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Shade trees are alternative hosts of the cocoa pathogen *Phytophthora megakarya*

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Abstract

Two methods of isolation, direct plating on selective agar medium and baiting with cocoa pod husks, were used to isolate *Phytophthora megakarya* from root pieces of some shade trees. Isolates were identified on the basis of their growth rates, colony morphology and sporangium characteristics. Pathogenicity tests were conducted on detached green mature cocoa pods and stems of the relevant host trees. After 36 months of sampling and baiting, *P. megakarya* was isolated from the roots of four out of 34 shade tree species examined. The host trees were *Funtumia elastica* (Apocynaceae), *Sterculia tragacantha* (Sterculiaceae), *Dracaena mannii* (Agavaceae) and *Ricinodendron heudelotii* (Euphorbiaceae). *P. megakarya* isolations were made in both the dry and wet seasons. The rate of recoveries were very low in both seasons ranging from 0.6% to 1.2%. The highest recoveries were in October and the lowest in December and February. In general, plating onto medium was slightly superior to cocoa pod husk baiting for the recovery of *P. megakarya*. Colonies of *P. megakarya* isolates from the trees were morphologically indistinguishable from a reference isolate, but were less virulent on cocoa pods than the reference isolate from cocoa. The epidemiological significance of these findings are not clear, but roots of the host trees were likely to be sites for survival and not for multiplication of *P. megakarya*. Field observation indicated that levels of black pod incidence on cocoa trees around the affected shade trees were not greater than those in other parts of cocoa plantation. This is the first reported isolations of *P. megakarya* from roots of plants other than cocoa.

Keywords: *Phytophthora megakarya*; Alternative hosts; Cocoa

1. Introduction

Two species of *Phytophthora*, *P. palmivora* and *P. megakarya* are the main causal pathogens of black pod disease of cocoa in West Africa. *P. palmivora* has been reported on a large number of host plants. Ashby (1929) described *P. palmivora* as an omnivorous tropical fungal pathogen of world-wide distribution, existing as a number of morphologically and sometimes pathologically distinguishable strains on a wide range of cultivated plants. Over 60 host plants are known to be attacked by *P. palmivora* and of these about 40 occur in Ghana (Turner, 1961; Macfarlane, 1968). Chee (1969) also listed 138 plant species as hosts of *P. palmivora* of which 78 are economically important whilst the rest are ornamental, shade or hedge plants. The host plants were grouped into their respective families by Nienhaus (1960), and these included members of the Sterculiaceae, Palmae, Euphorbiaceae, Araceae and Caricaceae.

From available literature, the only known host of *P. megakarya* is *Theobroma cacao* (Brasier and Griffin, 1979b). The world distribution of *P. megakarya* suggests that the fungus is indigenous to West Africa, apparently confined to the West African Sub Region including Nigeria, Cameroun, Equatorial Guinea, Gabon, Togo and Ghana (Brasier and Griffin, 1979a; Djiekpor et al., 1981; Dakwa, 1987). To date, it is only in Cote d'Ivoire that *P. megakarya* incidence has not yet been reported. This suggests that *P. megakarya* had some wild or alternative host(s) plants before cocoa was introduced into the West African Sub Region. In Ghana, *P. palmivora* was reported as indigenous to forest soils (Dakwa, 1974), and the use of *Gmelina arborea* as a shade tree for cocoa was discouraged partly because its fruits supported growth of *P. palmivora* after falling on the soil (Asare-Nyako, 1969).

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In Ghana, studies to determine alternative hosts of *Phytophthora* spp. and their role in the epidemiology of the black pod disease on cocoa have not been carried out. The objectives of the presently reported research were to determine the alternative hosts of *P. megakarya,* to find out if roots of such hosts are sites for pathogen survival particularly during the dry season, and to determine the survival structures of the pathogen.

2. Materials and methods

2.1. Experimental site

The experiment was conducted on a 5 ha Cocoa Station plot at Bechem in the Brong Ahafo Region of Ghana. The plot was planted in 1984 with two hybrid families (T79/501 × Amel, and T60 × Na45) spaced at 8×8 m and 10×10 m. Approximately 3 ha of the cocoa farm had a closed canopy and about 2 ha an open canopy, and a few weeds were present at the start of the experiment.

Cocoa plants in the test plot were known to be infected mainly with *P. megakarya*. Out of the 50 isolates recovered from cocoa pods in 1995 before the experiment began, 48 (96%) were identified as *P. megakarya* and only two (4%) as *P. palmivora*. Other diseases prevalent on the plot were stem canker (caused by *P. megakarya*), mealy pod (caused by *Trachysphaera fructigena*), charcoal rot (caused by *Botryodiplodia theobroma*) and white thread (caused by *Marasmus scandens*).

2.2. Root sample collection

Thirty-four (34) shade trees (Table 1) growing on the test site were identified. Superficial feeder roots of ≈1–2 cm thick were taken from a depth of between 20 and 50 cm (depending on the type of shade tree) from two sides of each tree. Root samples had no visible lesions. Each sample was placed in a black plastic polythene bag and stored in a refrigerator at 4°C for 1–2 weeks during which isolations were made. Samples were collected in June, August, October, December, February and April during the1996/97, 1997/98 and 1998/99 cocoa crop seasons.

2.3. Isolation and identification of Phytophthora species

The roots were washed under running tap water to remove soil and pieces of other root segments. Approximately 1–2 cm pieces were excised from the roots with a razor blade, washed in three changes of sterile distilled water (SDW), then surface sterilized by a 5 min immersion in 10% sodium hypochlorite solution and blotted dry on a paper towel. The root pieces were then washed again in SDW on a flask shaker for 1 h. One hundred root pieces were cut from each test tree and these were then divided into two groups of 50 root pieces each.

Two methods of isolation were used: baiting with cocoa pod husks and direct plating on *P. megakarya* and *P. palmivora* agar (PPMA) (Opoku, 1994). Fifty root pieces from each test tree were inserted into whole green mature cocoa pod husks (10 pieces/pod), sprayed with SDW and incubated at room temperature (25–28°C) in a humid transparent polythene bag for 8 d and developing lesions transferred onto 10% Campbell 'V8' vegetable juice agar (V_8A). With the PPMA medium (containing 10 μg/ml pimaricin, 25 μg/ml rifamycin, 100 μg/ml PCNB and 25 μg/ml hymexazol in 1% V_8A), aliquots of 10 ml were placed in 9 cm petri dishes and 50 root pieces per test tree plated (10 pieces/plate), incubated in the dark at 25–28°C and examined daily for 5 d for the presence of *P. megakarya* and *P. palmivora*. Emerging colonies from the pod husks and the PPMA were subcultured and stored on slants of oatmeal agar until they could be identified.

Table 1
Forest trees tested to determine their susceptibility to *P. megakarya*

Botanical name (plants tested)	Family
Milicia excelsa (2)	Moraceae
Spathodea campanulata (1)	Bignoniaceae
Terminalia superba (3)	Combretaceae
Funtumia elastica (3)	Apocynaceae
Ricinodendron heudelotii (3)	Euphorbiaceae
Pycnanthus angolensis (3)	Myristicaceae
Triplochiton scleroxylon (4)	Sterculiaceae
Petersianthus macrocarpus (1)	Lecythidaceae
Antiaris toxicaria (2)	Moraceae
Sterculia tragacantha (2)	Sterculiaceae
Cola nitida (2)	Sterculiaceae
Ficus asperifolia (1)	Moraceae
Persea americana (2)	Lauraceae
Alstonia boonei (2)	Apocynaceae
Amphimas pterocarpoides (2)	Caesalpiniaceae
Albizia zygia (2)	Mimosaceae
Celtis mildbraedii (2)	Ulmaceae
Hannoa klaineana (2)	Simaroubaceae
Entandrophragma angolense (3)	Meliaceae
Tetrapleura tetraptera (1)	Mimosaceae
Lannea welwitschii (2)	Anacardiaceae
Ficus exasperata (1)	Moraceae
Manihot glaviovii (1)	Euphorbiaceae
Bombax buonopozense (1)	Bombacaceae
Cleistopholis patens (1)	Annonaceae
Ficus capensis (1)	Moraceae
Citrus sinensis (1)	Rutaceae
Myrianthus arboreus (1)	Moraceae
Carica papaya (1)	Caricaceae
Albizia ferruginea (1)	Mimosaceae
Dracaena manii (2)	Agavaceae
Gliricidia sepium (2)	Papillionaceae
Trichilia monadelpha (1)	Meliaceae
Holarrhena floribunda (1)	Apocynaceae

Isolates were identified on the basis of growth rate on V_8A agar and green mature cocoa pods, colony morphology, sporangium production and sporangia characteristics.

2.4. Pathogenicity test

Stock cultures of isolates recovered from the test trees were transferred onto fresh plates of 20% V_8A, incubated in the dark at 25°C for 5 d and a further 5 d in the light to induce adequate sporangia production. Zoospores were harvested from the sporangia by flooding the plates with 20 ml SDW (previously chilled to 4°C) and kept at 4°C for 20 min, followed by another 20 min at 25°C in a darkened incubator. The concentrations of the resulting zoospores were adjusted to 300 spores/ml. Five green mature (≈4-month-old) cocoa pods (variety Amel × T79/501) per isolate were inoculated by dropping 50 µl zoospore suspension on the surface of each pod. A typical cocoa isolate of *P. megakarya* (GHBA 31) from Bechem, which is moderate in virulence and sporangia production, was used as a reference. The pods were incubated in large humid transparent polythene bags at 25–28°C for 8 d. Disease severity for each isolate was assessed on the basis of lesion expansion and sporangium production. Numbers of sporangia in lesions were determined by cutting 5 mm discs (3 discs/isolate) from the lesions 8 d after inoculation, shaking these in 10 ml SDW on a rotamixer for 1 h and the sporangia suspensions counted using a haemocytometer. The main stems of the host trees were also inoculated ≈1 m from the ground by punching holes into the tree bark, inserting 5 mm discs of actively growing cultures of the test isolate on V_8A and sealing the holes with cellulose tape. The size of resulting lesions was measured after 3 months.

3. Results

After 3 years of sample collection and baiting from shade trees, *P. megakarya* was recovered from roots of four out of 34 trees tested (Table 2). The four host trees belong to different families. The rate of recovery, however, was low ranging from 0.6% to 1.2%. *P. megakarya* was isolated from roots of the host trees both in wet and dry seasons. However, isolations were more frequent in the wet months (June, August and October) than in the dry months (December and February). The greatest numbers of isolations were made in October and the fewest in December and February.

In general, more isolations of *P. megakarya* were from *Dracaena mannii* and the lowest were from *Ricinodendron heudelotii*. PPMA was slightly better than cocoa pod husk as a selective medium for recovering *P. megakarya*. Apart from *R. heudelotii*, the recoveries of *P. megakarya* isolations from roots of *Funtumia elastica*, *Sterculia tragacantha* and *D. mannii* were more frequent on PPMA than in cocoa pod husk. Out of a total of 58 isolations made, 31 (53%) were on PPMA and 27 (47%) were from cocoa pod husk.

3.1. Identity of Phytophthora species

Slight variations in growth rates and patterns were observed amongst the isolates. However, the morphological characters of all the isolates examined in pure culture on V_8A indicated that all the isolates were *P. megakarya*. All the isolates produced colonies with deep or moderate cottonwool-like aerial mycelium. Their sporangia were caducous, i.e. readily dislodged when agitated gently in water. The colony morphology and sporangium characteristics of isolates from the test trees were also similar to the reference isolate (Table 3). Isolate GHBBA-AH 01 (from *F. elastica*) and GHBBA-

Table 2
Isolation (on two selective media) of *P. megakarya* from four hosts in different months over 3 cocoa seasons (1996/97, 1997/98, 1998/99)

Host tree	Family name	Selective medium	Total number of isolations[a] on month						Medium total	% Recovery
			Feb	Apr	Jun	Aug	Oct	Dec		
Funtumia elastica	Apocynaceae	Pod husk	1	1	1	2	1	0	6	0.7
		PPMA	0	1	1	1	3	1	7	0.8
Sterculia tragacantha	Sterculiaceae	Pod husk	0	2	0	1	1	1	5	0.6
		PPMA	0	0	3	2	3	0	8	0.9
Dracaena mannii	Agavaceae	Pod husk	1	3	1	2	2	1	10	1.1
		PPMA	2	1	2	1	4	1	11	1.2
Ricinodendron heudelotii	Euphorbiaceae	Pod husk	1	1	2	1	1	0	6	0.7
		PPMA	0	2	0	1	2	0	5	0.6
Monthly totals			5	11	10	11	16	4	57	

[a] Each sample consists of a total of 150 root pieces over 3 cocoa seasons.

Table 3
Mean sporangium characteristics and mean growth rates of *P. megakarya* isolates

Isolate	Source	Sporangium dimensions (μm)[a] ± SE				Colony growth rate (mm/d)[b]	Colony morphologies[c]
		Length (L)	Breadth (B)	L/B	Pedicel length		
GHBBA-AH 01	*Funtumia elastica*	33 ± 4.3	26 ± 5.3	1.3	12.7 ± 1.3	20	Dense aerial
GHBBA-AH 02	*Sterculia tragacantha*	30 ± 6.3	27 ± 7.1	1.1	13.5 ± 1.5	21	Moderate aerial
GHBBA-AH 03	*Dracaena mannii*	35 ± 7.3	25 ± 3.9	1.4	13.4 ± 1.3	20	Moderate aerial
GHBBA-AH 04	*Ricinodendron heudelotii*	28 ± 5.1	25 ± 4.5	1.1	12.8 ± 1.3	22	Dense aerial
GHBA 31	*Theobroma cacao*	36 ± 7.2	29 ± 6.1	1.2	12.9 ± 1.3	29	Dense aerial
LSD 5%		n.s.	n.s.	—	—	1.83	—

[a] Mean of 50 sporangia per isolate.
[b] Growth rates assessed on V_8A for 4 d.
[c] Colony morphologies assessed 4 d after incubation.

AH 04 (from *R. heudelotii*) had dense, fluffy cotton-wool-like aerial mycelium with regular margins and were morphologically indistinguishable from the reference isolate. Isolates GHBBA-AH 02 (from *S. tragacantha*) and GHBBA-AH 03 (from *D. mannii*), however, had moderate aerial mycelium but regular margins. The sporangium length-to-breadth ratio (L/B) and pedicel length were generally similar and typical of *P. megakarya*. The sporangium L/B ratio for the isolates ranged from 1.1 to 1.4 μm and the pedicel length ranged from 12.8 to 13.5 μm. These were similar to a L/B ratio of 1.2 and pedicel length of 12.9 μm for the reference isolate. The growth rates of all the isolates from the test trees on V_8A, were slower ($P<0.05$) than the reference isolate. The growth rate of isolate GHBBA-AH 04 was, however, slightly greater ($P<0.05$) than isolates GHBBA-AH 01, GHBBA-AH 02 and GHBBA-AH 03.

3.2. Pathogenicity test

Isolates recovered from all the test trees were highly pathogenic on cocoa (Table 4). All the isolates produced lesions typical of *P. megakarya*. Brown lesions appeared on all pods 2–3 d after inoculation, and after the 6 d, the mean lesion size ranged from 24 to 27 mm × 25–31 mm, compared to 39 × 42 mm for the reference isolate. Sporangium production also begun after 4–5 d, and was at its peak 7–8 d after inoculation. Sporangia covered the entire surface of each lesion except the advancing margins.

Isolates GHBBA-AH 01 and GHBBA-AH 02 grew faster ($P<0.05$) on detached pods than isolates GHBBA-AH 03 and GHBBA-AH 04, but slower ($P<0.05$) than the reference isolate (Table 4). On the contrary, GHBBA-AH 03 and GHBBA-AH 04 were more prolific than isolates GHBBA-AH 01 and GHBBA-AH 02. Apart from the reference isolate, isolates from the test trees with moderate aerial mycelium produced more sporangia than those with deep aerial mycelium (Table 4).

All the four test isolates were not highly pathogenic on stems of the test trees. The isolates induced very small lesions when stems of the test trees were inoculated (Table 4). The length of lesions of isolates from the test trees were about three times smaller than those from the reference isolate on cocoa. Three months after inoculation, the mean length of lesions on the test plants ranged from 1.4 to 2.7 cm compared to 7.8 cm on the reference isolate. There were no statistically significant differences between the breadth of lesions (Table 5).

4. Discussion

A host is a plant that is invaded by a parasite, from which the parasite obtains its nutrients (Agrios, 1997), whereas an alternative host is another plant on which a fungus can live. Reports on parasitism of some species of *Phytophthora* from cocoa on other crops are well documented. For example, *P. palmivora* has been reported to parasitise plants of 51 genera in 29 families of flowering plants (Hickman, 1958). Similarly, *P. citrophthora* is known to be pathogenic to plants other than citrus (Kellam and Zentmyer, 1981), and *P. capcisi* pathogenic to plants other than capsicum (Tsao and Tummakate, 1977). Results from the present study give evidence of parasitism of *P. megakarya* on four different tree species belonging to Apocynaceae (*F. elastica*), Sterculiaceae (*S. tragacantha*), Agavaceae (*D. mannii*), and Euphorbiaceae (*R. heudelotii*). The available literature suggests that this is the first report of alternative hosts for *P. megakarya*.

Available evidence also suggests that the *Phytophthora* species of cocoa have a soil phase and that the inoculum of *P. palmivora* (Turner and Asomaning, 1962; Onesirosan, 1971; Newhook and Jackson, 1977), *P. megakarya* (Ward and Griffin, 1981), *P. capsici* and *P. citrophthora* (Pereira, 1988) persists in soil and are associated with living roots of cocoa (Gregory et al., 1984). Our results showed low levels of recovery of

Table 4
Mean size of lesions and mean number of sporangia produced by *P. megakarya* isolates on green mature cocoa pods

Isolate	Source	Mean size of lesion (mm)[a]		Mean number of sporangia/ml ($\times 10^3$)[b]
		Length	Breadth	
GHBBA-AH 01	*Funtumia elastica*	27	31	21
GHBBA-AH 02	*Sterculia tragacantha*	27	32	22
GHBBA-AH 03	*Dracaena mannii*	24	26	25
GHBBA-AH 04	*Ricinodendron heudelotii*	24	25	19
GHBA 31	*Theobroma cacao*	39	42	37
LSD 5%		2.3	2.6	6.0

[a] Mean of five pods 6 d after inoculation.
[b] Mean of three counts on three 5 mm pod discs 8 d after of incubation.

Table 5
Mean size of lesion of *Phytophthora* canker 3 months after inoculation of stems of host plants

Host plant	Mean size of lesions (cm)[a]	
	Length	Breadth
Funtumia elastica	1.5	1.6
Sterculia tragacantha	1.4	1.4
Dracaena mannii	2.5	2.7
Ricinodendron heudelotii	2.7	2.3
Theobroma cacao	7.8	3.7
LSD 5%	2.6	n.s

[a] Each figure is an average of two measurements from two inoculation points.

Phytophthora from roots of alternative host plants. This is not surprising because in natural infections, particularly from apparently healthy plants, the frequency of isolations is expected to be low (Onesirosan, 1971). However, these low levels of occurrence are able to ensure the survival of the fungus from one season to the next by colonization of small proportions of root systems. In the present study, the method of sampling and the sample size were probably some of the factors which might have accounted for the low numbers of recovery. All the test trees had large biomasses and taking 100 root pieces of $\approx$1–2 cm in length from each tree was probably inadequate. The consistently low levels of recovery from the test trees, however, suggests that roots of the alternative hosts plants are not sites for multiplication, but rather for conservation of the fungus.

Identification of the surviving propagules of *P. megakarya*, which was one of the initial objectives of the study, was later abandoned because of the extremely low levels of recovery of the pathogen. In earlier studies on cocoa seedlings, however, there was enough evidence to suggest that *P. megakarya* survived in cocoa roots as fragments of mycelium (Opoku and Wheeler, in press). The studies did not determine where the fungus survived in the root pieces, but since the roots were surface-sterilized before isolation, this suggests that *P. megakarya* invaded the roots. Other reports also suggest the presence of *Phytophthora* inside cocoa roots (Ward and Griffin, 1981; Pereira, 1988; Ravise, 1970).

Our results suggest that sampling time is very important to the success of recovery of *P. megakarya* from roots of host plants. Generally, more recoveries were consistently made in the wet months of the year, particularly October, than in the dry months of December and February. This confirms earlier findings by Ward and Griffin (1981) that *P. megakarya* could be recovered more readily during wet months than in dry months. Opoku and Wheeler (in press) have also emphasised the importance of soil moisture in the survival of *P. megakarya* and *P. palmivora*. In Ghana, *P. megakarya* black pod is more prevalent in September and October than in any other month of each year (Opoku et al., 1997).

The colony morphologies and sporangium characteristics of isolates from the test plants were all similar to the reference isolate and were also similar to previous descriptions of *P. megakarya* (Brasier and Griffin, 1979). Although all the isolates were moderately, but less, virulent than the reference isolate, this demonstrates that the virulence of isolates of the same species can vary. The variation in virulence between the isolates from the newly recorded host trees and the reference isolate from cocoa may be due to the fact that the test isolates were more adapted to their hosts than cocoa.

The role of alternative hosts in the epidemiology of *P. palmivora* and *P. megakarya* has not yet been evaluated in Ghana. Two of the new host plants, *F. elastica* and *R. heudelotii*, are among the desirable or recommended shade trees for cocoa plantations in Ghana. It is unlikely, however, that the presence of the identified host trees will have any significant influence on the levels of black pod disease in cocoa plantations. In the present study, there was no visual evidence to suggest that incidence of black pod infections of cocoa trees around the host trees was greater than those in other areas. We

suggest that the epidemiological significance of the use of *F. elastica* and *R. heudelotii* as shade trees for cocoa plantations should be studied in detail.

5. Conclusions

This is the first record of *F. elastica*, *S. tragacantha*, *Dracaena mannii* and *R. heudeloti* as hosts of *P. megakarya*. The role of root infections of these hosts in the epidemiology of *P. megakarya* black pod is not clear and requires further elucidation.

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