathotypes, is required to devise strategies for effective use of sources of resistance in breeding programs. Priority should be given to testing of selected resistant lines, including differentials, for their reaction to several strains or pathotypes of the pathogen from different regions of the world. This work should be possible in a country where groundnut is not grown and where *P. solanacearum* is not a problem. It is necessary to identify the most virulent strains so that they can be used for screening in breeding programs. Research efforts are needed to elucidate the mechanisms and components of wilt-resistance. Some cultural practices such as rotation with rice, maize or sugarcane and crop sanitation are effective in containing the disease. In irrigated areas or relatively high rainfall areas of southern Asia and Southeast Asia, crop rotation with paddy rice is feasible and is effective in reducing disease levels. 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. Although sanitation practices are helpful in reducing disease levels, the impact of crop sanitation practices, particularly management of crop residues and weeds, on the BW pathogen and the disease needs o be demonstrated. The soil solarisation approach to wilt control should be investigated; this may prove effective in humid tropical countries. Emphasis should be placed on an integrated approach to bacterial wilt control, involving wilt-resistant cultivars, rotation with non-host crops (rice, sugarcane or maize), and crop sanitation.

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