Current status of Panama disease in Thailand

R C Ploetz
A Vázquez
J Nagel
D Benscher
University of Florida, IFAS
Tropical Research
and Education Center
18905 SW 280th Street
Homestead, Florida 33031-3314
USA

P Sianglew
S Srikul
Suratthani Horticultural
Research Center
PO Box 53 Muang
Suratthani 84000
Thailand

S Kooariyakul
Chiang Rai Horticultural
Research Centre Muang District
Chiang Rai 57000
Thailand

W Wattanachaiyingcharoen
Phichit Horticultural
Research Center
Rongchang Muang
Phichit 66000
Thailand

P Lertrat
Chanthaburi Horticultural
Research Center
Khung, Chanthaburi 22110
Thailand

D Wattanachaiyingcharoen
Naresuan University
Faculty of Agriculture
Natural Resources and
Environmental Sciences
Phitsanulok 65000
Thailand

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ABSTRACT
During a survey of banana-production areas in Thailand, Kluai nam wa was essentially the only banana cultivar that was affected by Panama disease. Four different vegetative compatibility groups (VCGs) of the causal fungus, *Fusarium oxysporum* f sp *cubense* (FOC), were recovered. VCG 01218 was found mainly in Southern Thailand (provinces of Narathiwat and Yala), and prior to the survey had only been collected in Java, Sumatra and peninsular Malaysia. It may have been introduced into Southern Thailand from these areas by Yawi-speaking Muslim populations which reside in these areas. VCG 01221 was found only in the north (provinces of Chiang Rai and Nan), and constitutes a new VCG for FOC. In contrast, VCGs 0123 and 0124-0125 were widespread, and had been previously reported in the country. These results are discussed in reference to the population structure of the pathogen in Thailand.

KEYWORDS
Thailand, *Musa*, plant diseases, *Fusarium oxysporum*, vegetative compatibility groups.

État de la maladie de Panama en Thaïlande.

RÉSUMÉ
Une enquête menée dans les régions de production de la banane en Thaïlande a montré que le cultivar Kluai nam wa était pratiquement le seul à y être touché par la maladie de Panama. Quatre groupes de compatibilité végétative différents (VCGs) ont été déterminés pour l'agent pathogène impliqué, *Fusarium oxysporum* f sp *cubense* (FOC). Le groupe VCG 01218 a surtout été observé dans le sud du pays (provinces de Narathiwat et de Yala), et, avant cette enquête, il n'avait été collecté qu'à Java, Sumatra et dans la péninsule malaysienne. Il aurait pu être introduit dans le sud de la Thaïlande à partir de ces régions par les populations Muslim parlant le yawi et installées dans cette zone. VCG 01221 n'a été trouvé que dans le nord (provinces de Chiang Rai et de Nan) et constitue un nouveau groupe de FOC. En revanche, les groupes 0123 et 0124-0125, plus largement distribués, avaient déjà été signalés dans ce pays. Ces résultats sont discutés par rapport à la structure des populations du pathogène en Thaïlande.

MOTS CLÉS
Thaïlande, *Musa*, maladie des plantes, *Fusarium oxysporum*, groupe de compatibilité végétative.

Estado de la enfermedad de Panama en Tailandia.

RESUMEN
Una encuesta llevada a cabo en las regiones de producción del banano en Tailandia mostró que el cultivar Kluai nam wa era prácticamente el único siendo tocado por la enfermedad de Panama. Cuatro grupos de compatibilidad vegetativa diferentes (VCGs) fueron determinados por el agente patógeno implicado, *Fusarium oxysporum* f sp *cubense* (FOC). El grupo VCG 01218 fue sobre todo observado en el sur del país (provincias de Narathiwat y de Yala), y antes de esta encuesta, solamente se colectó en Java, Sumatra y en la península malasiana. Se podría haber introducido en el sur de la Tailandia a partir de estas regiones por las poblaciones Muslim que hablan el Yawi e instaladas en esta zona. VCG 01221 se encontró solamente en el norte (provincias de Chiang Rai y de Nan) y constituye un nuevo grupo de FOC. En cambio, los grupos 0123 y 0124-0125, más abundantemente distribuidos, estaban ya señalados en este país. Estos resultados son discutidos respecto a la estructura de las poblaciones del patógeno en Tailandia.

PALABRAS CLAVES
Thailandia, *Musa*, enfermedades de las plantas, *Fusarium oxysporum*, grupo de compatibildad vegetativa.

introduction

Bananas, *Musa* spp, are the most important fruit in Thailand (POLPRASID, 1990). During a 1984--1985 census, the Department of Agricultural Extension determined that 197 000 ha were planted to the crop which, in turn, yielded an estimated 627 900 tons of fruit. Bananas are used mainly for baby food and as dessert items, although many secondary uses for the crop exist in the country.

Thailand is located in the primary center of diversity for banana (SIMMONDS, 1962), and many different cultivars are grown in the country; SILAYOI (1990) listed 58. Given this array of germplasm, it is surprising that 74% of the land planted to banana in Thailand is of a single cultivar, Kluai nam wa ABB (Pisang awak) (POLPRASID, 1990). Among the reasons for its popularity are the diverse ways in which its fruit can be utilized (they can be eaten either cooked or raw), and the cultivar's drought tolerance, a key asset in a country with a monsoon climate.

Unfortunately, Kluai nam wa is susceptible to Panama disease. This lethal, vascular disease, which is also known as fusarium wilt, is caused by a soilborne fungus, *Fusarium oxysporum* f sp *cubense* (FOC). Panama disease is one of the most destructive diseases that affects banana (PLOETZ, 1994). Known locally as 'tai-prai' (dies off), it was first reported from Thailand (Siam) by REINKING (1934), and is now recognized as a major production constraint (VALMAYOR et al, 1990). However, despite its importance, little is known about the disease and causal agent in the country (SINGBURAUDOM, 1991).

The present paper is a synopsis of Panama disease surveys conducted in Thailand during the 1990s, but focuses primarily on a survey conducted in 1995. Objectives of the latter mission were to collect FOC from areas in Thailand that had not been previously surveyed, and to investigate whether wild populations of *Musa acuminata* were affected by the disease in these areas. Ancillary objectives of this work were to summarize the known distribution of the disease and clones that are affected in the country, and to assess diversity and relationships among populations of the pathogen in Thailand via vegetative compatibility analyses. Vegetative compatibility groups (VCGs) represent clonally derived populations of fungal taxa (LESLIE, 1993). For an asexual taxon like FOC, VCGs can provide important information on population structure, as well as insight into the origins of populations in a given area and their relationships with populations in other geographical locations (PLOETZ, 1994).

materials and methods

surveys

Prior to 1995, tissue samples from banana plants with symptoms of Panama disease were collected in Thailand[1]. Monoconidial isolates from LESLIE's samples were identified as *F oxysporum* by NELSON[2], and forwarded directly to PLOETZ for VCG determinations. Samples collected by JONES, KOOARIYAKUL and SINGBURAUDOM were forwarded to PEGG and MOORE[3], in Australia.

During May and June, 1995, another survey was conducted in Thailand with a primary objective of collecting FOC from areas that had not been covered during the above surveys. In total, the major banana-producing areas in the country had been assessed when the 1995 survey was completed.

During the 1995 survey, ca 140 locations in Northern, Southern, Southeastern and Eastern Thailand were examined for Panama disease. Locations were either sites in which plants with external symptoms of Panama disease were observed, or were those with wild *M acuminata*. At all locations, plants were examined internally for symptoms of Panama disease. Tissue pieces were collected mainly from plants with internal symptoms, but additional samples were taken from some asymptomatic plants to determine whether these plants were also infected by FOC. All tissue samples were partially dried by blotting in newspaper, and shipped by airmail to RCP's laboratory in the USA. Upon receipt, tissue pieces were processed for recovery of monoconidial isolates of FOC as described previously (PLOETZ et al, 1994).

(1) The following individuals took part in the banana tissue sample collections: David Jones, Inibap, Montpellier, France; Surachart Kooariyakul, Chiang Rai Horticultural Research Centre, Chiang Rai, Thailand; John Leslie, Kansas State University, Department of Plant Pathology, Manhattan, KS, USA; Narong Singburaudom, Microbiology Division, Kasetsart University, Chatuchak, Bangkok 10900, Thailand.

(2) Paul Nelson, Pennsylvania State University, USA.

(3) Ken Pegg and Natalie Moore, QDPI, Indooroopilly, Australia.

VCG determinations

Nitrate-nonutilizing (*nit*) mutants were generated for monoconidial isolates from LESLIE's and the 1995 surveys, and classified for *nit* phenotype as described by CORRELL et al (1987). NitM and *nit*1 mutants were paired, respectively, with *nit*1 and NitM testers of VCGs 0120–01220 in the FOC collection of PLOETZ. If complementation between *nit* mutants of the survey isolates and testers did not occur, additional NitM X *nit*1 pairings were made among the non-complementing mutants. All complementation pairings were conducted at least twice.

Isolates from samples collected by JONES, KOOARIYAKUL and SINGBURAUDOM were classified to VCG by PEGG and MOORE (MOORE and PEGG, unpublished; PEGG et al, 1993, 1994). These isolates are listed in table I with the corresponding collector.

results

Although 140 locations were visited during the 1995 survey, tissue samples were collected from only 78 plants. Many plants which had what appeared to be external symptoms of Panama disease were free of internal symptoms of the disease. This was especially common on Kluai nam wa and a cultivated clone of *M balbisiana*, Kluai tani. The factors that were most often associated with these false symptoms were water-logged soils and damage caused by the stem borer, *Odioporus longicollis*.

Four of the 78 samples were from cultivars other than Kluai nam wa. Single samples were recovered from Kluai lanka? AAB (resembled Mysore), Kluai thong AAB, Kluai hak muk ABB (Bluggoe), and Kluai tani; only the former plant had internal symptoms of Panama disease and ultimately yielded FOC. Wild diploid bananas (*M acuminata* ssp *malaccensis* and *M acuminata* ssp *siamea*) were observed throughout the country, but were most common in the south and central plain. However, none of these plants were ever observed with external or internal symptoms of Panama disease, and the few asymptomatic plants that were harvested and assayed for FOC did not yield the pathogen.

Seventy-three of the 78 samples were taken from symptomatic plants, and 57 of these (78%) yielded isolates that could eventually be placed in one of four different VCGs (table I). Five isolates were in the VCG 0124-0125 complex (PLOETZ, 1990), based on compatibility amongst testers for these VCGs, and six isolates were in VCG 01218, a VCG that had been reported previously from Java, Sumatra and peninsular Malaysia, but not Thailand (PEGG et al, 1994). Four other isolates were neither compatible with testers for VCGs 0120–01220, nor with other isolates from the survey. However, they were compatible amongst themselves, and comprise a new VCG, 01221.

Although 42 of the isolates were in VCG 0123, this became evident only after extensive compatibility tests were conducted. Twenty-two of the 42 isolates in VCG 0123 were not compatible with testers for VCG 0123 when paired in standard NitM × *nit*1 combinations (CORRELL et al, 1987), and, in preliminary tests, several of these isolates were compatible with less than 10% of the other Thai isolates that had been tentatively placed in VCG 0123.

To further investigate these relationships, more than 300 different pairings were made between NitM and *nit*1 mutants of a subset of 31 of these isolates (table II). In general, isolates fell into two distinct subgroups. One subgroup of isolates complemented 0123 testers 79% of the time (19 of 24 pairings) and were compatible amongst themselves 84% of the time (169 of 200). Isolates in the other subgroup did not complement 0123 testers, but were compatible in 60% (12/20) of the pairings amongst themselves. When isolates in the two subgroups were compared, complementation was observed in only 10% of the pairings (9 of 94). For the purpose of discussion, the 0123 subgroups will be referred to, respectively, as 0123A and 0123B.

In general, subgroup 0123B, and VCGs 01218 and 01221 had restricted geographic distributions in Thailand (fig 1). With single exceptions, 0123B was found in Southeastern Thailand (provinces of Chanthaburi, Nakhon Nayok, Si Sa Ket and Ubon Ratcha-

Tableau I
VCGs, and location and cultivar from which isolates of *Fusarium oxysporum* f sp *cubense* were recovered in Thailand.

Accession	Cultivar	Collector[a]	Location
		VCG 0123	
JLTH 4[b]	Kluai nam wa sai daeng	LESLIE	Smoeng hwy 1269, Chiang Mai Province
JLTH 5	Kluai nam wa sai daeng	LESLIE	Smoeng hwy 1269, Chiang Mai Province
THAI 1-2	Kluai nam wa	SINGBURAUDOM	Ban Sakainam, Phetchabun Province
THAI 2-1	Kluai nam wa	SINGBURAUDOM	Ban Sakainam, Phetchabun Province
THAI 2-2	Kluai nam wa	SINGBURAUDOM	Ban Sakainam, Phetchabun Province
THAI 2-3	Kluai nam wa	SINGBURAUDOM	Ban Sakainam, Phetchabun Province
THAI 3-1	Kluai nam wa	SINGBURAUDOM	Pak Chong, Nakorn Ratchasima Province
THAI 4-2	Kluai nam wa	SINGBURAUDOM	Suwan Farm, Pak Chong
THAI 10	Kluai nam wa	SINGBURAUDOM	Kampangsan, Nakorn Pathom Province
THAI 19-1	Kluai nam wa	SINGBURAUDOM	Chiang Mai
THAI 19-2	Kluai nam wa	SINGBURAUDOM	Chiang Mai
THAI 20-2	Kluai nam wa	SINGBURAUDOM	Thasae, Chumphon Province
THAI 21	Kluai nam wa	JONES	Bangkra Thum, Phitsanuloke Province
THAI 25	Kluai nam wa	KOOARIYAKUL	Mea Chan District, Chiang Rai Province
THAI 29	Kluai nam wa	KOOARIYAKUL	Muang Nan District, Nan Province
THAI 30	Kluai nam wa	KOOARIYAKUL	Sung Men District, Phrae Province
THAI 31	Kluai nam wa	KOOARIYAKUL	Den Chai District, Uttaradit boundary
THAI 32	Kluai nam wa	KOOARIYAKUL	Laplae District, Uttaradit Province
THAI 33	Kluai nam wa	KOOARIYAKUL	Mae Lao District, Chiang Rai Province
THAI 34	Kluai nam wa	KOOARIYAKUL	Mae Suai, Chiang Rai Province
THAI 36	Kluai nam wa	KOOARIYAKUL	Mae Lao District, Chiang Rai Province
THAI 37	Kluai nam wa	KOOARIYAKUL	Muang Chiang Rai District, Chiang Rai Province
THAI 38	Kluai nam wa	KOOARIYAKUL	Theong District, Chiang Rai Province
RPTH 1	Kluai nam wa	PLOETZ	Ban Na, Nakhon Nayok Province
RPTH 2	Kluai nam wa	PLOETZ	Ban Na, Nakhon Nayok Province
RPTH 3	Kluai nam wa	PLOETZ	Ban Na, Nakhon Nayok Province
RPTH 6	Kluai nam wa	PLOETZ	Pong Nam Ron, Chanthaburi Province
RPTH 7	Kluai lanka ?[c]	PLOETZ	Pong Nam Ron, Chanthaburi Province
RPTH 9	Kluai nam wa	PLOETZ	Pong Nam Ron, Chanthaburi Province
RPTH 10	Kluai nam wa	PLOETZ	Pong Nam Ron, Chanthaburi Province
RPTH 11	Kluai nam wa	PLOETZ	Ban Tareang District, Chanthaburi Province
RPTH 12	Kluai nam wa	PLOETZ	Ban Tareang District, Chanthaburi Province
RPTH 13	Kluai nam wa	PLOETZ	Ban Tareang District, Chanthaburi Province
RPTH 15	Kluai nam wa	PLOETZ	Ban Mai, Satun Province
RPTH 16	Kluai nam wa	PLOETZ	Ban Mai, Satun Province
RPTH 17	Kluai nam wa	PLOETZ	Ban Mai, Satun Province
RPTH 18	Kluai nam wa	PLOETZ	Ban Mai, Satun Province
RPTH 20	Kluai nam wa	PLOETZ	Thale Ban National Park, Satun Province
RPTH 21	Kluai nam wa	PLOETZ	Sikao, Trang Province
RPTH 23	Kluai nam wa	PLOETZ	Kapang District, Trang Province
RPTH 25	Kluai nam wa	PLOETZ	Bang Bat Yai, Surat Thani Province
RPTH 26	Kluai nam wa	PLOETZ	Na-Tawee, Songkhla District, Songkhla Province
RPTH 35	Kluai nam wa	PLOETZ	Ban Huay Yang, Ubon Ratchathani Province
RPTH 37	Kluai nam wa	PLOETZ	Ban Huay Yang, Ubon Ratchathani Province
RPTH 38	Kluai nam wa	PLOETZ	Ban Huay Yang, Ubon Ratchathani Province
RPTH 40	Kluai nam wa	PLOETZ	Ban Huay Yang, Ubon Ratchathani Province
RPTH 41	Kluai nam wa	PLOETZ	Ban Huay Yang, Ubon Ratchathani Province
RPTH 46	Kluai nam wa	PLOETZ	Si Sa Ket, Si Sa Ket Province
RPTH 50	Kluai nam wa	PLOETZ	Tha Tum, Surin Province
RPTH 51	Kluai nam wa	PLOETZ	Tha Tum, Surin Province
RPTH 52	Kluai nam wa	PLOETZ	Tha Tum, Surin Province
RPTH 57	Kluai nam wa	PLOETZ	Chiang Rai
RPTH 58	Kluai nam wa	PLOETZ	Chiang Rai
RPTH 59	Kluai nam wa	PLOETZ	Mae Chan, Chiang Rai Province
RPTH 60	Kluai nam wa	PLOETZ	Mae Chan, Chiang Rai Province
RPTH 61	Kluai nam wa	PLOETZ	Mae Chan, Chiang Rai Province

Tableau I (continued)

Accession	Cultivar	Collector[a]	Location
		VCG 0123 (continued)	
RPTH 62	Kluai nam wa	PLOETZ	Mok Cham Royal Project (Ahka vill) Chiang Mai Prov
RPTH 66	Kluai nam wa	PLOETZ	Lampang, Lampang Province
RPTH 68	Kluai nam wa	PLOETZ	Rong Kwang District, Phrae Province
RPTH 71	Kluai nam wa	PLOETZ	Tha Wang Pha, Nan Province
RPTH 72	Kluai nam wa	PLOETZ	Tha Wang Pha, Nan Province
RPTH 76	Kluai nam wa	PLOETZ	n. of Thung Chang, Chiang Krang Dist., Nan Prov.
RPTH 77	Kluai nam wa	PLOETZ	Sung Men District, Phrae Province
RPTH 78	Kluai nam wa	PLOETZ	Northeast of Uttaradit, Uttaradit Province
RPTH 79	Kluai nam wa	PLOETZ	Luba Lae District, Uttaradit Province
		VCG 0124-0125	
JLTH 1	Kluai nam wa	LESLIE	Smoeng hwy 1269, Chiang Mai Province
JLTH 2	Kluai nam wa sai daeng	LESLIE	Smoeng hwy 1269, Chiang Mai Province
JLTH 3	Kluai nam wa sai daeng	LESLIE	Smoeng hwy 1269, Chiang Mai Province
JLTH 7	Kluai nam wa sai daeng	LESLIE	Smoeng hwy 1269, Chiang Mai Province
JLTH 15	Kluai nam wa	LESLIE	Chai Yo hwy
JLTH 16	Kluai nam wa	LESLIE	Ban Nok
JLTH 17	Kluai nam wa	LESLIE	Ban Nok
JLTH 18	Kluai nam wa	LESLIE	Ban Nok
JLTH 19	Kluai nam wa	LESLIE	Ban Nok
JLTH 20	Kluai nam wa	LESLIE	Ban Nok
JLTH 21	Kluai nam wa	LESLIE	Ban Nok
THAI 6-1	Kluai nam wa	SINGBURAUDOM	Ban Pa Kew, Kanchana Buri Province
THAI 7-1	Kluai nam wa	SINGBURAUDOM	Ban Thunga, Kanchana Buri Province
THAI 7-2	Kluai nam wa	SINGBURAUDOM	Ban Thunga, Kanchana Buri Province
THAI 8-1	Kluai nam wa	SINGBURAUDOM	Thaiyok, Kanchana Buri Province
THAI 9-1	Kluai nam wa	SINGBURAUDOM	Thongphapoom, Kanchana Buri Province
THAI 9-2	Kluai nam wa	SINGBURAUDOM	Thongphapoom, Kanchana Buri Province
THAI 12-1	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 12-2	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 13	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 14	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 15-1	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 15-2	Kluai nam wa	SINGBURAUDOM	Kanchana Buri Province
THAI 17	Kluai nam wa	SINGBURAUDOM	Ayutthaya
THAI 26	Kluai nam wa	KOORIYAKUL	Mae Ai District, Chiang Mai Province
THAI 39	Kluai nam wa	KOOARIYAKUL	Theong District, Chiang Rai Province
RPTH 14	Kluai nam wa	PLOETZ	Ban Mai, Satun Province
RPTH 49	Kluai nam wa	PLOETZ	Tha Tum, Surin Province
RPTH 63	Kluai nam wa	PLOETZ	Ma Ai, Chiang Doa District, Chiang Mai Province
RPTH 64	Kluai nam wa	PLOETZ	Sarapi District, Chiang Mai Province
RPTH 70	Kluai nam wa	PLOETZ	Nan, Nan-Pua Road, Nan Province
		VCG 01218	
RPTH 28	Kluai nam wa	PLOETZ	hwys 410 X 4063, Yala Province
RPTH 29	Kluai nam wa	PLOETZ	Ba Cho, hwy 42, Narathiwat Province
RPTH 30	Kluai nam wa	PLOETZ	hwys 42 X A18, Narathiwat Province
RPTH 31	Kluai nam wa	PLOETZ	Tak Bai, Narathiwat Province
RPTH 33	Kluai nam wa	PLOETZ	hwys 42 X 4155, Narathiwat Province
RPTH 67	Kluai nam wa	PLOETZ	hwys 11 X 102, Uttaradit Province
		VCG 01221	
RPTH 54	Kluai nam wa	PLOETZ	north of Chiang Rai, hwy 1
RPTH 55	Kluai nam wa	PLOETZ	north of Chiang Rai, hwy 1
RPTH 56	Kluai nam wa	PLOETZ	north of Chiang Rai, hwy 1
RPTH 75	Kluai nam wa	PLOETZ	Thung Chang, Chiang Krang District, Nan Province

[a] See note (1).
[b] This strain was erroneously reported to be in VCG 0124 in a previous publication (PEGG et al, 1993). Kluai nam wa sai daeng is a mutant of Kluai nam wa whose fruit has red flesh (SILAYOI and CHOMCHALOW, 1987).
[c] Since this plant resembled Myrose, it was assumed to be Kluai lanka (SILAYOI and CHOMCHALOW, 1987).

Tableau II
Isolates of *Fusarium oxysporum* f sp *cubense* from Thailand: vegetative compatibility within VCG 0123.

	T	J5	7	11	13	15	16	18	20	21	23	25	26	38	41	50	51	52	57	58	59	60	61	62	68	1	2	3	6	35	40	46	66	
T	+	+	–	–	+	+	+	+	–	+	+	+	–	+	–	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	T
J5		+	+	+	+	–	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	–				–		+		J5
7			+			–	+			–	+			+	–	+	+	–	+	+	–	+	+	–	–	–	–	–	+	–	+	+	+	7
11											+				–	+	+		+	+		+	+									–		11
13						+					+				–	+	+		+	+		+	+									–		13
15							+			+	+		169/200		–	+.	+		+	+		+	+	+				9/94				–		15
16										+	+				+	+	+		+	+		+	+									–		16
18										–	+				–	+	+		+	+		+	+	–								+		18
20											+					+	+		+	+	–	+	+	–								–		20
21										+	+			+	+	+	+	+	+	+	+	+	+	–	+	–	–	–	–	–	–	–	–	21
23											+	+	+	+	+	+	+	+	+	+		+	+	–	+	–	–	–	–	–	–	–		23
25															–	+	+		+	+		+	+									–		25
26															–	+	+		+	+		+	+									–		26
38															+	+	+		+	+			+									+		38
41															–	+	+	–	+	+		+	+	–	–	–	–	–	–	–	–	–		41
50																+	+	+	+	+	+	+	+		+	–	–	–	–	–	–	–		50
51																	+	+	+	+	–	+	+	–	+	–	–	–	–	–	–	–		51
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62																								+	+	–	–	–	–			–		62
68																												–						68
1																										+		+	–			–		1
2																												+		–		–	–	2
3																												+		–	–	+	–	3
6																												12/20				+	+	6
35																																	+	35
40																																+	+	40
46																																+	+	46
66																																		66
	T	J5	7	11	13	15	16	18	20	21	23	25	26	38	41	50	51	52	57	58	59	60	61	62	68	1	2	3	6	35	40	46	66	

+ = At least one NitM and *nit*1 combination of the specified wildtypes complemented each other; – = no complementation between one to several NitM and *nit*1 combination of the specified wildtypes. T = testers for VCG 0123 from world FOC collection of senior author, and the remaining isolates are listed in table I; J5 = JLTH 5, and 1 to 66 = RPTH 1 to RPTH 66.

thani), and VCG 01218 was found in Muslim areas in the southern tip of the country (provinces of Yala and Narathiwat). Without exception, VCG 01221 was found only in the far north (provinces of Chiang Rai and Nan). In contrast, the 0123A subgroup and 0124-0125 complex were widely distributed in Thailand.

discussion

PITAKPRAIWAN (1985) surveyed production areas in Thailand for banana diseases. Panama disease was reported from the Central plain and the Northeastern portions of the country, and Kluai nam wa was the only cultivar that was affected. Based on subsequent surveys, it is now clear that the disease occurs in virtually all production areas in the country (fig 1). However, with one exception from the 1995 survey (Kluai lanka), the disease is still found only on Kluai nam wa.

Kluai hom thong AAA was observed frequently during the 1995 survey, often in close proximity to dying plants of Kluai nam wa (Pisang awak), a race 1 suscept (STOVER, 1990). In none of these cases were internal or external symptoms of Panama disease noted on Kluai hom thong. STOVER and SIMMONDS (1987) indicated that Kluai hom thong (Klue hom tong in their book) is a synonym of Gros Michel, also a race 1 suscept, but SILAYOI and CHOMCHALOW (1987) listed it as synonym of Giant Cavendish (K Hom Thong or K Hom in their paper), which is resistant to race 1. Thus, there is some confusion as to whether the absence of Panama disease on Kluai hom thong in the above cases was anomalous. Based on the pale pink or green coloration of leaf undersheaths of Kluai hom thong versus the red coloration expected of the Cavendish subgroup, and the bright yellow coloration of its fruit when ripe, which are greenish in the Cavendish clones, it is clear that Kluai hom thong is a member of the Gros Michel group. Kluai hom thong does, however, have a shorter stature than Gros Michel and might be more closely aligned to Highgate or Lowgate, dwarf variants of the former cultivar. Both of the later clones are also susceptible to race 1. Thus, since affected race 2 and race 4 suscepts, respectively Kluai hak muk (Bluggoe) and Kluai hom khew AAA (Cavendish), were not observed during the survey, it is possible that an unique race may affect Kluai nam wa in Thailand. Work is needed to determine the racial structure of FOC in this country.

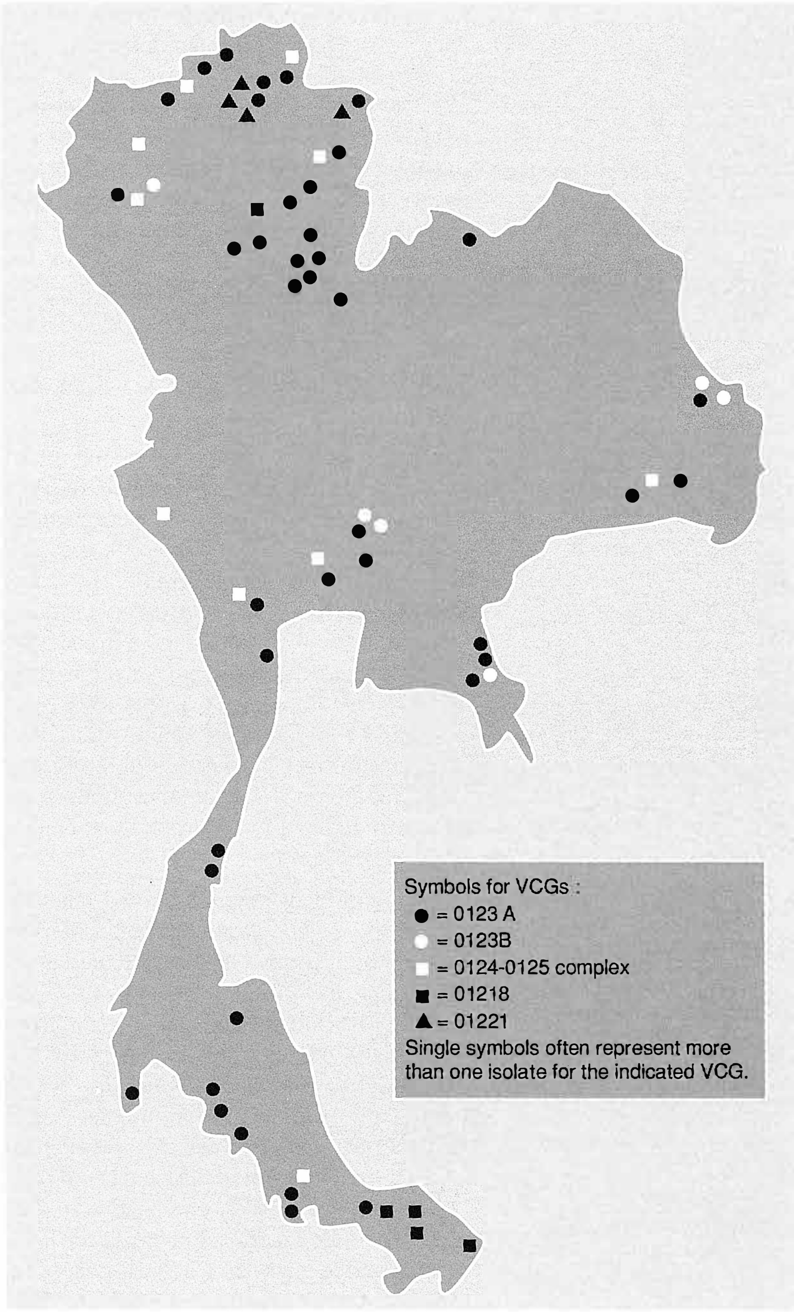

Figure 1
Locations of different vegetative compatibility groups (VCGs) in Thailand. Data for map were taken from table I and II.

Panama disease has a worldwide distribution, but is thought to have originated in Southeast Asia (PEGG et al, 1994; PLOETZ, 1994). Several different types of data support this assumption, including the diversity of VCGs that have been reported from the region. In no other production region are there as many VCGs as are found in Southeast Asia. However, most of this diversity is restricted to Indonesia and Malaysia, and relatively few VCGs are found in other countries in the region. For example, only VCGs 0123 and 0124–0125 had been reported from Thailand before the present paper (PLOETZ, 1994). Although two additional VCGs were found in the country during the 1995 survey, 01218 and 01221, it is clear that diversity in this pathogen is narrow in Thailand when compared to its neighboring countries to the south.

Eight and nine VCGs have been reported from, respectively, Indonesia and Malaysia. More importantly, the range of cultivars that are affected in these countries is extensive and includes some that were thought previously to resist Panama disease (eg, Cavendish and Pisang mas AA) (PEGG et al, 1994; PLOETZ, 1994). Although the factors that are responsible for the distinctly different situations in Thailand versus Indonesia and Malaysia are not clear, the following possibilities are suggested.

The significance and long history of a single cultivar in Thailand should influence FOC diversity in the country. Kluai nam wa has probably been the most important cultivar in Thailand for centuries. PLOETZ observed paintings of this cultivar on a temple wall in Nan that were more than 300 years old, and Thailand's monsoon climate indicates that only a drought-tolerant banana like Kluai nam wa would do well during the country's long dry season. Once native people had identified a cultivar that was well-adapted, they may have felt little need to introduce new cultivars and, hence, new populations of FOC.

More important, however, may be the routes by which ancient people migrated through Thailand. Almost always, these ethnic groups have come from the north, east and west (ULACK and PAUER, 1988). The scant data that exist for FOC in some of these areas indicate that the pathogen may be even less diverse in these areas than in Thailand. To date, only the VCG 0124-0125 complex has been found in China, India and Vietnam (PEGG et al, 1994; PEGG, personal communication). However, migrations from the south have also occurred to a limited extent (ULACK and PAUER, 1988).

With the arrival of new ethnic and religious groups, one might expect FOC populations in Thailand to diversify. In fact, circumstances surrounding the presence of VCG 01218 in Southern Thailand suggest that this may have happened in this area. Although Thailand is 95% Buddhist, Muslims account for major portions of the populace in the far south (COLLINS, 1992). This is especially true in areas in which VCG 01218 was detected during the 1995 survey (provinces of Narathiwat and Yala). Yawi, the traditional language of Java, Sumatra and peninsular Malaysia is spoken by the Muslim populations in Southern Thailand (COLLINS, 1992). It is precisely the former locations in which VCG 01218 was first detected (PEGG et al, 1994). In addition, Southern Thailand is one of the few areas in the country where Kluai hin ABB (Saba or Pisang batu) is grown. Kluai hin is used exclusively by the Muslim populations in the south, and it is one of the original cultivars from which VCG 01218 was recovered on Sumatra. Although definitive proof is lacking, it is possible that Muslim populations in Indonesia or Malaysia may have introduced VCG 01218 into southern Thailand on Kluai hin or other susceptible cultivars.

Coevolution of plant pathogens and their hosts is a widely accepted phenomenon that is felt to play a major role in plant: pathogen interactions in natural communities (BURDON and JAROSZ, 1988). If FOC coevolved with banana in Southeast Asia, one might expect to observe Panama disease on wild diploids that occur throughout Thailand. However, despite the frequent occurrence of wild diploids in the surveyed areas, Panama disease was not found on these plants. Thus, these results shed no light on whether susceptibility to Panama disease arose in native diploid populations. If FOC were to be found on wild diploids in the future, its relationship to populations of the pathogen from cultivated bananas could provide important information on the evolution of this pathosystem.

The bridging phenomenon observed during this work between the A and B subgroups of VCG 0123 is analogous to that previously reported to occur between VCGs 0124 and 0125 (PLOETZ, 1990). In the latter study, ca one-half of the isolates in VCG 0124 were compatible with those in VCG 0125, and virtually all isolates within a given VCG were compatible (respectively, 100% and 98%). The 0123 situation differs in that complementation, especially between isolates in the two subgroups, was much less frequent. Clearly, unless promiscuous or more than a single set of testers were used in the present work, many of these isolates would not be considered to be members of VCG 0123. Means by which promiscuous testers could be identified would be very useful.

In summary, the number of isolates of FOC from Thailand that are now available for study was increased more than two-fold by the described collecting mission. Readers who desire more information on this research, or wish to obtain isolates or mutants listed in this article, should contact the senior author.

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