16

Effect of Prophylactic Measures on the dissemination of *Phytophthora palmivora*

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Sources of contamination and general mechanism of infection

As with all cryptogamic diseases, field dissemination of cocoa black pod due to *P. palmivora* depends on the extent of the sites where the parasite survives or multiplies, on the abundance of primary and secondary inoculum in these sites, on factors which ensure their effectiveness as sources of contamination, and on vectors of the reproductive organs of the parasite.

It is not possible here to give a complete and detailed review of these various points, especially of the parasite's places of survival which are dealt with in other chapters to which the reader is referred.

Sites of survival of the parasite as primary sources of infection

Some sites for survival may be inferred by simple logic: in particular, diseased pods left in a withered state on trees, and also pod shells scattered on the ground or placed in heaps in pod-breaking sites. Other sites, such as the soil, are less self-evident. Finally, others are more concealed and have been located with certainty only by close observation: this category includes flower cushions, bark of cocoa and shade trees, mosses and other epiphytes covering the bark, and the leaves on shoots.

One special primary source of inoculum which must be mentioned is the bark cankers caused by the parasite from which it can be liberated to infect pods.

These sources of contamination, which are primary because they are at the origin of the initial black pod attacks, obviously remain active all through the season and are therefore 'permanent' sources of infection.

Secondary sources of inoculum

Once the infection breaks out at the beginning of the wet season, coming from the survival sites just mentioned, the affected pods constitute a site of intense multiplication of the fungus. The pod lesions become covered with fructifications, and so become sources of active contamination. This source of inoculum, secondary in the chronological sense, assumes progressively greater importance during the course of the season because the number of diseased pods increases steadily thus forming a 'permanent' source of infection.

General mechanism of disease dissemination in plantations

Progress of infection in the plantation is both vertical, i.e. from one pod to another on a given tree, and also horizontal from one tree to the next.

Vertical dissemination, which takes place in both the descending and ascending directions, brings into action simple mechanisms: direct contact between healthy and diseased pods, spread of parasite fructifications by rain water dripping from diseased pods on to healthy pods below, scattering of zoospores on to healthy pods through the impact of rain drops falling on diseased pods or on the ground which acts as a reservoir of the parasite.

Vertical dissemination is also accomplished by insects or other invertebrates which are vectors for the parasite: contamination from the ground of the lower pods occurs not only by scattering soil particles under the impact of rain drops, but also as a result of ground insects or crawling invertebrates passing over the soil or pod fragments on the ground and moving on to healthy pods at the base of the trunk, as shown experimentally in Cameroon.

Observing cocoa trees in plantations shows that an enormous number of ants circulate vertically without interruption in both directions on the trunks. Various authors have shown that they are fungus vectors, which might have been inferred by simple logic without any special study since it is well known that, as far as dissemination of micro-organisms is concerned, anything that moves is a potential and effective vector.

Horizontal dissemination from one tree to the next, or from one plantation to the next, is not always so obvious. This is mainly because in areas where the disease has attained serious proportions, since the ground is of principal importance as a primary source of contamination, infection often begins simultaneously in numerous places in the plantation. Often, however, favoured centres of infection can be recognized where the disease makes its first appearance regularly every year. These foci may be characterized either by being located on the actual sites of a particularly abundant source of inoculum which is easily visible (for example, heaps of shells after pods have been opened), or less obviously by the fact that they are exactly located in a microclimate which is particularly favourable for the disease, for example under dense shade.

Starting from these well characterized foci, or from the multiple centres of primary infection which are found scattered in the plantation, the disease spreads progressively to neighbouring trees.

This horizontal spread occurs easily at the level where nearby branches of trees become intertwined, sometimes providing direct contact between pods, or simply bringing the pods of neighbouring trees closer together thus facilitating the action of vector insects.

In general, this horizontal spread of the disease appears much slower than vertical spread, and it may even be said that it is generally masked by the much greater amount of vertical spread. This is undoubtedly due to the fact that the spores of the parasite do not seem to be carried by the wind, or at least only to a very small extent: results from attempts at aerial capture are very poor [but see Thorold, 1952, 1955 (Editor)]. The only vectors involved in this horizontal spread are therefore insects and other invertebrates (for example, slugs).

Rapid dissemination in a horizontal direction can only be observed clearly around particularly large and abundant sources of contamination, such as heaps of shells left after pod-breaking, where not only is the mass of inoculum considerable, but in addition flying insects reproduce in considerable numbers; or again around sites where these insects multiply on fruit of certain shade trees which has fallen to the ground.

Possibilities of intervention

Destruction of shell fragments abandoned in the plantation

To anyone who has lived in Cameroon plantations, the role of shell fragments is so clear that it requires no special study or lengthy research: one has only to observe the actual outbreak and veritable spread of rot caused by the presence of these shell heaps and involving all the trees in their neighbourhood. There is no doubt that pod shells, which in Cameroon breed fungus spores on a large scale, are a direct source of contamination for trees standing in their immediate vicinity, and that they contribute to maintaining a high degree of colonization by *P. palmivora* on all other hosts available to it in the plantation.

Table 20 Percentages of pods affected with ***Phytophthora palmivora***

	After 15 days	*After 30 days*	*After 45 days*	*After 60 days*
Trees with 5 rotted pods around the base	35·7	77·6	91·7	94·2
Trees without any rotted pods around the base	11·3	26·7	57·1	75·8

We have ourselves exploited the effectiveness of rotten pods on the ground as a source of contamination: in order to homogenize the infection in an experimental design which we have designed (comparing the pods growing on trunks of 2 trees, growing as close together as possible, one tree receiving the test treatment and the other acting as a control) we placed 5 pods infected with *P. palmivora* 40 cm from the foot of each tree. We proved by accurate counts

Table 21 Progress of infection at various levels of trees in East Cameroon

Results expressed as weekly cumulated percentages of pods affected by P. palmivora *at each level, in relation to the total number of pods affected during the year, on the tree as a whole.*

(*Observations made on* 2,000 *cocoa-trees: Yaounde*, 1957–8)

	Trunks				*Branches*
	Levels				
Dates	*0–0·5 m*	*0·5 m–1 m*	*1 m and over*	*Total trunks*	
May					
29	0·10	0·01	0·00	0·12	0·00
June					
6	0·70	0·08	0·02	0·80	0·02
12	1·52	0·25	0·05	1·82	0·05
19	2·33	0·55	0·18	3·06	0·06
26	3·34	0·86	0·30	4·50	0·07
July					
3	3·65	1·01	0·34	5·00	0·09
10	4·05	1·15	0·35	5·50	0·09
17	4·39	1·33	0·38	6·10	0·11
24	4·57	1·47	0·44	6·61	0·14
31	4·82	1·71	0·55	7·08	0·23
Aug.					
7	5·11	2·10	0·69	7·90	0·46
14	5·37	2·41	0·78	8·56	0·67
21	5·56	2·56	0·85	8·97	0·77
28	5·74	2·74	0·92	9·40	0·96
Sept.					
4	6·06	3·01	1·05	9·89	1·18
11	6·58	3·49	1·36	11·42	1·81
18	7·37	4·29	1·90	13·56	2·85
25	8·27	5·51	2·67	16·46	5·03
Oct.					
2	9·08	7·14	3·73	19·95	9·00
9	10·04	8·72	5·16	23·91	17·63
16	10·09	9·99	6·50	27·37	26·82
23	11·30	10·70	7·28	29·28	35·20
30	11·64	11·11	7·57	30·31	41·14
Nov.					
6	11·82	11·44	7·85	31·13	48·83
13	11·90	11·64	8·05	31·58	54·54
20	11·93	11·77	8·18	31·87	59·16
27	11·95	11·89	8·30	32·14	65·50
Dec.					
4	11·96	11·91	8·31	32·18	66·37
11	11·97	11·92	8·33	32·24	67·20
18	11·97	11·92	8·34	32·23	67·56
25	11·97	11·92	8·34	32·23	67·65
Jan.					
1	11·97	11·92	8·34	32·23	67·70
8	11·97	11·92	8·34	32·23	67·75
22	11·97	11·92	8·34	32·23	67·75
29	11·97	11·92	8·34	32·23	67·78

(Table 20) that the speed of infection is much greater when pods are present at the foot of the trees. Moreover the percentage standard deviation of the results, expressed as percentages of pods affected with rot, is three times as high after 15 days, almost five times as high after 30 days, almost four times as high after 45 days, and almost twice as high after 60 days for trees lacking pods at their base compared with trees which had diseased pods placed at their base.

Possibly in certain cocoa-producing countries the role of these shell fragments dispersed over the plantations as a whole or concentrated in heaps at points where pod-breaking is carried out will be less obvious than in Cameroon. Indeed, we have observed that fructifications of *P. palmivora* are particularly abundant on these fragments in Cameroon, apparently more so than in other regions for example, of West Africa or Central and South America which we had occasion to visit.

But we do not believe that this difference in the apparent fruiting capacity of strains of *Phytophthora* eliminates the possibility that the parasite will fruit heavily enough even in countries where it seems weaker to constitute an effective source of infection of major importance. We believe, on the contrary that this phenomenon which is obvious in Cameroon, must be considered as real (although at a different level) even in regions where it appears less acute.

Consequently we very strongly recommend the removal from plantations of all pod fragments, whether scattered on the ground or in heaps.

Destruction of diseased pods left on trees

Weekly observations for three years on 10,000 cocoa trees distributed over nine plantations located within a radius of 30 km around Yaounde (East Cameroon), which is one of the main zones of production in Cameroon, has given us a clear picture of the modes of infection in this region.

An equatorial type of climate prevails in this zone comprising:

a small rainy season from 15 March to 15 July;
a small dry season from 15 July to 30 August;
a main rainy season from 1 September to 30 November;
a main dry season from 1 December to 15 March.

Rainfall totals approximately 1,800 mm annually.

Blossoming of the cocoa tree lasts from the beginning to the end of the small rainy season.

Harvest takes place from September to January.

The first attacks of *P. palmivora* can be observed in May; the disease attains two peaks of maximum intensity corresponding to the two rainy seasons. These two peaks are of unequal importance, the disease reaching its greatest intensity during the second rainy season in October and November.

At the beginning of the cocoa season, if the trees still carry dead pods from the preceding season, these pods can contaminate newly formed pods in contact with them or in their vicinity, and this happens at all levels: the infection immediately becomes generalized.

If, on the contrary, care was taken during the dry season to clear the trees of these dead pods, it is observed regularly that the first pods to be infected are the lowest ones, in contact with or near the ground. From there the infection reaches higher and higher pods in an ascending progression.

During the first rainy season this ascending contamination involves practically only the pods on the trunk and lower branches; during the second rainy season the ascending progression is more rapid and reaches the pods on the branches, even the highest ones. The extent of this can be understood by examining Table 21, and Figs. 30 and 31.

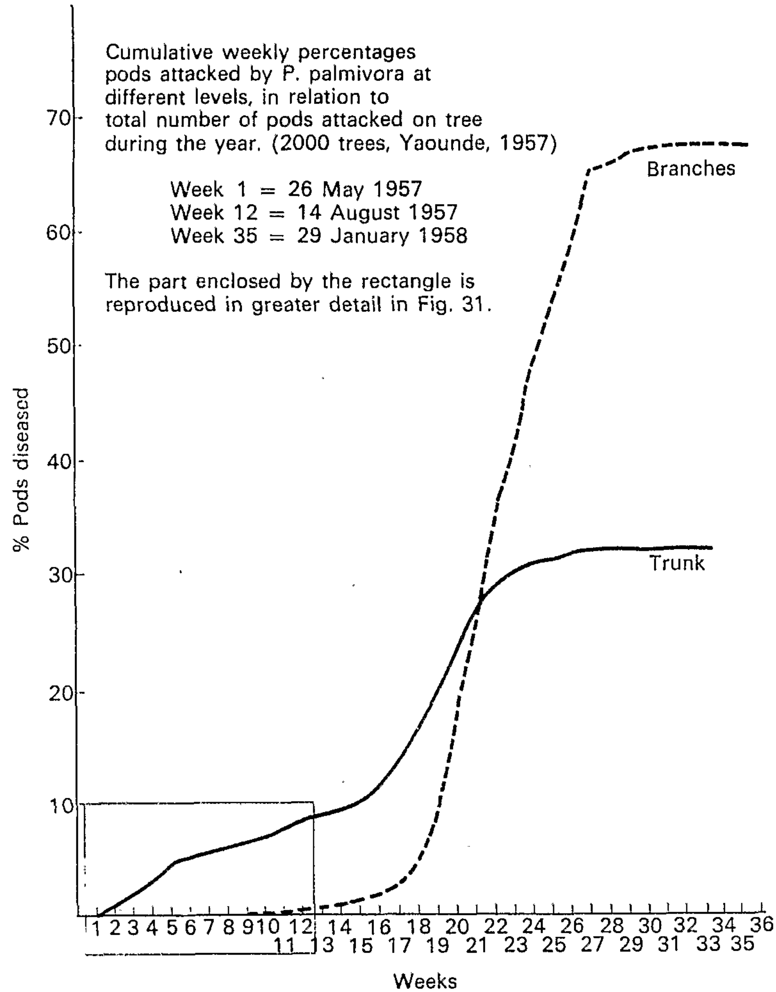

Fig. 30 Cumulative weekly percentages of pods attacked by *Phytophthora palmivora* at different levels with reference to the total number of pods attacked on the tree during the year. (2,000 trees, Yaoundé, 1957). Week 1 = 26 April 1957; Week 12 = 14 August 1957; Week 35 = 29 January 1958. The area within the rectangle (lower left) is repeated in greater detail in Fig. 31.

Thus in East Cameroon, in the absence of dead pods from the previous season, infection starts from the ground. Other sources of contamination (flower cushions, bark, mosses and epiphytes, etc.), which exist there as elsewhere, do not seem to play a part as sources of contamination, at least at the beginning of the season.

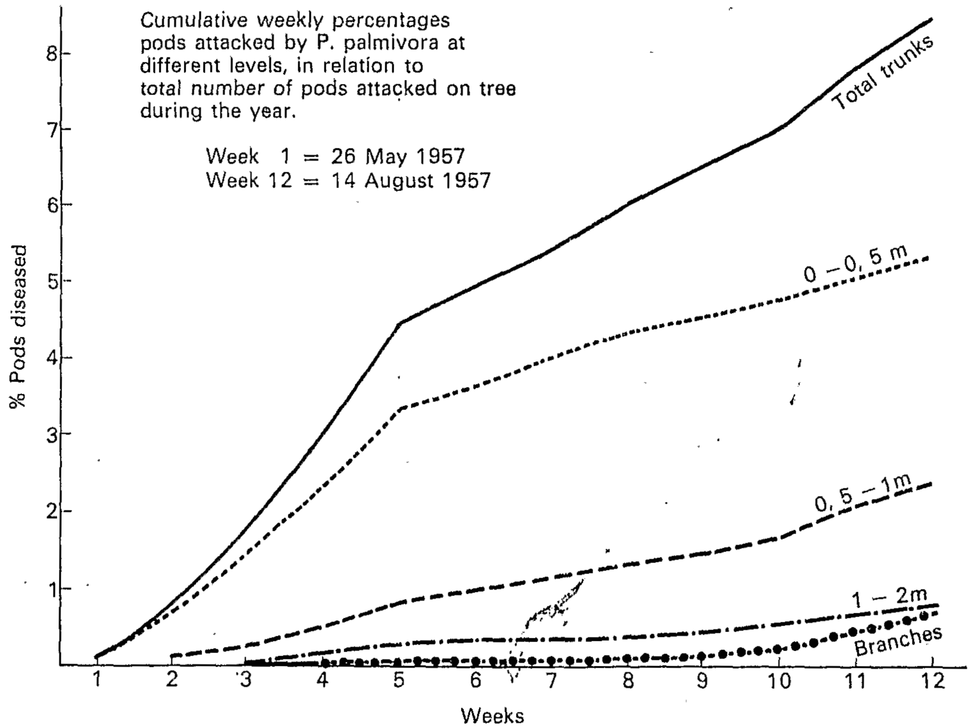

Fig. 31 As Fig. 30, but with expanded time scale, and showing cumulative percentages of pods attacked at different levels on trunk.

This observation, whose practical consequences are considerable making it possible to limit fungicidal treatments to the lower pods only during a large part of the year, strikingly underlines the role played by dead pods on the trees in the development of infection in the field.

We do not claim that this phenomenon is so noticeable everywhere, and we have ourselves observed that it does not always show up so clearly. In West Cameroon, in a particularly rainy zone (3,000 to 4,000 mm of rain) in commercial type plantations under dense cover and therefore insufficiently ventilated, we were unable to observe this phenomenon of ascending contamination but found on the other hand a random infection affecting all levels from the start, although, as in the preceding example, the trees had been cleared of old diseased pods during the previous season. In this zone therefore (unlike East Cameroon) the soil does not seem to be the most effective primary source of infection, and its importance is apparently equalled by other primary sources which become very efficient at the very outset of the season through the special climatic conditions prevailing in this highly watered region with its high relative humidity:

firstly, the flower cushions and bark, which are very damp, are undoubtedly more likely to liberate an active inoculum than in the Eastern zone where they are drier;
secondly, the pods remain wet during long periods and consequently are all the more vulnerable.

But we believe that the infection would have been still more intense if the trees had not been cleared of dead pods, because each one, wherever sited, would have been all the more likely, because of the humid conditions, to act as a primary source of contamination, the reality of which is obvious in East Cameroon.

In West Cameroon elimination of dead pods does not affect the epidemic qualitatively, but exerts a quantitative effect on the extent of the attack.

Conditions in East Cameroon have made it possible to bring out the essential role of dead pods from the previous season as a primary source of contamination; it is reasonable to suppose that this is a general phenomenon which does not always show clearly, however, under other conditions.

It is therefore necessary to destroy dead pods.

Destruction of diseased pods during the season

There can be no doubt, even if the primary sources mentioned above continue to act as permanent sources throughout the season, that the diseased pods become in their turn the most effective and abundant source of contamination. This is an observed fact, quite evident in conditions in Cameroon where the fructifications of the parasite are particularly abundant and where veritable eruptions of rot starting from a single diseased pod can be seen on trunks where pods are formed in high density. Precise counting showed that weekly removal of affected pods helps to reduce the rate of attack to a significant extent. Table 22 shows the reduced rate of attack obtained by weekly elimination of rotted pods in comparison with the rates of attack on trees left under natural conditions.

Table 22 shows that the effectiveness of removing rotted pods once a week:

is highly variable from one year to the next, and that this variation can be quite substantial for a given plantation (e.g. 1–2 and 3);
is largely conditioned by the climate; whereas a decrease of almost 39 per cent in the rate of attack was obtained in 1958–9, a year with low rainfall of 1,380 mm, only 6 per cent reduction was obtained in 1959–60, a year with average rainfall of 1,790 mm giving the fungus a particularly high virulence in sites with a high infection rate (plantations 1–2 and 3).

Regular destruction of rotted pods is therefore insufficient by itself to ensure a satisfactory control of the disease, but is of very great value in years which are unfavourable to infection, or – what amounts to the same thing – in places with a low infection potential; we have noted repeatedly in Cameroon that it was an indispensable auxiliary to chemical treatments whose efficacy is thus reinforced.

Table 22 Reduction in the rate of attack, as per cent of control trees

Years	*Plots*	*Removal of rotted pods*
1958–9	1	42·0
	2	41·1
	3	7·2
	4	47·6
	5	55·9
Average for the year		38·76
1959–60	1	−27·9
	2	−64·4
	3	−17·4
	4	53·8
	5	28·4
	7	45·0
	9	25·1
Average for the year		6·09

Animal vectors of *P. palmivora*

Importance of invertebrate vectors

Flying insects. The possible role of winged insects as effective vectors of *P. palmivora* appeared clearly on several occasions in Cameroon. When cocoa trees are under the shade of certain fruit trees such as guava, various species of citrus, wild mango, etc., outbreaks of black pod suddenly occur just as the fruit trees are shedding their fruits in abundance; the ground is strewn with fruits which, as they rot, become a site for multiplication of insects, particularly Drosophilae, which settle first on diseased pods and then on healthy pods which they contaminate. This phenomenon has caught us unawares several times in the course of various trials, and have been forced to abandon the plots so involved. We now avoid including cocoa trees growing under fruit trees in our trials.

Special conditions (fall of fruit) have therefore clearly brought out the role of flying insects. It must therefore be assumed that under ordinary conditions they exert an influence which, though not obvious, is nevertheless quite real and permanent.

Ground insects. The role of ground insects in contaminating low placed pods, on which they move around after having circulated on the ground, has been demonstrated in Cameroon. In a trial comprising nineteen pairs of cocoa trees bearing 10 pods per tree, the following were compared:

rotted pods in a ring at the foot of the tree;
rotted pods in a ring at the foot of the tree, and a strip of 'Vaseline' smeared

at the bottom of the trunk below the lowest pod, designed to act as a trap, or simply to stop the approach of non-winged insects coming from the ground.

Statistical analysis of the results by Student's method shows that:

differences between treatments are significant at $P = 0{\cdot}05$ for the first observation, 15 days after starting the test;
there is no significant difference later.

These differences indicate that wingless insect such as ants play a certain role in the transmission of *Phytophthora* from the ground towards the lower placed pods. This role is nevertheless limited. The other vectors (simple projection of soil particles by rain, and winged insects) provide sufficient contamination at the outset to lead subsequently to a very rapid progressive infection.

Other invertebrates. Other invertebrates such as centipedes or molluscs such as snails and slugs are also possible vectors of *P. palmivora,* as has been shown by certain authors.

It should be noted that these vectors transport fungus organs not only externally but can also do so internally, as many of them feed on shell fragments which carry the parasite: it was shown for some of them that the organs of the parasite pass unchanged through their digestive tract and are thus conveyed and deposited at a distance with the excrement.

Measures to be taken

Consideration could be given to the systematic destruction of vectors by the systematic application of pesticides, and in particular insecticides: it will be seen in another chapter (Chapter 23) that some work has been carried out in this direction. But we do not believe that the systematic use of pesticides can be recommended in view of the danger which they constitute for the equilibrium of the natural fauna.

We only believe that if plantations are maintained in a high state of cleanliness by applying the measures defined above, aimed at eliminating sources of inoculum, the opportunities for animals to play their role as vectors will be correspondingly reduced.

Conclusion

We have seen that the spread of the disease in the plantation, its extent and modes of dissemination, depend largely on certain primary and secondary sources of contamination.

By intervening directly at these levels, significant action is exerted on the infection from a qualitative standpoint by modifying the epidemiological scheme, as we have done in Cameroon, and from a quantitative standpoint by slowing down the progress of the infection.

These sanitary measures are not of course sufficient to wipe out the infection, but there is no doubt that they help to reduce its incidence.