

PHYTOPHTHORA POD ROT AND THE RAGING ENEMIES OF COCOA PRODUCTION IN NIGERIA: A REVIEW

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SUMMARY

Theobroma cacao is of major economic importance to Nigeria and other growing countries across the tropics. Being one of the fastest selling commodities in the world, demand for its beans is very robust. But contrary to what generally operates in the global scene, cocoa production in Nigeria has in recent years decreased, plunging the country to the sixth position in the world production table. The problems of pests and diseases, significant among which is *Phytophthora* pod rot (black pod), has been said to be hugely responsible for this challenge. *Phytophthora palmivora* and the highly virulent *P. megakarya* among others, have however been discovered to be major causative agents of the disease, with the latter so far reported only in West and Central Africa. In Nigeria, *P. megakarya* has over the years replaced *P. palmivora* as the main causative agent of black pod disease. The pathogens cause brown to black lesions on infected cocoa pods at every stage of development. Loss due to black pod disease of cocoa is between 20-100% annually. The infection does not only affect the pods, it also spoils the beans. Several measures have been reportedly taken by Nigerian farmers to combat cocoa pod rot, prominent among which is the use of synthetic fungicides. This, though highly effective and reliable when used at recommended dosage, has remained hazardous and expensive. Ineffectively checked proliferation of the pathogen probably due to increasingly high cost of control, has been hugely responsible for the dwindling cocoa production levels experienced in Nigeria in recent years. Long time survival of the pathogen in the soil/debris and climatic factors has made a reasonably significant control of the disease a big challenge to Nigerian farmers. Detailed exploration of

the use of botanicals with other safe and affordable techniques would therefore help keep the problems at bay.

Keywords: Cocoa, pod rot, *Phytophthora*, production, Nigeria

CACAO is an important crop around the world. It is a cash crop for growing countries and a key import for processing and consuming countries. The crop is a member of the large family, Malvaceae, which is comprised of former families Sterculiaceae (cocoa and kola), Bombaceae (baobab, durian and kapok), Malvaceae *sensu lato* (cotton, hibiscus and okra) and Tiliaceae (basswood) (Ploetz, 2007). It can grow in soils ranging from acidic to slightly alkaline, with a pH of 6.5 optimal for nutrient uptake by the trees (Vanegtern *et al.*, 2015). The crop flourishes well under a humid, warm and constant environmental condition of between 25 and 35°C with a wide rainfall range of between 1,000 and 3,000mm per annum or more. In Nigeria and other African countries where cocoa is grown, a minimum of 25% of clay is required for the crop to be healthy and highly productive (Opeke, 2005). In high-rainfall areas however, increased soil moisture can increase the potential for black pod rot (Vanegtern *et al.*, 2015).

Cocoa remains one of the fastest selling and most desirable agricultural commodities in both the

local and international markets. Demand for it is very robust, moving in tandem with the rapid growth and expansion of chocolate confectioneries and other related products. Cocoa has an added advantage because it is a perennial crop and can survive for decades. Once planted, nurtured to maturity and harvested, farmers are most likely to cash out for a very long time (PII, 2017).

Worldwide production of cocoa in the 2012/2013 season stood at over 3,575,000 metric tonnes, which was lower than the about 4,205,000 tonnes produced in 2016/17, indicating a noticeable overall increase in production. While Nigeria ranked sixth on the 2016/17 world cocoa production table, some other West African neighbours: Ivory Coast and Ghana (with the production levels of 2,010,000 and 950,000 metric tonnes) ranked first and second respectively. Ivory Coast has been said to account for more than 35% of the entire world cocoa production over the past five years (Table 1).

In Nigeria, cocoa was a major agricultural export crop and a top foreign exchange earner in the 1950s

and 60s. Prior to the discovery of crude oil in commercial quantities in the 1970s, Nigeria became the world's second largest producer of the crop. Average cocoa production declined from 420,000 tonnes in the '60s to 170,000 tonnes in 1999. Production climbed to 389,272 tonnes between years 2000 and 2010, but fell back in subsequent years. Nigeria's cocoa production status significantly reduced from 248,000 metric tonnes in the 2013/2014 season to 195,000, 200,000 and 225,000 metric tonnes in the 2014/2015, 2015/2016 and 2016/2017 seasons respectively. Some years after dropping to fourth place, Nigeria has now become the sixth largest cocoa producer in the world (PII, 2017; Table1).

Cacao is grown in fourteen out of the thirty-six states of Nigeria. The cacao growing states are grouped into three ecological zones which include, the ideal cocoa climate ecology (comprising of Ondo, Ekiti, parts of Osun and Edo States) with annual rainfall range of 2,000 to 2,500mm, the ideal cocoa soil ecology (comprising of Cross River, Akwa Ibom and parts of Abia States) with deep clayed, chocolate coloured soil and rainfall in excess of 4,000mm per annum, and the marginal cocoa ecology (comprising of parts of Oyo, Kwara, Ogun, Kogi,

Delta, Adamawa and Taraba States) (Olaiya, *et al.*, 2006).

Despite the availability of environmental conditions necessary for survival of the crop in Nigeria and some other tropical countries where it's being cultivated, cacao productivity/production is known to be hugely faced with the menace of pests and diseases (Samuels *et al.*, 2012; Meinhardt *et al.*, 2008). The low and declining cocoa yields currently being experienced in the country has been alluded to pests and disease attacks as well as inconsistent production patterns. Low levels of mechanization with dependence on cutlass and hoe agriculture and ageing of cocoa fields play a role in decreased productivity, especially in the southwestern states which contribute nearly 80% of national cocoa yields. If no steps were taken, the unrelenting challenges of a weak infrastructure, corruption, political instability, poor (and expensive) access to financing and weak implementation capacity have great probability to further negatively affect the industry's potential in the country (Adelodun, 2017; PII, 2017).

Some of the major diseases and pests affecting cocoa in the tropics include black pod (*Phytophthora* pod rot), cherelle wilt, frosty pod rot, cocoa swollen shoot disease, charcoal rot,

cocoa mirids, mealy bug, and cocoa pod borer. The black pod disease has been identified as the most serious disease of cocoa in West Africa,

especially in Nigeria. It is mostly caused by a fungus *Phytophthora megakarya* in the region (Ali *et al.*, 2017).

Table 1: Top cocoa beans producing countries in 2012/2013 – 2016/2017

S/N	Country	Amount produced (Thousand metric tonnes)/Season				
		2012/2013	2013/2014	2014/2015	2015/2016	2016/2017
1.	Côte d'Ivoire	1,449	1,746	1,796	1,581	2,010
2.	Ghana	835	897	740	778	950
3.	Indonesia	410	375	325	320	290
4.	Ecuador	192	234	250	232	270
5.	Cameroon	225	211	232	211	240
6.	Nigeria	238	248	195	200	225
7.	Brazil	185	228	230	140	180
8.	Papua New Guinea	41	36	36	36	40

Source: Statista (2018)

The *Phytophthora* pod rot

Phytophthora pod rot, also known as black pod rot or black pod disease of cacao, is caused by some pathogens in the genus *Phytophthora*, literally translated as the “plant destroyer.” This is the same genus responsible for the Irish potato famine of 1845–1852. These pathogens were originally classified as fungi but

have since been reclassified into the kingdom *Stramenopila* (Cook, 2018; Acebo-Guerrero, 2012). There are more than 80 species of *Phytophthora* that cause plant diseases, out of which seven have been named as causative agents of black pod disease all over the world. The seven implicated species are *P. capsici*, *P. citrophthora*, *P. megasperma*, *P. katusae*, *P.*

palmivora, and *P. megakarya*. While all of these pathogens can cause black pod disease, the two major pathogens are *P. palmivora* and *P. megakarya* (Guest, 2007).

Black pod rot is the most important disease of cacao on a global scale with losses estimated at 700,000 metric tonnes in 2012 (Ploetz, 2016). *Phytophthora palmivora* is present in most of the cacao growing countries around the globe and has a broad host range (McHau and Coffey, 1994). *Phytophthora megakarya* occurs only in the countries of West and Central Africa and is considered a significant pathogen only on cacao. *P. megakarya* is the most virulent species in the *Phytophthora* genus causing 60–100% cocoa pod/crop losses if not managed (Opoku *et al.*, 2000), whereas *P. palmivora* generally causes losses of 20–30% annually (Flood *et al.*, 2004). Cankers caused by the pathogen may kill up to 10% of all trees each year (PII, 2017).

Phytophthora megakarya was first identified taxonomically as a species in 1979 (Ali *et al.*, 2017). By the mid-1980s, the pod rot pathogen became predominant on cacao in Nigeria, Cameroon, Equatorial Guinea, Gabon, and Togo (Ali *et al.*, 2017), was confirmed in Ghana in 1985 (Dakwa, 1987), and continues to spread (Ali *et al.*, 2016).

Phytophthora palmivora is no longer routinely isolated from cacao in Cameroon and Nigeria (Nyasse *et al.*, 1999; Ndubuaku and Asogwa, 2006; Djocgoue *et al.*, 2007), but how *P. megakarya* has displaced *P. palmivora* from cacao in these countries is still unclear (Ali *et al.*, 2016).

P. palmivora tends to have a more rapid growth rate than *P. megakarya* in culture, possibly contributing to its ability to cause accelerated necrosis in mechanically wounded cacao tissues compared to *P. megakarya* (Ali *et al.*, 2016). In a susceptible cacao genotype, mechanical wounding is almost irrelevant for *P. megakarya* infection (Ali *et al.*, 2016). Although cacao remains the only economically important host of *P. megakarya*, isolates of the organism were not grouped taxonomically with *P. palmivora* isolates until 1979, when it was recognized as a new species (Brasier and Griffin, 1979; Despréaux, 2004). Despréaux *et al.* (1987) however reported that *P. megakarya* is not saprophytically active in the absence of the host. They found the infection potential of the soil decreased rapidly with time outside epidemic periods.

Disease History

Phytophthora megakarya is primarily known for the damage it causes to the cocoa pod. It has also been found to subsist on cacao roots (Gregory *et al.*, 1984) and can cause dieback of seedlings (Bowers *et al.*, 2001). Since all *Phytophthora* spp. causing black pod disease of cacao in Africa were classified as *P. palmivora* prior to 1979 (Brasier and Griffin, 1979), it is unknown when *P. megakarya* was first “discovered.” The center of origin of the specie is however believed to be primary forests of Central and West Africa. To date, *P. megakarya* has only been reported in these geographical regions (Nyasse *et al.*, 1999).

Disease cycle, symptoms and signs

Phytophthora megakarya, like *P. palmivora*, undergoes series of developmental stages throughout the cocoa pod rot disease cycle (Figure 2). This includes the formation of mycelium and three main spore types, i.e., sporangia, zoospores and chlamydospores that may directly or indirectly cause infection. Primary inoculum in the form of mycelium in soil and bark cankers develop into sporangia, which germinate during wet and humid conditions to establish an infection (Luterbacher, 1994).

A successful infection results in the generation of secondary inoculum of sporangia containing motile biflagellate zoospores. The most important developmental factor in *P. megakarya* is its ability to emit zoospores earlier and also two times more than *P. palmivora*. Zoospores actively detect and swim toward cacao plant tissue to infect it (direct infection) or encyst in the absence of free water, and germinate later to infect susceptible plant tissue (indirect infection). Under humid conditions, a single pod may produce up to 4 million sporangia (containing motile zoospores) that are disseminated by rain, movement of planting materials, insects and rodents, and contaminated harvesting tools and pruning implements. Chlamydospores are the principal long-term survival structures of *P. megakarya* in soils. These chlamydospores develop into mycelia and infect cacao tissue (Vanegtern *et al.*, 2015).

Black pod disease starts when the infected pod shows some little yellow spots, which eventually turn brown and enlarge to a dark brown or black lesion within five days. The lesion is fast growing and covers the entire pod after eight days of infection. The infection does not only occur on the pod surface, it also invades inside the pod, affecting the

beans. The growth of white mycelia on black pod is visible after 11 days and the sporulation is initiated. The dispersal of sporangia or zoospores through water, ants and other insects occurs at this stage and will infect other healthy pods nearby. Direct contact of a black pod with healthy pods also leads to the spread of disease (Philip-Mora and Cerda, 2009).

In addition, infected flower cushion and mummified pods are the locations for *P. palmivora* survival during dry season, where the pathogen will grow and continue to infect other developing pods. The infection occurs at any stage of pod development where it causes wilting and dying of young pods and destroys the beans of mature pods. When pods are infected (or become mummified), they can produce a massive amount of inoculum to

infect other pods; it is especially abundant in the infections caused by *P. megakarya*. *P. megakarya* causes similar symptom as *P. palmivora*, but the occurrence is faster and generally produces greater number of spores (Guest, 2007; Luseni and Kroma, 2012; Opoku, *et al.*, 2000).

In addition, as *Phytophthora* can persist in soil and debris for months to several years and susceptible pods may be present on the trees most of the year, the pathogen may always be present in the canopy, ready to cause major epidemics when environmental conditions become favourable for sporulation and dispersal. In addition, factors such as rain and wind, as well as biotic elements such as ants, beetles and insects in general should be considered of importance for black pod spread (Acebo-Guerrero *et al.*, 2012).

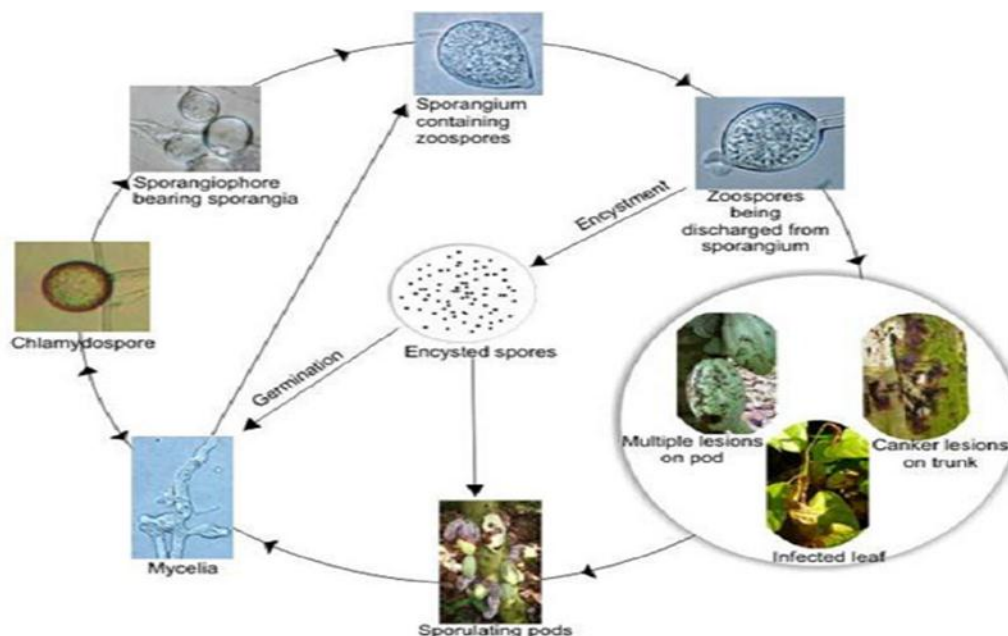


Figure 2: Disease cycle of *P. megakarya* on cacao

In the cycle, (a) sporangiophore bearing sporangia, (b) sporangia containing zoospores, (c) zoospores being discharged from sporangium, (d) infection on cacao pod, (d) infection on tree trunk, (e) infection on leaf, (f) different levels of infection on cocoa pods, mycelia and encysted zoospores are shown.

Source: Akrofi (2015)

In determining the survival of *P. palmivora* and *P. megakarya* in soils, the two species were introduced into

plantation soil before the dry season. *Phytophthora palmivora* could be recovered for ten months and *P. megakarya* for 18 months after the introduction. The long time survival of *P. megakarya* in soil and infected debris, and evidence of its adaptation in soil and survival on roots of cacao and other forest trees (Opoku *et al.*, 2002) makes the control of *P. megakarya* difficult. Therefore, management of the disease should be approached from different angles (Acebo-Guerrero, 2012).



Plate 1: A cacao pod and bean mass consumed by *Phytophthora palmivora*.

Source: Vanegtern (2015)

Mode of dispersal

The spread of spores through air from infected pods was observed and some assumption regarding this mechanism of dispersion has been made in previous studies. It was assumed that under close canopy, less water will reach the sporulating pods to spread the inoculum. However, rain drops from leaves and branches could also splash the inoculum to the surroundings. Infected pods laying on the ground or litter could also spread the inoculum, yet greater infection was observed on pods located under infected pods hanging on the tree compared to pods at the same level

with the infected pods. It was reported that splash of wind-blown droplets from the infected pods are also able to infect pods on different trees nearby. The disease spreads primarily through dissemination of sporangia via rain and wind, insects, and human transmission (Maddison and Griffin, 1981; Opoku *et al.*, 2007).

The black pod rot pathogen is dispersed by caducous sporangia, and the disease is clearly polycyclic. Sporangia form on the surface of infected pods at relative humidities in the range 60-80% RH and temperatures between 20-30°C. Sporangia can germinate directly via

a germ tube, or indirectly to release about 30 zoospores. Wet, showery conditions are essential for infection and spread. Wood (1974) has shown that long periods of relative humidity at saturation point are required for the rapid spread of disease. The theory that relative humidity is the most important climatic factor helps to explain the higher incidence in Nigeria than in Ghana, and the almost complete absence of black pod disease in Malaysia (CABI, 2017).

The spread of infection to pods above bare soil was shown to be greater relative to pods above litter. The reason for this is due to the splash of rain from bare soil spreads

the inoculum to pods. However, litter under the tree prevented water droplets from splashing the soil particles as well as the inoculum beneath the litter to the above pods (Maddison and Griffin, 1981).

Diagnosis

Phytophthora megakarya can be readily isolated from diseased pods through plating onto V-8 agar or potato dextrose agar media containing antibiotics such as P10VP medium. Tissue for plating should be selected from the advancing margin of the lesion. If the fungus is sporulating on the surface of the pod, sporangia can be picked off with sterile forceps and plated directly (CABI, 2017, Plate 3a-b).

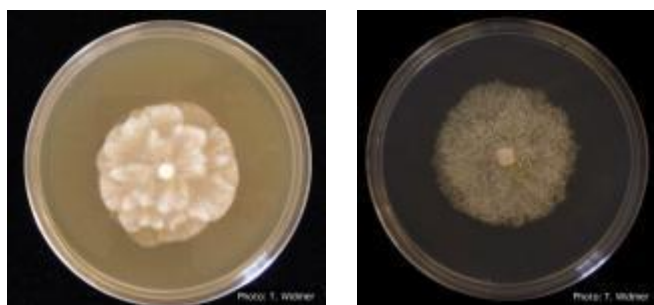


Plate 3a-b: Growth of *P. megakarya* on V8 agar (left) and potato dextrose agar (right)

Source: *Widmer and Hebbar (2013)*

STRATEGIES ADOPTED FOR CONTROL OF PHYTOPHTHORA POD ROT IN NIGERIA

Cultural Control

The recommended cultural practices for the control/management of black pod disease of cocoa involve adequate tree spacing (3.1m x 3.1m) and pruning. These are important for cocoa planting in order to allow in more light and air flow around the trees. Konam and Guest (2002) opined that the level of humidity that causes black pod disease would be reduced as a result. The lowered humidity would enhance a quicker drying of the pod surface. Planting under thinned jungle is commonly employed in West Africa. This, though cheap and simple, provides uneven shade which is difficult to regulate. Shade is however, critical in young trees to promote the development of the most productive canopy shape. Clear felling of jungle, followed by planting of temporary and permanent shade trees, allows more effective regulation of light (CABI, 2017).

Removal of pods with black pod symptoms should also be done to eliminate the sources of inoculum. Phytosanitary pod removal was observed to significantly reduce disease occurrences by 9–11% to

22–31%, where this practice removes the source for secondary inoculum. However, increase in disease incidence after raining season was observed to be most likely due to the spread of inoculum from survival site by the rain. The application of fungicide following sanitation is commonly performed for an effective control of disease, as sanitation practice alone would not completely eliminate the source of inoculum but still causes greater black pod incident compared to sanitation followed by at least one fungicide application (Adesiji *et al.*, 2007; Opoku *et al.*, 2007; CABI, 2017).

Chemical control

Fungicides have been extensively used for black pod control. In Nigeria, commercial applications began in 1953, using carbide bordeaux mixture. The application of copper fungicides has been shown to significantly reduce a great number of black pod incidences in the country. Metalaxyl (*Ridomil*) and cuprous oxide (*Perenox*) were identified to be successful in increasing the number of harvested healthy pods compared to the application of fosetyl aluminium (*Aliete*) and control treatment. In Togo, the use of metalaxyl and red copper oxide reduced losses from

80% to 3% and 19% respectively (Djiekpor *et al.*, 1981). On top of that, the timing of fungicide application has some positive effect on the final pod yield where sprayed plot produced greater yield than the unsprayed plot. The application was done before August, which is before the main disease epidemic that usually occurs in September and October. The recommended standard for fungicide application to control black pod disease caused by *P. megakarya* for a season is 6 to 8 times of application in every 3–4 weeks (Opoku *et al.*, 2007).

However, the adoption of recommended application was very low among farmers in Ghana. Therefore, an experiment with a reduced number of fungicide applications demonstrated that there was 25 to 45% reduction in disease incidence (Opoku *et al.*, 2007). In terms of disease control and yields, sanitation and three applications of *Ridomil 72 plus* (12% metalaxyl + 60% copper-1-oxide) fungicide showed a better control compared to sanitation alone and sanitation with one or two fungicide applications. However, reduced fungicide application was shown to be significantly less effective than the recommended standard fungicide application. It was suggested that the understanding regarding the source

of inoculum, the amount of infective inoculum production and how the disease is disseminated is important in order to identify the appropriate and economical method in fungicide application as well as for an effective control of the disease. For example, the application of fungicide on the trunk will help farmers to control the spread of the disease up in the canopy, as it is difficult to reach the canopy during fungicide application. This will eventually save more time, labor and cost for disease management (Opoku *et al.*, 2007). Researchers have proposed integrated control of the disease based on cultural and chemical treatments, plus the use of resistant planting material (CABI, 2017).

The use of fungicides and some other broad-spectrum pesticides have public health and environmental implications. Other problems associated with the use of chemical pesticides on cocoa include excessive tree height (which makes infected pods disperse inoculum from high in the canopy), high cost of chemicals, labour and poor cocoa prices (Adejumo, 2005; Akrofi, *et al.*, 2013).

Biological control

Heavy application of chemical fungicide would eventually lead to the resistance of pathogens and result

in soil and water pollutions. Hence, more sustainable and environmentally friendly methods such as biological control should be established and implemented. Several species of fungi from the genera of *Trichoderma* was identified to be a beneficial endophyte, to control black pod caused by *Phytophthora spp.* An isolate of *Trichoderma asperellum* from soil was observed as a potential mycoparasite for *P. megakarya* where this fungus has the potential to reduce black pod incidence under field condition in Cameroon. It was reported that moderate black pod cases (47%) occurred in the *T. asperellum* treatment to control black pod disease compared to trees with untreated (71%) and chemical fungicide (1.73%). Another species, which is *T. virens* also has been documented to reduce some black pod incident in Peru. In Brazil, a new species known as *Trichoderma martiale* was identified as an endophyte on cocoa, which has the ability to reduce black pod symptoms caused by *P. megakarya*. This endophyte species survives on cocoa pods, and has the ability to establish a long endophytic association with the host (about 3.5 months). Despite documented research efforts in Cameroon and some other cocoa producing countries, the use of biocontrol

agents has not found a solid footing in Nigeria. Nevertheless, the protection against black pod via biological control is not as effective as the control involving the use of chemical fungicides (Deberdt *et al.*, 2008; Hanada *et al.*, 2008; Krauss and Soberanis, 2002).

Use of botanicals

In Nigeria and many other developing countries, the use of plant species as both pesticides and local medicines has been reported (Adejumo, 2005). One of the available alternatives to the use of chemical fungicides is the use of phyto-extracts of tropical plant-source which has been observed to be eco-friendly, bio-degradable, much cheaper, available and safe. Some of the extracts have been found to be effective in the control of some plant diseases (Babalola *et al.*, 2017).

Tijani and Omondiagbe (2006) reported the use of Siam weed (*Chromolaena odorata*) among cocoa farmers in Osun State, Nigeria for crop protection. Solution made of Siam weed, alum, black soap and water- called Siam weed soap solution (SWSS) was prepared, tested and found to be preliminarily effective against fungus diseases affecting cocoa. The SWSS has also been found to be very effective in the

control of cocoa pests with no visible side effects on the crop. Siam weed soap solution has also been reported to have demonstrated prominent advantages over copper sulphate and other innovations such as kerosene soap solution, neem soap solution and tobacco soap solution against the pests and diseases of cocoa in Osun State, Nigeria. 82

In an *in vitro* study conducted by Babalola *et al.* (2017), cold water extracts of *C. odorata* was suggested as a suitable replacement (though with intermittent application) for chemical fungicide in the control of cocoa black pod disease. The authors however suggested an urgent confirmation of their findings on the field.

Adejumo (2000) had earlier reported the potentials of *C. odorata* and *Piper guineense* in controlling the disease. *Tiwantiwa*, a herbal plant mixture containing roots of four trees and leaves of another set of herbal plants of different known weights was developed by a peasant farmer at Akure, Nigeria in 1988 as a treatment against black pod disease of cocoa. It was evaluated both at the laboratory and on the field at the Cocoa Research Institute of Nigeria, Ibadan. Olunloyo (1994) reported 10% of the extracts as the minimum concentration at which zones of

inhibition could be detected. The compound was a diterpinoid and there was no significant difference between the performance of 20% concentration of the herbal extracts and Bordeaux mixture on the field (Olunloyo, 1994).

Resistant variety

The use of resistant varieties in the control of cocoa black pod disease is most applicable, low cost to farmers and an attractive disease control technology. Governments and private companies in developed countries invest heavily in this and have produced most encouraging output by contributing significantly to increased productivity (Adejumo, 2005).

There is no specific variety of cocoa that proved to be outrightly resistant to *Phytophthora* infections and the establishment and utilization of resistant varieties will most likely depend on the region. Numerous breeding programs have been established worldwide in order to screen and test for local hybrids for disease resistance to *Phytophthora spp.* For example, a study in Cameroon assessed the performance of local cocoa cultivars (the southern and northern Cameroon cultivar) compared to the local and international gene bank cultivars. The local gene bank cultivar

consisted of F1 hybrid of Upper Amazon x Trinidad, and an international cultivar from Papua New Guinea, and Latin America were provided through International Cocoa Genebank, Trinidad (Efombagn *et al.*, 2007).

Integrated pest management (IPM)

Adejumo (2005) clearly suggested the need for farmers to adopt an integration of all available cocoa disease control methods such as biological control, genetic and induced resistance, cultural practices, natural products (botanicals), and limited use of chemicals into a single program. In this program, reduction of the overall use of fungicides to an absolute minimum was emphasized, while maximizing their benefits. Various cultural techniques including shade reduction, regular harvesting and frequent weed control, and other agronomic practices as well as the choice of resistant cultivars could also be integrated for effective disease control. There are cooperative research efforts that include various national and international research institutes with a goal to identifying biological control strategies to be used in the integrated pest management systems to fight cocoa diseases (Adejumo, 2005).

CONCLUSION AND RECOMMENDATION

Highly virulent *Phytophthora megakarya* has over the years replaced *P. palmivora* as the main causative agent of black pod disease of cocoa in Nigeria. The seemingly unchecked proliferation of the pathogen is one of the major factors responsible for the dwindling cocoa production levels being witnessed in the country in recent years. Long time survival of the pathogen in the soil and debris as well as some disease-encouraging climatic factors has made a reasonably significant control of the disease a big challenge to Nigerian farmers.

Effective control of *Phytophthora* pod rot disease of cocoa in Nigeria can however be achieved through the integration of (preventive) cultural control measures with timely application (but limited use) of chemical fungicides and/or other control measures.

Since the continuous use of chemical fungicides/pesticides is hazardous, expensive and encourages the development of resistance by plant pathogens (including *Phytophthora spp.*), there is a valid need for the exploration of botanicals and other crop protection techniques which are much safer, cheaper and less dependent on chemicals.

REFERENCES

1. Acebo-Guerrero, Y., Hernández-Rodríguez, A., Heydrich-Pérez, M., El Jaziri, M. and Hernández-Lauzardo, A. N. 2012. Management of black pod rot in Cacao (L.): A review. *Fruits*, 67(1): 41-48. Print84
2. Adejumo, T. O. 2000. An investigation into the antifungal effect of higher plants to control black pod disease of cocoa, *Theobromae cacao* L.-Preliminary Report. *Bull. Sci. Asso. Nigr.*, 23:1-5.84
3. Adejumo, T. O. 2005. Crop protection strategies for major diseases of cocoa, coffee and cashew in Nigeria. *African Journal of Biotechnology*, 4(2): 143-150.
4. Adelodun, A. 2017. Cocoa production in Nigeria: A literature review, In *Analysis, Food and Agribusiness*. www.cpparesearch.org/nu-en-pl/cocoa-production-in-nigeria
5. Adesiji, G. B., Adekunle, O. A. and Omokore, D. F. 2007. Indigenous Control Practices of Pests and Diseases of Cocoa by Farmers in Osun and Ekiti States of Nigeria. *Agricultural Journal*, 2: 662-666.
6. Akrofi, A. Y., Assuah, M. K. and Amoako-Attah, I. 2013. Procedure for screening “New fungicides” for the control of *Phytophthora* pod rot (black pod) disease of cocoa in Ghana. *CRIG Technical Bulletin*, 27: 2-3.
7. Akrofi, A. Y. 2015. *Phytophthora megakarya*: A review on its status as a pathogen on cacao in West Africa. *African Crop Science Journal*, 23(1): 67 – 87.
8. Ali, S. S., Shao, J., Lary, D. J., Strem, M. D., Meinhardt, L. W. and Bailey, B. A. 2017. *Phytophthora megakarya* and *P. palmivora*, causal agents of black pod rot, induce similar plant defense responses late during infection of susceptible cacao pods. *Frontiers in Plant Science*, 8(169): 1-18.
9. Ali, S. S., Amoako-Attah, I., Bailey, R. A., Strem, M. D., Schmidt, M. and Akrofi, A. Y. 2016. PCR-based identification of cacao black pod causal agents and identification of biological factors possibly contributing to *Phytophthora megakarya*’s field dominance in West Africa. *Plant Pathol.*, 65: 1095–1108. doi: 10.1111/ppa.12496.
10. Aryantha, I. P., Cross, R. and Guest, D. I. 2000. Suppression of *Phytophthora cinnamomi* in potting mixes amended with

- uncomposted animal manures. *Phytopathology*, 90: 775-782.
11. Babalola, E. A., Ogundeji, B. A., Adio, S. O. and Adeji, A. O. 2017. Effect of time of exposure on the antimicrobial potentials of some tropical plants against cocoa pod rot pathogen-*Phytophthora megakarya* (B & G) in Nigeria. *International Journal of Plant & Soil Science*, 20(4): 1-8.
 12. Bowers, J. H., Bailey, B. A., Hebbar, P. K., Sanogo, S. and Lumsden, R. D. 2001. The impact of plant diseases on world chocolate production. *Plant Health Progress*.
 13. Brasier, C. M., Griffin, M. J. 1979. Taxonomy of *Phytophthora palmivora* on cocoa. *Transactions of the British Mycological Society*, 72(1): 111-143.
 14. Brasier, C. M., Griffin, M. J., Maddison, A. C. 1981. "Cocoa black pod *Phytophthoras*". In Gregory, P. H. and Maddison, A. C.), *Epidemiology of Phytophthora on cocoa in Nigeria*. UK/Commonwealth Mycological Institute, Kew. pp. 18-30.
 15. Centre for Agriculture and Bioscience International, CABI (2017). *Phytophthora megakarya* (black pod of cocoa), <https://www.cabi.org/isc/datasheet/40979#tosymptoms>.
 16. Cocoa Research Institute of Nigeria, CRIN. 2008. Cocoa production survey 2007 final report. Submitted to the National Cocoa Development Committee (NCDC), p.14.
 17. Cook, L. R. 2018. "Cacao". *Encyclopaedia Britannica*. <https://www.britannica.com/plant/cacao/Pests-and-diseases#ref710340>
 18. Dakwa, J. 1987. "A serious outbreak of black pod disease in a marginal area of Ghana," in *Proceedings of the 10th International Cocoa Research Conference (Santo Domingo)*, 447-451.85
 19. Deberdt, P., Mfegue, C. V., Tondje, P. R., Bonm, M. C., Ducamp, M., Hurard, C., Begoude, B. A. D., Ndoumben-Nkeng, M., Hebbar, P. K, and Cilas, C. 2008. Impact of environmental factors, chemical fungicide and biological control on cacao pod production dynamics and black pod disease (*Phytophthora megakarya*) in Cameroon. *Biol. Control*, 44: 149-159.
 20. Dennis, J. J. C., Konam, J. K. 1994. *Phytophthora palmivora* cultural control methods and their relationship to disease

- epidemiology on cocoa in Papua New Guinea. *11th International Cocoa Research Conference. Cocoa Producers Alliancem*, 11: 953–957.
21. **Despreaux D; Cambrony D; Clement D; Nyasse S; Partiot M, 1987.** Study of cocoa black pod in Cameroon: description of new control methods. *Proceedings of the Tenth International Cocoa Research Conference, Santo Domingo, Dominican Republic, 17-23 May 1987.* London, UK: Cocoa Producers' Alliance, 407-412
22. **Djiekpor EK; Goka K; Lucas P; Partiot M, 1981.** Cocoa black pod rot caused by *Phytophthora* sp. in Togo: assessment and control strategies. *Cafe Cacao The*, 25(4):263-268
23. **Djocgoue, P., Boudjeko, T., Mbouobda, H., Nankeu, D., El Hadrami, I., and Omokolo, N. 2007.** Heritability of phenols in the resistance of *Theobroma cacao* against *Phytophthora megakarya*, the causal agent of black pod disease. *J. Phytopathol.* 155, 519–525. doi: 10.1111/j.1439-0434.2007.01268.x86
24. **Efombagn, M.I.B.; Nyassé S.; Sounigo O.; Kolesnikova-Allen M. and Eskes A.B. 2007.** "Participatory cocoa (*Theobroma cacao*) selection in Cameroon: *Phytophthora* pod rot resistant accessions identified in farmers' fields". *Crop Prot.* 26: 1467–1473. doi:10.1016/j.cropro.2006.12.008 .
25. **Gregory P. H; Griffin M. J; Maddison A. C. and Ward M. R. 1984.** Cocoa black pod: a reinterpretation. *Cocoa Growers' Bulletin*, No. 35:5-22.
26. **Gregory P. H and Maddison A. C. (Editors). 1981.** Epidemiology of *Phytophthora* on cocoa in Nigeria. Final Report of the International Cocoa Black Pod Research Project. *Phytopathological Papers*, No. 25:188 pp.
27. **Gregory, P. H. and Maddison A.C. 1981.** Epidemiology of *Phytophthora* on Cocoa in Nigeria. UK: Commonwealth Mycological Institute, Kew.
28. **Guest, D. 2007.** "Black Pod: Diverse pathogens with a global impact on cocoa yield". *Phytopathology.* 97: 1650–1653. doi:10.1094/phyto-97-12-1650.A86
29. **Hanada, R. E; Souza T. J.; Pomella A. W. V.; Hebbar K. P.; Pereira J. O.; Ismaiel A. and Samuels G.J. 2008.** "*Trichoderma martiale* sp. nov., a new endophyte from sapwood of

- Theobroma cacao with a potential for biological control". Mycol. Res. 112: 1335–1343. doi:10.1016/j.mycres.2008.06.022.
30. **ICCO, International Cocoa Organization. 2013.** "Pest and Diseases", <https://www.icco.org/about-cocoa/pest-a-diseases.html>
31. **Konam, J.K. and Guest D.I. 2002.** "Leaf litter mulch reduces the survival of Phytophthora palmivora under cocoa trees in Papua New Guinea". Aust. Plant Pathol. 31: 381–383. doi:10.1071/ap02043.
32. **Krauss, U. and Soberanis W. 2002.** "Effect of fertilization and biocontrol application frequency on cocoa pod diseases". Biol. Control. 24: 82–89. doi:10.1016/s1049-9644(02)00007-5.
33. **Luseni, M.M. and Kroma S. 2012.** "Black pod disease of cacao" (PDF). www.plantwise.org.
34. **Luterbacher, M.C. 1994.** The identification, epidemiology and control of *Phytophthora megakarya* on cocoa in West Africa. PhD Thesis, University of London. 369pp.
35. **Luz, E. D.M.N. and Mitchel, L. D. J. 1994.** Effects of inoculum forms and densities on cocoa root infection by *Phytophthora* spp. Agrotropica, 6(2):41-51.
36. **Maddison A.C. and Griffin M.J. 1981.** "Detection and movement of inoculum". In P.H. Gregory and A.C. Maddison. Epidemiology of *Phytophthora* on Cocoa in Nigeria, Phytopathological. UK: Commonwealth Mycological Institute, Kew. pp. 31–49.
37. **McHau, G. R., and Coffey, M. D. 1994.** Isozyme diversity in *Phytophthora palmivora*: evidence for a southeast Asian centre of origin. Mycol. Res. 98, 1035–1043. doi: 10.1016/S0953-7562(09)80430-9M87
38. [Meinhardt, L. W., Rincones, J., Bailey, B. A., Aime, M. C., Griffith, G. W., Zhang, D. and Pereira, G. A. 2008.](#) "Moniliophthora perniciosa, the causal agent of witches' broom disease of cacao: what's new from this old foe?" 9 (5): 577 - 588.
39. **Ndubuaku, T. and Asogwa, E. 2006.** Strategies for the control of pests and diseases for sustainable cocoa production in Nigeria. Afr. Sci. 7, 209–216. Available online at: <http://docplayer.net/12580205-Strategies-for-the-control-of-pests-and-diseases-for->

- sustainable-cocoa-production-in-nigeria.htm88
40. Nyasse, S., Grivet, L., Risterucci, A., Blaha, G., Berry, D. and Lanaud, C. 1999. Diversity of Phytophthora megakarya in Central and West Africa revealed by isozyme and RAPD markers. *Mycol. Res.* 103, 1225–1234. doi: 10.1017/S0953756299008369
41. Olaiya, A. O., Hammed, L. A. and Adedeji, A. R. 2006. “Ecophysiology of cocoa in West Africa: A case study of multiple cocoa cropping systems in Nigeria.” Paper presented at the inaugural meeting of INFORESTA held at Hotel RAMADAN, 15-18 October, 2006, San Jose, Costa Rica, p.5.
42. Olunloyo, O. A. 1994. Efficacy of “Tiwantiwa” herbal plant substance in the control of black pod disease of cocoa-Preliminary Results. *Ann. Rept. Cocoa Res. Inst. Nigr.* 1994:21.
43. Opeke, L. K. 2005. “Tropical commodity tree crops.” Spectrum Books Ltd. (2nd Edition), Paris, pp. 39-59.
44. Opoku Y., Assuah, M. K. and Aneani, F. 2007. Management of black pod disease of cocoa with reduced number of fungicide application and crop sanitation. *African Journal of Agricultural Research* 2(11):601-604.
45. Opoku, I.Y.; Akrofi A.Y. and Appiah A.A. 2002. Shade trees are alternative hosts of the cocoa pathogen *Phytophthora megakarya*. *Crop Prot.* 21: 629–634. doi:10.1016/s0261-2194(02)00013-3.
46. Opoku, I., Appiah, A., Akrofi, A. and Owusu, G. 2000. *Phytophthora megakarya*: a potential threat to the cocoa industry in Ghana. *Ghana J. Agric. Sci.* 33, 237–248. doi: 10.4314/gjas.v33i2.1876
47. Philip-Mora, W. and Rolando C. 2009. Catalog: Cacao Diseases in Central America (PDF). Tropical Agricultural Research and Higher Education Center, CATIE. Archived from the original (PDF) on 2013-12-12. Retrieved 20 November 2013.
48. Ploetz, R. 2016. The impact of diseases on cacao production: a global overview. In: Cacao Diseases: A History of Old Enemies and New Encounters, eds P. A. Bailey and L. W.Meinhardt (New York, NY: Springer International Publishing), 33–59.
49. Ploetz, R. C. 2007. Cocoa diseases: important threat to chocolate production worldwide.

- Paper presented at the annual meeting of The American Phytopathological Society joint with the Canadian Phytopathological Society and the Mycological Society of America, Quebec, Canada, 97(12): 1634-1639.
50. Proshare intelligent investing PII. 2017. Reviving the Cocoa Industry in Nigeria, <https://www.proshareng.com/news/Agriculture/Reviving-the-Cocoa-Industry-in-Nigeria/37675>
51. Samuels, G. J., Ismaiel, A., Rosmana, A., Junaid, M., Guest, D., McMahon, P., Keane, P., Purwantara, A., Lambert, S., Rodriguez-Carres, M, and Cubeta, M. A. 2012. Vascular streak dieback of cacao in Southeast Asia and Melanesia. In: planta detection of the pathogen and a new taxonomy. *Fungal Biology* 116: 11-23.
52. Sengooba, T. 1992. Crop Protection strategies for resource-poor farmers. R. W. Gibson, A. Sweetmore (Eds.) Proceedings of a seminar on crop protection for resource-poor farmers. Pp 17-23. Isle of Thorns Conference Centre, East Sussex, United Kingdom, November 4-8, 1991.
53. Statista 2018. World cocoa production by country from 2012/2013 to 2016/2017 (in 1,000 metric tonnes). www.statista.com/statistics/263855/cocoa-bean-production-worldwide-by-region/
54. Tijani, A. A. and Omodiagbe, K. F. 2006. Profitability of indigenous pest control methods: The case of cocoa farmers in Osun State, Nigeria. *UNISWA Research Journal of Agriculture, Science and Technology*, 9(2):140-148. 89
55. Vanegtern, B., Rogers, M. and Nelson, S. 2015. Black pod rot of cacao caused by *Phytophthora palmivora*, *Plant Disease*, 108: 1-5.
56. Waller, J. M. and Holderness, M. 1997. Beverage crops and palms. In: Hillocks RJ, Waller JM, eds. *Soilborne Diseases of Tropical Crops*. Wallingford, UK: CAB International, 225-253.
57. Widmer, T. L. and Hebbbar, P. K. 2013. *Phytophthora megakarya*. *Forest Phytophthoras*, 3(1). doi:10.5399/osu/fp.3.1.3386
58. Wood, G. A. R. 1974. Black pod meteorological factors. In: Gregory PH, ed. *Phytophthora Diseases of Cocoa*. London, UK: Longman.

- 59. Zentmyer, G. A. 1987.** Taxonomic relationships and distribution of species of *Phytophthora* causing black pod of cocoa. Proceedings of the Tenth International Cocoa Research Conference, Santo Domingo, Dominican Republic, 17-23 May 1987. London, UK: Cocoa Producers' Alliance, 391-395.