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FULL RESEARCH PAPER

Assessment of sanitation and fungicide application directed at cocoa tree trunks for the control of *Phytophthora* black pod infections in pods growing in the canopy

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Abstract Studies were conducted in two cocoa-growing areas of Ghana, one solely affected by *Phytophthora palmivora* and the other predominantly by *Phytophthora megakarya*, to determine the effectiveness of sanitation practices and fungicide application on tree trunks for the control of black pod disease in the canopy. Sanitation practices including weeding, pruning, thinning, shade reduction and removal of mummified pods were carried out prior to fungicide applications, and diseased pods were routinely removed at monthly intervals during harvesting. Three types of fungicides were used: systemic (Foli-R-Fos 400) applied as injection into the main trunks, semi-systemic (Ridomil 72 plus) and contact (Nordox 75, Kocide 101, Kocide DF, Blue Shield and Funguran-OH) applied as sprays onto pods on the main trunk. Sanitation combined with fungicide application on the trunk significantly reduced black pod disease incidence in the tree canopy. For fungicides applied as a spray, Ridomil 72 plus at 3.3 g l^{-1} and Kocide DF at 10 g l^{-1} and as injection, 40 ml Foli-R-Fos 400 injected twice a year, performed better than the other fungicide treatments. The position of pods significantly influenced the incidence of canopy black pod infection in the *P. megakarya* predominantly affected area but to a lesser extent in the *P. palmivora* solely affected area. However, no significant interactions were found between fungicide treatments and the position of pods on the tree in both disease areas. The determined trunk-canopy relationship in the development of black pod disease on cocoa can be used in disease control programmes to maximise the impact of sanitation practices, achieve judicious application of fungicides, thereby reducing the environmental impact of fungicides on the cocoa ecosystem, and ultimately increase the economic returns.

Keywords *Phytophthora megakarya* · *Phytophthora palmivora* · *Theobroma cacao* · Trunk · Canopy · Systemic and contact fungicides · Disease control

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Introduction

Cocoa varieties commonly grown in Ghana are the Amelonados and mixed Amazons, and crosses of the two groups are also common in neighbouring west and central African cocoa-growing countries. Together, these countries account for 65% of the world's cocoa production (ICCO, 1998; Appiah, Flood, Archer, & Bridge, 2004). Cocoa varieties, particularly the Amelonados grown in these countries, are able to grow to heights of 4–10 m at maturity depending on spacing and the extent of shade. Cocoa trees may grow up to 20 m in the wild of primary forest and under poor management of heavy shade (Wood & Lass, 1985). In this region, black pod disease caused by *Phytophthora* species is the most important disease problem facing the entire subregion (Appiah, Flood, et al., 2004). In Ghana, two *Phytophthora* species, *P. palmivora* and *P. megakarya*, are the main causal agents of black pod disease of cocoa, and are differentially distributed in the cocoa-growing regions of the country. *Phytophthora palmivora* is found in all the six (Eastern, Ashanti, Brong Ahafo, Central, Volta and Western) cocoa-growing regions whiles *P. megakarya*, since its first report in the Ashanti region in 1986, has spread to other regions with the exception of the eastern region (Appiah, 2001; Akrofi, Appiah, & Opoku, 2003). These regions are within the same agroclimatic belt but differ in the amounts of annual rainfall. Of the two species, *P. megakarya* is more aggressive, causing significantly greater losses (Appiah, 2001; Akrofi et al., 2003; Appiah, Flood, et al., 2004), and has been threatening the livelihood of many cocoa farmers (Opoku, Appiah, Akrofi, & Owusu, 2000).

During fungicide application, cocoa pods within the tree canopy that are beyond the reach of the extended standard knapsack-spraying machine lance are not directly sprayed and therefore may not be protected from infections. The spray beam reaches mainly pods on the tree trunk up to hand height, approximately 3.5 m from the ground (Opoku, Akrofi, & Appiah, 1995). Also, due to difficulties in harvesting pods higher up in the tree canopy, diseased pods are often left hanging on the trees for several years. These diseased pods may serve as sources of primary inoculum in subsequent seasons (Tarjot, 1971; Muller, 1974) and lead to an increase in disease incidence in the canopy.

Although the cultivated upper Amazon hybrids do not grow as tall as the Amelonados, problems of severe canopy infection persist. The long-term solution to this problem lies in the breeding of shorter and early branching cocoa varieties. However, a large number of cocoa pods in the canopy currently remain unprotected from black pod diseases and farmers rely on the use of crop sanitation practices as the main method of controlling canopy infection. Many farmers have requested the provision of extension lances to the knapsack spraying machines to extend the reach of fungicide sprays to cover pods higher up in the tree canopy. However, while this is possible at extra cost, there is growing concern about the amount of fungicides used in the cocoa ecosystem.

This paper reports the effectiveness of sanitation practices and application of fungicides on the trunk in controlling black pod diseases caused by *P. palmivora* and *P. megakarya* in the tree canopy. The tree trunk and canopy relationship in the development of black pod diseases caused by the two *Phytophthora* species can be used to achieve effective and profitable integrated disease management. Experiments were designed to investigate whether sanitation and timely application of fungicides to the tree trunks could provide protection against black pod infection in the tree canopy. The benefits of this work include reduction in the amount of fungicides sprayed onto cocoa, and consequently a reduction in the cost of black pod disease control, minimised effects of fungicides on non-target organisms in the cocoa ecosystem and increased economic returns.

Materials and methods

Experimental sites

The trials were conducted at Tafo in the Eastern Region (an area predominantly infected by *P. palmivora*) and Bechem in the Brong Ahafo Region (an area predominantly infected by *P. megakarya*) of Ghana for two seasons (1995/96 and 1996/97) on mixed Amazons and Amazon × Amelonado cocoa trees aged over 20 years. The heights of the test trees at both sites ranged from 7.5–12.8 m with a mean of 8.4 m at Tafo and 8.9 m at Bechem. On the basis of the number of candidate fungicides available, thirteen treatments were tested in the Tafo trial and eleven at Bechem. In both areas, each treatment plot consisted of 30 trees and all the treatments in the two seasons were replicated five times in a completely randomized block design.

Sanitation practices

The sanitation practices, including weeding, pruning, thinning, reduction of shade and removal of mummified pods, were carried out in April and May before application of fungicides. Immature cocoa pods with black pod disease symptoms were subsequently removed at monthly intervals during the harvesting of mature pods and recorded. The sanitation practices were carried out on all experimental plots including the untreated (no fungicide) control plots.

Application of fungicides

Fungicide application treatments were superimposed on the sanitation practices and carried out on all the plots except the untreated control. Five contact fungicides: Nordox 75 (75% cuprous oxide *ai*, Nordox Industrier, Oslo, Norway) applied at the rate of 6.7 g l^{-1}; Kocide 101 (77% cupric hydroxide *ai*, Griffin Corporation, Valdosta, GA, USA) at 6.7 g l^{-1}; Kocide DF (61.4% copper hydroxide *ai*, Griffin Corporation, Valdosta, GA, USA) at 6.7 and 10 g l^{-1}; Blue Shield (77% cupric hydroxide *ai*, Albaugh Inc., Germantown, USA) at 6.7 g l^{-1}; and Funguran-OH (82% copper hydroxide *ai*, Spiess-Urania Chemicals Gmbh, Hamburgh, Germany) at 6.7 g l^{-1} were tested. Each plot was sprayed with 15 l of the appropriate test fungicide. Two other fungicides: Ridomil 72 plus (12% metalaxyl and 60% copper-1-oxide *ai*, Ceiba Geigy Ltd., Basle, Switzerland), a semi-systemic fungicide, applied at the rate of 3.3 g l^{-1} and Foli-R-Fos 400 (40% potassium phosphonate (H_3PO_3) *ai*, UIM Agrochemicals [Aust] Pty Ltd, Brisbane, Australia), a fully systemic fungicide, were also tested. The H_3PO_3 suspension was applied at two dosages of 20 and 40 ml once (single injection) and twice (double injection) in each season.

Two methods of fungicide delivery were employed in the trials. The contact and semi-systemic fungicides were applied through jet spraying using a pneumatic knapsack spraying machine (Technoma T15, Eperney, France) to a height of approximately 3.5 m from the ground level at 3-weekly intervals from June to October. The systemic fungicide (H_3PO_3) was delivered through injections into the tree trunks using special 20 ml spring-loaded self-dispensing syringes, Chemjet (UIM Agrochemicals [Aust] Pty Ltd, Brisbane, Australia). Approximately 1 cm deep holes were made at about 1 m height (from the ground level) on the trunks with a carpenter's drill and the H_3PO_3 treatments were injected into the trees after release of the plunger of the syringe.

Disease and yield assessments

Monthly harvesting of matured healthy and diseased pods as well as immature diseased pods was done from August to February in each season. At each harvest, pods from the main trunk (approximately 3.5 m from the ground), which received fungicide sprays, were separated from those in the canopy (parts of the tree above 3.5 m from the ground). The pods were categorised as either healthy ripe pods (HRP), fermentable or useable (i.e. diseased but of commercial value) black pods (FBP) or non-fermentable (of no commercial value) black pods (NFBP). The total black pods (TBP = FBP + NFBP), the percent disease incidence (%DI), percentage of pod losses (%NFBP) and total fermentable pods (HRP+FBP) were calculated. The yield estimate in kg ha^{-1} (Lockwood &Edward, 1980) was calculated as follows: Yield,

$$y = \left[\frac{\text{Number of tree/ha}}{\text{No. of test trees/plot} \times \text{No. of years}} \times \frac{\text{Total number of fermentable pods}}{\text{Number of pods/kg} \times \text{No. of years}}\right]$$

In this study, number of tree/ha = 800, number of tree/plot = 30, number of pods/kg ≡ 28 and the number of years = 2. Therefore, $y = 0.2381x$, where total number of fermentable pods is represented by x.

Analysis of variance (ANOVA) was performed on the trunk and canopy data separately for positional effects. The combined data were analysed for the overall fungicide effects and the possible interactions between position and treatments were also tested. The pods data were statistically analysed after log transformations while the % DI data were analysed after arcsin transformations. Data sets showing significant treatment effects ($P \le 0.01$) were subjected to Least Significant Difference tests (LSD) to compare treatment effects. The efficacies of treatments were assessed on the basis of %DI, HRP, %NFBP and useful yield data. Meteorological data, particularly the amount of rainfall recorded throughout the year at weather stations located at the two sites, were collected for the two seasons (1995/96 and 1996/97) since black pod incidence among other factors is strongly influenced by the amount of rainfall and humidity (Thorold, 1975).

Results

Assessments of percent disease and pod losses

The %DI of all the fungicide treatments on the tree trunk at Tafo, a solely *P. palmivora* affected area were significantly ($P \le 0.01$) lower than the untreated (no fungicide) control with the exception of the 20 ml H_3PO_3 single injection (Table 1). The Kocide DF (10 g l^{-1}), Ridomil 72 plus, Nordox 75 and 40 ml H_3PO_3 double injection treatments significantly reduced the disease incidence to below 10%. The %DI data from the tree trunk at Bechem, a *P. megakarya* predominantly affected area, also showed highly significant ($P \le 0.01$) differences between treatments (Table 2). Similar to the observed trend at Tafo, the Ridomil 72 plus and 40 ml double injection of H_3PO_3 had significantly lower %DI (below 25%) on the tree trunk than the other treatments. However, comparing the two sites, the disease incidence at Bechem was generally higher than at Tafo, with most treatments being more than twice the levels of the control. For instance, at Bechem the incidence was 71.6% whilst it was 28.9% at Tafo.

In the canopy, all the fungicide treatments at Tafo produced significantly lower disease incidence than the control: the 40 ml H_3PO_3 double injection was the most effective (Table 1). Likewise, at Bechem, highly significant differences ($P \le 0.01$) were observed between fungicide treatments and the untreated control: the Blue Shield, Ridomil 72 plus and H_3PO_3 40 ml injections were the most effective (Table 2). The H_3PO_3 injections had lower disease incidence in the canopy compared to the trunk, but with the spray fungicides this was only evident at Bechem.

The percentage pod losses data from both sites (Table 3) showed significant reductions in losses due to fungicide treatments (with the exception of 20 ml H_3PO_3 injections at Tafo) compared with the untreated control. Similar to the trend obtained from the %DI data, the spray fungicide treatments produced comparable losses on both the trunk and canopy, whilst the injection treatments (particularly at the Tafo site) led to the least pod losses in the canopy. Overall (combining the trunk and canopy), the 40 ml H_3PO_3 injections and Ridomil 72 plus generally had the most fungistatic effect away from the area of application at both sites in the canopy.

Assessments of healthy ripened pods and total yield data

At Tafo, the healthy ripe pods (HRP) and the total yield data from the tree trunk generally followed similar trends (Table 1). All the fungicide treatments produced significantly ($P \le 0.01$) more healthy pods and consequently higher total yield than the control plots. The two Kocide DF treatments (6.7 g l^{-1} and 10 g l^{-1}) performed significantly better than the other fungicide treatments. In terms of HRP, these were followed by Funguran (6.7 g l^{-1}), Nordox 75 (6.7 g l^{-1}), Kocide 101 (6.7 g l^{-1}) and 40 ml H_3PO_3 double injection. For yields, Kocide DF was followed by Funguran-OH at 6.7 g l^{-1}, 40 ml H_3PO_3 double injection and Kocide 101 (6.7 g l^{-1}), Nordox 75 (6.7 g l^{-1}) and Ridomil 72 plus. However, at Bechem, significantly greater ($P \le 0.01$) HRP and total yield were obtained from the Ridomil 72 plus treatment, followed by Kocide DF 10 g l^{-1}, Blue Shield, Kocide DF 6.7 g l^{-1}, H_3PO_3 at 40 ml double injection and H_3PO_3 at 20 ml double injection (Table 2). In terms of total yield, the following treatments: Funguran-OH at 6.7 g l^{-1},

Table 1 The effects of fungicide application on black pod incidence and yield of cocoa on the tree trunk and canopy[a] at Tafo (1995/96–1996/97)[b]

Treatment[c]	Percent disease incidence (%DI)		Healthy ripe pods (HRP)		Total yield (kg ha^{-1})
	Trunk	Canopy	Trunk	Canopy	
Fungicide sprayed:					
Kocide DF (6.7 g l^{-1})	11.2 ± 0.1 g	10.8 ± 0.1 cd	3168 ± 51.7 b	5899 ± 207.5 a	2254 ± 46.2 a
Kocide DF (10 g l^{-1})	6.6 ± 0.0 i	9.2 ± 0.1 fgh	3710 ± 5.8 a	5480 ± 144.3 b	2270 ± 27.2 a
Kocide 101 (6.7 g l^{-1})	15.2 ± 0.1 d	14.4 ± 0.1 b	2234 ± 93.5 g	5188 ± 68.3 cd	1875 ± 7.3 cd
Blue Shield (6.7 g l^{-1})	12.8 ± 0.2 ef	11.1 ± 0.1 c	2322 ± 5.8 f	4691 ± 82.7 ef	1766 ± 30.1 f
Funguran-OH (6.7 g l^{-1})	11.9 ± 0.0 fg	10.8 ± 0.1 cd	2707 ± 4.2 c	5300 ± 92.6 c	2004 ± 2.9 b
Funguran-OH (10 g l^{-1})	13.6 ± 0.1 e	11.2 ± 0.0 c	2360 ± 34.6 f	4539 ± 98.3 f	1717 ± 4.6 fg
Nordox 75 (6.7 g l^{-1})	9.2 ± 0.1 h	9.9 ± 0.3 def	2200 ± 3.7 g	5272 ± 38.6 c	1843 ± 27.2 de
Ridomil 72^{+} (3.3 g l^{-1})	7.4 ± 0.1 i	9.5 ± 0.1 efg	2607 ± 4.3 d	4717 ± 61.5 e	1815 ± 22.4 de
H_3PO_3 injection:					
20 ml once	31.0 ± 0.4 a	8.2 ± 0.0 h	2060 ± 18.6 h	4094 ± 55.2 g	1611 ± 4.9 h
20 ml double	20.2 ± 0.1 c	10.4 ± 0.0 cde	2350 ± 4.4 f	4576 ± 60.9 ef	1677 ± 4.0 gh
40 ml once	12.3 ± 0.2 f	8.6 ± 0.1 gh	2502 ± 188.3 e	4574 ± 53.4 ef	1782 ± 5.0 ef
40 ml double	9.8 ± 0.1 h	6.9 ± 0.1 i	2736 ± 5.9 c	5062 ± 54.6 d	1943 ± 23.4 bc
Untreated control	28.9 ± 0.6 b	18.8 ± 0.1 a	1848 ± 22.9 i	3684 ± 39.5 h	1441 ± 9.0 i
Mean	14.6	10.8	2523.4	4852	1846

a = Pods on the trunk are those harvested from ground level up to hand height (0–3.5 m high; areas sprayed with fungicide) and the canopy are those from heights >3.5 m; areas apparently not sprayed with fungicides. Data represent mean values ± standard errors of the means

b = Pod data were analysed after log transformations; % DI analysed after arcsin transformations

c = Treatment results followed by the same letter(s) in the same column are not significantly different after analysis using LSD test at $P \leq 0.01$

Table 2 The effects of fungicide application on black pod incidence and yield of cocoa on the tree trunk and canopy[a] at Bechem (1995/96–1996/97)[b]

Treatment[c]	Percent disease incidence (%DI)		Healthy ripe pods (HRP)		Total yield (kg ha^{-1})
	Trunk	Canopy	Trunk	Canopy	
Fungicide sprayed:					
Kocide DF (6.7 g l^{-1})	34.4 ± 1.1 d	33.2 ± 1.0 def	2112 ± 58.6 c	1726 ± 60.7 c	1111 ± 8.5 c
Kocide DF (10 g l^{-1})	31.5 ± 0.3 de	33.7 ± 1.6 de	2460 ± 52.9 b	1941 ± 117.8 b	1267 ± 3.8 b
Blue Shield (6.7 g l^{-1})	28.7 ± 0.2 e	29.1 ± 0.5 fg	2477 ± 52.2 b	1923 ± 58.0 b	1225 ± 11.0 b
Funguran-OH (6.7 g l^{-1})	43.5 ± 1.3 b	45.6 ± 0.2 b	1248 ± 54.6 f	994 ± 35.6 f	693 ± 4.2 f
Funguran-OH (10 g l^{-1})	39.6 ± 1.0 c	40.6 ± 0.5 c	1270 ± 52.0 f	1198 ± 56.1 e	720 ± 35.0 ef
Ridomil 72 plus (3.3 g l^{-1})	22.4 ± 1.2 f	25.9 ± 1.1 g	3367 ± 81.6 a	2674 ± 115.8 a	1683 ± 9.0 a
H_3PO_3 injection					
20 ml once	41.2 ± 0.2 bc	40.4 ± 0.9 c	1334 ± 64.3 f	1008 ± 1.8 f	687 ± 5.7 f
20 ml double	38.9 ± 0.0 c	35.7 ± 0.5 d	1510 ± 5.8 e	1530 ± 11.7 d	911 ± 7.8 d
40 ml once	32.7 ± 0.1 d	31.3 ± 0.7 ef	1766 ± 6.6 d	1336 ± 59.2 e	890 ± 4.5 d
40 ml double	21.4 ± 0.3 f	31.7 ± 0.5 def	2154 ± 27.7 c	1584 ± 46.8 cd	1076 ± 6.4 c
Untreated control	71.6 ± 0.3 a	56.5 ± 1.3 a	520 ± 11.3 g	1193 ± 3.3 e	783 ± 4.3 e
Mean	36.9	36.7	1838	1555.2	1004.2

a, b and c = As in Table 1

Funguran-OH at 10 g l^{-1} and H_3PO_3 at 20 ml single injection were not significantly better than the untreated control.

In general, higher numbers of healthy ripened pods were recorded in the canopy at Tafo (Table 1) than at Bechem (Table 2).

Table 3 The effects of fungicide application on percentage pod losses due to black pod disease at Tafo and Bechem (1995/96–1996/97)

Treatment	Percentage of pod losses due to black pod disease[a]			
	Tafo		Bechem	
	Trunk	Canopy	Trunk	Canopy
Fungicide sprayed				
Kocide DF (6.7 g l^{-1})	7.8 f	6.6 d	20.7 d	18.1 d
Kocide DF (10 g l^{-1})	3.8 j	5.3 f	18.5 e	18.2 d
Kocide 101 (6.7 g l^{-1})	11.0 d	10.5 b	–	–
Blue Shield (6.7 g l^{-1})	7.8 f	6.0 e	29.2 b	28.7 b
Funguran-OH (6.7 g l^{-1})	7.2 fg	6.3 de	28.2 b	24.9 bc
Funguran-OH (10 g l^{-1})	9.1 e	7.5 c	16.7 f	17.1 de
Nordox 75 (6.7 g l^{-1})	5.9 h	6.6 d	–	–
Ridomil 72 plus (3.3 g l^{-1})	4.5 ij	5.3 f	9.6 g	12.5 ef
H_3PO_3 injection				
20 ml once	34.5 a	3.7 gh	29.1 b	24.5 bc
20 ml double	13.2 c	6.0 e	23.6 c	19.7 cd
40 ml once	6.4 gh	3.9 g	18.4 ef	18.0 d
40 ml double	4.9 i	3.3 h	10.4 g	11.0 f
Untreated control	21.6 b	11.5 a	48.2 a	37.8 a
Mean	10.6	6.3	23.0	21.0

a = Percentage pod losses is the number of pods destroyed by black pod in each category (trunk and canopy) as proportion of the total number of pods harvested

Approximately, twice the number of healthy pods on the trunk was recorded in the canopy at Tafo. In contrast, lower numbers of healthy ripened pods were obtained from the canopy than from the trunk at Bechem except the untreated control and 20 ml H_3PO_3 double injection.

The statistical analysis of the combined data showed that the position of pods was significant ($P \leq 0.01$) but no significant interactions were found between the fungicide treatments and the position of pods on TBP, %DI and yield at Tafo (data not shown). However, at Bechem (a predominantly *P. megakarya* area), there were no significant positional effects on both %DI and healthy ripened pods as well as no significant interactions between the position of pods and fungicide treatments for disease or yield variables assessed (data not shown).

The rainfall data collected showed similar patterns at both sites but different amounts of rainfall during the 1995–1997 (Fig. 1). Slightly more rainfall was recorded in Tafo than in Bechem during the period. Generally the primary rainfall peak was in June–July.

Discussion

In the Tafo trials (a solely *P. palmivora* affected area), the average %DI for the two seasons on the tree trunk (14.6%) was higher than that of the canopy (10.8%), while in the Bechem trials (a predominantly *P. megakarya* area) similar values (36.9% and 36.7% respectively) were obtained. However, the lower %DI recorded at Tafo was against the backdrop of the slightly higher rainfall in the black pod season in Ghana (May–October), a factor which may significantly increase the level of black pod disease incidence. The %DI values of the untreated trunk and canopy controls for the Tafo trials (28.9% and 18.8% respectively) and those of the Bechem trials (71.6% and 56.5% respectively) support the evidence that under field conditions *P. megakarya* produces significantly more zoospores for infection than *P. palmivora* (Luterbacher, 1994; Opoku, 1994). This difference between the two species makes disease control (particularly against *P. megakarya*) more difficult as significantly more zoospores of *P. megakarya* are produced and can consequently overwhelm the protective barrier of contact fungicides under field weathering conditions.

The significantly higher %DI obtained from the trunk data also indicates that the disease pressure was higher for the control on the trunk than the canopy. However, higher pod losses were sustained in the canopy particularly at Bechem where *P. megakarya* infection is predominant. Therefore, if pods on the trunk (close to the ground) are protected particularly from primary infections of *P. megakarya* through fungicide application, the rate of secondary infections (including those in the canopy) will be reduced. This is more important in the regions of Ghana (Ashanti, Brong Ahafo, Volta and Western) where *P. megakarya* infections are prevalent. In these areas, field observations have shown that under favourable conditions, whole crops can be destroyed within two to three weeks after primary infections had occurred (Opoku & Owusu, 1995; Opoku et al., 2000).

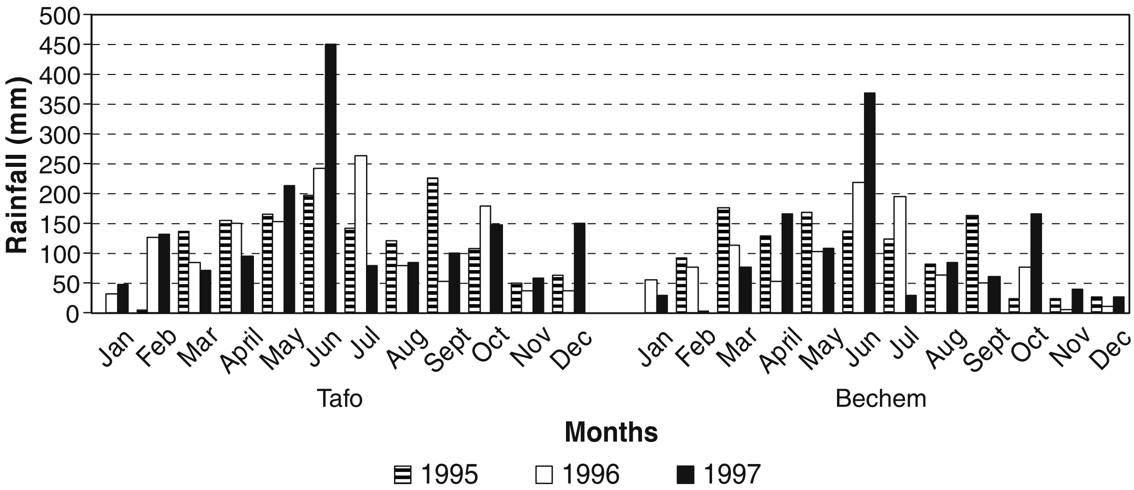

Fig. 1 Monthly rainfall pattern at Tafo (Eastern Region) and Bechem (Brong Ahafo Region) of Ghana from 1995–1997

The soil is the main source of primary inoculum for black pod disease caused by *P. megakarya*, and therefore pods close to the ground tend to get the initial infection and subsequent infections generally occur in an ascending order on the tree trunk (Dakwa, 1987; Maddison & Griffin, 1981; Muller, 1980). *Phytophthora palmivora* on the contrary survives the dry season in infected flower cushions and mummified pods on trees from where it grows out to infect developing pods (Brasier, Griffin, & Maddison, 1981). Therefore, most of the primary infections of black pod disease caused by *P. palmivora* occur on the main trunk. It is also known that cankers are evident mainly on the main trunk and rarely found on older branches and in the canopy (Appiah, Opoku, & Akrofi, 2004; Maddison & Griffin, 1981; Opoku et al., 2000; Schieber & Zentmyer, 1978). Hence good control of black pod disease on the main trunk in the *P. palmivora* area could also offer indirect control in the canopy. Similarly, if the pods on the trunk, particularly those close to the ground are sufficiently protected from black pod infections, the inoculum potential will be lower and the progression of the disease into the canopy reduced considerably. The present data suggest that control of black pod disease on the main trunk through application of effective fungicides offers indirect protection to pods higher up in the canopy.

The differences observed in %DI and healthy ripened pods between the trunk and the canopy at Tafo (a solely *P. palmivora* affected area) confirms the accumulated evidence that the sources of inoculum for primary infections of black pod disease caused by *P. palmivora* are mainly from cankers and flower cushions (Appiah, Opoku, et al., 2004; Asare-Nyako, 1972; Brasier et al., 1981; Dade, 1928; Dakwa, 1974; Newhook & Jackson, 1977; Tarjot, 1971). Furthermore, cankers are known to occur predominantly on the main trunk (Maddison & Griffin, 1981; Schieber & Zentmyer, 1978), and the majority of cankers caused by *P. palmivora* were distributed below 2 m from the ground (Appiah, Opoku, et al., 2004). Therefore, this explains the observed higher disease incidence recorded on the trunk and the higher number of healthy ripened pods in the canopy. Nevertheless, the position of the pod was more important in the *P. megakarya* prevalent area than in the solely *P. palmivora* affected area. This observation is accounted for by the differences in the nature of disease progression and spread characteristics of the two *Phytophthora* species. Black pod disease caused by *P. megakarya* usually starts from the ground and moves up the tree, whilst there is no such clear pattern of disease progression with *P. palmivora.*

The efficacy of a fungicide among other things depends on its re-distribution ability within the crop after application, and this in turn depends on the type, formulation, mode of action and the method of application. Systemic fungicides spread better than non-systemic fungicides due to translocation with other solutes through the vascular system. Similarly, fungicides containing spreaders cover a wider area than those without. Potassium phosphonate is a fully systemic fungicide that is translocated up and down the xylem and phloem vessels (Guest & Bompeix, 1990), whilst metalaxyl (Ridomil 72 plus) is a semi-systemic fungicide, which is translocated acropetally in the xylem vessels. The other test fungicides were contact in their mode of action and these tend to wash off more quickly under persistent rainfall. On both the trunk and canopy, the efficacy of the semi-systemic metalaxyl was better than most of the H_3PO_3 treatments and many of the contact fungicides. However, at both trial sites, the most effective dosage (40 ml double treatment) of the systemic fungicide (H_3PO_3) offered better aerial protection to pods in the canopy than the contact fungicides due to its mode of action.

On the other hand, the yield obtained from tree trunks in the Tafo trial (an area where data have shown that disease pressure is low) for Kocide DF at 10 g l^{-1} (a contact fungicide) was better than for the systemic fungicides. The generally increased yields obtained in Tafo are attributed among other factors to the slightly higher levels of rainfall experienced during the peak period of cocoa pod development (June–October) throughout the two seasons, and the lower disease pressure exerted by *P. palmivora*, which is the sole species causing black pod disease in this area.

Taken together, for effective chemical control of black pod disease on cocoa, an understanding of epidemiology of the species involved such as the primary sources of inoculum, the extent of production of infective propagules and pattern of disease spread are very important. These influence where to target fungicides as demonstrated by the trunk and canopy data on the levels of infection. The influence of fungicide applied to the trunk on pods in the canopy is also very important as it is difficult for farmers to reach pods in the tree canopy during fungicide application. Therefore protection of pods in the canopy, following fungicide application on the main trunk only, has several benefits to farmers. These include a reduction in the amount of fungicides applied on cocoa, a reduction in application time and cost of labour. Consequently, farmers will achieve higher returns on their economic yields as this is significantly influenced by fungicide application inputs and labour cost (Akrofi et al., 2003). As a result of the targeted and effective fungicide regimes, significant time savings will be made compared to up to nine routine fungicide applications for the season. It is therefore very important to establish the most effective dosage of the candidate fungicide for the control of particular *Phytophthora* species under different agroclimatic environments and apply integrated disease management measures at the right time of the season in order to take full advantage of the protection fungicide application on the tree trunk offers to pods in the canopy.

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References

Akrofi, A. Y., Appiah, A. A., & Opoku, I. Y. (2003). Management of *Phytophthora* pod rot disease on cocoa farms in Ghana. *Crop Protection, 22*(3), 469–477.

Appiah, A. A. (2001). Variability of *Phytophthora* species causing black pod disease of cocoa (*Theobroma cacao* L.) and implications for assessment of host resistance. London, UK: PhD Thesis University of London.

Appiah, A. A., Flood, J., Archer, S. A., & Bridge, P. D. (2004). Molecular analysis of the major *Phytophthora* species on cocoa. *Plant Pathology, 53*, 209–219.

Appiah, A. A., Opoku, I. Y., & Akrofi, A. Y. (2004). Natural occurrence and distribution of stem cankers caused by *Phytophthora megakarya* and *Phytophthora palmivora* on cocoa. *European Journal of Plant Pathology, 110*, 983–990.

Asare-Nyako, A. (1972). Sources of primary inoculum of *Phytophthora palmivora* in cocoa fields in Ghana (pp 65–68). Annual Report Cocoa Research Institute of Ghana, 1967–1970.

Brasier, C. M., Griffin, M. J., & Maddison, A. C. (1981). Cocoa black pod Phytophthoras. In: P. H. Gregory & A. C. Maddison (Eds.), *Epidemiology of Phytophthora on Cocoa in Nigeria, Phytopathological Paper No. 25* (pp. 18–30). U.K.: Commonwealth Mycological Institute Kew.

Dade, H. A. (1928). The relationship between diseased cushions and the seasonal outbreaks of black pod disease of cocoa. *Bulletin Department of Agriculture Gold Coast, 13*, 85–88.

Dakwa, J. T. (1974). The occurrence of *Phytophthora palmivora* (Butl) Butl in soil in Ghana. *Ghana Journal of Agricultural Science, 7*, 37–41.

Dakwa, J. T. (1987). A serious outbreak of black pod disease in a marginal area of Ghana. In: Cocoa Producers' Alliance (Ed.), Proceedings of the 10th International Cocoa Research Conference (pp. 447–451). Santo Domingo, Dominican Republic.

Guest, D. I., & Bompeix, G. (1990). The complex mode of action of phosphonates. *Australasian Plant Pathology, 19*(4), 113–115.

ICCO (1998) *ICCO Quarterly Bulletin on Cocoa Statistics* (Vol. XXIV(3)). London, UK: International Cocoa Organization.

Lockwood, G., & Edward, D. F. (1980). Determination of pod and bean characters in progeny trials with cocoa. *Tropical Agriculture, 57*, 289–300.

Luterbacher, M. C. (1994). Identification, epidemiology and control of *Phytophthora megakarya* on cocoa in West Africa. London, UK: PhD Thesis University of London.

Maddison, A. C., & Griffin M. J. (1981). Detection and movement of inoculum. In: P. H. Gregory & A. C. Maddison (Eds.), *Epidemiology of Phytophthora on Cocoa in Nigeria, Phytopathological Paper No 25* (pp. 31–49). UK: Commonwealth Mycological Institute, Kew.

Muller, R. A. (1974). Integrated control methods. In: P. H. Gregory (Ed.), *Phytophthora disease of cocoa* (pp. 259–268). London: Longman.

Muller , R. A. (1980). Survival in soil. In: G. A. Enriquez & G. A. Zentmyer (Eds.), Proceedings of the American Regional Group of *Phytophthora palmivora* on cocoa (p. 6), 1980. Technical Report 16 .

Newhook, F. J., & Jackson, G. V. H. (1977). *Phytophthora palmivora* in cocoa plantation soils in the Solomon Islands. *Transactions of the British Mycological Society, 69*(1), 31–38.

Opoku , I. Y. (1994). Survival of *Phytophthora palmivora* and *Phytophthora megakarya* in soil and in cocoa roots. London: PhD Thesis, University of London.

Opoku, I. Y., & Owusu, G. K. (1995). A severe type of black pod disease in Ghana. *Newsletter Cocoa Research Institute of Ghana, 11*, 1–4.

Opoku, I. Y., Akrofi, A. Y., & Appiah, A. A. (1995). *Phytophthora* pod rot control studies: On-station researcher managed field trials (pp. 111–127). Annual Report of the Cocoa Research Institute of Ghana.

Opoku, I. Y., Appiah, A. A., Akrofi, A. Y., & Owusu, G. K. (2000). *Phytophthora megakarya*: A potential threat to the cocoa industry in Ghana? *Ghana Journal of Agricultural Science, 33*, 237–248.

Schieber, E., & Zentmyer, G. A. (1978). An important canker disease of *Grevilla* in Guatemala. *Plant Disease Reporter, 62*(10), 923–924.

Tarjot, M. (1971). Quelques precisions sur le role de l'environement dan le comportment des cabosses decacoyer envers le *Phytophthora palmivora* (Butl). *Butl. en Cote d'Ivoire. Café Cacao Thé, XV*, 215–240.

Thorold, C. A. (1975). *Diseases of Cocoa* (423 pp). Oxford: Clarenden Press.

Wood, G. A., & Lass, R. A. (1985). Cocoa (4th ed.). London: Tropical Agricultural Series, Longman.