BLACK POD DISEASE PROFILING AND MODEL STRUCTURING FOR PREDICTION OF FUTURE OCCURRENCE IN *Theobroma cacao* LINN. IN FARMS WITHIN SOUTHWESTERN NIGERIA

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ABSTRACT

Severe destruction of cocoa pods in fields by Black Pod Disease (BPD) caused by *Phytophthoramegakarya* (Pm) is a major challenge to cocoa growing farmers. The inability of cocoa farmers in Nigeria to predict BPD outbreak encourages indiscriminate use of environmentally toxic fungicides. Prediction of time of BPD occurrence can provide information on the possible Areas Under Severe BPD Attack (AUSBPDA), minimise fungicide misuse and increase control accuracy. However, there is a dearth of information on BPD outbreak in Nigeria. Therefore, this study was designed to investigate and develop a modified model for BPD outbreak in Southwestern Nigeria.

Structured questionnaires were administered to 12 cocoa farmers and 12 commercial cocoa farms in Adaàgbà, Dáagi-Lógbà, Iyánfowórogi, Mòyè, Olórò and Wáàsimi, with two locations in Ọbáfémi-Owódé, Òwenà, and Owódé-Igàngán. Farms were visited from May, 2015 to May, 2016 to determine the frequency of fungicide application as well as monitor BPD occurrence and severity. Infected cocoa pods (504) and topsoil (156) samples were collected for laboratory analysis. Isolation and identification of Pm were done using standard procedures. The Multiple Regression Model (MRM): $Y=\alpha+\beta_1X_1+\beta_2X_2+\ldots+\beta_nX_n$ where Y is Nx1 matrix of response variable, $X_1,X_2,\ldots X_n$ are NxK matrices of regressors, and $\beta_1,\beta_2,\ldots\beta_n$ regression coefficients was used in model development. Four existing models (MRM_1,...MRM_4) and the modified MRM_5 (ETAPOD) were fitted from real life BPD data. The performance of the models were ascertained using Standard Error of Regression (SER), Root Mean Square Error of Prediction ($RMSE_{Pred.}$) and Adjusted R^2 ($R\text{-}Sq_{Adj.}$). Prediction(s) made by the best fitted model was compared to field observations of monthly BPD occurrence (MBO), Total Annual Occurrence (TAO), and Average Annual Occurrence (AAO) from 2015/2016 season.

All the cocoa farmers used fungicides for BPD control and 64% applied it monthly. The percentage BPD occurrence for Adaàgbà, Dáagi-Lógbà, Iyánfowórogi, Wáàsimi, Ọbáfémi-Owódé, Òwenà, and Owódé-Igàngán were 16, 15, 16, 23, 22, 30, and 9, respectively. The percentage BPD severity in Òwenà and Ọbáfémi-Owódé was 100, while Adaàgbà, Dáagi-Lógbà, Iyánfowórogi, Owódé-Igàngán and Wáàsimi were 95.1, 84.3, 90.9, 71.1, and 96.7, respectively. Severity in Mòyè and Olórò was undetermined. Photomicrograph of Pm

showed hyaline, septate and heterogeneously branched sporangiophores with uniflagillated, ellipsoidal zoospores. The mycelia appeared cotton-white with secretion of lemon-yellowish metabolite. The preferred model was ETAPOD followed by MRM_4, MRM_1, MRM_2, and MRM_3 in terms of SER (0.22, 0.39, 0.45, 0.45 and 0.45), $RMSE_{Pred.}$(0.30, 039, 0.46, 0.46 and 0.46) and R-$Sq_{Adj.}$(0.67, 0.49, 0.32, 0.32, and 0.31), respectively. Predictions made with ETAPOD showed that MBO, TAO and AAO forÒwenà and Wáàsimi were 9.05, 72.3 and 6.0% compared with observed BPD values of 9.5, 70.0, and 5.8%, respectively. Adaàgbà, Iyánfowórogi, and Owódé-Igàngán had 9.43, 77.8, and 6.5% as their predicted BPD values compared with the observed values of 9.0, 53.5, and 4.46%, respectively. ETAPOD performed better than other models and its predicted values were within the range of real life occurrence.

The modified model (ETAPOD) was effective in the prediction of black pod disease occurrence. This will minimise problems of fungicide misuse and improve cocoa production in Nigeria.

Keywords: Cocoa pod disease, *Phytophthora megakarya*, Fungicide misuse, Multiple regression models

Word count: 500

CERTIFICATION

We certify that the research work was carried out by Peter Mudiaga, Etaware of the Department of Botany, University of Ibadan, Ibadan, Nigeria under our supervision

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DEDICATION

This research work is dedicated to God almighty and to my loving and caring parents in persons of Chief John O. and Mrs. Esther Etaware.

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ABBREVIATIONS

⇨ **NBS**: National Bureau of Statistics

- **Nimet**: Nigerian Meteorological Station
- **PDA**: Potato Dextrose Agar
- **FGN**: Federal Government of Nigeria
- **GNI**: Gross National Income
- **ICCO**: International Cocoa Organization
- **CSSV**: Cocoa Swollen Shoot Virus
- **CRIN**: Cocoa Research Institute of Nigeria
- **BPD**: Black Pod Disease
- **AUSBPDA**: Areas Under Severe Black Pod Disease Attack
- **MRM**: Multiple Regression Model
- **SER**: Standard Error of Regression
- **$RMSE_{pred.}$**: Root Mean Square Error of Prediction
- **$R\text{-}Sq_{Adj.}$**: Adjusted R^2
- **MBO**: Monthly Black Pod Disease Occurrence
- **TAO**: Total Annual Occurrence
- **AAO**: Average Annual Occurrence
- **DOS**: Disease Occurrence Status
- **CV**: Cross Validation
- **CBN**: Central Bank of Nigeria
- **ETAPOD**: The name of the developed model (Not an Acronym)

CHAPTER ONE

Introduction

1.0 Background of the study

Agriculture played a major role in sustaining the Nigerian economy (Oyedele, 2007). In the past, itwas the major occupation of Nigerians, it generated high income, it was self-sustaining and a means of livelihood to many Nigerians (Adeniyi and Ogunsola, 2014). *Theobroma cacao* Linn. (Cocoa) is native to South America but widely cultivated in Africa, Europe, Asia and Australia, cocoa cultivation was a major source of income for most 3rd world countries (FAOSTAT, 2018). The largest proportion of global cocoa beans (59%) is from West Africa, with Côte d'Ivoire and Ghana producing 1,472,313 and 858,720 tonnes respectively (FAOSTAT, 2018). In Nigeria, cocoaexportused to be themajorsource of Gross National Income (GNI) with ahigh foreign exchange capacity (Oluyole andLawal, 2008).

Cocoa has high nutritional and financial benefits and also a valued agricultural produce that accounted for about 37.9% of agricultural exports in Nigeria in 1997 (Oduwole, 2001), surpassing the financial values of Rubber, Palm fruits, Groundnut, Yam, Cassava, Maize, Millet, Sorghum etc. Ajakaye(1977) reportedthat cocoa export made over 80% of the Gross National Income (GNI) of the Nigeria economy before 1960. Prior to Nigerian independence from colonial rule, cocoa was responsible for the provision of massive employment opportunities for Nigerians, profitable income for rural farmers, raw materials for manufacturing industries, foreign exchange and internally generated revenue (IGR) for the nation (Alamu, 2013).

In subsequent times, Cocoa production in Nigeria became drastically reduceddue to several limiting factors and the rapid growth in the petroleum industry(CBN, 2003; Folayan*et al*., 2006).Cocoa is highly susceptible to pests and diseases (Evans, 2007) which occur seasonally due to change in weather and other factors, and they affect cocoa pods at different developmental stages in the field (Opoku *et al*., 2000).Cocoa farmswere deserted between 1976 and 1985 as a result of low price incentives (Fasina*et al*., 2001), total neglect of the agricultural sector and lack of support from the government, inadequate capital and lack of manpower (Oduwole, 2004).

The oil sector now serve as the pivot of the Nigerian economybut still the level of poverty and unemployment is on the increase and the nation is indeed suffering from poor industrial growth (Alamu, 2013). The total dependence of the Nigerian economy on the wealth

generated from petroleum and the massive efflux of young Nigerians from farming to the oil sector rendered the agricultural sector unproductive which is one of the major factor(s) militating against the effective contribution of cocoa to modern day revenue generation in Nigeria (Alamu, 2013). In order to improve the agricultural sector and diversify the Nigerian economy, the Federal Government of Nigeria (FGN)in 2006, decided to rejuvenate the cocoa industry with emphasis on increased productivity. As a result, some innovations were made and introduced into the cocoa industry with the intent of rejuvenating and expanding the agricultural sector, increasing foreign exchange earnings, enhancing job creation and farmers' income (FGN, 2006).

Rejuvenating Cocoa farming in Nigeria was indeed a very important step to take because among all the cash crops produced in Nigeria, it was only cocoa that provided a significant contribution to national development in terms of generating finances for the economy (Eroarome, 2009).Globally, Cocoa was producedby well-established agro-industrial companies, multi-billionaire businessmen andin most rural communities by indigenous cocoa farmers;unfortunately the bulk of the cocoa beans in circulation worldwide comes from millions of these small scale rural cocoa farmers who have a few trees each (Adeniyi and Ogunsola, 2014).

Currently, a total land mass of 700,000 hectares is used for the cultivation of cocoa in Nigeria and the crop only effectively occupies only about 500,000 hectares (71.4%) of the total arable land mass (Fasina, 1999). The decline in cocoa production started in 1971 with a production output of 255,000 metric tonnes and 241,000 metric tonnes in 1972 (Are and Gwynne-Jones, 1974), and a further decline in yield in 1978 through 1979 with a poor output value of 137,000 metric tonnes. Crop yield declined further from a more productive value of about 350,000 metric tonnes in the mid-1980s to about 58,700 metric tonnes in 1986. However, the production rate as at 2000 to 2003 was between 165,000 and 180,000 metric tonnes (Taylor, 2000; ICCO, 2005). The decline in production was largely due to old age of most cocoa trees, recurrent invasion by diverse diseases and a fleet of pests attack (Iremiren, 2011), Villalobos (1989) also identified some factors serving as major constraints to cocoa farming most especially in the rural communities to include low yield, inconsistent production pattern, the use of simple farm tools, and constant attack by diseases and pests (Oluyole and Lawal, 2008).

Theearliest account of cocoa pestilence in Africa was reportedin a review by Thorold(1975), who stated that thefive (5) most invasive diseases of cocoa are black pod disease (causedby the Oomycetesfrom the genus "*Phytophthora*"), swollen shoot disease of cocoa caused by the cocoa swollen shoot virus (CSSV), witches' broomincited by the fungus *Moniliopthora* (*Crinipellis*) *perniciossa*, *Monilia*podrot caused by *Moniliopthorarorerii*, and vascular-streak dieback (Opoku *et al*., 2000).Acombination of any of these diseases can result in massive destruction of up to 44% of the world's total cocoa production annually(Agbeniyi and Oni, 2014), resulting in acute financial meltdown anda serious devastating effect in an economy that is solely dependent on cocoa as its major source of revenue.Opoku *et al*. (2000) reported that the most recurrent, highly destructive and dreaded of all these diseases is black pod which has been found in all cocoa growing countries of the world, the disease,however, seems more established in West Africathan in other cocoa growing regions worldwide (Opoku *et al*., 2000). In economic terms, black pod disease is the most influential and the greatest set-back to economic production of cocoa in Nigeria, with up to 90% crop lose in areas with high disease outbreak (Oluyole and Lawal, 2008).

Prior to the mid-1980s, it was reported by Dakwa(1987) that the only known black poddisease in Ghana was that caused by *Phytophthora palmivora*. In 1085, a severe outbreak of black pod disease,which appeared different from that previouslyknown, was reported in the Akomadan area of the Ashanti region. Laboratory investigation by Dakwa (1987) on diseased cocoa pod samples showed that *P. megakarya* was the causal agent,and this had subsequently beenconfirmed (Luterbacher and Akrofi, 1993; Opoku,1994). This was the first reported incidence ofthe species in Ghana, but earlier observations andresearch activities carried out in the Volta region indicated that the disease mighthave existed there, perhaps as far back as the early1970s (Opoku, 1994). *Phytophthora megakarya* had beenreported in many other African nations reputed for massive Cocoa production including Togo, Gabon,Equatorial Guinea, and Cameroun before 1985when it was first reported in Ghana by Brasier andGriffin (1979), making *P. megakarya* a serious threat to cocoa production and cocoa industry in West Africa (Opoku *et al.,*2000).

Adegbola(1972) estimated the average occurrence of the disease to be about 40% in several parts of West Africa and up to 90% in certain places in Nigeria because of the variations in the level of rainfall, the amount of moisture present in the atmosphere and the ambient

temperatures of the surrounding environment (Oluyole and Lawal, 2008). In Cameroun and Togo where the weather pattern is quite similar to that of Nigeria, pod losses due to *P. megakarya* were up to 90% (Annon, 2004). The degree of infection of Cocoa pods by black pod disease varies to a great extent with the varieties (Tijani, 2005). The occurrence of *P. megakarya* in West Africa has changed the status of black pod disease in Ghana, Nigeria, Cameroun and other regions involved in cocoa production. The disease now poses a serious threat to the cocoa industry and has caused great anxietyin many cocoa producingareas (Opoku *et al.,* 2000).

Cocoa pod losses to *P. megakarya* aremassive andsome indigenous cocoa farmers in the affected regions have had virtually no crops for many seasons (Akrofi, 2015). As a result ofthe disease, cocoa farms are being neglected ortotally abandoned (Anonymous, 1995) and some farmersseemingly have little or no enthusiasm inestablishing new cocoa farms in areas with favorable weather conditions for black pod disease establishment where the percentage occurrence is very high(Opoku *et al.,*2000).Unless concerted efforts are made to effectively manage the disease (Agbeniyi and Adedeji, 2003) black pod disease will greatly reduce cocoa production in Nigeria and around the world (Opoku *et al*., 2000). There is an urgent need for a more advanced scientific approach in the management of black pod disease in Nigeria (Agbeniyi and Oni, 2014).

Traditionally, most farmers apply growth stage based fungicide routinely for disease control, which is based principally on the manufacturer's recommendations for the duration of the fungicide's effectiveness (Luo, 2008). Fungicides are applied routinely even when environmental conditions do not favour disease development (Luo, 2008). Environmental safety and food security are major concerns worldwide (Dahab*et al*., 2017). Diseases and pests management have great impact on agricultural production, in terms of yield reduction, high cost of chemical acquisition and increase in the cost of production budget (Chattopadhyay*et al*., 2017). Regardless of the high cost for acquisition of chemicals for plant disease control, its widespread application has been preferred by indigenous farmers due to the benefits they provide in agriculture, particularly by protecting their crops from damage (Dahab*et al*., 2017). On the other hand, pesticide poses a serious danger to human health and environment (Dahab*et al*., 2017). Indigenous farmers directly involved in the handling of chemicals have high chances of chemical poisoning (Soares and De Souza-

Porto, 2009). Also, the use of toxic chemicals that are banned, incorrect application techniques, poorly maintained or totally inappropriate spraying equipment, inadequate storage facilities, and often the re-use of old pesticide containers as drinking or food vessels, poor use of personal protection equipment and other safety measures due to lack of knowledge are serious problems faced by rural farmers (Jallow*et al*., 2017).

Various human health related concerns were associated with chemical exposure, ranging from short term impacts resulting in ailments such as headaches and nausea, to chronic impacts such as cancers, birth defects, infertility, and endocrine disruption (Bourguet and Guillemaud, 2016). Children, in particular, are more endangered by short term and chronic exposure to pesticides (Dahab*et al*., 2017). Furthermore, excessive use of pesticides may lead to the destruction of biodiversity, secondary pest outbreaks and destruction of non-target species, more so, there may arise soil, water and air contamination (Recena*et al*., 2006). Indigenous and commercialFarmers all over the world are now interested in reducing their reliance on fungicides in order to lower production cost while preventing severe disease outbreaks (Luo, 2008). In addition to the financial costs of fungicide applications, consumers are more concerned about chemical residues on consumable products and its environmental impact. These changes have generated interest in new methods to minimise the use of fungicide for plant diseasemanagement. Dynamic disease forecasting models for the optimisation of fungicide applications represent one such method of disease control (Luo, 2008).

Therefore, this study was designed to develop a system for black pod disease prediction in order to provide useful and timely information on black pod disease occurrence, its severity and the specific areas expected to be affected. This will minimize fungicide misuse, increase cocoa productivity, reduce the risk of chemical poisoning, increase farmers' profit, foreign exchange and internally generated revenue (IGR), and ensure the availability of disease-free and non-toxic raw materials for cocoa processing industries. Lastly, it will create a clean and healthy environment for the sustenance of all forms of life.

1.1 Statement of Research Problem

Black pod disease infection on cocoa pods caused by *Phytophthora* species poses serious problems to cocoa merchants and indigenous cocoa farmers around the world. It has the

capacity to limit yield (productivity) up to zero percent if unchecked. It is fast spreading and devastating in effect. The intensity of black pod disease, its prevalence and spread is immense during the rainy season and it is widely pronounced across cocoa producing states in Nigeria.The change in the virulence of the causal agent (*Phytophthora*sp) is greatly influenced by climate change which makes it nearly impossible to manage the disease below epidemic levels. The inability of indigenous cocoa farmers in Southwest, Nigeria to predict the time of black pod disease outbreak encourages the indiscriminate and frequent use of harmful chemicals to control the disease without due consideration for life and the environment. These harmful chemicals have been identified to constitute health hazards to all forms of life (humans, animals, plants and microorganisms) and the environment.

1.2 Justification

Diseases and pests attacks are major factors that limit Cocoa production in Nigeria. The extent of damage caused by these pests and pathogens causing a number of diseases on cocoa and other food crops determine the level severity of food scarcity. The change in rainfall pattern of a particular terrain, a fluctuation in temperature, precipitation or the amount of moisture present in the air (relative humidity), sunshine duration and the availability of viable or pathological sufficient inoculum of *Phytophthora* species are factors responsible for the irregular black pod disease pattern experienced worldwide. Biological control has been proposed as an alternative means for the control of black pod disease rather than the use of hazardous and systemic fungicides (Chemical), but the problem of massive destruction of both unripe and ripe cocoa pods in the field still lingers on.

A rational system for prediction of black pod disease outbreak in Nigeria will prevent the misuse of fungicide by indigenous cocoa farmers, it will increase the control level of any management strategy adapted based on precise quantification of the expected disease level, it will reduce cost and uncertainty, and it is a better tool to safeguard life and the environment. Furthermore, the provision of qualitative and quantitative description of black pod disease pressure within the Southwest will also enable farmers to make decisions regarding the type, level and frequency of chemical treatment needed to manage the disease, resulting in economic gain and minimizing health risk, or on the contrary, if the amount of disease expected is unlikely to cause an epidemic,indigenous cocoafarmers will be advised

to desist from the use of chemicals in order to safe life, conserve money, generate more profit and to create a clean and healthier environment for our children.

1.3 Aim of the Research

The aim of this research was:

- To monitor black pod disease incidence and severity in cocoawith a view of developing a model for predicting future outbreak in Southwest, Nigeria.

1.4 Objectives of the research

The objectives of this study were:

- To determine the occurrence of black pod disease in some selected cocoa growing areas in Southwest, Nigeria.
- To isolate and identify the pathogen responsible for causing black pod disease from infected cocoa pods collected from the study sites.
- To determine the effects of weather pattern in the study sites on disease incidence and severity and how it affects black pod disease outbreak.
- To evaluate cultural practices within the study sites and how itaffectsblack pod disease development and spread.
- To develop a modified model and evaluate the trial version for future predictions of black pod disease outbreak in Nigeria.

CHAPTER TWO

Literature Review

2.0 The Cocoa Plant

Cocoa is one of the twenty two (22) species assigned to the genus *Theobroma*, a member of the subfamily Sterculioidea, which was further classified by modern taxonomist as an affiliate of the mallow family Malvaceae(Smulders*et al*., 2012). The genus

"*Theobroma"*derives its generic name from the ancient Greek language, it is a combination of two Greek words "θεος" (*Theos*), meaning "god," and "βρώμα" (*broma*), which means "food" (Orwa*et al*., 2009). *Theobroma cacao* is a relatively common understory tree that is small and evergreen, growing to about 4–8m tall*,* native to the deep tropical region of South American forest (Acebo-Guerrero *et al*., 2012). The seeds (beans) obtained from the pods are used to make cocoa powder and chocolate (Orwa*et al*., 2009).

Cocoa (*Theobroma cacao* Linn.) is a tree plant that produces flowers and fruits from its main stem and woody trunks (cauliflorous), it is a tropical woody plant that sheds its foliage for a short period of time (semi-deciduous or semi-evergreen plant), it is a short growing tree reaching up to 5 -10m height on the average(Orwa*et al*., 2009). The main stem is short with whorls of branches up to five (5), the cocoa plant is dimorphic i.e. it bears vertical suckers(chupons)which grow from the stem, the chupons bear leaves that are arranged in clusters of five (5) or eight (8) on an axis (A phenomenon referred as phyllotaxy). The lateral branches (fans) have two (2) to four (4) clusters of leaf arrangement (half phyllotaxy). The petiole has two (2) enlarged sections (pulvini), one at its base and the other at the point of insertion of the leaf(Orwa*et al*., 2009). Cocoa leaves are alternate, entire, non-partite, 10cm to 40cm in length and 5cm to 20cm wide. Flowers are tiny and formed in clusters directly on the stem and older branches (Plate 2.1), this is known as cauliflory.The flowers are small, 1cm to 2cm in diameter, with pink calyx. After fertilization, the young embryo develops into a young fruit called the coupon (Plate 2.2), which further develops into the cherelle after few weeks (Plate 2.3). The fruit is referred to as a cocoa pod (Plate 2.4) and it is oval, 15cm to 30cm long and 8cm to 10cm wide with a noticeable colour change at maturity from green through yellow to orange. The pod contains 20 to 60 seeds, usually called "beans", embedded in a white pulp (Clement *et al*., 2010).

Based on the variety of cocoa cultivated, the cocoa pods (fruits) can vary in shape from ovoid to oblong or sometimes pointed and constricted at the base or even almost spherical with ten (10) furrows of which five(5) are prominent. The cocoa beans are arranged inside the cocoa pod in axial placentation, the beans (seeds)are covered in mucilage. The cocoa beans are flat or round with white or purple cotyledons depending on the variety(Orwa*et al*., 2009).The seeds are the main ingredient for chocolate, while the pulp is used in some countries to prepare a refreshing juice(Clement *et al*., 2010). Each seed contains a significant

amount of fat (40–50%) referred to as cocoa butter. The most important active constituent of the cocoa bean is “Theobromine”, a compound similar in its chemical structure to caffeine (Clement *et al*., 2010).

2.1 Major cocoa varieties existing worldwide

There are three broad varieties of cocoa existing worldwide, within these varieties abounds several cultivars (Motamayor and Lanaud, 2002). Due to advancement in technology, more cultivars have been discovered and classified separately. In 2008, ten (10) new cultivars were classified based on the genetic data obtained; they were Amelonado, Criollo, Contamana, Curaray, Guiana, Iquitos, Marañon, Nacional, Nanay and Purús (Motamayor*et al*., 2008). The difference in their chromosomal numbers and other genetic composition may lead to difference in yield or productivity, size of cocoa pods, and their ability to resist or become susceptible to pests and diseases attack (Surujdeo-Maharaj*et al*., 2001; Clement *et al*., 2003).

Regardless of the cultivar or genetic disparity that abound in cocoa, cocoa pods found in wide circulation all over the world fall into three (3) major categories:

2.1.1 The Forastero variety

The word “Forastero” is a Spanish word that simply means “foreign” in English. This species of cocoa tree (Forastero) originated from the Amazon basin. The tree is much hardy (resilient to harsh weather conditions), more adaptable, and more resistant to disease than other varieties (Luxby, 2013). Forastero cocoa tress are known to produce bulk beans with tough flavor (Smulders*et al*., 2012). The flavour produced by the beans is inferior to that produced by the beans of other cultivars/varieties of cocoa. The thick-skinned cocoa pods (Plate 2.5) yield flat, violet coloured beans, with high astringent taste which require a longer fermentation period to eliminate (Luxby, 2013). Forastero beans are mostly renowned for their characteristic cinnamon spiciness.

It is generally believed that ‘Bulk' cocoa beans are known to come from Forastero trees, but there are exceptions; according to Enríquez (1993) the Nacional trees in Ecuador (considered to be Forastero by some, but with traits distinguishing them from all other

groups) produce fine flavoured cocoa beans, while cocoa beans produced in Cameroon are from Trinitario trees (Smulders*et al*., 2012), whose cocoa powder has a distinct and sought-after red colour, are classified as bulk cocoa beans. “Amelonado” is a variety of Forastero most widely grown in West Africa and Brazil. It has a smooth yellow pod with thirty or more pale to deep purple beans (Acebo-Guerrero *et al*., 2012), when opened, forastero beans are easily recognized by their dark purplish cotyledons and flat-shaped beans. However, there are some varieties known for their aromatic properties, such varieties include the Amelonado cocoa of the lower Amazon region, the Nacional cocoa of Ecuador, Amazon I, II and III from West Africa, and the beans from the West African island republic of São Tomé.

In fact, Nacional cocoa is sometimes regarded as an entirely different subgroup and is considered a flavoured cocoa bean which is widely sought after for its unique subtlety (Luxby, 2013).The Forastero cocoa variety accounts for approximately 75% to 90% of the world cocoa production and is often referred to as “bulk beans”. Forastero trees grow in all cocoa growing regions, in places like Africa, the Caribbean, Central and South America and the Pacific Rim. An estimated 70% of the crop comes from West Africa, with Ghana, Ivory Coast, Nigeria, and Cameroon being the predominant suppliers (Luxby, 2013).

Plate 2.1. The flowers of a typical cocoa plant (Cauliflory)

Plate 2.2. The coupon stage of cocoa pod development

Plate 2.3. The cherelle stage of developing cocoa pod in the field

Plate 2.4. A typical unripe cocoa pod still attached to the trunk

Plate 2.5.Amelonadococoa cultivar (Forastero)

2.1.2 The Criollo cocoa variety

The Criollo variety of cocoa is a highly priced and well sort after cocoa variety with subtle flavour and great taste, widely cultivated during the pre-Columbian and Spanish colonial era by Central Americans, the people of Venezuela and Colombia (Motamayor*et al*., 2003). Restriction fragment length polymorphisms (RFLP) and microsatellite markers revealed that a high level of homozygosity (possession of two identical forms of a particular allele or gene) and significantly low genetic diversity within pure Criollo individuals, referred to as Ancient Criollo (Motamayor*et al*., 2002).

Criollo trees are not as hardy those cocoa trees from Forastero variety, and they produce lower yields (Luxby, 2013), softer and more delicate cocoa pods (Plate 2.6) which are sometimes red in colour, containing twenty (20) to thirty (30) white, ivory or very pale purple beans. This variety of cocoa is very fragile i.e. it is highly susceptible to diseases and pests attack, and difficult to cultivate, it is the rarest and most sought after of all the varieties of cocoa in existence. Criollo is a highly flavoured cocoa variety and it produces the finest of beans in terms of the flavour and aroma of the processed cocoa beans. Criollo means "Creole" in Spanish, translated as "native" in English. It originated from Mexico, Central America, and Venezuela. At the time of the Spanish exploration of the new world, it was the predominant type of cocoa (Luxby, 2013).

Today Criollo cocoa accounts for not more than 5% of the world's cocoa production and it is used for production of the world's finest chocolate. Some species of Criollo have been successfully transported to other countries. Due to the soft thin skin of the cocoa pods (Plate 2.1) and their fragile nature, Criollo variety is susceptibility to disease and low productivity and this variety is threatened with extinction (Luxby, 2013). The fresh beans are thick and have white or pink cotyledons, low acid levels and low bitterness. Once processed they produce an intensely aromatic, high quality, very flavoured, smooth chocolate that is very low in acidity, with deep and delicate undertones of varying degrees.

Plate 2.6.The soft, delicate pods of the Criollo cocoa variety

(Luxby, 2013)

2.1.3 The Trinitario cultivar

Historical data show Trinitario cacao originated in Trinidad and Tobago. The Trinitario cocoa variety resulted from natural hybridisation (which was accidental or by chance) between the highly priced and more delicate Criollococoa variety and the high yielding and more resilient Amelonadofrom the Forasterocultuvar (Motamayor*et al*., 2003). This particular species of cocoa is characterized by the production of hard pods (Plate 2.7), which are variable in colour and they contain thirty or more beans of different. The accidental cross-breed between theCriollo and Forastero cocoa trees which resulted in a more superior and resilient cocoa variety (Trinitario) took place in Trinidad around 1730.The hybrids generated from this union combined the superior taste of Criollo bean with the resilience of the Forastero bean (Luxby, 2013).

This cultivar of cocoa trees produces colourful pods (Plate 2.7), which ranges from lemon-yellow to reddish-violet (Luxby, 2013). Some Trinitario species are as highly prized too just like the finest of all Criollo cocoa beans. The cocoa cultivar “Trinitario” was named after its place of origin “Trinidad”. The event that brought about the accidental cross breed of the two distinct cultivars of cocoa was earlier reported as a fleet of "natural disaster" which wiped out nearly the entire Criollo crop of Trinidad in 1727. It was reported to be caused by either a by a fast spreading disease that was catastrophic or a hurricane (Luxby, 2013).

In an attempt to restore the crops population of the affected areas, many cocoa plantations were replanted with Forasterococoa trees which hybridized with the remaining Criollo; the resulting new variety of cocoa retained the delicate flavour of Criollo and the hardy nature and disease resistance of Forastero. The variety was not introduced to the American continent not until the 19th century, first in Venezuela and later in Ecuador. Today, Trinitario cocoa is grown in all the areas where Criollo was grown, areas like the Caribbean, Colombia, Mexico, Venezuela, Trinidad, and in South-East Asia (Luxby, 2013).Trinitario cocoa accounts for about 10% to 15% of the current world production. Chocolate bars such as El Rey's Carenero Superior, Domori's Rio Caribe and Pralus bars from Colombia, Ecuador, Jamaica and Venezuela are made exclusively from Trinitario beans (Luxby, 2013).

Plate 2.7. The smooth and hardy pod of the Trinitario cocoa variety (Luxby, 2013)

2.2 *Phytophthora megakarya*

The pathogen *Phytophthora megakarya* (Brasier and Griffin) responsible for inciting blackpod disease in West Africa was first reported in 1985by Brasier and Griffin (Opoku *et al*., 2000). In the past, the pathogen was erroneously identified as *Phytophthora palmivora*, with the recent advancement in research technology, *Phytophthora megakarya*can now be readily distinguished from *P. palmivora* due to its large gametangia nuclei which contain about 5-6 large chromosomes, compared to *P. palmivora* with 9-12 much smaller chromosomes (Opoku *et al*., 2000). The soil borne pathogen *Phytophthora megakarya* possess caducous sporangia that are easily detached and shed off at the early stages with medium stalk length (10-30 µm), while *P. palmivora* has short stalk length between 1-5 µm (Opoku *et al*., 2000).

New scientific evidence has resulted in the identification of a fourth species with papillate sporangia which also causes disease in cocoa (*Phytophthora citrophthora*).However, this species has obstinate sporangia and can thus be readily distinguished from the other species. Lee and Taylor (1992) used rDNA variation to study the evolutionary relationships among the species of *Phytophthora* identified to cause black pod disease. The internal transcribed spacer(ITS I and ITS II) regions showed low or undetectable intraspecific variability. However, interspecific nucleotide difference was 0.3-14.6%. A common lineage was proposed for *P. palmivora* and *P. megakarya*, while *P. capsici* and *P. citrophthora* also appear to show a close relationship (Taylor, 1992).

2.3 Botanical Description of the Pathogen

The Oomycetes*Phytophthora megakarya* is a Group II member of the genus *Phytophthora* as defined by Stamps *et al.* (1990). The soil borne pathogen produces a small nipple-like protuberance at the bases of easily detached sporangia (caducouspapillate sporangia) which bears their sexual structures on different thalli (heterothallic) and its antheridia are amphigynous i.e. the antheridium encircles the oogonium stalk as they develop. Sporangia are shaped like a lemon (limoniform), or shaped in the form of a pear (obpyriform) with the base at the narrower end or ellipsoid with rounded bases, varying from 20-60 x 13-41 µm, with a length-breadth ratio of 1.2-1.6 µm, and are formed in a sympodium. Sporangia are

easily detached and shed off at the early stages (caduceus), with pedicels ranging from 10-30 µm long (Jeffers, 2006).

Oogonia are produced in paired cultures of A1 and A2 compatibility types only. The A1 compatibility type is most frequently isolated. Oogonia range in size from 19-37 µm, and taper to form a funnel-shaped base at the oogonial stalk. Antheridia are amphigynous, spherical, averaging 13 µm long. Oospores are massively formed filling the whole oogonium space (plerotic) 23-28 µm in diameter with a wall thickness ranging from 1.5-3 µm (Jeffers, 2006).

2.4 Distribution of the Pathogen

The noxious soil borne pathogen *Phytophthora megakarya* appears to be confined to West Africa (Akrofi, 2015), where it is the most common species of *Phytophthora* causing black pod disease. *Theobroma cacao* Linn. (Cocoa) is indigenous to the New World and ranges from Southern Mexico in the north to Brazil and Bolivia in the south (Motamayor*et al*., 2002). The centre of origin is considered to be the basin of the Upper Amazon. This would indicate that if *P. megakarya* is only present in West Africa, it must have another host that is as yet undetermined and cocoa is a new host. Alternatively, *P. megakarya* may have co-evolved with cocoa in South America, and subsequently been introduced to West Africa.

Taxonomic tree of *Phytophthoramegakarya*

Domain: Eukaryota

Kingdom: Chromista

Phylum: Oomycota

Class: Oomycetes

Order: Peronosporales

Family: Peronosporaceae

Genus: *Phytophthora*

Species: *Phytophthora megakarya*

2.5 Mode of survival of*Phytophthora megakarya* outside the host plant

Despreaux*et al*. (1987) stated in his report that *P. megakarya* was found not to besaprophytically active in the absence of *Theobroma cacao* Linn. (the host plant).

Theresearch carried out by Despreaux*et al*. (1987)showed that the infection potential of the soil borne pathogen *Phytophthora megakarya*decreased rapidly with time outside epidemic periods for black pod disease (Despreaux*et al*., 1987). The pathogen affects Cocoa plant at different developmental stages such as flowering, fruiting, pre-emergence, seedling, and vegetative growing stages (Opoku *et al*. 2000).

2.6 Symptoms of black pod disease

Black pod disease symptoms caused by *Phytophthora megakarya* and *P. palmivora* can be distinguished because *P. megakarya* produces lesions on the cocoa pod with irregular edges whereas lesions formedon the cocoa pod by *P. palmivora* have regular borders and are generally smaller (Erwin and Ribeiro, 1996). Cocoa pods are susceptible at all stages of development and may be infected at any place on the surface. The first symptom is a brown to black spot on the pod, which spreads rapidly in all directions and eventually covers the whole pod. The cocoa beans (seeds) become infected internally about fifteen (15) days after the initial infection and are soon of no commercial value (Opoku *et al*., 2000).

Generally, pods closest to the ground are first infected, with the disease rapidly spreading to affect fruit on the entire tree. *Phytophthora megakarya* can also cause seedling blight and trunk cankers, but its capacity to cause root rot is equivocal. Luz and Mitchell (1994) reported that even at high inoculum levels i.e. massive proportion of the infectious propagules of *P. megakarya*present within the surrounding medium, the pathogen still caused little damage to roots and no seedling mortality was observed. Despreaux*et al*. (1987) also showed that *P. megakarya* is not pathogenic to Cocoa roots. Contrary to their report, Gregory *et al*. (1984) initially stated that *P. megakarya* was primarily a root-infecting pathogen.

2.7 Biology and Ecology*Phytophthora megakarya*

The capacity of *P. megakarya* to cause root infections was proven to be equivocal by Gregory *et al*. (1984), they reported that root infection and the surrounding rhizosphere was a reservoir of inoculum and propagules of *Phytophthora megakarya*, allowing zoospores to be released into the soil surface water. The zoospores were spread up the plant by small splash droplets in convection currents into the leaf canopy from the reservoir and

surrounding surface water. As soon as the zoospores land on cocoa pods, the first macroscopic sign of infection is observed about two (2) days after initial infection, and is manifested as a minute translucent spot on the cocoa pod surface. Insects, particularly the small black ant (*Crematogasterstriatula*) were reported to be responsible for moving the infectious propagules from the soil to the tree canopy (Evans, 1973). These ants also use old infected cocoa pod husk still hanging on the cocoa tree to construct tents. The major part of the mummified cocoa pods were the tents of these ants are form are around the pod peduncle on the Cocoa tree, and this can lead to infection from the peduncle region. Since there is a reservoir for accumulation of the spore of Phytophthora megakarya and the pathogen keeps on replicating when the surrounding conditions are favourable, black pod disease affecting cocoa can be said to be a polycyclic disease (Evans, 1973).

Sporangia are often formed on the surface of infected cocoa pods at high relative humidity in the range of between 60 and 80% and temperatures between 20 to 30°C. Sporangia can germinate directly through the formation of a germ tube, or indirectly to release about thirty (30) zoospores. Wet, showery conditions are essential for the infection and spread of black pod disease worldwide. Research has shown that long periods of relative humidity at saturation point are required for the rapid spread of black pod 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 (Chakabarty*et al*., 1999).

2.8 Impact of *Phytophthora megakarya*on Cocoa Production

The outbreak of black pod disease epidemic of cocoa (*Theobroma cacao* Linn.) in West Africa, which is caused almost exclusively by *P. megakarya*, still remains one of the most serious constraints to cocoa production in Nigeria, Ghana, Togo, Cameroun, Cote d'Ivoire etc. various field assessments carried out during the 1978 and 1979 harvest season in Togo revealed that the lose of cocoa pods was up to 80%, when no control measures were taken. Erwin and Ribeiro (1996) estimated a 20-30% loss of the world's cocoa crop to black pod disease, and in some areas they estimated that 90-95% of the crop was rendered unusable for production by various manufacturing industries (Erwin and Ribeiro, 1996).

2.9 Detection and Inspection of Black Pod Disease

Black pod disease of cocoa is readily recognized first and foremost by the presence of a brown to black spot on the pod, which eventually spreads to cover the entire cocoa pod. Under conditions of high humidity, a white bloom comprising fungal mycelia and sporangia may be present on the cocoa pod surface. In advanced stages, the fungus invades the internal tissues of the cocoa pod, including the seeds, causing shrinking and diseased pods eventually become totally mummified (Chakrabortyet *al*., 1999).

2.10 Similarities of *Phytophthora megakarya*to other *Phytophthora*sp

Four (4) papillate*Phytophthora* species are commonly associated with black pod disease of Cocoa, they are *P. palmivora*, *P. megakarya*, *P. capsici* and *P. citrophthora*(Chakrabortyet *al*., 1999). Erwin and Ribeiro (1996) provided a direct comparison of the morphological features of each of these except *P. citrophthora*. This species can be distinguished from the other three based on its persistent sporangia production. Sporangial pedicels of *P. palmivora* are short (2-5 µm), those of *P. megakarya* are intermediate (10-30 µm) and those of *P. capsici* are long (40-150 µm). The karyotype of *P. megakarya* also is n = 5-6 large chromosomes, whereas *P. capsici and P. palmivora* have n = 9-12 small chromosomes. Blaha (1983) suggested that *P. megakarya* could be readily separated from *P. palmivora* because *P. palmivora* is stimulated by white light, whereas vegetative growth of *P. megakarya* is inhibited. The differences were even more marked after exposure to green light.

2.11 Prevention and Control of Black Pod Disease

Control of *P. megakarya* revolves around three strategies; cultural methods, chemical control and disease resistance. At present, control relies upon cultural methods.

2.11.0 Cultural Control

The principle behind cultural practices imperative for black pod disease control simply implies the manual reduction of the population of *P. megakarya* in the absence of the host plant, and cocoa is the only known host. This affords opportunities to limit the spread through ensuring that disease-free nursery material are planted, with the aid of clonal or

genetically engineered planting materials used for propagation. Spread can also be restricted by surface disinfestation of harvesting tools and implements before moving from one tree to another.Improved control can also be obtained by avoiding bare earth (thus reducing spore splash) within the plantation (Waller and Holderness, 1997). Management of the amount of light entering the canopy is also critical, to ensure improved aeration and to promote the drying of the cocoa pod surface. Planting under thinned jungle is commonly employed in West Africa because it is cheap and simple, and it provides uneven shade which is difficult to regulate (Asare and David, 2011). Shade is critical for young trees to promote development of the most productive canopy shape.

Clear felling of jungle trees, followed by planting of temporary and permanent shade trees, allows more effective regulation of light (Asare and David, 2011). Other cultural control methods include improving sanitation by removing infected pods and pod husks. These need to be removed from the plantation to where they no longer provide an effective inoculum source. Also, ripe healthy pods should be regularly harvested, often daily (Asare and David, 2011). Soil tunnels built upon the trunk surface by ants are also responsible for moving inoculum of *P. megakarya* into the infection court (Gregory and Maddison, 1981). Sometimes tunnels are built onto the tops of pods as a shelter for tended mealy bugs, exacerbating the black pod disease problem. Ant management is a critical management issue.

2.11.1 Chemical Control

Fungicides have been extensively used for black pod control. In Nigeria, commercial applications began in 1953, with the wide use of carbide Bordeaux mixture (Agbeniyi and Oni, 2014). Copper derivatives are still commonly used in West Africa, in countries like Zambia and Zaire (Mabbett, 1997). In Togo, the use of metalaxyl and red copper oxide reduced losses from 80% to between 3-19%, respectively (Agbeniyi and Oni, 2014). These workers proposed integrated control based on cultural and chemical treatments, plus the use of resistant planting material. It has been recognized that Amelonado types of cocoa are more resistant to black pod diseases than Amazon, Trinitarioand Criollo types (Chakrabortyet *al*., 1999).

2.12 Climate Change and Plant Disease Development

The classic disease triangle recognizes the role of physical environment in plant disease as no virulent pathogen can induce disease on a highly susceptible host if weather conditions are not favourable. Weather influences all stages of host and pathogen life cycles as well as the development of disease. Relationships between weather and disease are routinely used for forecasting and managing epidemics, and disease severity over a number of years can fluctuate according to climatic variation (Scherm and Yang, 1995). The interrelated climate, land, water, vegetation and human activity determine the ever-changing environment on Earth.

Increased emissions of CO_2 and other active gases from industrial and agricultural development are changing the atmospheric composition. There is a strong interactive link between the large-scale clearing of forests in the humid tropics for logging and intensive agriculture, which alters global carbon balance and climate (IPCC, 2007). Global change, including a changing climate, is one of the most critical issues facing our future today as terrestrial and aquatic ecosystems which sustain life on Earth are being increasingly affected by it. While the global population continues to rise, productive land resource, necessary for food production, shrinks. Currently, the growing concern in most communities and the world at large revolves round the potential impacts of climate and air pollution changes on plant diseases (Chakraborty*et al*., 1998; Suthers*et al*., 2006).

2.13 The advances in IDM using plant disease forecasting

There are numerous disease-forecasting models that use short-term weather data for tactical disease management, but very few models link disease prevalence or severity to long-term climate data (Chakraborty*et al*., 2008). Trawling of plant diseases driven by multiyear climatic cycles is an essential first step to find fingerprints of slow, long-term global change on disease dynamics (Chakraborty*et al*., 2008). Links between the wheat scab forecast model (ENSO) and wheat scab pathogen(*Fusariumgraminearum*) prevalence in China, and between ENSO and wheat stripe rust in China, and stem rust in the USA (Scherm and Yang, 1995) serve as examples.

Jeger andPautasso (2008) emphasized that there is a need for availability of long-term data sets which is a prerequisite for finding fingerprints of inter-annual climatic variation on plant diseases. The long-term Broadbalk experiment on wheat at Rothamsted in the UK is an excellent example of long-term data and archived plant samples since 1844. Two recent works have used this resource spanning over 160 years, applying polymerase chain reaction methods, for demonstrating a link between fluctuations in two wheat pathogens *Phaeosphaerianodorum* and *Mycosphaerellagraminicola* and changes in rainfall, temperature and SO_2 emission (Bearchell*et al*., 2005; Shaw *et al*., 2008). Long-term variation in DNA content of these two pathogens in leaf and grain samples were determined by weather factors occurring over a period longer than the growing season.

In a recent study that used datasets spanning 69 years Hannukkala*et al*. (2007)had linked the early occurrence and increased frequency of potato late blight epidemics in Finland to the effectsof climate change and a lack of rotation crops. Fungicide use in Finland increased 4-fold from 1980 to 2002 because of more frequent and earlier epidemics, although the aggressiveness of *Phytophthora infestans*only had a minor effect on the onset of epidemics after 1991. Using datasets covering only 40–50 years, Woods *et al*. (2005)demonstrated a strong relationship between increase in rainfall and *Dothistromaseptosporum*needle blight of *Pinuscontorta* var. *latifolia*in Northwestern Britain, Columbia, Canada.

CHAPTER THREE

Materials and Methods

3.0 Study sites

The criteria for selection of study sites were: the size of the cocoa farm, consistency in cocoa production, cropping system and Locality. The study sites selected within Southwest, Nigeria were:Ọwenà (Two study locations) and Wáàsimi (Ondo East Local Government Area, Ondo State), Adaàgbà and Iyánfọwọrọgi(Ife South L.G.A, Osun State), two (2) study locations in Owódé-Igàngán (Àtàkúnmòsà East L.G.A., Osun State), two (2) study sites in Ọbáfẹmi-Owódé L.G.A., Ogun State, Mòyè village Ọnà-AràLGA, Dáagi-Lógbà (Atérè Village) in Ọmi-Adió area of Ìddó LGA, and Olórò Village (also known as Ọlọrunda village) in Àkànràn, Ọnà-Arà LGA of Oyo State.The total study sitesearmarked for the disease assessment were twelve (12) in number distributed within four (4) of the six (6) States categorized under Southwest, Nigeria with the exception of Ekiti and Lagos States (Table 3.1) .The study sites were selected based on their involvement in Cocoa farming, consistency in Cocoa production, and the farm capacity used for Cocoa cultivation. The study sites were shown in Fig3.1 with their global positions (GPS Coordinates).

3.1 Farm size, altitude and GPS co-ordinates of the study sites

The co-ordinates and the altitude of the study sites were determined using the blackberry mobile Global Positioning System (GPS)device(version 6.0) and a mobile satellite GPS receiver model GARMIN Etrex 10 obtained from the Department of Botany, Faculty of Science, University of Ibadan, Ibadan, Nigeria. The farm size was measured using a surveyor's measuring tape (100ft by 30m) Lufkin FM100CME 2-Sided, Metric/English 13mm ½ inch x.Figs 3.1 and 3.2 showed the mapped out areas for this research and the states producing cocoa in Nigeria.

Table 3.1.Locations, Altitude, and Farm Size of the Study Areas Selected in Southwest,Nigeria

Location of cocoa farms	Local Govt. Area	State	Latitude	Longitude	Altitude	Farm size (Sq.)
Ọbáfẹmi-Owódé (Post 1)	Ọbáfẹmi-Owódé	Ogun	$7^0 08^I 30.37^{II} N$	$3^0 25^I 56.71^{II} E$	187m	10,000 m^2
Ọbáfẹmi-Owódé (Post 2)	Ọbáfẹmi-Owódé	Ogun	$7^0 08^I 30.32^{II} N$	$3^0 25^I 56.73^{II} E$	192m	10,000 m^2
Adaàgbà	Ife South	Osun	$7^0 22^I 13.80^{II} N$	$4^0 33^I 34.42^{II} E$	262m	40,000 m^2
Owódé-Igàngán (Inland)	Àtàkúnmòsà East	Osun	$7^0 29^I 59.99^{II} N$	$4^0 48^I 59.99^{II} E$	276m	50,000 m^2
Iyánfọwọrọgi	Ife South	Osun	$7^0 21^I 55.22^{II} N$	$4^0 34^I 16.54^{II} E$	259m	20,000m^2
Owódé-Igàngán (Outskirt)	Àtàkúnmòsà East	Osun	$7^0 29^I 53.45^{II} N$	$4^0 48^I 59.01^{II} E$	282m	50,000m^2
Ọwenà (Down-Stream)	Ondo East	Ondo	$7^0 12^I 11.52^{II} N$	$5^0 00^I 55.76^{II} E$	289m	10,000m^2
Ọwenà (Up-Stream)	Ondo East	Ondo	$7^0 12^I 11.50^{II} N$	$5^0 00^I 55.76^{II} E$	291m	10,000m^2
Wáàsimi	Ondo East	Ondo	$7^0 10^I 42.78^{II} N$	$4^0 59^I 31.34^{II} E$	249m	30,000m^2
Mòyè village	Ọnà-Arà	Oyo	$7^0 18^I 54.54^{II} N$	$4^0 01^I 09.34^{II} E$	205m	20,000m^2
Dáagi-Lógbà	Ìddó	Oyo	$7^0 20^I 47.58^{II} N$	$3^0 44^I 30.59^{II} E$	174m	20,000m^2
Olórò village	Ọnà-Arà	Oyo	$7^0 20^I 44.00^{II} N$	$3^0 59^I 34.00^{II} E$	179m	10,000m^2

Fig 3.1.The global positions of the cocoa farms used as study sites

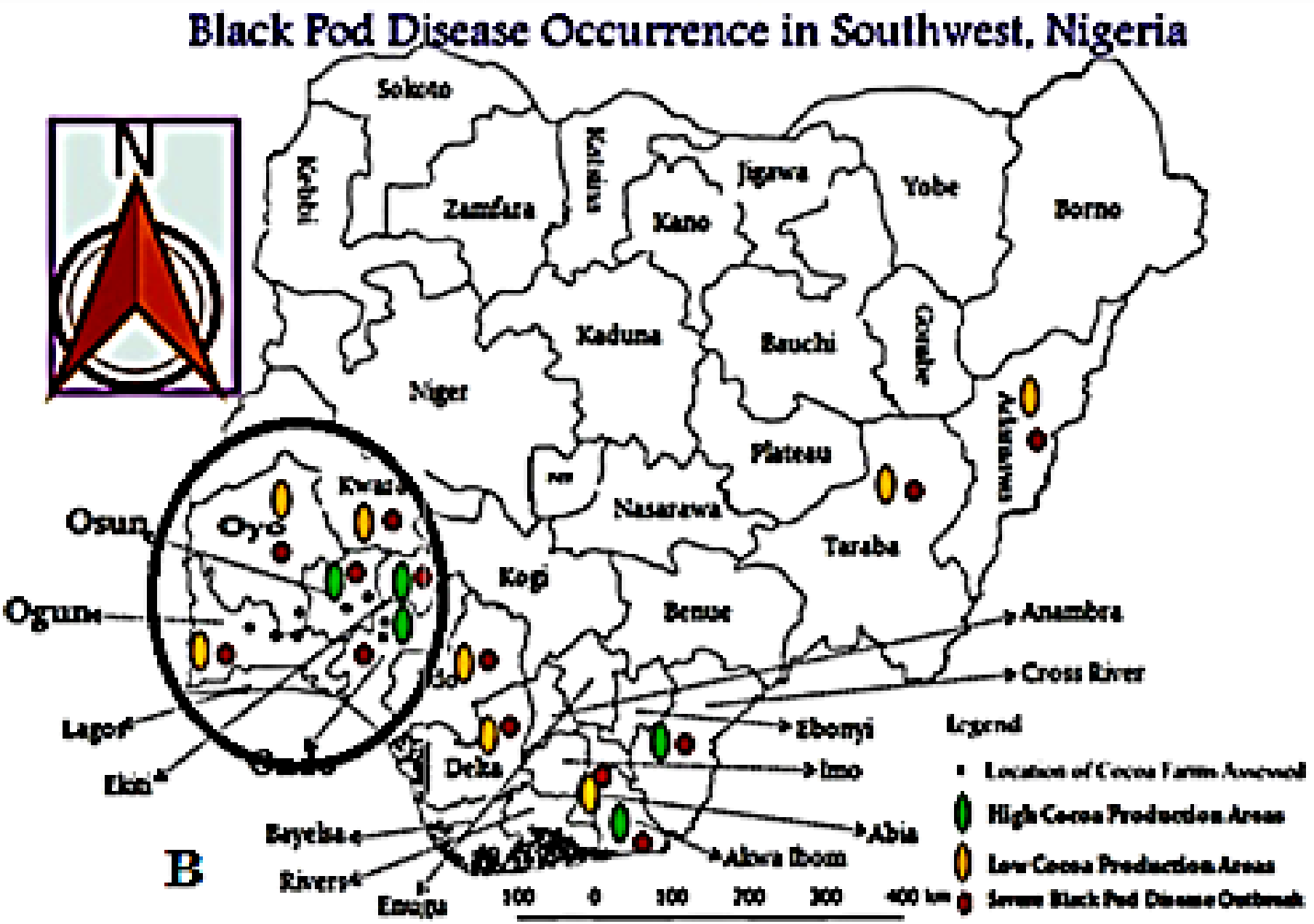


Fig 3.2. Cocoa production and BPD outbreak in Nigeria and within Southwest, Nigeria

3.2 Sample Collection

Five hundred and four (504) infected cocoa pods and one hundred and fifty six (156) topsoil samples were collected for laboratory analysis (isolation and identification of the pathogen only) from the study sites. The topsoil was collected from the root rhizosphere and the dumpsite for shredded Cocoa pod husks (Garage) within 0-20cm depth. The collected samples were aseptically packaged in sterile polyethylene bags, labelled appropriately, placed in a portable ice chest (a cooler) to prevent desiccation and transported to the Mycology/Pathology Laboratory, Department of Botany, Faculty of Science, University of Ibadan, for analysis. Questionnaires were administered to indigenous Cocoa farmers within the study areas to determine the way and manner fungicides were applied and the type of fungicides usually preferred as control agents.

3.3 Sterilization of glass wares and other apparatus

All glass wares were washed with liquid detergent, rinsed with sterile distilled water and air-dried. McCartney bottles were wrapped in aluminium foil and arranged inside the oven (Model Gallenkamp Hotbox oven, Gallenkamp, UK.) and spaces was left between items to aid expansion and contraction of materials without cracking while heating or in the process of cooling down. The oven was heated at 160^{o}C for one hour. The sterilized materials were used within two (2) days of sterilization to avoid recontamination.

3.4 Media Preparation

Severalmedia were used in this experiment in order to effectively determine the morphology of the isolate.The media were prepared according to the manufacturer's prescription.

3.4.1 Potato Dextrose Agar (PDA)

One (1) litre of potato dextrose agarwas prepared by weighing out 39g of the powder, whichwas gently decanted into a graduated conical flask containing one (1) litre of sterile distilled water. The conical flask was plugged with a stopper and sealed with aluminium foil. The solution was gently swirled while homogenizing in a water bath at 70^{o}C to aid solubility.After total homogenization, it was then transferred to the autoclave for sterilization

at 121^{o}C for 15 minutes. The medium was allowed to cool down in the lamina air flow chamberto 35-40°Cand 500mg of Streptomycin was aseptically added to avoid bacterial contamination, after which 15ml was aseptically dispensed into each Petri dishes.

3.4.2 V_8 juice Media

The procedure employed was a modified method ofDrenth and Sendall (2001). The materials needed for the preparation of the media are listed below.

- Calciumtrioxocarbonate (IV) 10g ($CaC0_3$) or Calciumchloride 100ml ($CaCl_2$)
- Amended V8 juice (200mg)
- Distilled/Deionized Water (800 ml)
- Agar-Agar (7.5g)

Two hundred milligram (200mg) of V8 juice was well shaken and decanted into one (1) litreconical flask and 10g of calciumtrioxocarbonateIV ($CaC0_3$) was added to it and stirred for 20 minutes to adjust acidity. The amended V8 juice was diluted to 20% with the addition of 800ml of sterile distilled water. The final concentrationwas autoclave at 121°C for 20 minutes. It was allowed to cool downin the lamina air flow chamber to 35-40°C and 500mg of streptomycin was aseptically added before 15ml was aseptically dispensed into each Petri plates.

3.4.3 Cornmeal agar (CMA)

The proposed method of preparation was given by Drenth andSendall(2001).Maize grains without spots or physical damage were sorted out and 200g weighed using a weighing balance. The corn (maize) was ground using a blender and boiled in 200ml distilled water for one hour (1hr) with intermittent stirring. The resulting mixture was then filtered through a layer of muslincloth and the filtrate was made up to onelitre (1ltr) by adding 800ml of sterile distilled water. A total of 15g of agar-agar was aseptically added and autoclaved at 121°C for 15minutes. After sterilization, 500mg of streptomycin was aseptically added before dispensing into plates.

3.5 Isolation of the pathogen from cocoa pods (Direct plating)

The method of Bush *et al*. (2006) was employed for direct plating of the specimens.Twenty five (25) radial fragments of 8mm diametercut out of the infected cocoa pods from each location were assayed for the presence of the pathogen using direct plating technique for internal infestation as described by Pitt and Hocking(1997). Cocoa pods was surfaced sterilized for 30 sec in 2.5% of Sodium hypochlorite solution (NaOCl), and was rinsed in three (3) successive changes of sterile distilled water. The excised fragments were directly placed under aseptic conditions on PDA, and it was incubated at 22^{o}C and observed after three (3) days for fungal growth.

3.6 Isolation of the pathogen from soil (Baiting technique)

Phytophthora megakarya was isolated from soil samples by "baiting" with greencocoa pod husk using the method described byDrenth and Sendall(2001).Twenty five (25) radial fragments of 8mm diameterwerecut out of the outer surface of a healthy Green Cocoa pod husk, sterilized by dipping in 70% ethanol for 60sec and rinsed in three (3) successive changes of sterile distilled water. Three (3) pieces of the 8mm radial pod husk were then embedded in 20g of soil sample in McCartney bottles and incubated at room temperature (25±2^{o}C) for 48-72hrs. The inoculated 8mm radial pod husk fragments were then aseptically transferred into freshly prepared PDA and incubated at the same temperature in an incubator. Mycelia growth was observed for 7 days.

3.7 Purification of Isolates

Freshly prepared PDA amended with streptomycin was the basic medium used for the purification of the isolates. A total of 15ml of PDA was aseptically poured into each sterile Petri-dish, and they were allowed to solidify. The plates were labeled according to the location of isolation. Each fungi was gently picked using inoculating needle and placed on the media. They were then incubated at 22^{o}C for several days. The isolates were sub-cultured several times to obtain a pure culture and stock cultures were made on slant in McCartney bottles.

3.8 Preparation of stock cultures

Freshly prepared PDA was aseptically dispensed into sterile McCartney bottles and autoclaved at 121°C for 15 minutes. The bottles were placed in a slant position (to obtain a slant). The McCartney bottles were labelled and the mycelia of *Phytophthora* sppwasaseptically inoculated using sterile inoculating needle in a laminar air flow chamber. The inoculated McCartney bottles were incubated in a sterile incubatorat 22^{o}C for several days.

3.9 Sporulation of the Pathogen(s)

Production of asexual and sexual structures was necessary for identification of *Phytophthoramegakarya*. The isolated putative *Phytophthora*sppwas transferred into freshly prepared PDA (95%) amended with 5% clarified V_8 agar which provides sterols necessary for sporulation. Culturedplates were then incubated at room temperature (25±2^{o}C) under continuous 40-watt fluorescent illumination for 1 to 4 days and observed for sporangia production. Also the same experiment was repeated in the dark using the same procedure and pure cultures of isolates grown in V_8-amended media after incubating in the dark was stained and observed under the microscope to determine the presence of sexual structures.Sexual structures were confirmed to be homothallic according to the description of Erwin and Ribeiro (1996).

3.10 Identification of *Phytophthora megakarya*

Identification of the pathogen was carried out by microscopy with preference to zoospores and mycelia structures described byAkrofi (2015)which were exclusively peculiar to Phytophthora megakarya. Photomicrographs of the pathogen were taken using Olympus X330 Mounted Digital Microscope (with zoom facilities)at the Department of Botany, Faculty of Science, University of Ibadan, Ibadan, Oyo State, Nigeria.

3.11 Epidemiological Survey

Black pod disease assessment was conducted for thirteen (13) consecutive months (May 2015 –May 2016), the major (March to October) and the optimum cocoa growing period (July to August) in the rainy season, and the minor cocoa production period (November to

April) in the dry season. The minimum Cocoa farm size considered for the assessment of black pod disease incidence and severity was ten thousand square meters (10,000 m^2) or one hectare (1 hectare).

The disease assessment was conducted both in the rainy season and dry season to determine the level of variation of black pod disease outbreak and severity brought about by seasonal changes. Also, the altitude of the study areas was considered in other to determine its effects on the disease development and spread. Therefore, the study locations were classed accordingly and the observations made were grouped based on the established criterion.

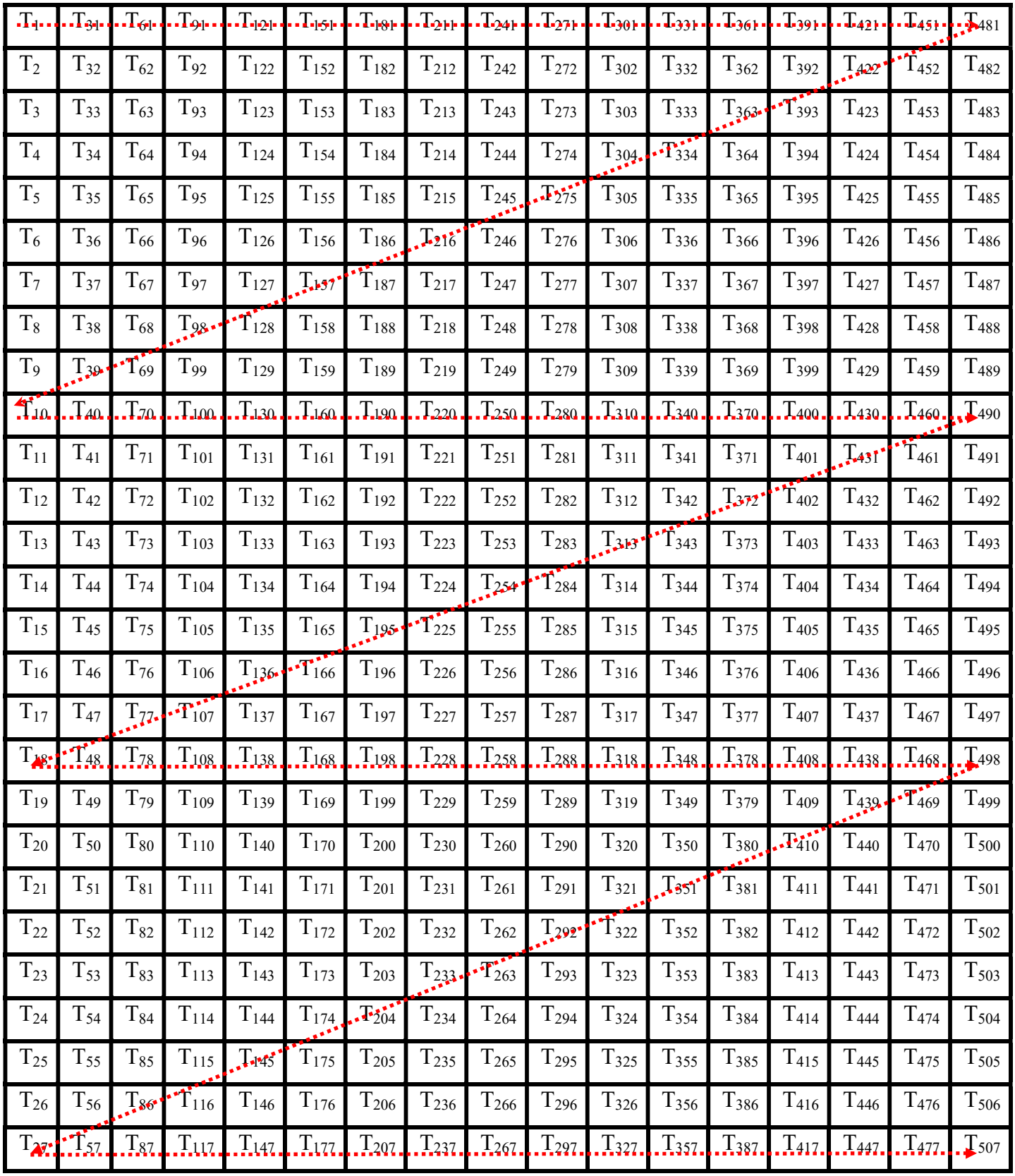
3.12 Black Pod Disease Incidence

The modified method of Luo (2008) was adapted for black pod disease incidence determination. Cocoa trees were assessed in a transverse and diagonal mode as described in Fig 3.3 and Plate 3.1within each study location. Green and ripe Cocoa pods from each tree were inspected for the symptoms of black pod disease, the rain splash zone described by Akrofi *et al*. 2003(Plate 3.2) was of interest. If an infected pod was detected on the tree, the stand (tree) was noted as being infected. The assessment was repeated for a total of one hundred (100) trees and the observations noted. Each tree stand was noted as disease free (Healthy) or Infected based on the presence or absence of black pod disease symptoms.

$$\text{Black Pod Disease Occurrence (\%)} = \frac{\text{No. of Infected Trees} \times 100\%}{\text{Total No. of sampled Trees}}$$

3.13 Black Pod Disease Severity

Cocoa trees were also assessed in a transverse and diagonal mode as described in Fig 3.3 and Plate 3.1 within each study location using the modified methods of Luo (2008).Black pod disease severity was determined using the modified methods of Akrofi *et al*. (2014). Each infected cocoa pod on a stand was assessed and a score from 0 to 5 ascribed (Table 3.2). This score served as the disease severity rating for that particular cocoa pod. The average level of disease severity was calculated for each cocoa stand. The assessment was repeated for a total of one hundred (100) trees and the observations noted. The scorefor black pod disease severity was described in Table 3.2.



T - Cocoa tree

Fig 3.3. A semi-biased mode of disease sampling within thestudy areas

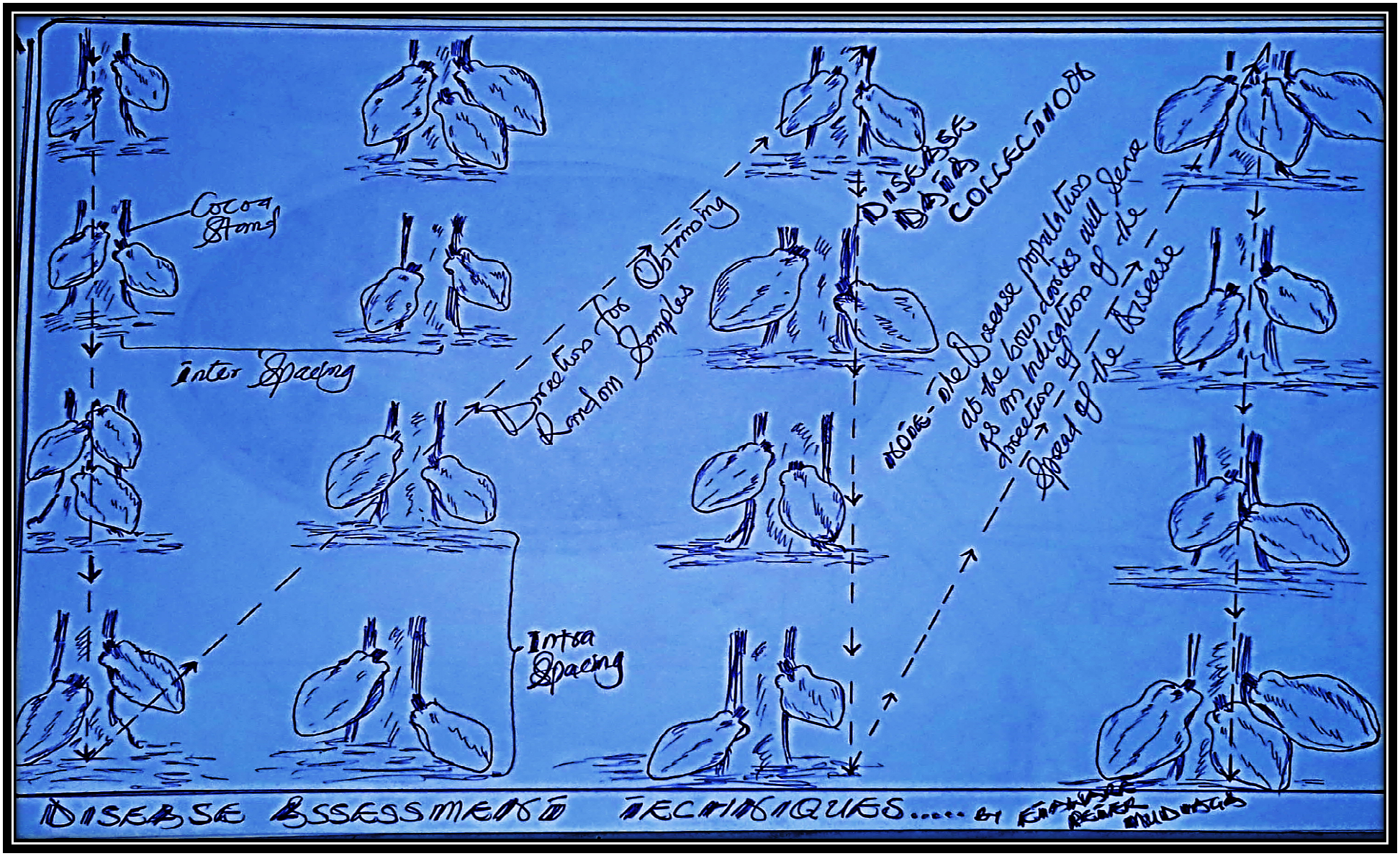


Plate 3.1.A representation of the pattern of black pod disease assessment (2015/2016)within the study areas

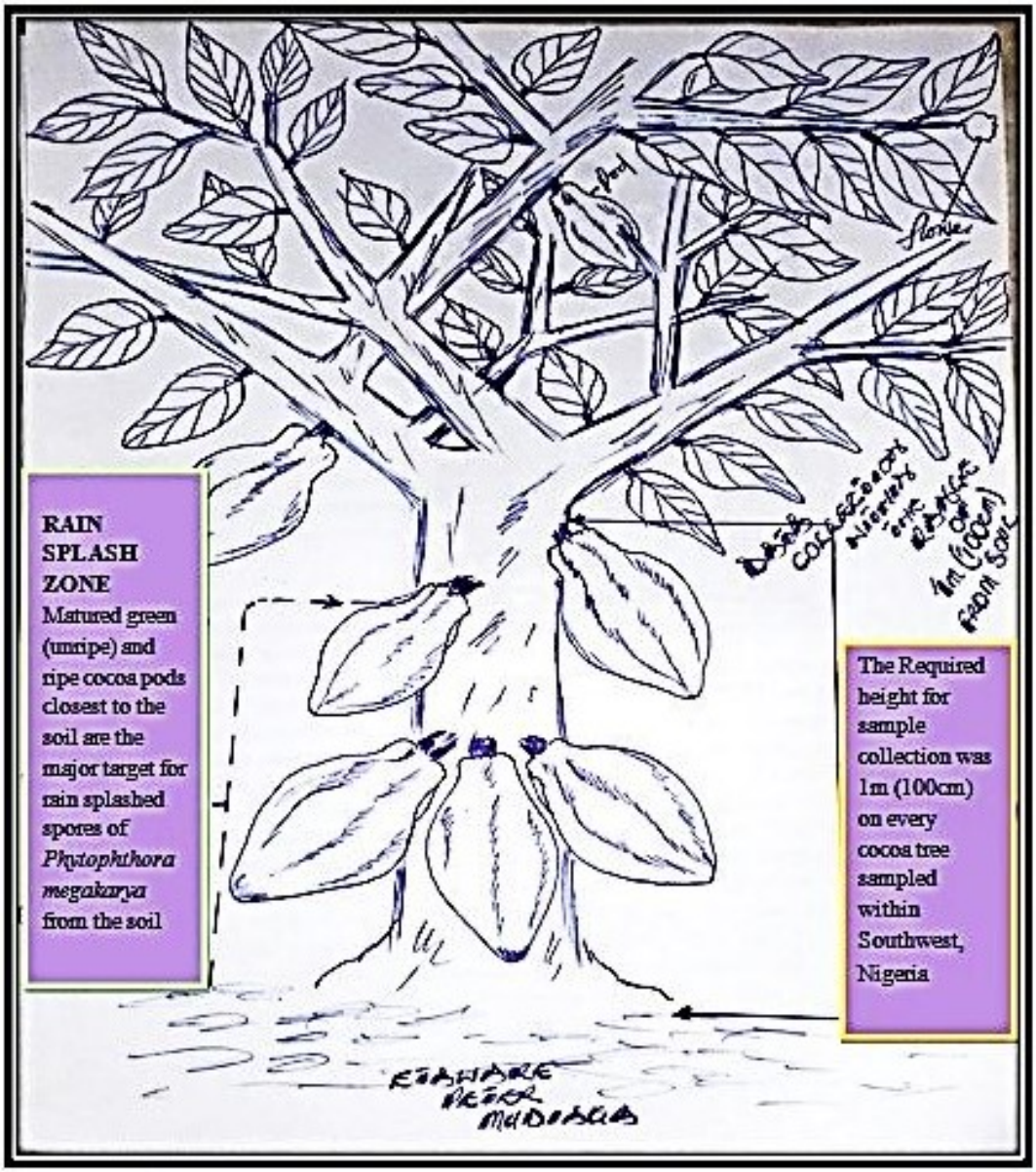


Plate 3.2. The rain-splash zone for each cocoa stand as described by Akrofi *et al*. (2003)

Table 3.2. Black pod disease severity status determination for the selected study sites

BPD INFECTION per COCOA POD (BPD Severity)				
Score	Disease Range	Infected Portion	Percentage Infection	Inference
0	0	None	0%	Healthy
1	1-20	$^{1}/_{5}$	20%	Not Severe
2	21-40	$^{2}/_{5}$	40%	Mildly Severe
3	41-60	$^{3}/_{5}$	60%	Averagely Severe
4	61-80	$^{4}/_{5}$	80%	Severe
5	81-100	All	100%	Extremely Severe

(*An Adaptation of the modified methods of* Akrofi *et al*., 2014)

BPD – Black pod disease

The following mathematical equations were developed to project the effects of black pod disease at different levels. They are:

- A projection of seasonal influence on BPD development drawn from the research locations:

$$\mathbf{SI}\ (\%) = \frac{\mathbf{SOS_i}}{\mathbf{SL_{total}}}$$

- A projection of the influence of farm altitude on BPD development drawn from the study areas:

$$\mathrm{AI}\ (\%) = \frac{\mathbf{SOA_i}}{\mathbf{SL_{total}}}$$

- A projection of BPD Status in Southwest, Nigeria (drawn from the study areas):

$$\mathbf{BSS}\ (\%) = \frac{\mathbf{SO_i}}{\mathbf{SL_{total}}}$$

- A projection of BPD Status within the States (drawn from the research locations):

$$\mathbf{BST}\ (\%) = \frac{\mathbf{ST_i}}{\mathbf{SL_{total}}}$$

Where,

SI = Seasonal Influence on BPD Status

SOS_i = Sum of all observations made per Season (per month)

BSS = BPD Status in Southwest, Nigeria

SO_i = Sum of all observations (per month) from the stations

AI = Altitudinal influence on BPD Status

SOA_i = Sum of all observations made per altitudinal Level (per month)

BST = BPD Status in each State

ST_i = the sum of BPD Status from all the sampled stations within a State (per month)

SL_{total} = The Total No. of study locations assessed

3.14 Previous black pod disease record

The previous records of black pod diseases occurrence(1985 to 2014) was obtained from Cocoa Research Institute of Nigeria (CRIN), Ìdí-Ayunrẹ, Ibadan, Oyo State, Nigeria and the report of Lawal and Emaku (2008). The previous black pod disease records and the weather data collected were used in the development of the forecast model. The primary data obtained on the field during disease assessment (2015/2016) was used in the validation of the developed model.

3.15 Meteorological data collection

Past and present weather reports were collected from the National Bureau of Statistics (NBS) Ibadan, Oyo State, the Meteorological Station of Cocoa Research Institute of Nigeria (CRIN), Ìdí-Ayunrẹ, Ibadan, Oyo State, Nigerian Meteorological Station (Nimet), Nigerian Institute for Oil palm Research (NIFOR), Benin City, Edo State, Nigeria, and the Department of Geography, University of Ibadan, Ibadan, Oyo State, Nigeria.

3.16 Data Analysis

The proposed forecast model(s) were multiple regression equation(s) developed from the meteorological data and previous black pod disease records collected (Secondary data), designed using Minitab 16.0 software and programmed on Microsoft Excel Worksheet 2007 service pack for easy access. The validity of the developed models was tested using Pearson's Product Moment of Correlation (PPM) to determine the Coefficient of Correlation (R-Sq), and the Adjusted Coefficient of Correlation of the Developed Models ($R\text{-}Sq_{Adj.}$). The Standard Error of Regression (SER) and Root Mean Square Error of Prediction ($RMSE_{pred.}$) were also determined as a valid tool for black pod disease forecast model selection. Predicted results of black pod disease outbreak were validated using the observations made on the field (Primary data) during the 2015/2016 black pod disease assessments in the study areas. The Error of prediction was also determined using $E=(Y-\hat{Y})^2$. Qualitative data were represented as charts and graphs plotted using SPSS(version 20), while the analysis of variance was carried out using COSTAT 6.451 software. The homogeneity of means wasdetermined using Least Significant Difference [LSD] ($P<0.05$), Duncan Multiple Range Test (DMRT) and Fishers' Pairwise Comparison (FPC).

CHAPTER FOUR

Results

4.0 Black pod disease incidence in the study sites (2015/2016)

The presence of black pod disease was first noticedin the outskirt of Owódé-Igàngán(9.0%)and Iyánfọwọrọgi (3.0%) in May 2015 (Table 4.0). In June2015,black pod disease incidence was observed in research locations like Wáàsimi (12.0%),Iyánfọwọrọgi(11.0%),the Up- and Down-Stream locations in Ọwenà(8.0 and 7.0%, respectively),and Adaàgbà(7.0%).In July 2015, the level of black pod disease incidence increased in most of the research locations and it was highest in the down-stream research location in Ọwenà(20.0%). Other research locations i.e. Wáàsimi, Iyánfọwọrọgi,Adaàgbà and Dáagi-Lógbàhad16.0, 15.0, 12.0 and 6.0% black pod disease incidence, respectively. Some study areas still had no disease incidence (Table 4.0).

The period of heavy black pod disease incidence was noted to be August 2015, almost all the research locations had peak level of the disease.It was more in the down-stream research location inỌwenà (30.0%), Wáàsimi (23.0%),Dáagi-Lógbà(16.0%),Adaàgbà (9.0%), Iyánfọwọrọgi(7.0%) and in the post 1 research location in Ọbáfẹmi-Owódé (3.0%), as shown in Table 4.In September 2015, there was a drop in the level of black pod diseaseincidence within the research locations, the farm site in Adaàgbàrecorded 16.0% black pod disease incidence, Ọbáfẹmi-Owódé (15.0%), Dáagi-Lógbà(14.0%), Wáàsimi (12.0%),the down-stream research location in Ọwenà (10.0%), and Iyánfọwọrọgi(7.0%). In October 2015,Dáagi-Lógbàhad 0.0% black pod disease incidence, Wáàsimi (4.0%),the down-stream research location in Ọwenà (6.0%), Iyánfọwọrọgi(7.0%) and Adaàgbà (13.0%).The study location in Ọbáfẹmi-Owódé had an increase in black pod diseases incidence (22.0%) as recorded in Table 4.0. Black pod disease incidence was 0.0% in November and December 2015, January, February, March, April and May 2016(Table 4.0).

Table 4.0.Black pod disease incidence in the research locations (2015/2016 Assessment)

	Black Pod DiseaseIncidence (%)											
Period	A	B	C	D	E	F	G	H	I	J	K	L
05/2015	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	3.0^{b}	9.0^{a}	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	na	na
06/2015	7.0^{b}	8.0^{b}	12.0^{a}	7.0^{b}	11.0^{a}	na	na	0.0^{c}	0.0^{c}	na	na	na
07/2015	20.0^{a}	na	16.0^{b}	12.0^{c}	15.0^{b}	na	na	0.0^{e}	0.0^{e}	na	6.0^{d}	na
08/2015	30.0^{a}	na	23.0^{b}	9.0^{d}	7.0^{d}	na	na	na	3.0^{e}	na	16.0^{c}	na
09/2015	10.0^{c}	na	12.0^{bc}	16.0^{a}	7.0^{d}	na	na	na	15.0^{a}	na	14.0^{ab}	na
10/2015	6.0^{c}	0.0^{e}	4.0^{d}	13.0^{b}	7.0^{c}	0.0^{e}	na	na	22.0^{a}	0.0^{e}	0.0^{e}	0.0^{e}
11/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
12/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
01/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
02/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
03/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
04/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
05/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}

Means with the same alphabets across the row are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Key

Code	**Study Sites**
A	Òwẹ̀nà (Down-Stream)
B	Òwẹ̀nà (Up-Stream)
C	Wáàsimi
D	Adaàgbà
E	Iyánfọ̀wọ̀rọ̀gi
F	Owódé-Igàngán (Inland)
G	Owódé-Igàngán (Outskirt)
H	Ọ̀báfẹ̀mi-Owódé (Post 1)
I	Ọ̀báfẹ̀mi-Owódé (Post 2)
J	Mòyè
K	Dáagi-Lógbà
L	Olórò

4.1 A projection of BPD incidencein Ogun, Ondo, Osun and Oyofrom the study areas

The symptoms of black pod disease (BPD) were first spotted in research locations withinOsun State (1.5% average BPD incidence)in May 2015 (Table 4.1). In June 2015, research locations in Ondo and Osun States recorded significant increase in black pod disease incidence (9.5 and 9.0% average BPD incidence, respectively). Black pod disease incidence was more intense within study areas earmarked for disease assessment in July and August, 2015 with farm sites located in Ondo State having 18.0 and 26.5% average BPD incidence, respectively, while those in Osun State (13.5 and 8.0%, respectively), Oyo State (0.0 and 16.0%, respectively) and Ogun State (0.0 and 3.0%, respectively) had similar increase in black pod disease incidence too (Table 4.1).

An increase in black pod disease incidence was experienced in research locations within Ogun State from September (15.0%) through October (22.0%) in 2015, whereas those situated in Osun, Ondo and Oyo State had decline in black pod disease incidence from 11.5 to 10.0, 11.0 to 5.0, and 14.0 to 0.0%, respectively.There was no incidence of black pod disease prevalence in the dry season for all the research locations within each State (Table 4.1).

4.2 The influence of farm altitude on black pod disease incidence within the study sites

Study sites located above 200m from sea level (>200m) had an early break to black pod disease incidence (0.8%) starting from May 2015 through August 2015 (17.3%) followed by a decline in September (11.3%) through October (7.5%) and 0% in the dry season (Fig 4.0). Cocoa research farmlands located below 200m above sea level (≤200m) had late development of black pod disease (3.0% in July 2015), which slowly increased to 14.5% in September 2015 and a decline in October 2015 (11.0%) through May 2016 (0%) as shown in Fig 4.0.

Table 4.1.Projected BPD incidence in Ogun, Ondo, Osun and Oyo (based onstudy sites)

	Projected BPDIncidence (%)			
Period	Ondo	Osun	Ogun	Oyo
05/2015	0.0^{b}	1.5^{a}	0.0^{b}	0.0^{b}
06/2015	9.5^{a}	9.0^{a}	0.0^{b}	0.0^{b}
07/2015	18.0^{a}	13.5^{b}	0.0^{d}	6.0^{c}
08/2015	26.5^{a}	8.0^{c}	3.0^{d}	16.0^{b}
09/2015	11.0^{a}	11.5^{a}	15.0^{a}	14.0^{a}
10/2015	5.0^{c}	10.0^{b}	22.0^{a}	0.0^{d}
11/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
12/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
01/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
02/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
03/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
04/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
05/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}

Means with the same alphabets across the row are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

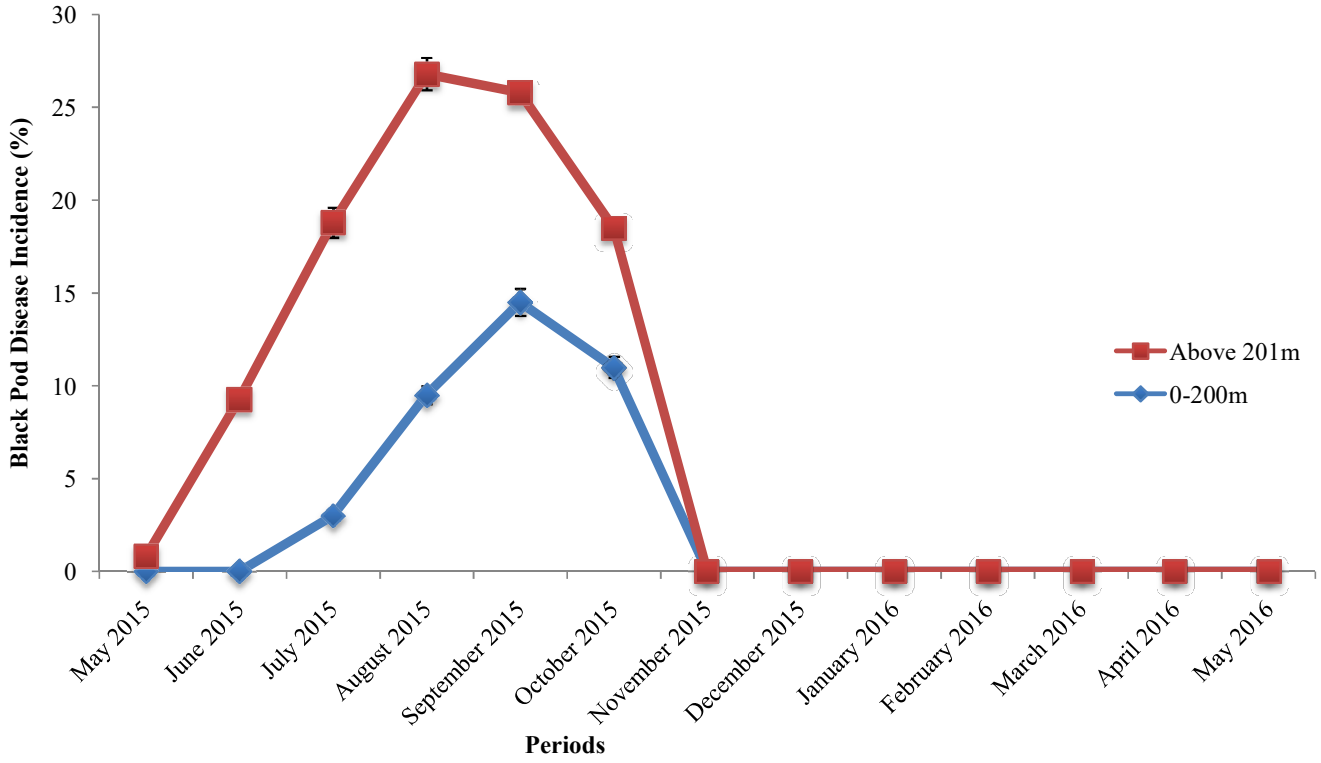


Fig4.0.Farm altitude and its influence on black pod disease incidence

For each line, the vertical line represents the standard error of the means

4.3 The influence of farm altitude on black pod disease severity within the study site

The height of the research farms were brought into consideration with regards to the black pod disease severity. Black pod disease was severe in study sites located on high altitudes (above 200m height from sea level) in May 2015 (15.0%) just immediate after the onset of the rainand 0.0% for cocoa plantations located within or below 200m above sea level (Table 4.2). The disease was observed in study sites located within 200m or below (0-200m height above sea level), two (2) months after it was noticed in study sites located on high altitudes (Table 4.2). The disease severity was at its peak in August 2015 for study sites situated above 200m from sea level (88.7%) and September 2015 for study sites within and below 200m height from sea level (85.5%) as shown in Table 4.2. Black pod disease was not noticed in all the study sites during the dry season (0%).

4.4 BPD status in Southwest, Nigeria (A projection from the study areas-2015/2016)

It was observed that black pod disease incidence and severity in Southwest, Nigeria was on the increase from the onset of the rainy season till August (for black pod disease incidence) and September (for black pod disease severity) before undergoing a steady decline from the assessment conducted in 2015/2016. The average projected black pod disease incidence in Southwestern Nigeria from the study sites as at May 2015 was 0.4%. In June 2015, the projected level of disease incidence rose to 4.6%; 9.4% in July 2015 and 13.4% in August 2015. This was the highest projected record of black pod disease incidence in Southwest, Nigeria from the research conducted. A decline in the disease incidence was recorded in September 2015 (12.9 %) through November, December 2015, January, February, March, April and May 2016 with no black pod disease expressed (Fig 4.1).

The same trend of disease report was observed within this zone for the disease severity. The peak of disease intensity was projected in September 2015 with a mean value of 86.8%. The least projected black pod disease severity for Southwest, Nigeria were in the months of November, December 2015, January, February, March, April and May 2016 with 0% disease intensity, which was largely due to the fact that most farmers have harvested their cocoa pods and the Cherelles (young pods) are still in the juvenile stage (Fig 4.2).

Table 4.2.Cocoa farm height and its effects on black pod disease severity

	BPD severity level (%)	
Period	0 - 200m	Above 201m
05/2015	0.0[b]	15.0[a]
06/2015	0.0[b]	84.8[a]
07/2015	38.4[b]	71.9[a]
08/2015	70.9[b]	88.7[a]
09/2015	85.5[a]	88.1[b]
10/2015	50.0[a]	48.5[a]
11/2015	0.0[a]	0.0[a]
12/2015	0.0[a]	0.0[a]
01/2016	0.0[a]	0.0[a]
02/2016	0.0[a]	0.0[a]
03/2016	0.0[a]	0.0[a]
04/2016	0.0[a]	0.0[a]
05/2016	0.0[a]	0.0[a]

Means with the same alphabets across the row are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

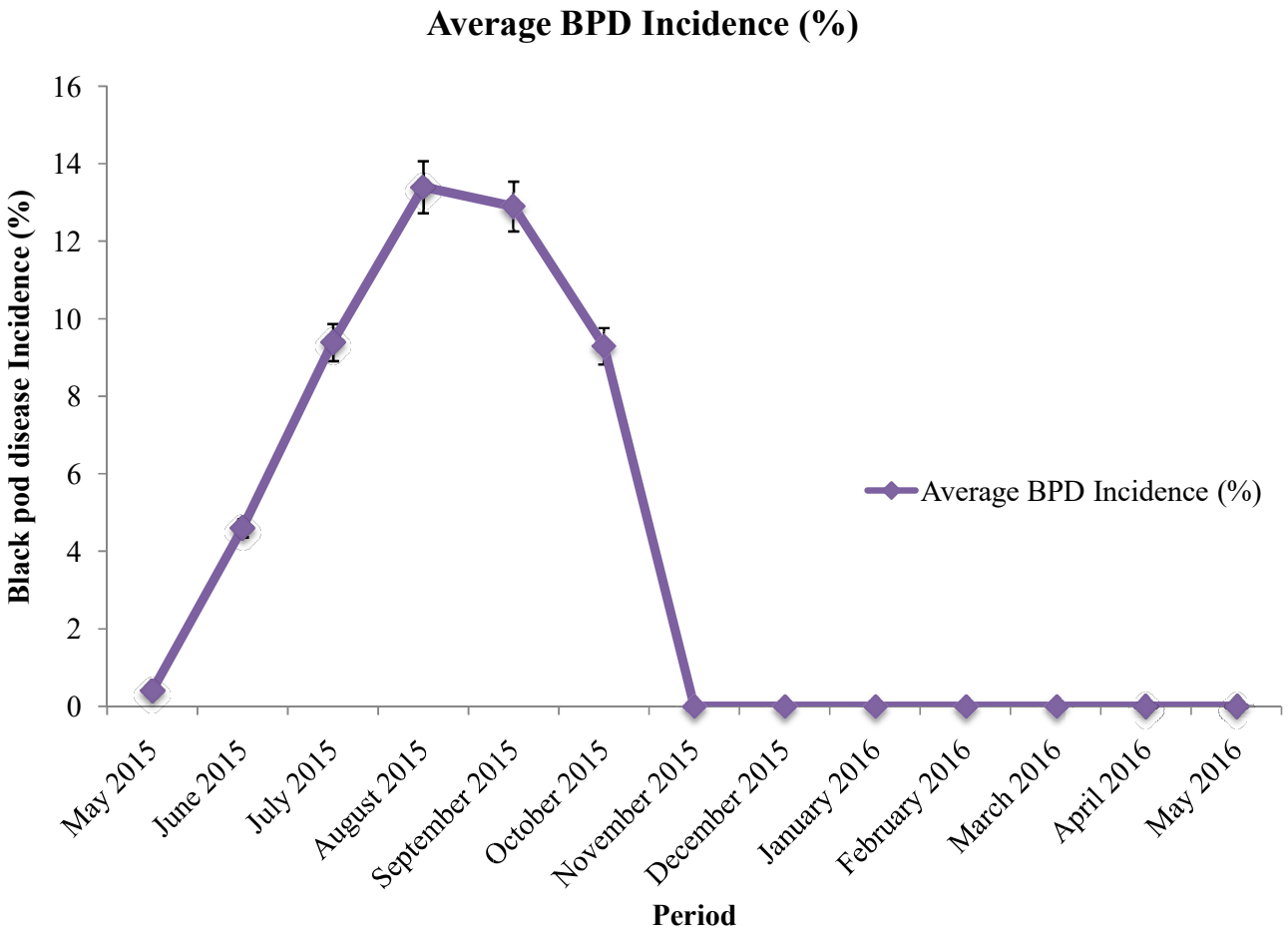


Fig4.1.Projected BPD incidence in Southwest, Nigeria (2015/2016)

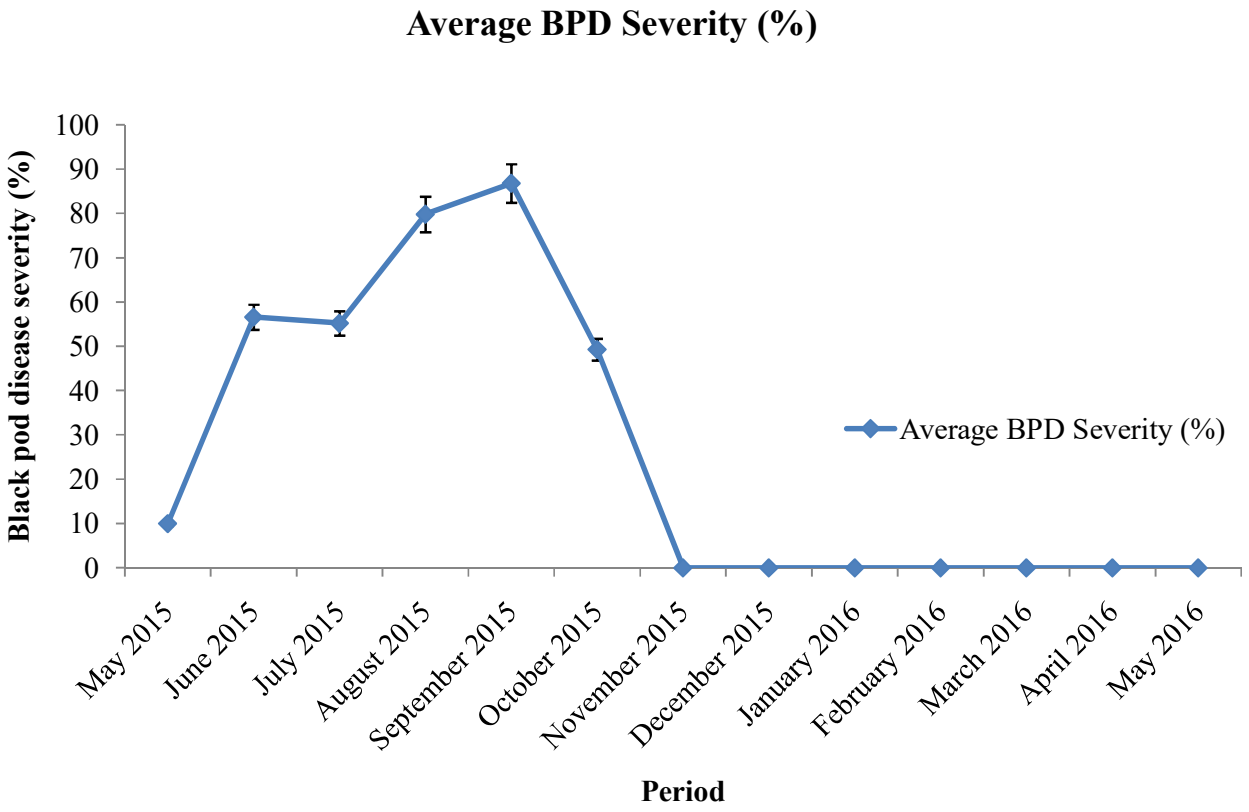


Fig 4.2.Projected BPD severity in Southwest, Nigeria (2015/2016)

4.5 A projection of seasonal effects on black pod disease status in some selected States

Black pod disease development was projected for each State from the study sites used for the purpose of this research. The study sites in Ondo State had the highest level of black pod disease Incidence and those farm sites in Osun State had the highest level of disease severity with average annual highest values of 8.8% for black pod disease incidence(Ondo) and 53.1%(Osun) for the black disease severity (Table 4.3) in the rainy season. The mean annual disease incidence and severity of black pod diseaserecorded for the research locations classified according to their Stateswere; Ondo State (8.8%, 46.2%), Osun State (6.7%, 53.1%), Ogun State (5.0%, 31.7%), and Oyo State (4.5%, 39.3%) as described inTable 4.3.There was 0.0% black pod disease incidence and severity in the dry season.

4.6 A projection of seasonal effects on black pod disease status in Southwest, Nigeria

A projection of the development of black pod disease in Southwestern Nigeria was drawn for the study sites investigated during the 2015/2016 assessment. The mean annual severity level of black pod disease calculated for Southwest of Nigeria (based on observations made in the research locations) was 42.6%, while the level of disease incidence was 6.2% for every one hundred (100) cocoa trees investigated within the region (Table 4.4). There wasno black pod disease incidence or severity during the dry season.

4.7 Black pod disease severity in the research locations (2015/2016)

Black pod disease was more severe in Owódé-Igàngán (71.1%) and Iyánfọwọrọgi (60.0%) than any other research locations earmarked for this study in May 2015. In June 2015, the disease severity increased in Wáàsimi (93.9%), Ọwenà down- and up-stream cocoa farm locations (62.5 and 60.0%, respectively), Adaàgbà (95.1%), and Iyánfọwọrọgi (90.9%). In July 2015, Ọwenà (down-stream research location) had 87.5%, Adaàgbà (78.1%), Dáagi-Lógbà (76.7%), Iyánfọwọrọgi (62.2%), and Wáàsimi (60.0%) had similar increase in black pod disease severity too (Table 4.5).

In August 2015, Wáàsimi had 93.0% black pod disease severity. The result for other research locations had were: Ọwenà down-stream research location (92.7%), Iyánfọwọrọgi (89.2%), Adaàgbà (80.0%), Dáagi-Lógbà (75.0%), and Ọbáfẹmi-Owódé

(66.7%) as stated in Table 10.Total (100%) black pod severity was recorded in September 2015 in the Ọwenà down-stream research location; Wáàsimi had 96.7%, Ọbáfẹmi-Owódé (86.7%), Iyánfọwọrọgi (85.7%), Adaàgbà (70.0%), and Dáagi-Lógbà (84.3%). There was a massive decline in black pod disease severity in some research locations in the month of October like Dáagi-Lógbà (0.0%), Wáàsimi (55.0%), Ọwenà (Down-Stream) was 0.0%, Iyánfọwọrọgi (74.3%) and Adaàgbà (64.6%). Ọbáfẹmi-Owódé had 100.0% in the month of October 2015 (Table 4.5). Black pod disease severity was 0% for the months of November and December, 2015; January, February, March, April and May 2016 (Table 4.5).

4.8 A projection of BPD severity in Ogun, Ondo, Osun and Oyo from the study areas

The level of black pod disease severity was milder in the early periods of the 2015/2016 cocoa production season and research locations in Osun State had an average of 30.0% black pod disease severity (May 2015), whereas, other research locations within other States showed no symptoms of the disease. The disease was more severe in June across cocoa farms located in Osun State (93.0%) and Ondo State (76.7%) as well. There was increase in black pod disease severity in July and August with a climax in September 2015 (Table 4.6), but research locations in Ogun State had 100.0% disease severity in the month of October 2015 which was different from the trend of disease progress in other States (Table 4.6).

4.9 *Phytophthora megakarya* on PDA

The mycelia appeared cotton white on PDA at the early stages (between day 3 and 7). The cotton white mycelia turned pale-yellow as the culture ages (Plate 4.0a).

4.10 Micro-image of *Phytophthora megakarya*

Micro-images of the reproductive hyphae (Sporangiophore) appeared hyaline, septate and dichotomously branched with double walled thin layers and the production of uni-flagillated zoospores on them. The zoospores produced were double layered, ellipsoidal/oval in shape, with a pointed node each for attachment to the Sporangiophore. Each zoospore had a single flagellum that facilitates mobility. The flagellum was short and located at the posterior of the spore. The spore stained purple to violet when exposed to lactophenol in cotton blue dye (Plate 4.0b).

Table 4.3.A projection of seasonal effects on black pod disease status in some States

	Black Pod Disease Status			
	Incidence (%)		Severity (%)	
State	Rainy Season	Dry Season	Rainy Season	Dry Season
Ondo	8.8[a]	0.0[a]	46.2[ab]	0.0[a]
Osun	6.7[b]	0.0[a]	53.1[a]	0.0[a]
Ogun	5.0[bc]	0.0[a]	31.7[c]	0.0[a]
Oyo	4.5[c]	0.0[a]	39.3[bc]	0.0[a]

Means with the same alphabets down the column are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Table 4.4.A projection of seasonal effects on black pod disease status in Southwest, Nigeria

	Black Pod Disease Status	
Black Pod Disease	Rainy Season(%)	Dry Season(%)
Incidence	6.2[a]	0.0[b]
Severity	42.6[a]	0.0[b]

Means with the same alphabets across the row are not significantly different at P<0.05 using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Table 4.5. Black pod disease severity in the research locations (2015/2016)

	BPD severity in the research locations (%)											
Period	A	B	C	D	E	F	G	H	I	J	K	L
05/2015	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	60.0^{b}	71.1^{a}	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	na	na
06/2015	60.0^{b}	62.5^{b}	93.3^{a}	95.1^{a}	90.9^{a}	na	na	0.0^{c}	0.0^{c}	na	na	na
07/2015	87.5^{a}	na	60.0^{c}	78.1^{b}	62.2^{c}	na	na	0.0^{d}	0.0^{d}	na	76.7^{b}	na
08/2015	92.7^{a}	na	93.0^{a}	80.0^{c}	89.2^{b}	na	na	na	66.7^{e}	na	75.0^{d}	na
09/2015	100.0^{a}	na	96.7^{b}	70.0^{e}	85.7^{c}	na	na	na	86.7^{c}	na	84.3^{d}	na
10/2015	0.0^{e}	0.0^{e}	55.0^{d}	64.6^{c}	74.3^{b}	0.0^{e}	na	na	100.0^{a}	0.0^{e}	0.0^{e}	0.0
11/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
12/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
01/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
02/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
03/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
04/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0
05/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	na	na	0.0^{a}	0.0^{a}	0.0^{a}	0.0

Means with the same alphabets across the row are not significantly different at P<0.05 using Duncan Multiple Range Test (DMRT) for separation of statistically significant means. (na – not available)

Key

Code	**Research Location**
A	Òwẹnà (Down-Stream)
B	Òwẹnà (Up-Stream)
C	Wáàsimi
D	Adaàgbà
E	Iyánfọwọrọgi
F	Owódé-Igàngán (Inland)
G	Owódé-Igàngán (Outskirt)
H	Ọbáfẹmi-Owódé (Post 1)
I	Ọbáfẹmi-Owódé (Post 2)
J	Mòyè
K	Dáagi-Lógbà
L	Olórò

Table 4.6.A projection of BPD severity in Ogun, Ondo, Osun and Oyo from the study sites

	Black Pod Disease Severity (%)			
Period	Ondo	Osun	Ogun	Oyo
05/2015	0.0^{b}	30.0^{a}	0.0^{b}	na
06/2015	76.7^{b}	93.0^{a}	0.0^{c}	na
07/2015	73.8^{b}	70.1^{c}	0.0^{d}	76.7^{a}
08/2015	92.9^{a}	84.6^{b}	66.7^{d}	75.0^{c}
09/2015	98.3^{a}	77.9^{d}	86.7^{b}	84.3^{c}
10/2015	27.5^{c}	69.5^{b}	100.0^{a}	0.0^{d}
11/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
12/2015	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
01/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
02/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
03/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
04/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
05/2016	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}

Means with the same alphabets across the row are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

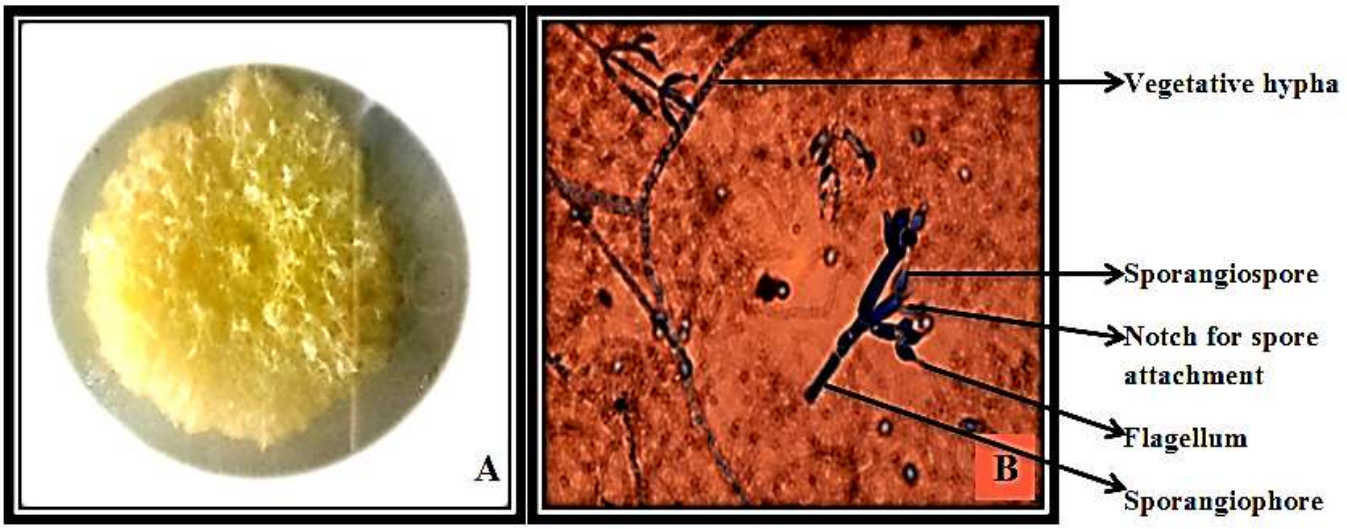


Plate 4.0. Mycelia Orientation on PDA (A) and Photomicrograph (B) of *Phytophthora megakarya*

4.11 A survey of the rainfall pattern of Ogun, Ondo, Osun and Oyo States (2005-2016)

The average annual rainfall distribution for Ogun, Ondo, Osun and Oyo States in 2005 was 924.2, 1,317.1, 1,130.2 and 1, 192.0mm, respectively (Table 4.7). Although, Ondo had the highest annual rainfall distribution in 2005, Osun State experienced heavy down pour in 2006, 2007 and 2008 (1,469.7, 1,421.7 and 1,597.6mm, respectively) more than any of the other States (Table 4.7). In 2009, Oyo State had the highest rainfall value among all the other States, with a mean annual rainfall value of 1,702.1mm. Osun State had the highest rainfall value for 2011 (2,381.0mm), whereas from 2012 to 2016 Ondo State recorded more rainfall than any of the other States assessed during the course of this research work i.e. 1,405.0mm (2012), 1,629.0mm (2013), 1,618.0mm (2014), 1,519.0mm (2015) and lastly 1,524.0mm in 2016 (Table 4.7). The major weather parameters affecting the establishment and proliferation of black pod disease in the Southwest include rainfall, temperature, relative humidity and sunshine duration. The amount of moisture present in the soil majorly determines the microbial activities of the pathogen such as the frequency of spore dispersal, germination and other pre-penetration activities.

4.12 Weather pattern for Ogun, Ondo, Osun and Oyo and how it affects black pod disease development

The weather distribution for the Southwest in the early 1900s showed that the height of rainfall across the four (4) States investigated falls within the months of March through October from 1991 to 1995, suggesting the possibility of infection within these periods (Table 4.8). *Phytophthora megakarya* thrives better when the ambient temperature ranges between 20^{o}C and 30^{o}C, therefore the specific periods of the year that provides such temperatures as their peak/maximum values in Ogun, Ondo, Osun and Oyo States were June, July, August, and September in 1991 to 1995 (Table 4.9). On the Contrary, the minimum temperature all year round favours the proliferation of the pathogen where other pertinent factors are available for pre-penetration, penetration and infection (Table 4.10).

A relative humidity value of 75% and above favours the establishment of black pod disease, therefore, periods of the year that favour black pod disease prevalence based on the humid nature of the surrounding environment are March through October from the early morning readings taken 1991 to 1995, suggesting the possibility of infection within

these periods also (Table 4.11). Judging by the trend of afternoon readings the periods of June through September across all the years investigated and within all the States analyzed, favours disease proliferation (Table 4.12). The overall diagnosis is an indication of the parameter pertinent for disease establishment and when they combine favourably in favour of the noxious pathogen to aid the proliferation, ramification and destruction of cocoa pods across their paths.

4.13 Black pod disease trend in Southwest, Nigeria

The trend of black pod disease occurrence on cocoa plants within Southwest, Nigeria was shown in Table 4.13. there was a steady decline in black pod disease occurrence within the Southwest from 1985 (8.93%) through 1991 (2.60%), followed by an intermittent increase and decrease in black pod disease occurrence as the years progresses through 1992 (6.51%) to 1999 (8.35%) as shown in Table 4.13. The highest values of black pod disease documentation around the Southwest of Nigeria were recorded in the years 2000 (16.90%), 2001 (13.90%), 2002 (16.67%), through to 2006 (11.25%). Also, a combination of a low temperature (23.4-32.4^{o}C), high relative humidity (70-100%) and heavy rainfall (1036.9 – 1604.4mm) resulted in massive black pod disease occurrence as shown in 1985-1987, and 1999-2014 (Table 4.13).

Table 4.7.Annual rainfall data for Southwest, Nigeria

	Annual Rainfall (mm)			
Year	Ogun	Ondo	Osun	Oyo
2005	924.2	1,317.1	1,130.2	1,192.0
2006	1,142.1	1,381.0	1,469.7	1,260.2
2007	876.2	1,405.7	1,421.7	1,218.8
2008	1,371.7	1,466.1	1,597.6	889.4
2009	1,465.5	1,309.6	1,277.7	1,702.1
2010	na	na	na	na
2011	1,232.0	1,379.0	2,381.0	1,091.0
2012	1,035.0	1,405.0	1,333.0	1,275.0
2013	1,500.0	1,629.0	1,365.0	1,406.0
2014	1,353.0	1,618.0	1,531.0	1,190.0
2015	1,331.0	1,519.0	1,441.0	1,208.0
2016	1,605.0	1,524.0	1,441.0	1,194.0

Source: National Bureau of Statistics (NBS) and Nigerian Meteorological Station (Nimet)

Table 4.8.Monthly rainfall distribution for the Southwest, Nigeria

		Rainfall (mm)/Months											
State	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1991	2.5	60.0	38.1	118.1	127.1	179	236.2	84.3	194.4	129.4	0.0	4.0
	1992	0.0	0.0	8.4	149.7	116.9	175.7	235	44.3	224.3	105.5	20.7	TR
	1993	na	na	na	na	na	na	na	na	na	na	na	na
	1994	12.1	1.6	124.1	60.2	82.9	120.7	130.5	21.2	212.5	212.5	15.7	0
Ogun	1995	0.0	4.0	150.6	124.8	220.1	120.8	133	195.7	163.5	97.1	na	na
	1991	1.2	98.6	136	223.2	201.2	163.7	463	203.6	200.7	152.6	TR	10.4
	1992	0.0	0.0	40.8	107.8	151.1	127	265.3	101.7	347.6	194.6	25.6	0.0
	1993	na	na	na	na	na	na	na	na	na	na	na	na
	1994	31.3	50.9	74.5	186.2	192.2	263.3	305.7	271.4	219.1	65.7	39.2	0.0
Ondo	1995	0.0	28.4	128.0	196.3	146.4	214.2	268.6	379.6	262.3	87.3	14.2	0.0
	1991	TR	165.5	19	174.1	135.3	82.3	219.9	191.4	170.4	182.8	2.2	26.4
	1992	0.0	0.0	28.5	92.9	103.6	237.4	202.3	107.8	127.4	152.5	36.2	0
	1993	0.0	na	141..7	44.0	145.9	187.5	262.0	na	235.5	183.2	na	48.3
	1994	2.1	30.2	20.7	75.4	na	62.9	177.4	125.9	128.8	112.7	17.6	0
Oyo	1995	0.0	11.4	106.3	118.5	256.6	267.8	188.9	188.1	84.9	185.1	36.6	TR
	1991	TR	165.5	19	174.1	135.3	82.3	219.9	191.4	170.4	182.8	2.2	26.4
	1992	0.0	0.0	28.5	92.9	103.6	237.4	202.3	107.8	127.4	152.5	36.2	0.0
	1993	0.0	na	141..7	44.0	145.9	187.5	262.0	na	235.5	183.2	na	48.3
	1994	2.1	30.2	20.7	75.4	na	62.9	177.4	125.9	128.8	112.7	17.6	0.0
Osun	1995	0.0	11.4	106.3	118.5	256.6	267.8	188.9	188.1	84.9	185.1	36.6	TR

Data Source: National Bureau of Statistics (NBS).na: Not Available

Table 4.9.Mean monthly maximum temperature reading for the Southwest, States of Nigeria

		Max. Temperature (°C)/Months											
State	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1991	34.3	37.4	35.6	33.7	32.6	31.6	29.5	28.4	30.1	30.5	33.6	33.6
	1992	34.5	37.3	36.3	35	32.7	30.3	38.3	28	29.2	31.9	33.2	34.8
	1993	35.1	35.8	34.6	35	33.1	31.1	na	29.7	30.8	32.0	33.6	33.8
	1994	34.0	36.3	35.6	34.3	32.5	31.7	28.5	29.3	30.4	31.7	33.9	35.2
Ogun	1995	35.5	na	na	na	33.1	31.2	na	na	na	31.5	na	na
	1991	32.2	33.4	32.6	31.3	30.7	29.6	28.2	26.9	28.8	29.3	31.8	32.1
	1992	33.0	36	33.8	32.5	31.1	29.0	27.0	26.9	27.9	30	31.2	23.8
	1993	na	na	na	na	na	na	na	na	na	na	na	na
	1994	32.0	34.1	33.9	32.5	26.8	29.0	na	na	29.0	30.4	32.7	na
Ondo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	33.5	34.9	34.6	33.0	31.6	31.0	29.3	27.7	28.1	30.0	32.2	32.0
	1992	32.9	36.2	35.5	33.7	31.8	29.9	28	27.2	28.3	30.9	32.1	33.3
	1993	33.1	34.6	33.5	33.1	32.0	30.0	na	28.1	29.7	na	31.9	na
	1994	32.7	34.9	35.5	34.0	32.0	30.7	27.9	na	30	30.7	33.2	33.8
Oyo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	33.5	34.9	34.6	33.0	31.6	31.0	29.3	27.7	28.1	30	32.2	32
	1992	32.9	36.2	35.5	33.7	31.8	29.9	28	27.2	28.3	30.9	32.1	33.3
	1993	33.1	34.6	33.5	33.1	32	30	na	28.1	29.7	na	31.9	na
	1994	32.7	34.9	35.5	34.0	32	30.7	27.9	na	30	30.7	33.2	33.8
Osun	1995	na	na	na	na	na	na	na	na	na	na	na	na

Data Source: National Bureau of Statistics (NBS).na: Not Available

Table 4.10.Mean monthly minimum temperature reading for the Southwest, States of Nigeria

		Minimum Temperature (^{o}C)/Months											
State	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1991	23.8	26	25.2	23.7	24.2	23.8	23.1	22.7	22.8	22.6	24.2	22.5
	1992	20.5	24.1	25.5	23.3	24	22.9	22.9	22.6	22.4	23.2	22.3	23.2
	1993	21.1	24.5	23.7	24.5	24.2	23.5	na	23.1	22.8	23.3	23.8	22.2
	1994	23.1	25.1	24.8	25.1	23.7	31.2	22.9	23	23.2	22.9	22.5	20.2
Ogun	1995	22.2	na	na	na	23.9	23.3	na	na	na	23.3	na	na
	1991	19.6	22.6	22.7	21.2	21.9	21.2	21	21.3	21	20.2	21.1	18.2
	1992	15.3	18.8	22.8	22.9	21.8	20.7	20.1	20.8	20.9	21.4	20.2	19
	1993	17.3	20.6	21.9	23.1	22.9	22	na	21.7	22.1	na	22.1	na
	1994	na	na	na	na	na	na	na	na	na	na	na	na
Ondo	1995	19.6	21.7	22.9	22.4	na	21.2	na	na	21.7	21.2	20.7	na
	1991	22.9	24	24.4	23.2	23.3	23	22.5	21.8	22	21.5	23.3	21.8
	1992	20.2	22.9	24.3	23.8	23.3	22.9	22	21.4	21.7	22.1	21.9	22.4
	1993	20.9	na	22.9	23.5	23.3	22.4	22	na	21.8	22.3	na	22.2
	1994	22.4	24.1	24.3	23.9	22.7	22.3	21.9	na	22.6	22.2	22.4	20.4
Oyo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	22.9	24	24.4	23.2	23.3	23	22.5	21.8	22	21.5	23.3	21.8
	1992	20.2	22.9	24.3	23.8	23.3	22.9	22	21.4	21.7	22.1	21.9	22.4
	1993	20.9	na	22.9	23.5	23.3	22.4	22	na	21.8	22.3	na	22.2
	1994	22.4	24.1	24.3	23.9	22.7	22.3	21.9	na	22.6	22.2	22.4	20.4
Osun	1995	na	na	na	na	na	na	na	na	na	na	na	na

Data Source: National Bureau of Statistics (NBS).na: Not Available

Table 4.11.Relative Humidity values for the Southwest, Nigeria

		Relative Humidity in the morning at 9.00GMT (%)/Months											
State	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1991	81	64	81	84	83	87	90	89	87	87	84	78
	1992	55	70	76	81	83	85	89	89	88	86	76	78
	1993	53	80	77	78	82	85	na	87	87	85	89	78
	1994	73	78	80	79	83	84	88	87	86	85	80	64
Ogun	1995	87	na	na	na	82	85	na	na	na	na	85	na
	1991	75	79	81	83	84	85	89	89	86	84	78	67
	1992	48	54	75	79	82	84	88	87	89	83	72	69
	1993	48	68	71	76	77	82	na	na	na	na	na	na
	1994	69	72	76	79	na	na	na	85	85	82	71	na
Ondo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	70	78	76	81	81	83	88	88	85	84	79	70
	1992	50	63	73	78	80	84	88	87	87	82	73	75
	1993	48	na	75	78	80	83	86	na	85	83	na	73
	1994	68	73	74	75	82	81	89	na	86	83	74	57
Oyo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	70	78	76	81	81	83	88	88	85	84	79	70
	1992	50	63	73	78	80	84	88	87	87	82	73	75
	1993	48	na	75	78	80	83	86	na	85	83	na	73
	1994	68	73	74	75	82	81	89	na	86	83	74	57
Osun	1995	na	na	na	na	na	na	na	na	na	na	na	na

Data Source: National Bureau of Statistics (NBS).na: Not Available

Table 4.12.Relative Humidity values for the Southwest of Nigeria

		Relative Humidity in the afternoon at 15.00GMT											
State	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1991	48	54	38	63	72	73	79	80	74	73	35	47
	1992	31	31	47	57	70	74	82	80	75	69	56	45
	1993	28	41	50	58	67	75	na	74	75	67	59	48
	1994	46	37	52	59	68	71	81	73	74	67	52	35
Ogun	1995	35	na	na	na	69	75	na	na	na	na	70	na
	1991	44	50	55	64	71	71	79	81	73	70	53	40
	1992	27	21	45	60	64	74	81	77	78	67	52	41
	1993	28	35	48	55	64	66	na	na	na	na	na	na
	1994	45	37	50	58	na	na	na	75	75	69	53	na
Ondo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	43	49	50	58	67	69	78	79	71	67	54	45
	1992	32	27	44	55	65	71	77	77	73	63	55	46
	1993	na	na	na	na	na	na	na	na	na	na	na	na
	1994	46	38	46	57	64	67	80	na	72	66	49	36
Oyo	1995	na	na	na	na	na	na	na	na	na	na	na	na
	1991	43	49	50	58	67	69	78	79	71	67	54	45
	1992	32	27	44	55	65	71	77	77	73	63	55	46
	1993	na	na	na	na	na	na	na	na	na	na	na	na
	1994	46	38	46	57	64	67	80	na	72	66	49	36
Osun	1995	na	na	na	na	na	na	na	na	na	na	na	na

Data Source: National Bureau of Statistics (NBS). na: Not Available

Table 4.13.Weather pattern, yield and black pod disease occurrence level

Period (Year)	Temperature (^{O}C)	Rel. Humidity (%)	Rainfall (mm)	Yield (No of Pods)	Infected Pods (No of Pods)	Disease Occurrence (%)
1985	23.8	75	1036.9	302,810	27,049	8.93
1986	24.3	72	1546.6	461,705	39,012	8.45
1987	23.4	74	1372.8	263,220	19,871	7.55
1988	24.2	70	1219.9	349,623	19,093	5.46
1989	23.7	74	1571.9	225,235	4,688	2.08
1990	23.6	76	1495.8	143,915	3,027	2.1
1991	24	76	1399.6	172,538	4,479	2.6
1992	23.3	74	1589.7	123,585	8,047	6.51
1993	23.9	73	1314.8	188,588	11,958	6.34
1994	23.9	76	1208.8	280,073	5,935	2.12
1995	27.7	75	1208.8	328,223	1,548	0.47
1996	27.1	75	1247	290,238	4,490	1.55
1997	27.1	72	1047.5	374,233	7,347	1.96
1998	27.6	72	786.8	355,508	2,361	0.66
1999	27	76	1540.0	320,198	26,730	8.35
2000	26.3	72	1165.3	344,005	58,120	16.9
2001	27.3	75	1054.1	323,675	44,994	13.9
2002	27.4	77	1348.5	222,560	37,094	16.67
2003	27.7	77	1604.4	523,765	46,724	8.92
2004	28.1	74	1105.1	639,058	50,649	7.93
2005	27.4	77.8	1205.7	388,904	33,449	8.6
2006	27.9	80.6	1151.9	345,592	38,874	11.25

Source: Cocoa Research Institute of Nigeria; Lawal and Emaku (2007)

Table 4.13.Cont'd

Period (Year)	Temperature (^{O}C)	Rel. Humidity (%)	Rainfall (mm)	Yield (No of Pods)	Infected Pods (No of Pods)	Disease Occurrence (%)
2007	27.3	83.9	1302.8	263,059	28,588	10.87
2008	27.3	77.6	1082.5	293,406	36,934	12.59
2009	27.5	82.2	1110.4	359,171	51,606	14.37
2010	28.3	80.5	1052	284,938	47,107	16.53
2011	27.7	81.3	1129.1	378,300	92,948	24.57
2012	27.1	77.3	1106	448,739	82,903	18.47
2013	27.8	81.3	1279.1	195,316	19,841	10.16
2014	32.4	100.0	1279.4	241,985	27,654	11.43

Source: Cocoa Research Institute of Nigeria;Lawal and Emaku (2007)

4.14 Independent disease management strategy for BPD control within the study areas

All the Indigenous Cocoa farmers in the research locations depend totally on the use of fungicides (100%), which is basically a chemical form of controlin the management of black pod diseasein the field rather than exploiting other possibility such as biological control which was unutilized (0.0%) or cultural(0.0%)methods (Table 4.14).Majority of the indigenous cocoa farmers (63.6%) apply fungicide monthly as their normal routine with or without the emergence of the disease (Table 4.8). A total percentage of these farmers (9.10%) apply fungicide twice annually preferably during the advent of the disease, 18.2% of the population of local cocoa farmers apply fungicide on their farmlands once in a year, and minority of the group of local cocoa growers investigated (9.10%) did not apply fungicides (chemicals) or employed the use of other management strategies to control black pod disease on their farmlands (Table4.15).

The distribution of local cocoa farmers based on their choice of fungicide used in the management of black pod disease of cocoa across the research locations most of the farmers apply a mixture of fungicides to control black pod disease(Table 4.16).A total of 75% of the local cocoa farmers applied Ridomil routinely for the control of the disease, 16.7% did not employ any form of black pod disease control during the 2015/2016 cocoa production season based on their lack of knowledge of the existence of other existing control strategies for the eradication of black pod disease and other financial factors (Table 4.17), and 8.3% each of the population of local cocoa growers investigated applied any ofthese fungicide i.e. Redfox, Rocket, Endosulfan 35 EC, Altimax, Super 10, Killer, Tari, Mackecknie-gold, Kocide 2000 for black pod disease control (Table 4.17).

Table 4.14:Disease management strategies employed in the study areas selected for assessment

Control Strategy	(%) Subscription
Cultural	0.0[b]
Biological	0.0[b]
Chemical	100[a]
TOTAL	**100**

Means with the same alphabets down the column are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Table 4.15.Frequency of fungicide application by indigenous Cocoa farmers in the study sites

Measures of Fungicide Application (%)	
Frequency	(%) Users
None	9.10[c]
Weekly	0.00[d]
Monthly	63.6[a]
Quarterly	0.00[d]
Three times Annually	0.00[d]
Twice Annually	9.10[c]
Annually	18.2[b]
TOTAL	**100.0**

Means with the same alphabets down the column are not significantly different at P<0.05 using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Table 4.16.Type of fungicide used in the management of black pod disease within the Southwest of Nigeria

S/N	State	Local Govt. Area	Location	Fungicide	Dosage
1	Ogun	Ọbáfẹmi-Owódé	Ọbáfẹmi-Owódé (Post 1)	None	None
2	Ogun	Ọbáfẹmi-Owódé	Ọbáfẹmi-Owódé (Post 2)	Rocket Endosulfan 35 EC	1Ltr./ha 0.875Ltr./ha
3	Osun	Ife South	Adaàgbà	Ridomil	50g/10Ltr.
4	Osun	Àtàkúnmòsà East	Owódé-Igàngán (Inland)	Ridomil	50g/10Ltr.
5	Osun	Ife South	Iyánfọwọrọgi	Ridomil	50g/10Ltr.
6	Osun	Àtàkúnmòsà East	Owódé-Igàngán (Outskirt)	None	None
7	Ondo	Ondo East	Ọwenà (Upstream)	Ridomil, Kocide 2000	50g/20Ltr.
8	Ondo	Ondo East	Ọwenà (Downstream)	Ridomil, Redfox, Altimax plus	50g/10Ltr.
9	Ondo	Ondo East	Wáàsimi	Ridomil	50g/10Ltr.
10	Oyo	Ọnà-Arà	MòyèVillage	Ridomil	50g/10Ltr.
11	Oyo	Ìddó	Dáagi-Lógbà	Ridomil, Super 10	50g/10Ltr.
12	Oyo	Ọnà-Arà	Olórò village	Killer, Ridomil, Tari, Mackecknie-gold	50g/15Ltr.

Table 4.17.Fungicide preference for BPD management in Southwest, Nigeria

Fungicide	No of Farms used	Relative Frequency	Percentage (%)
Ridomil	9.0[a]	0.75[a]	75.0[a]
Redfox	1.0[c]	0.08[c]	8.3[c]
Rocket	1.0[c]	0.08[c]	8.3[c]
Endosulfan 35 EC	1.0[c]	0.08[c]	8.3[c]
Altimax	1.0[c]	0.08[c]	8.3[c]
Super 10	1.0[c]	0.08[c]	8.3[c]
Killer	1.0[c]	0.08[c]	8.3[c]
Tari	1.0[c]	0.08[c]	8.3[c]
Mackecknie-gold	1.0[c]	0.08[c]	8.3[c]
Kocide 2000	1.0[c]	0.08[c]	8.3[c]
None	2.0[b]	0.17[b]	16.7[b]

Means with the same alphabets down the column are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

4.15 Cultural practices in the study sites and its effects on black pod disease distribution

The results from the questionnaire administered showed that majority of the indigenousCocoa farmers in the study areasonly indulge in weed removal (farm clearing) once or twice in a year (27.3%) specifically within periods close to the harvest season. Others perform this action tri-annually(18.2%), a few of them carry out farm clearing quarterly (9.1%) and monthly (18.2%). None of the local cocoa farmers within these regions perform the action of weed removal weekly or daily (0.0%) as stated in Table 4.18. Farm inspection, removal of tendrils and epiphytic plants on the cocoa trees was done by 9.1% of local cocoa farmers on daily basis, 45.5% of the farmers interrogated carried out general farm inspection weekly, 18.2% perform this task monthly and 27.3% do it annually (Table 4.18).Husk disposal has been a major problem for local cocoa farmers within the Southwest.All the farmers interviewed heap the husk on the surface of their farmlands (100%) after harvest in a portion they refer to as the “Garage”. Other forms of disposal like Burning (0.0%), Burying in the soil (0.0%) and other local methods (0.0%) were totally unutilized (Table 4.19).

Table 4.18. Farm inspection, weed removal, and farm clearing within the study sites

Frequency of Administration	Farm Clearing (%)	Removal of epiphytes on trees (%)
Daily	0.0[d]	9.1[d]
Weekly	0.0[d]	45.5[a]
Monthly	18.2[b]	18.2[c]
Quarterly	9.1[c]	0.0[e]
Tri-Annually	18.2[b]	0.0[e]
Bi-Annually	27.3[a]	0.0[e]
Annually	27.3[a]	27.3[b]
Total	**100.0**	**100.0**

Means with the same alphabets down the column are not significantly different at $P<0.05$ using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

Table 4.19.Method of husk disposal after harvest in cocoa farms located in Southwest Nigeria

Method	Husk Disposal (%)
Burry in Soil	0.0[b]
Heap on Surface	100[a]
Burn	0.0[b]
Others	0.0[b]
Total	**100**

Means with the same alphabets down the column are not significantly different at P<0.05 using Duncan Multiple Range Test (DMRT) for separation of statistically significant means.

4.16 Development of forecast system for black pod disease in the Southwest

The correlation analysis carried out showed that rainfall and average relative humidity had a positive relationship with black pod disease occurrence (0.445 and 0.477 respectively), while average temperature and sunshine duration had inverse relationship with the prevalence of black pod disease that affects *Theobroma cacao* Linn. (-0.420 and –0.364 respectively) as represented in the correlation analysis in Table 4.20 ($P<0.01$ and $P<0.05$).Several models were developed to assess the level of black pod disease development and its spread within the Southwest of Nigeria. In any case the individual predictor should be tested against the response variable to ascertain its role in disease development. In some cases the association or relationship of a predictor to the response variable could be in the reverse order, this is still acceptable. In a situation whereby a chosen predictor has no established relationship with the response variable, then that predictor should be discarded.

Theamount of rainfall recorded during the period when the research was conducted had positive correlation with black pod disease incidence with a linear correlation coefficient of 0.105 (Fig 4.3). The relationship between the average temperature and black pod disease incidence was an inverse relationship with a linear correlation coefficient value of 0.265 (Fig 4.4). The increase in the amount of saturated moisture present in the atmosphere (relative humidity)within the study sites had a positive correlation with black pod disease incidence with a linear coefficient of correlation value of 0.295 (Fig 4.5). as the hours for sunshine reduced, there was an increase in black pod disease incidence which resulted from an increase in microbial activities of *Phytophthora megakarya*. The corresponding coefficient of linear correlation for Sunshine duration and black pod disease incidence was 0.360(Fig 4.6). There was no established relationship between the study site locations (Fig 4.7), period for the disease assessment (Fig 4.8) and black pod disease incidence. The years of research conducted had a poor relationship with the level of black pod disease incidence with the coefficient of linear correlation value of 0.035 (Fig 4.9)

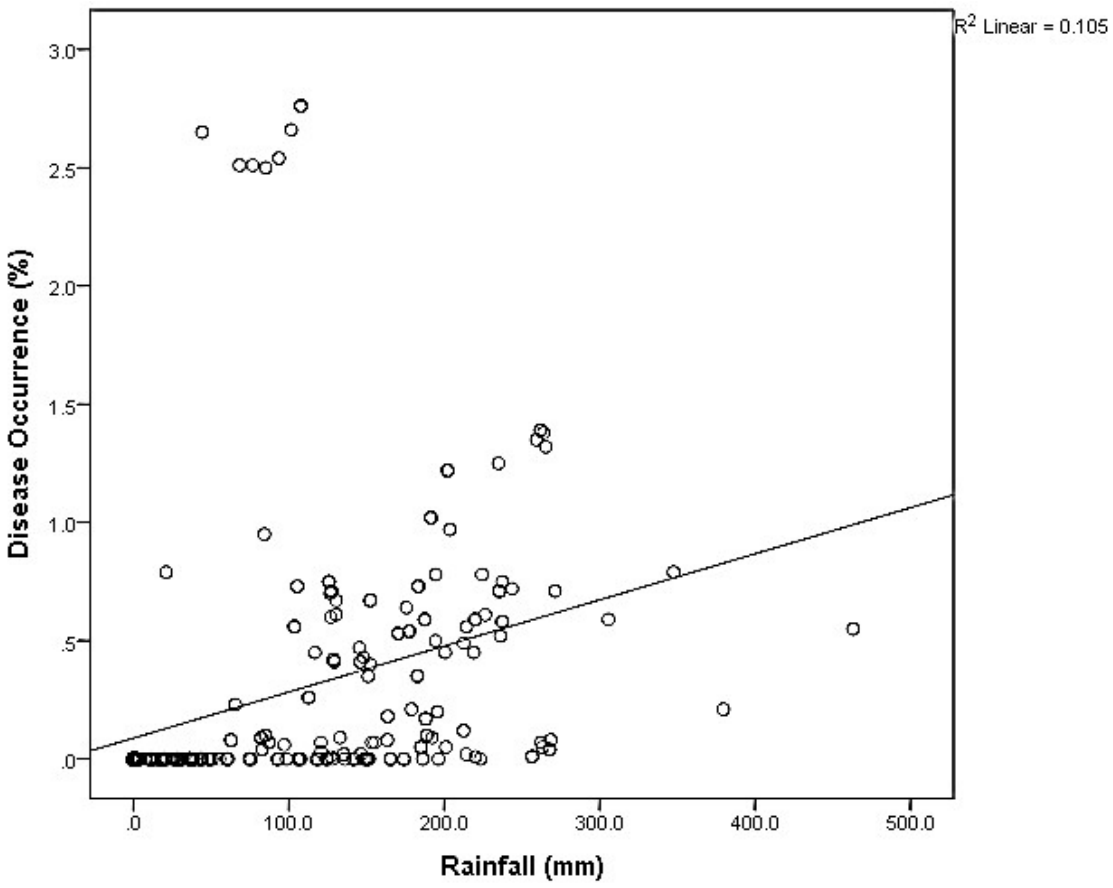


Fig 4.3. The relationship between disease occurrence and annual rainfall (mm)

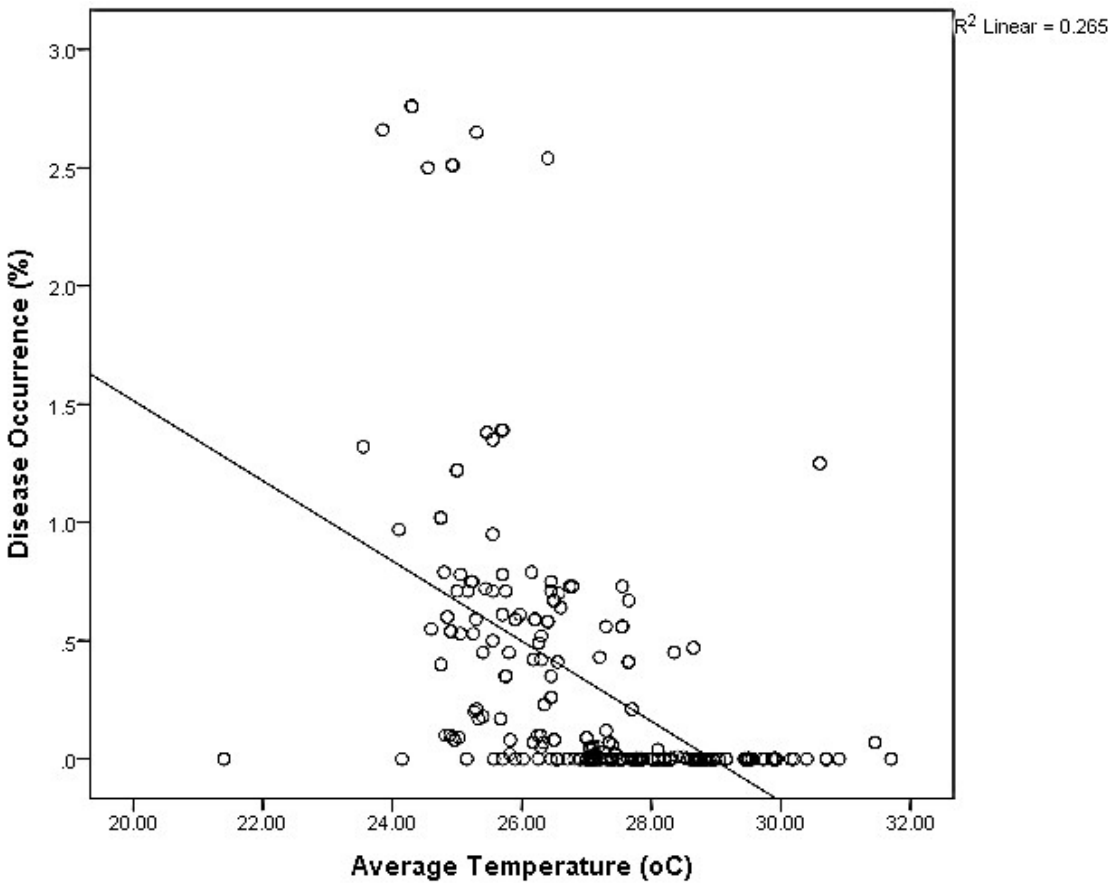


Fig 4.4. The relationship between disease occurrence and average temperature (^{o}C)

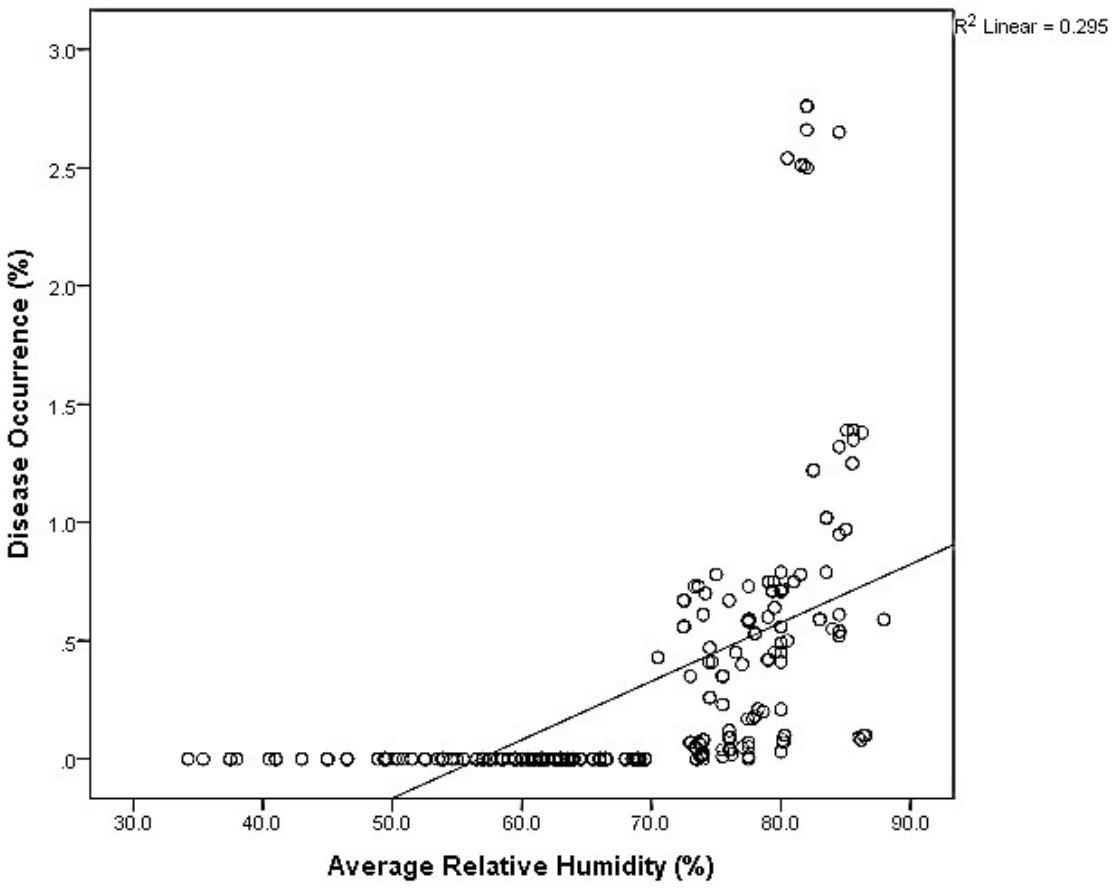


Fig 4.5. The relationship between black pod disease occurrence and average relative humidity (%)

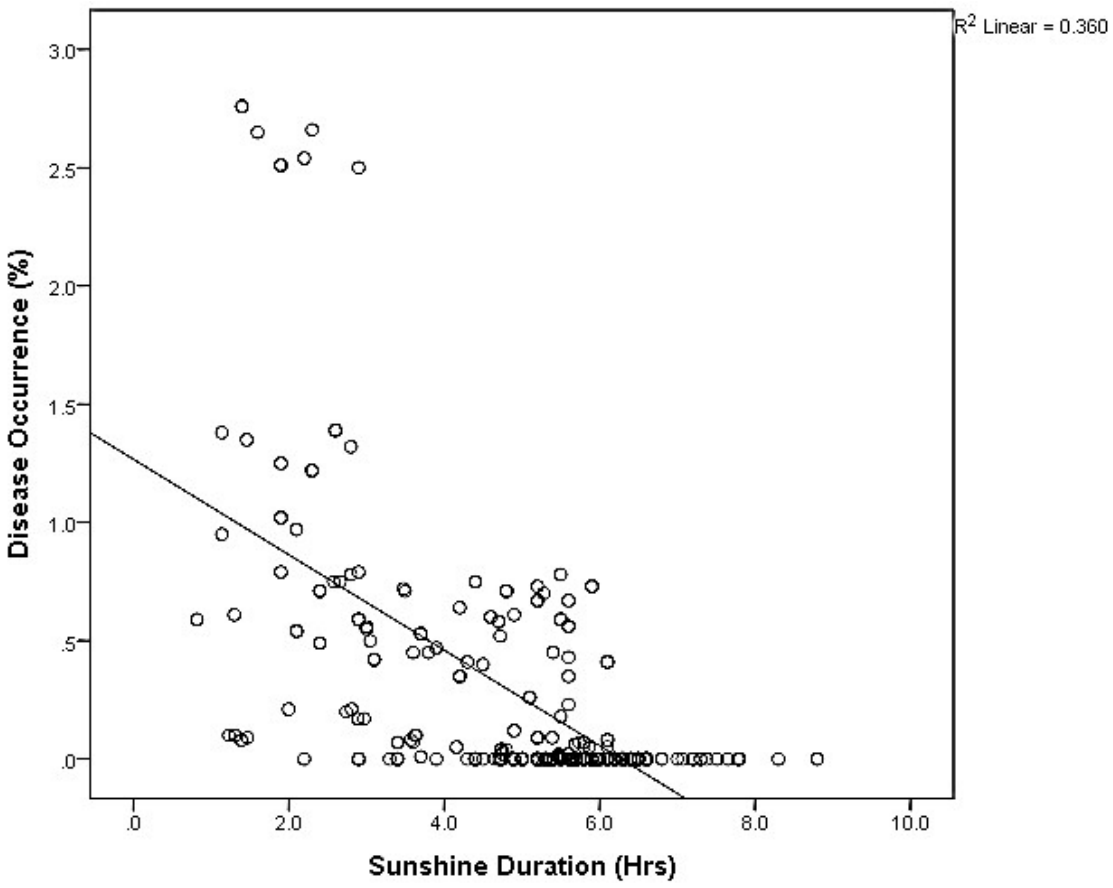


Fig 4.6.The relationship between disease occurrence and sunshine duration (Hours)

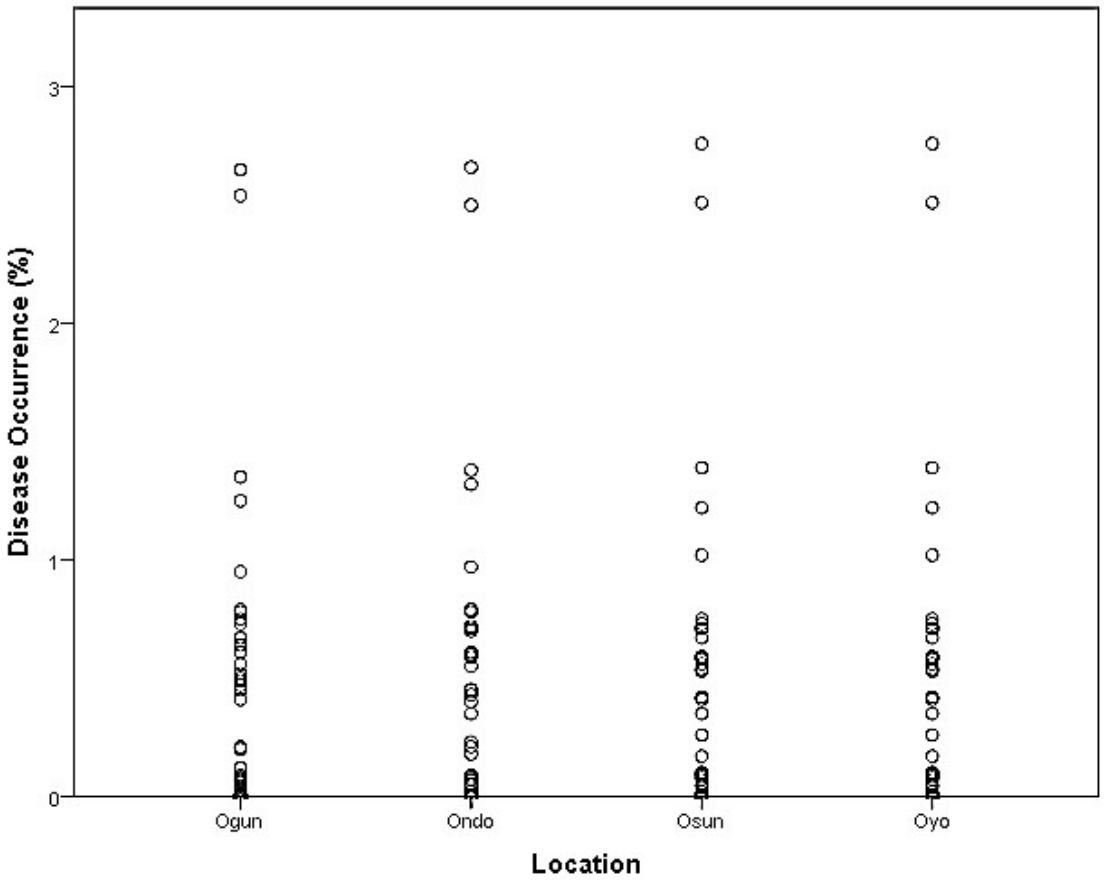


Fig 4.7.The relationship between black pod disease occurrence and location

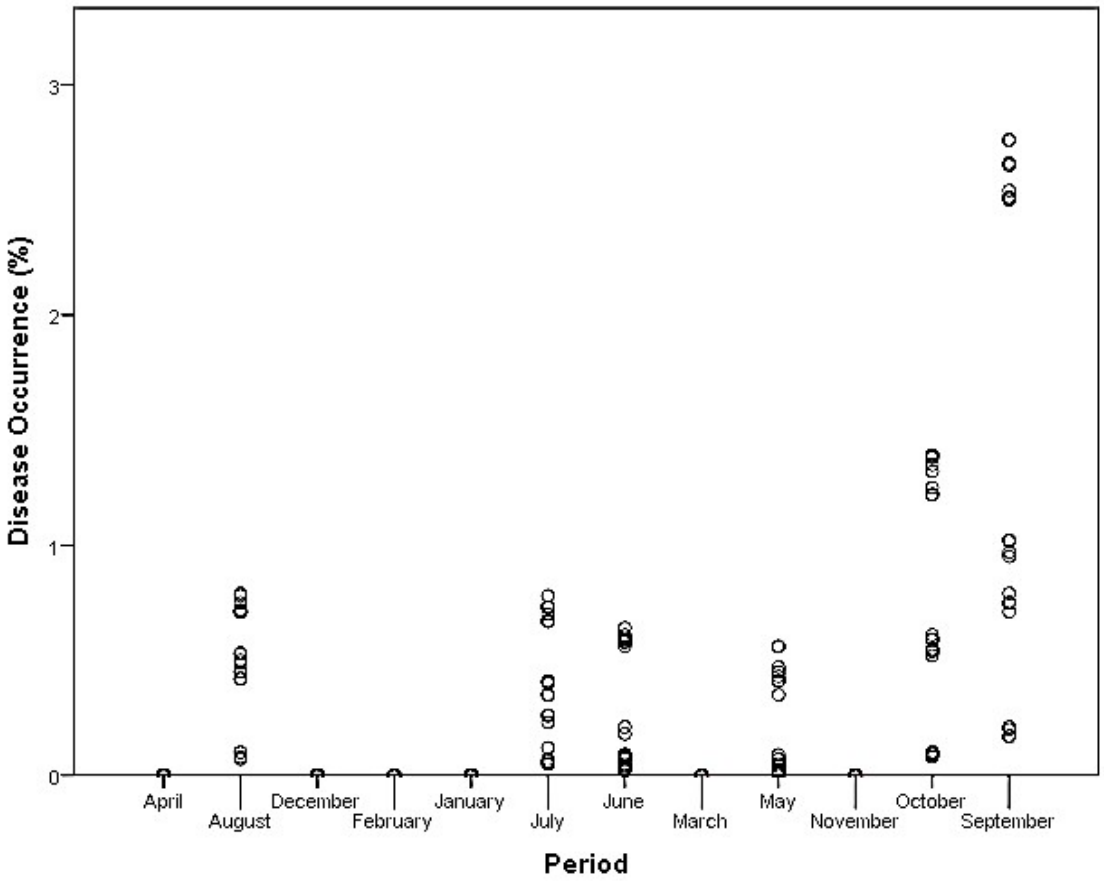


Fig 4.8. The relationship between disease occurrence and period (Months)

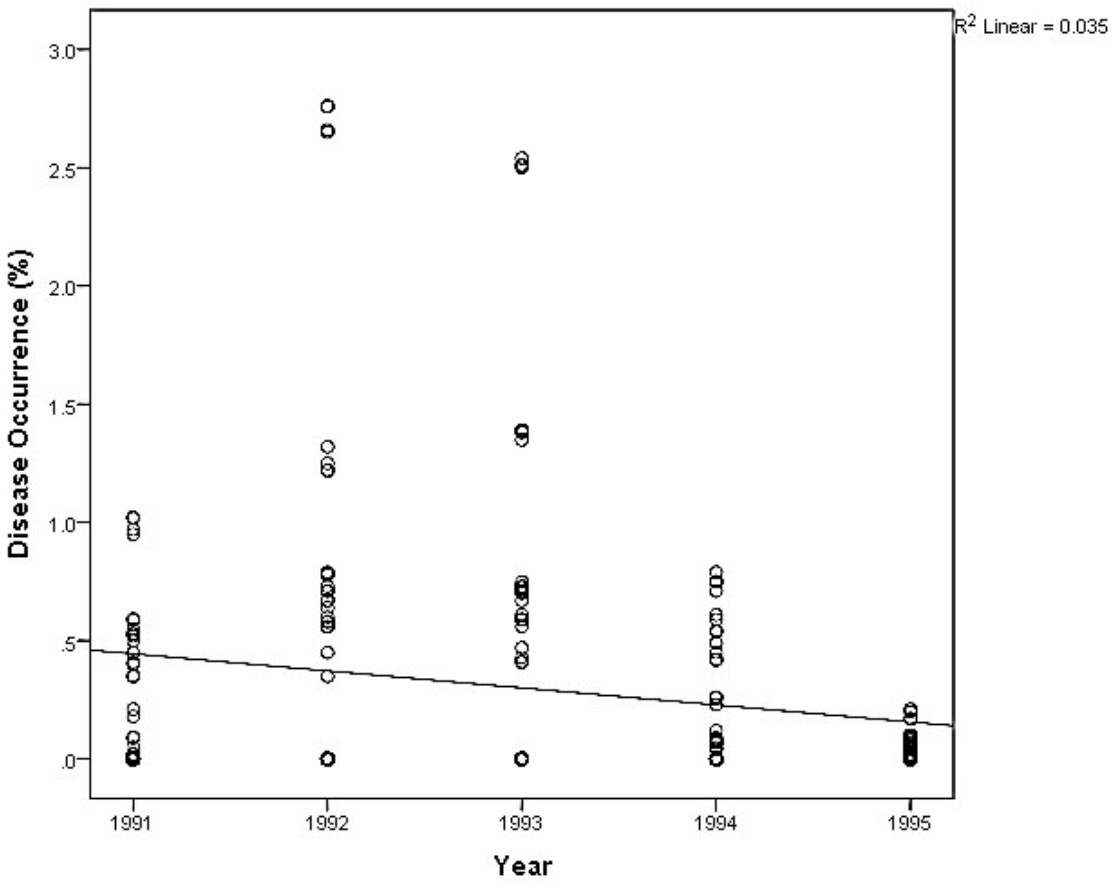


Fig 4.9. The relationship between disease occurrence and the year of disease outbreak

General Equation for Model One (1991-1995): **Model code-MRM_1**

$$Y = \alpha + \beta_1X_1 + \beta_2X_2 - \beta_3X_3 + \beta_4X_4 - \beta_5X_5 - \beta_6X_6 + \beta_7X_7 - \beta_8X_8 - \beta_9X_9$$

Model One:

Disease Occurrence (%) = 124.8 + 0.03 (Month) + 0.01(State) - 0.06 (Year) + 0.002 (Rainfall) - 0.003 (Max. Temperature) - 0.04 (Min. Temperature) + 0.01 (Relative Humidity [Morning]) - 0.0003 (Relative Humidity [Afternoon]) - 0.05 (Sunshine Duration)

General Equation for Model Two(1991-1995): **Model code-MRM_2**

$$Y = \alpha + \beta_1X_1 + \beta_2X_2 - \beta_3X_3 + \beta_4X_4 - \beta_5X_5 + \beta_6X_6 - \beta_7X_7$$

Model Two:

Disease Occurrence (%) = 129.9 + 0.03 (Month) + 0.005 (State) - 0.06 (Year) + 0.001 (Rainfall) - 0.03 (Average Temperature) + 0.005 (Average Relative Humidity) - 0.04 (Sunshine Duration)

General Equation for Model Three(1991-1995): **Model code-MRM_3**

$$Y = \alpha + \beta_1X_1 - \beta_2X_2 - \beta_3X_3 + \beta_4X_4 - \beta_5X_5 + \beta_6X_6$$

Model Three:

Disease Occurrence (%) = 127.8 + 0.02 (Month) - 0.002 (State) - 0.06 (Year) + 0.001 (Rainfall) - 0.05 (Average Temperature) + 0.007 (Average Relative Humidity)

General Equation for Model Four (1991-1995): **Model code-MRM_4**

$$Y = \alpha - \beta_1X_1 + \beta_2X_2 - \beta_3X_3 - \beta_4X_4 - \beta_5X_5 - \beta_6X_6 + \beta_7X_7 + \beta_8X_8 - \beta_9X_9$$

Model Four:

Disease Occurrence (%) = 101 - 0.008 (Month) + 0.02 (State) - 0.05 (Year) - 0.002 (Rainfall) - 0.02 (Max. Temperature) - 0.06 (Min. Temperature) + 0.01(Relative Humidity-Morning) + 0.01 (Relative Humidity-Afternoon) - 0.1 (Sunshine Duration)

General Equation for Model Five (1985-2014) [Accepted Equation]: **Model code-MRM_5**

$$Y = -\alpha - \beta_1X_1 + \beta_2X_2 + \beta_3X_3$$

Model Five (Accepted Model):

Disease Occurrence (%) = -20.4 - 0.004 (Rainfall) + 0.272 (Relative Humidity) + 0.511 (Temperature)

General Equation for Model Six (1991-1995): **Model code-MRM_6**

$Y = \alpha + \beta_1X_1 - \beta_2X_2 + \beta_3X_3 - \beta_4X_4 - \beta_5X_5 + \beta_6X_6 - \beta_7X_7$

Model Six:

Disease Occurrence (%) = 101.6 - 0.007 (Month) + 0.02 (State) - 0.05 (Year) - 0.002 (Rainfall) - 0.07 (Average Temperature) + 0.02 (Average Relative Humidity) - 0.1 (Sunshine Duration)

General Equation for Model Seven(1985-2014): **Model code-MRM_7**

$Y = -\alpha - \beta_1X_1 + \beta_2X_2 - \beta_3X_3 + \beta_4X_4$

Model Seven:

Disease Occurrence (%) = -1364 - 0.00099 (Rainfall) + 0.008 (Relative Humidity) – 1.38 (Temperature) + 0.705 (Year)

General Equation for Model Eight(1991-1995): **Model code-MRM_8**

$Y = -\alpha - \beta_1X_1 - \beta_2X_2 + \beta_3X_3 - \beta_4X_4$

Model Eight:

Disease Occurrence (%) = -1.64- 0.00152 (Rainfall) - 0.0727 (Average Temperature) + 0.02 (Average Relative Humidity) - 0.119 (Sunshine Duration)

Model Selection

Preliminary screening of the developed models was done using the co-efficient of correlation (R-Sq). The five (5) best fitted models (MRM_1, MRM_2, MRM_3, MRM_4, and MRM_5) for black pod disease prediction were considered for further validation prior to final selection. The posthoc analysis conducted showed that MRM_5 was the preferred model for black pod disease prediction followed by MRM_4>MRM_1>MRM_2>MRM_3 in terms of the Standard Error of Regression (SER) which was given as 0.22, 0.39, 0.45, 0.45, and 0.45 respectively; Root Mean Square Error of Prediction ($RMSE_{pred.}$): 0.30, 0.39, 0.46, 0.46 and 0.46 respectively; and the Adjusted Co-efficient of Correlation (R-

$Sq_{Adj.}$): 0.67, 0.49, 0.32, 0.32 and 0.31 for MRM_5, MRM_4, MRM_1, MRM_2, and MRM_3. The preferred model MRM_5 was named "ETAPOD" (Plate 4.1)

4.17 Prediction of BPD incidence in Ogun, Ondo, Osun and Oyo States (2015/2016)

The predicted level of black pod disease outbreak for Ogun State was 9.97% in May, June (11.54%), July (12.25%), August (11.24%), September (9.86%), October (9.24%), November (5.95%), December (2.25%) in 2015 and 1.03% for January, February (2.81%), March (4.74%), April (7.42%), May (9.97%), in 2016 (Plate 4.2). That of Ondo State was predicted thus: May, 2015 (8.58%); June, 2015 (9.05%); July, 2015 (11.48%); August, 2015 (10.26%); September, 2015 (10.09%); October, 2015 (8.17%); November, 2015 (4.50%) and December, 2015 (0.76%). While the predictions for 2016 was given thus: January (-1.40%), February (-0.04%), March (4.32%), April (6.48%), and May (8.58%), respectively (Plate 4.3).

For Osun State, black pod disease outbreak was predicted in 2015 as follows: May (8.64%), June (9.43%), July (11.82%), August (10.34%), September (10.26%), October (7.80%), November (4.94%), and December (1.67%); that of 2016 was predicted thus January (0.04%), February (1.25%), March (4.69%), April (6.89%) and May (8.64%), (Plate 4.4). Finally, the predictions for Oyo State was as follow: May (8.69%), June (9.43%), July (11.77%), August (10.39%), September (9.98%), October (7.80%), November (4.95%), December (1.67%) for 2015 and January (0.21%), February (1.29%), March (4.57%), April (6.87%) and May (8.69%) for 2016 growing season (Plate 4.5). A comparison was drawn with the observed values obtained in the field for the 2015/2016 cocoa production season.

Table 4.20.The Correlation Coefficients for disease occurrence, rainfall, temperature, relative humidity and sunshine duration in Southwest, Nigeria

	Month	State	Year	DO (%)	Rainfall	Max. Temp.	Min. Temp.	Avg. Temp.	RH-Morning	RH-Afternoon	Avg. RH	Sunshine
Month	1.00											
State	0.00	1.00										
Year	0.00	0.00	1.00									
Disease Occ	.300**	0.00	-.187**	1.00								
Rainfall	0.119	-0.01	0.002	.445**	1.00							
Max. Temp.	-.439**	-0.11	0.072	-.474**	-.587**	1.00						
Min. Temp.	-.232**	-0.07	0.063	-0.124	0.06	.308**	1.00					
Avg Temp.	-.441**	-0.12	0.084	-.420**	-.427**	.907**	.679**	1.00				
R H-Morning	.322**	-0.13	-0.071	.433**	.661**	-.601**	.292**	-.334**	1.00			
RH-A'noon	.333**	-0.05	-0.037	.481**	.776**	-.761**	0.101	-.542**	.875**	1.00		
Avg RH	.339**	-0.08	-0.051	.477**	.757**	-.724**	.175**	-.481**	.948**	.984**	1.00	
Sunshine	-0.097	0.089	0.04	-.364**	-.424**	.621**	.134*	.538**	-.437**	-.563**	-.533**	1.00

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

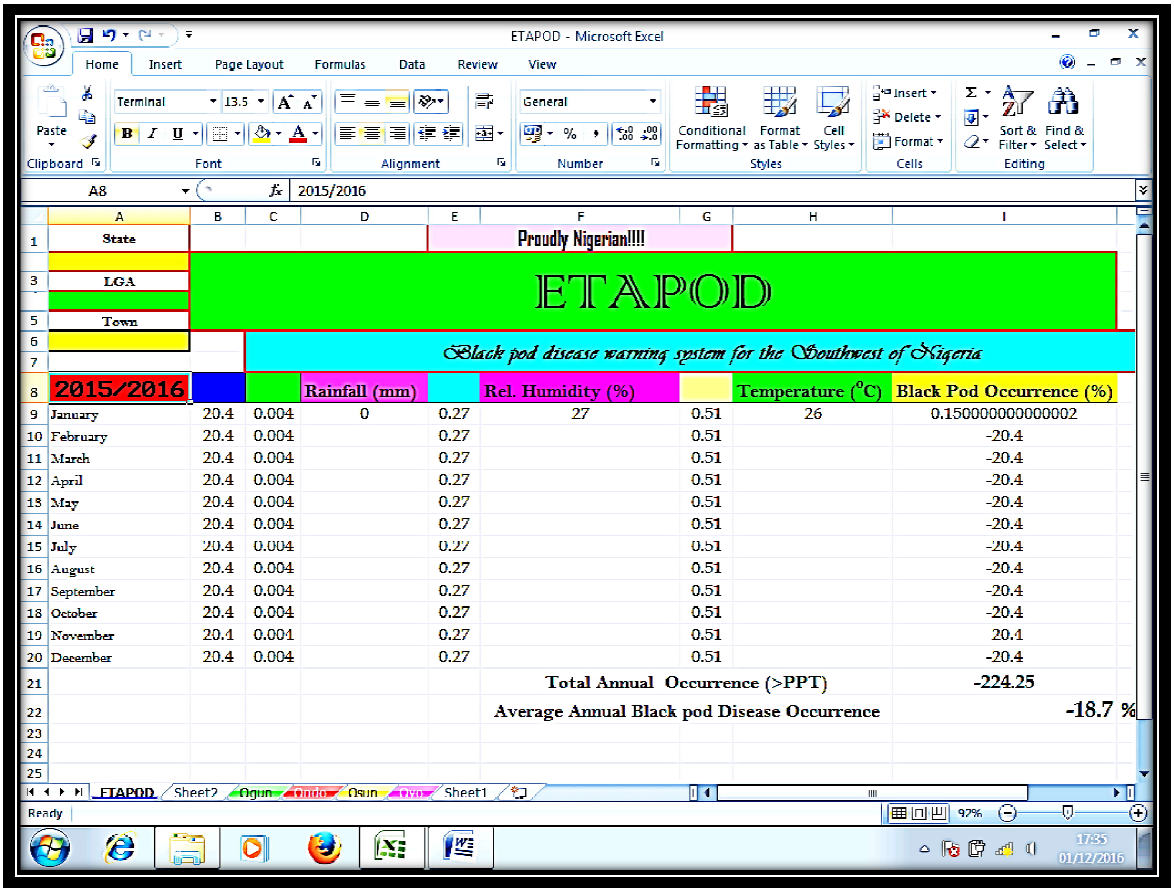
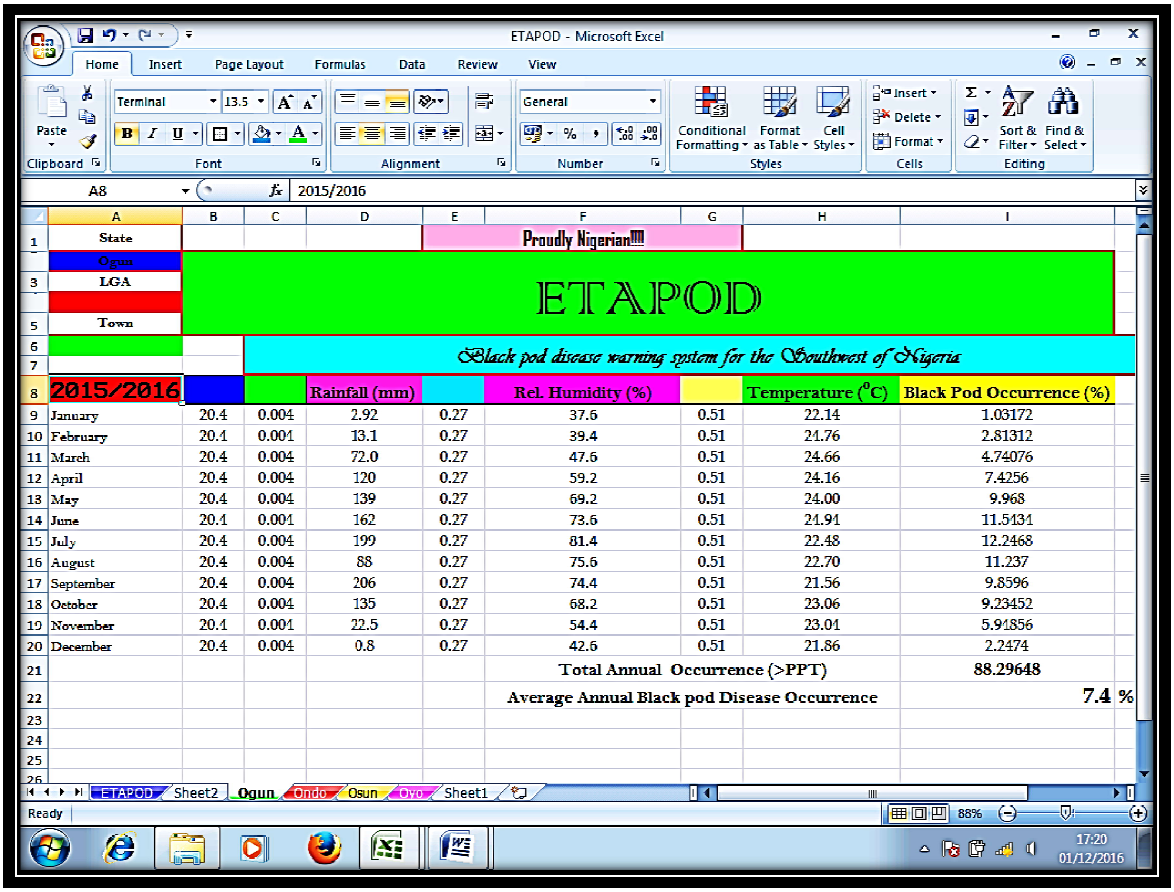
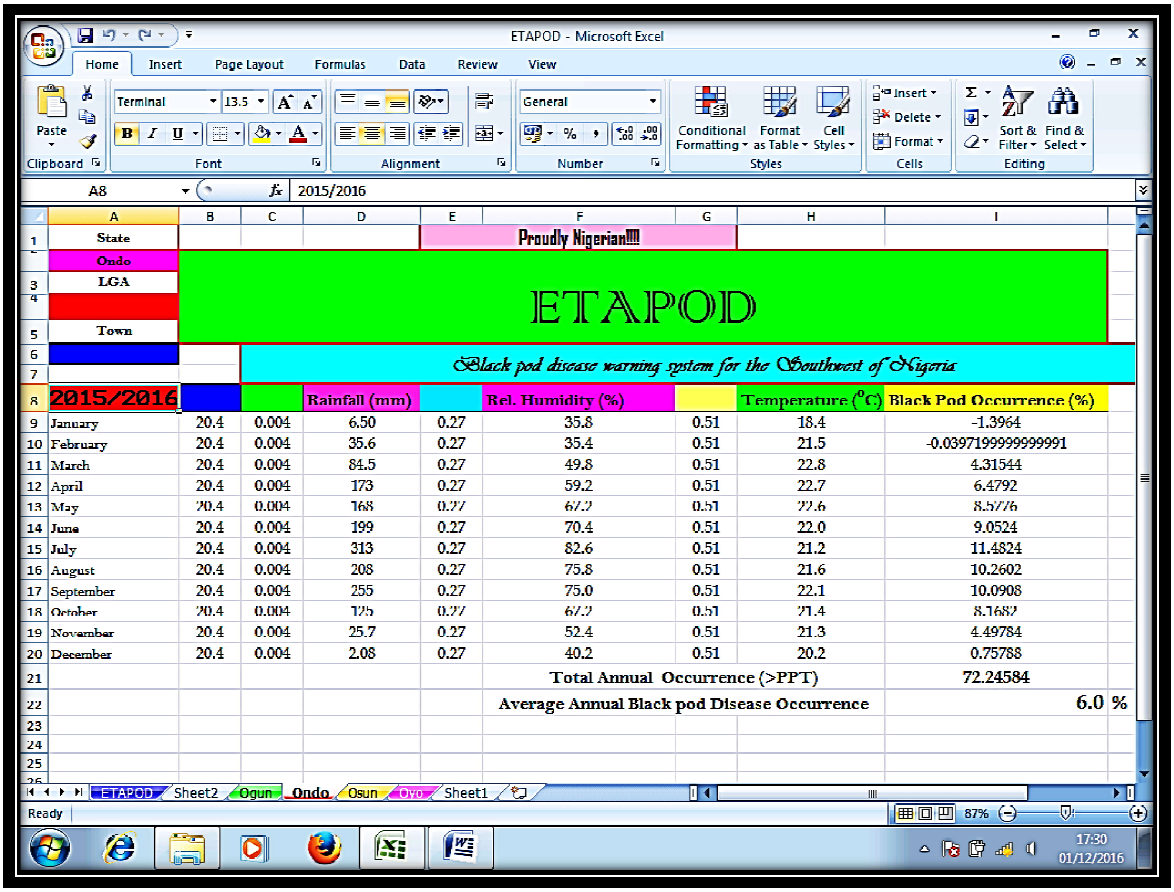


Plate 4.1."ETAPOD" The modified MRM_5 model for BPD prediction in Southwest, Nigeria



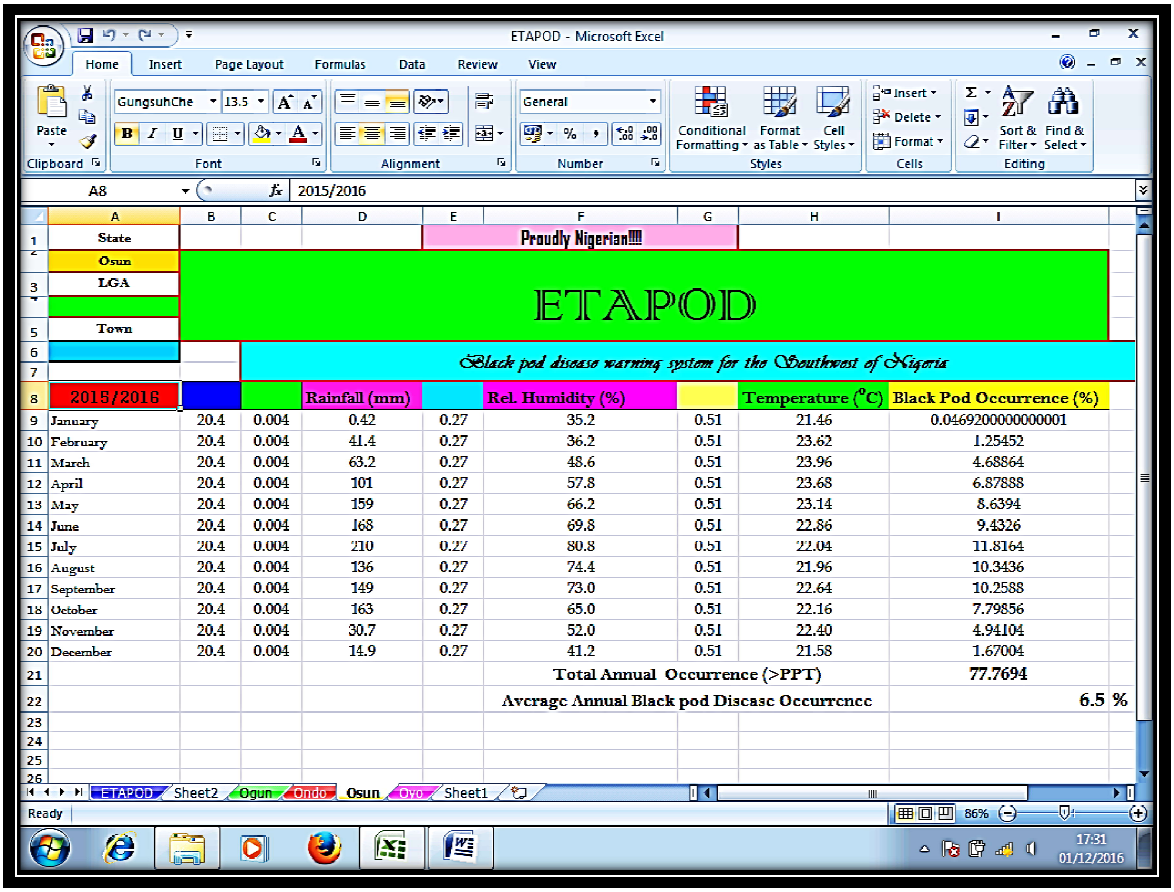
State					Proudly Nigerian!!!			
Ogun								
LGA					ETAPOD			
Town								
					Black pod disease warning system for the Southwest of Nigeria			
2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
January	20.4	0.004	2.92	0.27	37.6	0.51	22.14	1.03172
February	20.1	0.001	13.1	0.27	39.4	0.51	21.76	2.81312
March	20.4	0.004	72.0	0.27	47.6	0.51	24.66	4.74076
April	20.4	0.004	120	0.27	59.2	0.51	24.16	7.4256
May	20.4	0.004	139	0.27	69.2	0.51	24.00	9.968
June	20.1	0.001	162	0.27	73.6	0.51	21.91	11.5131
July	20.4	0.004	199	0.27	81.4	0.51	22.48	12.2468
August	20.4	0.004	88	0.27	75.6	0.51	22.70	11.237
September	20.4	0.004	206	0.27	74.4	0.51	21.56	9.8596
October	20.4	0.004	135	0.27	68.2	0.51	23.06	9.23452
November	20.1	0.001	22.5	0.27	54.4	0.51	23.01	5.91856
December	20.4	0.004	0.8	0.27	42.6	0.51	21.86	2.2474
					Total Annual Occurrence (>PPT)			88.29648
					Average Annual Black pod Disease Occurrence			7.4 %

Plate 4.2.BPD predictions for Ogun State, Nigeria (2015/2016)



	A	B	C	D	E	F	G	H	I
1	State					Proudly Nigerian!!!!			
2	Ondo								
3	LGA								
4									
5	Town								
6									
7									
8	2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
9	January	20.4	0.004	6.50	0.27	35.8	0.51	18.4	-1.3964
10	February	20.4	0.004	35.6	0.27	35.4	0.51	21.5	-0.0397199999999991
11	March	20.4	0.004	84.5	0.27	49.8	0.51	22.8	4.31544
12	April	20.4	0.004	173	0.27	59.2	0.51	22.7	6.4792
13	May	20.4	0.004	168	0.27	67.2	0.51	22.6	8.5776
14	June	20.4	0.004	199	0.27	70.4	0.51	22.0	9.0524
15	July	20.4	0.004	313	0.27	82.6	0.51	21.2	11.4824
16	August	20.4	0.004	208	0.27	75.8	0.51	21.6	10.2602
17	September	20.4	0.004	255	0.27	75.0	0.51	22.1	10.0908
18	October	20.4	0.004	175	0.27	67.2	0.51	21.4	8.1682
19	November	20.4	0.004	25.7	0.27	52.4	0.51	21.3	4.49784
20	December	20.4	0.004	2.08	0.27	40.2	0.51	20.2	0.75788
21						Total Annual Occurrence (>PPT)			72.24584
22						Average Annual Black pod Disease Occurrence			6.0 %

Plate 4.3.BPD predictions for Ondo State, Nigeria (2015/2016)



	A	B	C	D	E	F	G	H	I
1	State					Proudly Nigerian!!!			
2	Osun								
3	LGA								
4									
5	Town								
6									
7									
8	2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
9	January	20.4	0.004	0.42	0.27	35.2	0.51	21.46	0.0469200000000001
10	February	20.4	0.004	41.4	0.27	36.2	0.51	23.62	1.25452
11	March	20.4	0.004	63.2	0.27	48.6	0.51	23.96	4.68864
12	April	20.4	0.004	101	0.27	57.8	0.51	23.68	6.87888
13	May	20.4	0.004	159	0.27	66.2	0.51	23.14	8.6394
14	June	20.4	0.004	168	0.27	69.8	0.51	22.86	9.4326
15	July	20.4	0.004	210	0.27	80.8	0.51	22.04	11.8164
16	August	20.4	0.004	136	0.27	74.4	0.51	21.96	10.3436
17	September	20.4	0.004	149	0.27	73.0	0.51	22.64	10.2588
18	October	20.4	0.004	163	0.27	65.0	0.51	22.16	7.79856
19	November	20.4	0.004	30.7	0.27	52.0	0.51	22.40	4.94104
20	December	20.4	0.004	14.9	0.27	41.2	0.51	21.58	1.67004
21						Total Annual Occurrence (>PPT)			77.7694
22						Average Annual Black pod Disease Occurrence			6.5 %

Plate 4.4.BPD predictions for Osun State, Nigeria (2015/2016)

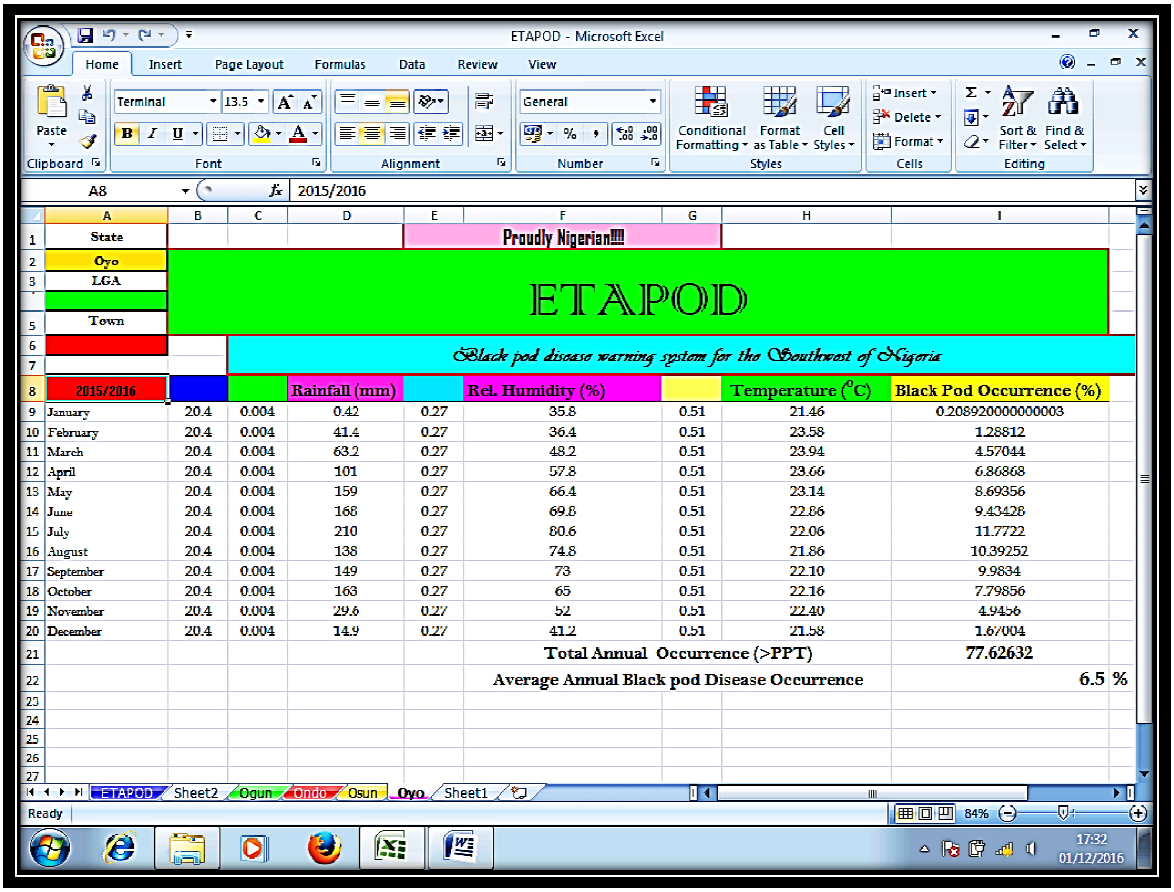


Plate 4.5.BPD predictions for Oyo State, Nigeria (2015/2016)

4.18 Comparison between predicted (Computer Simulations) and observed BPD values

Black pod disease outbreak for Ondo in the month of June was predicted as 9.05% and the actual observation made in the field was 9.5%, it was predicted as 11.5% in July (Actual observation was 18.0%), in August, predicted result of BPD outbreak was 10.3% (Actual BPD outbreak was 26.5%), in September (Predicted BPD Outbreak = 10.1%, Actual BPD Outbreak =11.0%), and in October (Predicted BPD Outbreak = 8.17%, while Actual BPD Outbreak = 5.0%) as stated in Table 4.21.

In Osun, the predicted BPD Outbreak for June was 9.43% (Actual BPD Outbreak = 9.0%), in July (Predicted BPD Occurrence = 11.8%, Actual BPD Occurrence = 13.5%), August (Predicted BPD Outbreak = 10.3%, Actual BPD Incidence = 8.0%), in September (Predicted Outbreak for black pod disease = 10.3%, Actual Value = 11.5%), and October (Predicted Result = 7.8%, Actual Occurrence = 10.0%). The predictions of black pod disease made by ETAPO for Ogun was [June (Predicted BPD Incidence = 11.5%, Actual BPD Occurrence = 0.0%), July (Predicted BPD Incidence = 12.2%, Actual BPD Incidence = 0.0%), August (Predicted BPD Incidence = 11.2%, Actual BPD Outbreak = 3.0%), September (Predicted BPD Outbreak = 9.86%, Actual BPD Occurrence = 15.0%), and October (Predicted BPD Outbreak = 9.23%, Actual BPD Outbreak = 22.0%)]. Finally, that of Oyo State was given thus: June (9.43%, 0.0%), July (11.8%, 6.0%), August (10.4%, 16.0%), September (9.98%, 14.0%), and October (7.8%, 0.0%) for both predicted and actual black pod disease outbreak (Table 4.21).

It was also observed that the range of disparity between the observed and predicted values for Ondo State was between -8.58% and 16.2%, Osun (-7.14% and 2.20%), Ogun (-11.5% and 12.8%) and Oyo (-9.43% and 5.60%) as recorded in Table 4.22. The estimated performance of the developed black pod disease occurrence forecast model was rated as follows: Ondo State had good black pod disease predicted values for the months of June, July, August, September 2015, January and February 2016; whereas, fair black pod disease occurrence was experienced in the months of October, November, December 2015 and March, 2016. Osun State had good black pod disease predicted values for the months of July, September, October 2015, and January 2016; and fair black pod disease predicted values for the months of June, August, November, December 2015, February and March 2016. Ogun State had black pod disease values predicted correctly for the months of September and October 2015 only; whereas, there was a

series of fair black pod incidence predicted values within the months of December 2015, January, February and March 2016. Finally, for Oyo State there was good black pod disease prevalence values predicted for the months of August and September 2015 only, and fair predicted black pod disease occurrence values for the months of November, December 2015, January, February, and March 2016 (Table 4.23).

4.19 The error of prediction for the developed BPD forecast model

The error of prediction was estimated statistically and the level of accuracy of the developed model for prediction of black pod disease occurrence was determined by simple statistical formula. The estimation of the monthly percentage error of prediction for each state was given thus: for Ondo State it was estimated to be 0.20% in the month of June 2015, July 2015 (42.25%), September 2015 (0.81%), October 2015 (10.05%), November 2015 (20.25%), December 2015 (0.58%), January 2016 (1.96%), February 2016 (0.0%), March 2016 (18.66%), and April 2016 (41.99%) as stated in Table 4.24. The statistical error of prediction of black pod disease occurrence in Osun State was low with the value estimated for the month of June 2015 being 0.18%, July 2015 (2.89%), August 2015 (5.29%), September 2015 (1.44%), October 2015 (4.84 %), November 2015 (24.4%), December 2015 (2.79%), January 2016 (0.0%), February 2016 (1.56%), March 2016 (22.0%), and April 2016 (47.33%) during the 2015/2016 cocoa production season across the Southwest of Nigeria (Table 4.24).

Ogun and Oyo States had similar estimated statistical error in black pod disease prediction. Although their estimated levels in the error of black pod disease prevalence predicted values were low, much work still need to be done to improve the quality of the result forecasted for these states. It was noted that the error of prediction for Ogun State was 26.42% for the month of September 2015, 35.4% for November 2015, December 2015 (5.06%), January 2016 (1.06%), February 2016 (7.9%), and March 2016 (22.47%). The statistical error of prediction for Oyo State was 33.64% for the month of July 2015, August 2015 (31.36%), September 2015 (16.16%), November 2015 (24.5%), December 2015 (2.79%), January 2016 (0.04%), February 2016 (1.66%), March 2016 (20.88%), and April 2016 (47.2%) as estimated in the 2015/2016 cocoa production season across the Southwest, states of Nigeria (Table 4.24).

Table 4.21.A comparison between the observed black pod disease incidence in the field across the Southwest and the computer simulated values (2015/2016)

Period	Black Pod Disease Incidence (%)							
	Ondo		Osun		Ogun		Oyo	
	Observed	Predicted (ME)	Observed	Predicted (ME)	Observed	Predicted (ME)	Observed	Predicted (ME)
05/2015	0.0	8.58	1.5	8.64	0.0	9.97	0.0	8.69
06/2015	9.5	9.05	9.0	9.43	0.0	11.5	0.0	9.43
07/2015	18.0	11.5	13.5	11.8	0.0	12.2	6.0	11.8
08/2015	26.5	10.3	8.0	10.3	3.0	11.2	16.0	10.4
09/2015	11.0	10.1	11.5	10.3	15.0	9.86	14.0	9.98
10/2015	5.0	8.17	10.0	7.80	22.0	9.23	0.0	7.80
11/2015	0.0	4.50	0.0	4.94	0.0	5.95	0.0	4.95
12/2015	0.0	0.76	0.0	1.67	0.0	2.25	0.0	1.67
01/2016	0.0	-1.40	0.0	0.05	0.0	1.03	0.0	0.21
02/2016	0.0	-0.04	0.0	1.25	0.0	2.81	0.0	1.29
03/2016	0.0	4.32	0.0	4.69	0.0	4.74	0.0	4.57
04/2016	0.0	6.48	0.0	6.88	0.0	7.43	0.0	6.87
05/2016	0.0	8.58	0.0	8.64	0.0	9.97	0.0	8.69

Key

ME: Minimum Expected values for the predicted result of black pod disease occurrence within the States

Table 4.22.An estimation of the difference that exist between the data set

Period	Estimated Difference (%)			
	Ondo	Osun	Ogun	Oyo
05/2015	-8.58	-7.14	-9.97	-8.69
06/2015	0.45	-0.43	-11.5	-9.43
07/2015	6.50	1.70	-12.2	-5.80
08/2015	16.2	-2.30	-8.20	5.60
09/2015	0.90	1.20	5.14	4.02
10/2015	-3.17	2.20	12.8	-7.80
11/2015	-4.50	-4.94	-5.95	-4.95
12/2015	-0.76	-1.67	-2.25	-1.67
01/2016	1.40	-0.05	-1.03	-0.21
02/2016	0.04	-1.25	-2.81	-1.29
03/2016	-4.32	-4.69	-4.74	-4.57
04/2016	-6.48	-6.88	-7.43	-6.87
05/2016	-8.58	-8.64	-9.97	-8.69

Table 4.23.Validation of predicted results for black pod disease incidence (2015/2016)

Period	Ondo	Osun	Ogun	Oyo
05/2015	-	-	-	-
06/2015	+	-/+	-	-
07/2015	+	+	-	-
08/2015	+	-/+	-	+
09/2015	+	+	+	+
10/2015	-/+	+	+	-
11/2015	-/+	-/+	-	-/+
12/2015	-/+	-/+	-/+	-/+
01/2016	+	+	-/+	-/+
02/2016	+	-/+	-/+	-/+
03/2016	-/+	-/+	-/+	-/+
04/2016	-	-	-	-
05/2016	-	-	-	-

Key.

+ = Accurate Disease Prediction

-/+ = Error in disease prediction less than 5%

- = Error in disease prediction more than 5%

Table 4.24.Percentage error in black pod disease prediction generated from the 2015/2016 cocoa production season

Periods	Error in prediction of black pod disease occurrence (%) [$E= (Y-\hat{Y})^2$]			
	Ondo	Osun	Ogun	Oyo
05/2015	73.62	50.98	99.4	75.52
06/2015	0.20	0.18	132.25	88.92
07/2015	42.25	2.89	148.84	33.64
08/2015	262.44	5.29	67.24	31.36
09/2015	0.81	1.44	26.42	16.16
10/2015	10.05	4.84	163.84	60.84
11/2015	20.25	24.4	35.4	24.5
12/2015	0.58	2.79	5.06	2.79
01/2016	1.96	0.00	1.06	0.04
02/2016	0.00	1.56	7.90	1.66
03/2016	18.66	22.00	22.47	20.88
04/2016	41.99	47.33	55.20	47.20
05/2016	73.62	74.65	99.40	75.52

CHAPTER FIVE

Discussion and Recommendations

5.0 Discussion

Black pod disease was a major threat to cocoa production within the assessed cocoa farmlandsas its incidence was recorded in all the study sites investigated. This was initially documented in the report of Oluyole and Lawal (2008). Black pod disease was totally absent in the dry season and it was massive in all the study sites during the rainy season. This was in line with the review of Akrofi (2015), who gave a similar trend of black pod disease incidence in certain places in Ghana and also Oluyole and Lawal, 2008 who also reported similar observations in Nigeria.It was further observed that there was massive deteriorationof ripe and unripe healthy cocoa pods in the field which was reflected in the high level of black pod disease severity on viablecocoa pods within the study sites. This was in agreement with the report of Appiah *et al*. (2004), and Opoku *et al.* (1996) who stated that black pod disease caused by *Phytophthora megakarya* causes immense cocoa pod losses and also inflicts severe stem canker resulting in the death of many cocoa trees.

Cocoa farms located in Osun had the first reported incidence of black pod disease, later in the season, there was a shift in disease gradient from cocoa farms in Osun to those situated in Ondo, subsequently to those in Oyo and lastly to cocoa farmlands in Ogun, suggesting the possible origin and mode of transfer of black pod disease in Southwest, Nigeria. This was a confirmation of the report given by Adisa and Adeloye (2012) who identified Osun State as a major reservoir for black pod disease pathogen. Ondo and Osun States had a seemingly similar level of disease incidence at a point in time during the research. This can be partly explained by the similarity in weather pattern based on proximity in distance and agro-ecological zoning of these States, a theme well described by Ziervogel *et al*. (2006) who stated that climate change has wide-ranging effects on the environment, socio-economic and other related sectors, including water resources, agriculture, food security, human health, terrestrial ecosystems, biodiversity and coastal zones.

Cocoa farmlands located in areas of high altitude (>200m) had early infection of black pod disease with increasing level as the season progresses, whereas, research cocoa farmlands located in regions with lesser altitude (≤ 200m) had a slow start to black pod

disease development with the height of black pod disease incidence for both levels closer to the end of the rainy season. A comparison between the two height levels showed that the activity of the pathogen and the infection of black pod disease was closely affected by the height of the cocoa farmland above sea level.Also, the rate of spread of the disease may be influenced to a great extent by the topography of the farmland. This report was in line with the research ofLuo who conducted a spatial-temporal assessment for the development and a spread of plant disease (2008).

Black pod disease was severe in almost all the study sites in September 2015 and almost not noticed in November, December 2015, January, February, March, April and May 2016 with insignificant disease intensity, which was largely due to the fact that most farmers have harvested their cocoa pods and the Cherelles (young pods) which are still in the juvenile stage were not the preferential target of *Phytophthora megakarya*. During these periods the farm environment was devoid of water which is a pertinent factor for the proliferation of the organism (*Phytophthoramegakarya*) that caused black pod disease. This was initially reported by Ziervogel *et al*. (2006). Ondo State had the highest level of black pod disease Incidence during the close of the year 2015 and Osun State had the highest level of disease Severity. This was in agreement with the research findings of Adisa and Adeloye who reported a high level of black pod disease outbreak in Osun State. The overall annual disease occurrence observed within Southwest,Nigeria for the cocoa production season ending 2015 and 2016 were mildly severe while the levels of black pod disease severity on the affected cocoa pods were moderately and extremely severe in some cases. The irregular black pod disease management rate achieved around the investigated region was due to the fact that the level of preparedness of the farmers within the affected region in terms of fungicide application and good cultural practices to wade of potential agents of propagation and spread of the disease differs greatly, partly due to ignorance and the level of information on the control of the disease available to the local cocoa farmers and majorly due to financial constraints. This was in line with the findings of the Cocoa Research Institute of Nigeria (2003 and 2008).

It was observed that while others study sites had a decline in black pod disease severity during the close of the rainy season, Ọbáfẹmi-Owódé showed a progressive geometric increase in black pod diseases severity. The basic rationale behind the heavy infestation by black pod disease outside the peak period was due to the lack of disease management strategy employed by the farmer. This was a confirmation of the research carried

outBerry and Cilas (1994) who stated that losses can reach up to 100% of the cocoa production in smallholders' plantations when no control measures are taken. With the onset of the dry season, culminating in a drastic reduction in the top soil surface water, reduced amount of rainfall, high ambient temperature, increased hours of sunshine (high luminous potentials), decreased air saturation (low relative humidity) and due to the fact that most cocoa farmers have harvested their pods from the farm, black pod disease severity for the months of November and December 2015, likewise January, February, March, April and May 2016 was drastically reduced to non-significant levels, and as such the disease posed no threats to farmers during these periods. This was in line with the assertion made by Ziervogel *et al*. (2006).

Osun State still led the chart for high ranking black pod disease severity in the Southwest of Nigeria, followed by Ondo State; other States had insignificant disease history for the month during the early periods of the disease assessment. There was rapid geometric increase in black pod disease expression and intensity within the months of July and August with a climax in September 2015 for Ondo State, Osun State, Oyo State and Ogun State. The same sequence for disease prevalence was earlier given by Opoku *et al*. (2000). Other preceding months had insignificant disease intensity status.

There was disease infestation recorded for cocoa farmlands located within areas situated in altitude higher than 200m above sea level (201m-300m) and none for areas located below 200m above sea level in the month of May 2015. The same trend was observed in June 2015. The disease intensity trend was progressive through the months of July and August 2015, with its peak value in September 2015 for cocoa farmlands located in areas situated 0- 200m height above sea level, follow by retrogression in disease intensity value in October 2015, through the dry season. This was as suggested by Opoku *et al*. (2007). *Phytophthora megakarya* (Brassier and Griffins) was identified in all the study sites from infected cocoa pod and soil samples. This was in agreement with the research of Opoku *et al*. (1994, 2000, and 2007); Akrofi *et al*. (2014) and Akrofi (2015) who also identified *Phytophthora megakarya* as the causal agent of black pod disease within cocoa farms in Ghana.

The major weather parameters affecting the establishment and proliferation of black pod disease in the Southwest include rainfall, temperature, relative humidity and sunshine duration. The amount of moisture present in the soil majorly determines the microbial activities of the pathogen such as the frequency of spore dispersal, germination and other

pre-penetration activities. The findings from this research was in line with the report of Opoku (1994)

The weather distribution for the Southwest in the early 1900s showed that there was recurrent and substantial amount of rainfall across the four (4) States investigated within the months of March through October from 1991 to 1995, suggesting the possibility of infection within these periods. This report coincided with the description of suitable weatherdistribution for black pod disease infection given by Akrofi (2015). The current studies affirms the fact that black pod disease thrives better during the months ofMarch through October, suggesting the possibility of infection within these periods also. The overall diagnosis is an indication of the parameters pertinent for disease establishment and when they combine favourably in favour of the noxious pathogen to aid the proliferation, ramification and destruction of cocoa pods across their paths.

A qualitative assessment of local cocoa farmers within twelve (12) strategic locations in rural and sub-urban communitieswithin four states (Ondo, Osun, Ogun and Oyo States) of the Southwest of Nigeria renowned for their prowess for cocoa farming showed that farmers within these regions depend totally on the use of chemicals in the management of diseases affecting cocoa rather than exploiting the possibility of using either biological or cultural methods as opposed to the warning of world health organization (WHO) on the reduction in the level of chemical exposure of food substances. This fervent use and total dependence on the use of chemical as the ultimate control for black pod disease within the Southwest has been reported by Agbeniyi and Oni (2014). Local farmers within these regions were oblivious of the fact that these chemicals penetrate the tissues of the cocoa pods to the beans and it can thrive for a longer time within the tissues of the cocoa bean as systemic residues which are harmful to consumers of such products. Hence, the need for close monitoring of farmers indulged in the misuse or inappropriate application of these chemicals. This was initially stated by Agbeniyi and Oni (2014) that although chemical control using systemic and copper-based contact fungicides is the most widely-used control method, it remains too expensive for the majority of smallholders. In the long run, chemical spraying also have adverse environmental impact.

There was a positive relationship between black pod disease occurrence andrainfall, this is due to the fact that the Oomycetes zoosporangia which are uniflagillated requires moisture for their activities. Black pod disease occurrence had a negative correlation with

temperature.This was partially due to the fact that *Phytophthora megakarya* thrives best at temperatures below 25^{o}C and are dormant at extremely low temperatures. At a very high temperature, the fungus undergoes desiccation and viable spores may be destroyed, or they form resistant spores called Chlamydospores which can withstand harsh environmental conditions. Chlamydospores are drought resistant and self-sustaining resting spores that allow the pathogen to hibernate during unfavourable weather conditions for several days, months or even years until the environment is favourable for proliferation. When the surrounding environment becomes humid, it promotes sporulation and accumulation of infectious inoculum, thereby facilitating the infection of susceptible cocoa trees. It was observed thatreduced sunshine duration within the study sites resulted in increased microbial activities of *Phytophthora megakarya* which was made manifest in the level of increase in black pod disease observed during that period. This is regarded as a reverse relationship that brings about disease establishment. This was in line with the requirements stipulated by Luo (2008) and Fernandes*et al*. (2011).

Farmers indulged in the misuse of chemical to control black pod disease in Nigeria.Indigenous cocoa farmers apply fungicides frequently on their crops to prevent black pod disease infection without prior knowledge of the danger associated with excessive usage of these chemical products. Majority of the farmers apply chemical monthly as their normal routine with or without the emergence of black pod disease. A few apply fungicide twice annually, preferably during the advent of the disease, and a armful of the population of local cocoa farmers interviewed applied fungicide on their farmlands once in a year. The frequent usage of fungicide by indigenous cocoa farmers has been reported by Agbeniyi and Adedeji (2003) and Orisajo*et al.* (2012). Some of these farmers desist from the use of fungicides, the reason for their actions was based on the financial implication and the man power needed to perform such tasks.

Indigenous cocoa farmers within the Southwest largely neglect their farmlands based on the information generated from the statutory disease assessment carried out within the zone. Majority of farmers and growers of cocoa within the Southwest only indulge in weed removal once or twice in a year specifically within periods close to the harvest season. Others perform this action three (3) times yearly, a few of them carry out weed removal quarterly and monthly, and was emphatically noted that none of the local cocoa farmers within these regions perform the action of weed removal weekly or daily. This is unhealthy and unethical for good cocoa production. Adisa and Adeloye (2012) reported

that a number of reasons have been given for the decline in cocoa production which includes small farm holding, aging cocoa trees, aging farmers, poor management practices and lack of effective extension approach. Also, Opoku *et al*. (2000) reported that *P. palmivora* infected pods shrivel to form mummified pods, which provide a reservoir of inoculum for at least Three (3) years, necessitating the removal of mummified pods during routine sanitary pruning. Mummified pods on tree trunks and branches are common on *P. Megakarya* infected farms and these pods may serve as potential sources of inoculum and possibly account for some of the "unknown" sources of inoculum in *P. megakarya* infected fields (Akrofi, 2015). Cocoa husk disposal has been a major problem for local cocoa farmers within the Southwest since the husk serves as a nest for which the noxious pathogen that causes black pod disease overwinters. Information gathered from the disease assessment exercise showed that all the farmers interviewed heap the husk on the surface of their farmlands after harvest in a portion they refer to as the "Garage". This is highly unethical as it serves as a source of nutrient and shelter for the ravaging pathogen. This was further buttressed by the research carried out by Opoku *et al*. (2002) thatthe long time survival of *P. megakarya* in soil and infected debris, andevidence of its adaptation in soil and survival on roots of cocoa and other forest trees makes the control of *P. Megakarya* difficult.

Thedeveloped prediction model for black pod disease incidence (ETAPOD) was able to forecast the amount of black pod disease expected in the 2015/2016 cocoa production season and describe the magnitude of black pod disease occurrence during the active cocoa production periods within the Southwest of Nigeria. ETAPOD was able to describe the disease pressure accurately for Ondo State i.e. between June and October, which were the peak period of cocoa production in Nigeria and sadly the climax for black pod disease infection. The research information generated from ETAPOD was in line with the observations made in Ghana.It is known in Ghana that primary infections usually occur around June, but the peak of black pod infection generally occurs between August and October (Opoku *et al*., 2000; 2007). Such information on periods for attaining disease infection peaks is useful in forecasting the pattern of disease development and it is an important tool for disease management since conditions immediately preceding the infection peaks must be favourable for disease development.

ETAPOD gave predictions that were useful to farmers in Osun State but these predictions were not as accurate as those obtained for Ondo State. The predictions for

Ogun and Oyo States still need to be perfected. Although much work need to be done to perfect the warning system, the predicted results still remains valid and can be implemented to better ameliorate the effects of black pod disease menace in the Southwest of Nigeria. This report was in line with the work of Luo (2008) who designed a forecast model for the prediction of foliar diseases of winter wheat caused by *Septoriatritici* across England and Wales.

The development of a warning system for black pod disease requires information specific to the area(s) of focus and as such made effective by the level of accuracy of the data obtained. It is imperative therefore to note that the disease prediction process is a long and cumbersome sequence of heterogeneous chains of independent events, acting independently in varying degrees to determine the prevalence and spread of black pod disease. Every forecast model generated requires constant update to increase the level of accuracy. The procurement of a relevant model for black pod disease prediction has to undergo a series of update and restructuring so as to meet up with the current need of accurate disease prescription.

5.1 Conclusion

ETAPOD harnesses the potentials to improve the functionality of other existing management strategies for the control of black pod disease in Nigeria by providing information regarding black pod disease occurrence, detect areas under severe attack by the disease (AUSA), and discourage fungicide misuse among local cocoa farmers. ETAPOD is unique in the sense that its primary functions in terms of black pod disease prediction are not geographically bound by location and as such the developed programme can be manipulated to provide optimum results anywhere needed in Nigeria, Africa and all around the world. Its ability to provide qualitative and quantitative description of the black pod disease pressure makes it superior to other forms of black pod disease control strategies in use.

Therefore, ETAPOD is a pertinent tool that can effectively minimize the prevalence of black pod disease of cocoa within Nigeria with minimal chemical application, decreasing the risk of chemical poisoning and increasing the production of healthy cocoa products nationwide. This is the surest and fastest way to ensuring sustainability of cocoa production in Nigeria and the world at large as a means to tackle the problem of food scarcity and unavailability of raw materials for production.

5.2 Contribution to knowledge

The use of biological, physical, cultural, and chemical control methods to combat black pod disease is a good approach for disease management, but a better and more profitable approach will be the use of a system that can clearly predict when and where the disease will occur and the magnitude of the disease expected before these measures (biological, physical, cultural, and chemical control) are applied in order to improve control efficacy and accuracy. Therefore, this research work was centered on developing a forecast model for black pod disease outbreaks in other to warn local farmers whether or not control measures are required for the current season and the areas likely to be heavily affected by the disease. A possible means of averting this disease by using preventive measures was the goal of this research so as to promote a cleaner and healthier environment.

5.3 Recommendation

ETAPOD harnesses several potentials and possibilities that can be improved onto obtain excellent results. The accuracy of the warning system developed for the prediction of black pod disease (ETAPOD) can be perfected if:

1. Weather parameters are obtained from meteorological stations situated in the farm or those closely located to the region where active cocoa production take place.
2. The level of accuracy of predicted weather reports is above 95%
3. Consistency of cocoa production within that locality is constant
4. The type of cropping system employed could be determined
5. cocoa is the major crop cultivated on the piece of land
6. Advanced digital image analysis could be used to improve measurement precision of disease prevalence and severity.

The recommendation actions and management strategies to be carried out after disease predictions were stated in Table 23.

Table 5.0.Recommended management strategies for cocoa farmers

Level	Disease Occurrence (%)	Recommendations
1st	Above 70	GAP + Chemical + Biological + Resistant Variety (Maximum Recommended Routine Application)
2nd	50 – 69	GAP + Chemical/Biological + Resistant Variety (Optimum Recommended Routine Application)
3rd	11 – 49	GAP + Chemical/Biological + Resistant Variety (Moderate Recommended Routine Application)
4th	0 – 10	GAP + Resistant Variety Only

Note: "GAP" means Good Agricultural Practice

References

Acebo-Guerero, Y., Hernandez-Rodriguez, A., Heydrich-Perez, M., El Jaziri, M., and Hernandez-Lauzardo, A. N. 2012. Management of black pod rot in cacao (*Theobroma cacao* L.): a review. *Fruit Journals*. 67: 41-48.

Adegbola, M. O. K. 1972. Cocoa diseases of West Africa.*7th International Cocoa Research Conference*, Douala, Cameroon.pg179-184.

Adeniyi, O. R. and Ogunsola, G. O. 2014. Cocoa Production and Related Social-Economic and Climate Factors: A Case Study of Ayedire Local Government Area of Osun State, Nigeria. Published by Science and Education Centre of North America, Agricultural Science. 2(4): 12-18

Adisa, B. O. and Adeloye, K. A. 2012.Analysis of Farmer Field School as an Extension Approach to Cocoa Production in Osun State, Nigeria.*World Journal of Agricultural Sciences* 8 (4): 421-428.

Agbeniyi, S. O. and Adedeji, A. R. 2003. Current Status of Black pod Epidemics in Nigeria, **In** *Proceedings of 14th International Cocoa Research Conference*. pp. 1377 – 1380.

Agbeniyi, S. O. and Oni, M. O. 2014.Field evaluation of copper based fungicides to control *Phytophthora* pod rot of cocoa in Nigeria.*International Journal of Development and Sustainability.*3(2): 388-392.

Ajakaye, D. O. 1977. An overview of the non-oil sector of the Nigeria economy.Central Bank of Nigeria Economic and Financial Review. 35(4): 14 – 25.

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

Akrofi, A. Y., Amoako-Atta, I., Assuah, M. and Kumi-Asare, E. 2014. Pink Disease Caused by *Erythriciumsalmonicolor*(Berk. and Broome) Burdsall: An Epidemiological Assessment of its Potential Effect on Cocoa Production in Ghana. *Journal of Pathology and Microbiology*.5:1.

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): 1-67.

Alamu, S. A. 2013. Analysis of Seedling Subsidy Policy and Cocoa Production in South-West Nigeria.*Journal of Educational and Social Research.*3 (4):59.

Annon 2004.Diversity and management of *Phytophthora* in Southeast Asia.Drenth A., Guest D. I. (Eds.), Canberra, Australia. *ACIAR Monograph*.pp114-118.

Anonymous 1995.Pest and disease, **In** *Report on recent decline in cocoa production in Ghana and measures to revamp the industry.*Report commissioned by the Office of the President of Ghana. pp. 43-44.

Appiah, A. A., Opoku, I. Y. and 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(10): 983-990.

Are, L. A. and Gwynne-Jones 1974.Cocoa in West Africa.Oxford University Press, Ibadan, Oyo State, Nigeria. 146pp.

Asare, R., and David, S. 2011. Good agricultural practices for sustainable cocoa production: a guide for farmer training. Faculty of Life Sciences, University of Copenhagen, Denmark.Pp 144.

Bearchell, S. J., Fraaije, B. A., Shaw, M. W., Fitt, B. D. 2005. Wheat archive links long term fungal pathogen population dynamics to air pollution. *Proceedings of the National Academy of Sciences,* USA. 102:5438-5442.

Blaha G, 1983. Effect of light on Phytophthora palmivora and Phytophthora megakarya, agents causing brown rot on cocoa pods.*Café Cacao Thé (Paris)*. 27:91-112.

Bourguet, D., Guillemaud, T. 2016. The hidden and external costs of pesticide use.Sustainable Agriculture Reviews.*Springer*.pp 35-120.

Brasier, C. M., and Griffin, M. J. 1979.Taxonomy of *Phytophthora palmivora* on cocoa.*Transaction of the British Mycological Society*. 72(1): 111-143

Bush, E. A., Stromberg, E. L., Hong, C., Richardson, P. A., and Kong, P. 2006. Illustration of key morphological characteristics of *Phytophthora* species

identified in Virginia nursery irrigation water, *Online Plant Health Progress.*4(5): 17-25

Central Bank of Nigeria (CBN) 2003.Annual Report and Statement of Accounts. Abuja, Nigeria: CBN Publication. *Central Bank of Nigeria Statistical bulletin,* Lagos, CBN Press. 13: 1-3.

Chakraborty, S, Murray, G. M., Magarey, P. A., Yonow, T., O'Brien, R., Croft, B. J., *et al*. 1998.Potential impact of climate change on plant diseases of economic significance to Australia.*Australasian Plant Pathology*. 27:15-35.

Chakraborty, S., Tiedemann, A. V., and Teng, P. S. 1999. Climate Change: Potential impact on plant diseases. *Elsevier Journals of Environmental Pollution* 108(2000): 317-326

Chakraborty, S., Luck, J., Hollaway, G., Freeman, A., Norton, R., Garrett, K. A., Percy, K., Hopkins, A., Davis, C., and Karnosky, D. F. 2008.Impacts of global change on disease of agricultural crops and forest trees.Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources.pp 16

Chattopadhyay, P., Banerjee, G., Mukherjee, S. 2017. Recent trends of modern bacterial insecticides for pest control practice in integrated crop management system. *Journal of Biotechnology*.pp 7.

Clement, D., Risterucci, A. M., Motamayor, J. C., N'Goran, J., and Lanaud C. 2003.Mapping QTL for yield components, vigor, and resistance to *Phytophthora palmivora* in *Theobroma cacao* L. *Genome.*46: 204–212.

Clement, C. R., de Cristo-Araújo, M., d'Eeckenbrugge, G. C., Alves-Pereira, A., Picanço-Rodrigues, D. 2010.Origin and Domestication of Native Amazonian Crops.*Diversity* 2(1): 72–106.

Cocoa Research Institute of Nigeria [CRIN] 2003.Bulletin of Cocoa Research Institution of Nigeria CRIN, Ibadan. (12): 11-14

Cocoa Research Institute of Nigeria (CRIN) 2008. Report of the Cocoa Production Scientific Survey of Nigeria submitted to the National Cocoa Development Committee (NCDC), pp 100.

Dahab, A. A., Jallow, M. F. A., and Albaho, M. S. 2017. Environmental and human health impacts of pesticides use in agriculture. Environmental and Life Sciences Research Centre, Kuwait Institute for Scientific Research, Kuwait.Pp 1-31.

Dakwa, J. T. 1987. A serious outbreak of black pod disease in a marginal area of Ghana.*Proceedings of the 10th International Cocoa Research Conference,* Santo Domingo, Dominican Republic.pg13-17.

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 10th International Cocoa Research Conference*, Santo Domingo, Dominican Republic, London, UK.Cocoa Producers' Alliance.pp 407-412.

Despreaux, D., and Eskes, A., 1997. An international project on the genetic bases of resistance of cacao to *Phytophthora*.*INGENIC Newsletter*.3:9.

Drenth, A. and Sendall, B. 2001.Practical guide to detection and identification of *Phytophthora*, *CRC for Tropical Plant Protection*, Brisbane Australia, pg1-42.

Enríquez, G. A. 1993. Characteristics of cacao ―nacional‖ of Ecuador. In: *Proceedings of the International Workshop on the Conservation, Characterisation and Utilisation of Cocoa Genetic Resources in the 21st Century*, *Port-of-Spain, Trinidad*. Cocoa Research Unit, Port of Spain, Trinidad, pp. 269-278.

Eroarome, M. A. 2009. Country pasture/forage resources profile, Animal science Department, School of Agriculture, the University of the South Pacific, Apia SAMOA. pp134-140

Erwin D. C., and Ribeiro O. K. 1996. Phytophthora Diseases Worldwide. St Paul, Minnesota, US. *American Phytopathological Society.*4(2): 8-12

Evans, H. C. 1973. Invertebrate vectors of *Phytophthora palmivora*, causing black pod disease of cocoa in Ghana.*Annals of Applied Biology.*75:331-345.

Evans, H. C. 2007. Cacao diseases- The trilogy revisited. *Journal of Phytopathology* 97:1640-1643.

Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) 2018. Database available from: http://www.fao.org/faostat/en/#data/RFN

Fasina, A. B. 1999. Sustainable tree crop development to support the manufacturing sector to boost Nigeria's foreign exchange earnings. Paper presented at Ebun Industries Ltd., International Seminar on Support for Manufacturing to boost Non-oil Export Earnings Using Agricultural Raw Materials, held at Abuja Sheraton Hotels and Towers, Abuja. pp13.

Fasina, A. B., Badaru, K. and Aikpokpodion, P. O. 2001. Development of the Nigerian cocoa industry: current issues and challenges for research and production. *Proceedings 13th International Cocoa Research Conference*.pp1367 – 1373.

Federal Government of Nigeria (FGN) 2006. Nigeria: National Report, *International Conference on Agrarian Reform and Rural Development*, Porto Alegre pg7-10 accessed 13th March 2006 at 13:34 GMT.

Fernandes, J. M., Pavan, W. and Sanhueza, R. M. 2011.SISALERT- A generic web-based plant disease forecasting system.**In**: Salampasis M., Matopoulos A. (eds.): *Proceedings of the International Conference on Information and Communication Technologies for Sustainable Agri-production and Environment.* pp. 225-233.

Folayan, J. A., Daramola, G. A. and Oguntade, A. E. 2006. Structure and performance evaluation of cocoa marketing institutions in South-Western Nigeria: An economic analysis. *Journal of Food, Agriculture and Environmen.t* 4 (2): 123-128.

Gregory, P. H., and Maddison, A. C. 1981.Epidemiology of *Phytophthora* on cocoa in Nigeria.Final Report of the International Cocoa Black Pod Research Project.*Phytopathological*.25:188.

Gregory, P. H., Griffin, M. J., Maddison, A. C., and Ward, M. R. 1984. Cocoa black pod: a reinterpretation. Cocoa Growers' Bulletin. 35:5-22.

Hannukkala, A. O., Kaukoranta, T., Lehtinen, A., and Rahkonen, A. 2007. Late blight epidemics on potato in Finland, 1933 2002; increased and earlier occurrence of

epidemics associated with climate change and lack of rotation. *Journal of Plant Pathology*.56:167- 176.

Intergovernmental Panel on Climate Change (IPCC) 2007.Summary for Policymakers.**In**: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, *et al*., editors. Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, NY, USA. pp5.

International Cocoa Organization [ICCO] 2005.World Cocoa production 2005. http://www.icco.org accessed on the 16th January, 2017 at 14:43GMT.

Iremiren, G. O. 2011. *Soil fertility and ageing cocoa farms in Nigeria*. WCF Partnership Meeting and Round Table Session, Accra, 26-27 accessed 16th October 2011 at 13:45 GMT

Jallow, M. F., Awadh, D. G., Albaho, M. S., Devi, V. Y., Thomas, B. M. 2017. Pesticide risk behaviors and factors influencing pesticide use among farmers in Kuwait.*Journal of Environmental Science*. 574: 490-498.

Jeffer, S. N. 2006. Identifying species of Phytophthora. Department of Entomology, Soils, and Plant Sciences, Clemson University, Clemson, SC. pp 9

Jeger, M. J., and Pautasso, M. 2008. Plant disease and global change the importance of long term data sets.*New Phytologist*. 177:8-11.

Lawal, J. O. and Emaku, L. A. 2007. Evaluation of the effect of climatic changes on cocoa production in Nigeria: Cocoa Research Institute of Nigeria (CRIN) as a case study. *African Crop Science Conference Proceedings* (8): 423–426

Lee, S. B., and Taylor J. W. 1992. Phylogeny of five fungus-like protoctistan Phytophthora species, inferred from the internal transcribed spacers of ribosomal DNA. Molecular Biology and Evolution. 9(4):636-653

Luo, W. 2008.Spatial/Temporal modeling of crop disease data using high-dimensional regression. Ph.D. Thesis submitted to the Department of Statistics, University of Leads. 223pg

Luterbacher, M. C., and Akrofi, A. Y. 1993.The current status and distribution of Phytophthora megakarya in Ghana.Proceedings of the 11th International Cocoa Research Conference, Yamoussoukro, Cote d'Ivoire.pp 29-35.

Luxby, 2013. Different types of cacao bean, http://luxby.sg/favicon.ico, accessed on May 19th 2016 at 14:30GMT.

Luz, E. D. M. N. and Mitchell, D. J. 1994. Effects of inoculum forms and densities on cocoa root infection by Phytophthora spp. Agrotropica. 6(2):41-51.

Mabbett, T. 1997. Copper bottomed pest control. African Farming and Food Processing, March/April:18-20. megakarya in soil and cocoa roots. Ph.D Thesis, University of London, London, UK. 234pg

Motamayor, J. C., and Lanaud, C. 2002.Molecular analysis of the origin and domestication of *Theobroma cacao* L.**In**: Managing Plant Genetic Diversity (J. Engels, V. RamanathaRao, A.H.D. Brown, M. Jackson, Eds) CABI Publishing. 12pg

Motamayor, J. C., Risterucci A. M., Lopez, P. A., Ortiz, C. F., Moreno, A., and Lanaud, C. 2002. Cacao domestication I: the origin of the cacao cultivated by the Mayas. *Heredity.*89: 380–386.

Motamayor, J. C., Risterucci, A. M., Heath, M., and Lanaud, C. 2003. Cacao domestication II: Progenitor germplasm of the Trinitario cacao cultivar. *Journal of Heredity*. 91:322-330.

Motamayor, J. C., Lachenaud, P., da Silva, E., Mota, J. W., Loor, R., Kuhn, D. N., Brown, J. S., and Schnell, R. J. 2008. Geographic and genetic population differentiation of the Amazonian chocolate tree (*Theobroma cacao* L.).*PLoS ONE Journals*.3 (33):11.

Oduwole, O. O. 2001. Sustainable cocoa production in Nigeria: Farmers perception of technology characteristics and socio-economic factors in adoption decision making. Proceedings from the 13th International Cocoa Research Conference, Cocoa Research Institute of Nigeria. pp. 1147 – 1152.

Oduwole, O. O. 2004. *Adoption of improved agronomic practices by cocoa farmers in Nigeria: A multivariate Tobit analysis*. Ph.D Thesis (Unpublished), Federal University of Technology Akure, Nigeria. pg1-295

Oluyole, K. A. and Lawal, J. O. 2008. Determinants of the occurrence of black pod disease of cocoa in Edo state, Nigeria: a multivariate probit analysis approach, Economics and Statistics Division, Cocoa Research Institute of Nigeria, Ibadan Nigeria, *Journal of innovative development strategy.* 2(2): 1-4

Opoku, I. Y., 1994. Survival of *Phytophthora palmivora* and *Phytophthora megakarya* in soil and cocoa roots. Ph.D. thesis, University of London, Uk. Pp 215

Opoku I. Y., Akrofi, A. Y. and Appiah, A. A. I996. The occurrence and distribution of *Phytophthora* canker on cocoa in Ghana. *12th International Cocoa Research Conference,* Salvador. Bahia.. Brazil. pp. 113-119

Opoku, I. Y., Appiah, A. A., and Akrofi, A. Y. 2000.*Phytophthora megakarya*: A potential threat to the cocoa industry in Ghana. *Ghana Journal Agricultural Sc*ience 33:135-142.

Opoku, I. Y., Akrofi, A. Y. and Appiah, A. A. 2002. Shade trees are alternative hosts of the cocoa pathogen *Phytophthora megakarya*. *Crop Protection* 21:629-634.

Opoku I. 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: 601-604.

Orisajo, S. B., Dongo, L. N., Agbeniyi, S. O., Adedeji, A. R., Otuonye, A. H., Okeniyi, M. O., Adeniyi, D. O., Oduwaye, O. F., Fademi, O. A., and Kolawole, O. O. 2012. Assessment of Ultimax Plus 72 W.P. for the Control of Black Pod Disease of Cocoa in Nigeria, *Journal of Basic and Applied Science Resources.* 1(8): 880-884.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., and Anthony, S. 2009. Agroforestree Database: a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

Oyedele, J. O. 2007. Enhancing the Sustainability of Cocoa Growing in Nigeria. A Paper Presented at the Cocoa Roundtable on a Sustainable World Cocoa Economy, Cocoa Research Institute of Ghana, Accra, Ghana. 4(2): 14-17.

Pitt, J. I. and Hocking, A. D. 1997.Fungi and food spoilage.Blackie Academic and Professional, Cambridge, UK. Pg13.

Recena, M. C. P., Caldas, E. D., Pires, D. X., and Pontes, E. R. 2006.Pesticides exposure in Culturama, Brazil—knowledge, attitudes, and practices.*Journal of Environmental Research*. 102: 230-236.

Scherm, H., and Yang, X. B. 1995. Inter-annual variations in wheat rust development in China and the United States in relation to the El Nino/Southern Oscillation. *Journal of Phytopathology*. 85:970-976.

Shaw, M. W., Bearchell, S. J., Fitt, B. D. L., and Fraaije, B. A. 2008.Long term relationships between environment and abundance in wheat of Phaeosphaerianodorum and Mycosphaerellagraminicola.*New Phytologist.*177:229-238.

Smulders, M. J. M., Esselink, D., Amores, F., Ramos, G., Sukha, D. A., Butler, D. R., Vosman B., and Van Loo, E. N. 2012. Identification of Cocoa (*Theobroma cacao* L.) varieties with different quality attributes and parentage analysis of their beans.*Plant Research International,* Wageningen, Netherlands. pp14.

Soares, W. L., de Souza, and Porto, M. F. 2009.Estimating the social cost of pesticide use: An assessment from acute poisoning in Brazil.Ecological Economics. 68: 2721-2728.

Stamps, D. J., Waterhouse, G. M., Newhook, F. J., and Hall, G. S. 1990.Revised tabular key to the species of *Phytophthora*.*Mycological Papers*. Wallingford, UK: *CAB International* 2(3): 14-17

Surujdeo-Maharaj, S., Umaharan, P., and Iwaro, A. D. 2001. A study of genotype-isolate interaction in cacao (*Theobroma cacao* L.): resistance of cacao genotype to isolates of Phytophthora Palmivora. Kluwer Academic Publishers, Netherland.*Euphytica*. 118: 295-303.

Sutherst, R. W., Baker, R. H. A., Coakley, S. M., Harrington, R., Kriticos, D. J., Scherm, H. 2006. Pests under global change Meeting your future landlords?**In** Canadell, J. J., Pataki, D. E., Pitelka, L. F., editors. Terrestrial Ecosystems in a Changing World.Springer, Berlin.pp 211 26.

Taylor, M. N. 2000. Review of Cocoa Production, Consumption, Stocks and Prices- 2, Cocoa Growers Bulletin. (52): 1-58

Thorold, C. A. 1975. Diseases of Cocoa. Clarendon Press, Oxford. 12-15.

Tijani, A. A. 2005. Profitability of fungicide use decisions among cocoa farmers in south western Nigeria. *Journal of Social Science.*2(2): 165-171

Villalobos, V. M. 1989. Advances in Tissue Culture Methods Applied to Coffee and Cocoa. Plant Biotechnologist for Developing countries: CTA\FAO\ Chayce Publication services, United Kingdom. Pp. 247

Waller, J. M., and Holderness, M. 1997. Beverage crops and palms.**In**: Hillocks R. J., Waller, J. M., eds. Soilborne Diseases of Tropical Crops. Wallingford, UK. CAB International. 225-253.

Woods, A., Coates, D. K., and Hamann, A. 2005. Is an unprecedented *Dothistroma*needle blight epidemic related to climate change? *Bioscience*. 55:761-769.

Ziervogel, G., Nyong, A., Osman, B., Conde, C., Cortes, S., and Dowing, T. 2006. Climate variability and change: Implications for household food security. *Assessments of Impacts and Adaptations to Climate Change (AIACC), Working Paper No. 20*. 14pg.

Appendix

UNIVERSITY OF IBADAN, IBADAN, NIGERIA

Department of Botany, Faculty of Science.

BLACK POD DISEASE PROFILING AND THE DEVELOPMENT OF FORECAST SYSTEM FOR PREDICTION OF FUTURE OCCURRENCE ON COCOA (*Theobroma cacao* LINN.) IN SOUTHWEST, NIGERIA

Dear Respondent,

The current study is a Doctoral research work aimed at "Modelling a template for prediction of black pod disease of cocoa "*Theobromacacao* Linn." in the Southwest, regions of Nigeria". The questionnaire is to solicit your assistance on provision of relevant information regarding the aforementioned study. All information provided will be treated discretely and with absolute confidentiality.

Kind regards.

ETAWARE Peter Mudiaga

Tick the appropriate option where necessary **[√]**

SECTION A (Measure of Agronomic Parameters and Geographic Locations)

1. Name of the Cocoa variety: Amazon I [ ] Amazon II [ ] Amelonado [ ] Trinitario [ ]

2. Average Age of the Cocoa Trees: 0-5yrs [ ] 6-10yrs [ ] 11-15yrs [ ] 16-20yrs [ ] Above 20yrs [ ]

3. Size of Cocoa Farm……

4. Location of Farm Site……

5. Total Number of Cocoa Trees on the Farm……

6. Co-ordinates……(*)

SECTION B (Measure of Farm Maintenance Practice)

1. Weed Removal: Daily [ ] Weekly [ ] Monthly [ ] Yearly [ ]

2. Husk Disposal: Burry in soil [ ] Heap on farm surface [ ] Burn [ ] others [ ] Specify…….

3. General Farm Sanitation: Daily [ ] Weekly [ ] Monthly [ ] Yearly [ ]

4. When last was a routine check up for diseases carried out on the cocoa trees? .....

5. Has there been any test carried out on the soil? Yes [ ] No [ ]

6. If No, why? ……

7. If Yes, what kind of test was carried out? ……

8. How often do you carry out soil test: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……

SECTION C (Measures of Disease Occurrence)

1. Has there been any form of disease outbreak in your farm: Yes [ ] No [ ]

2. What are the common diseases encountered on the field? Black pod [ ] Cherelle wilt [ ]

Leaf Blight [ ] Damage of pods by Insects [ ] Peeling off of stem bark (Canker) [ ]

3. During which season is the diseases mostly observed: Rainy Season [ ] Dry Season [ ]

4. Frequency of Disease Occurrence:

Black pod: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……

Cherelle wilt: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……

Leaf Blight: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……

Mechanical Damage of pods by Insects: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify….....

Peeling off of stem bark (Canker): Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify…….....

5. what part of the cocoa tree is affected by the disease: Pod [ ] Leaves [ ] Stem [ ] Root [ ] Flower [ ]

SECTION D (Measures of Fungicide Application)

6. Has there been any form of disease control carried out in the past: Yes [ ] No [ ]

7. What method of control was adopted? Cultural [ ] Biological [ ] Chemical [] Mechanical [ ]

8. Chemical Application: Yes [ ] No [ ]

9. Name of Chemical/Fungicide Used ……

10. Dosage (per Litreof Water) ……

11. Frequency of Application: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……..

12. Method of Application: Wetting manually [ ] Knapsack Sprayer [ ] Motorized Sprayer [ ]

SECTION E (Measures of Fertilizer Application)

1. Fertilizer Application: Yes [ ] No [ ]

2. Name of Fertilizer Applied ……

3. Dosage (per Tree) ……..

4. Frequency of Application: Weekly [ ] Monthly [ ] Yearly [ ] Others [ ] Specify……

5. Method of Application: Manually [ ] Mechanically [ ]

Any other observation(s) not listed above ……..

....

Signature and Date (Farmer) Signature and Date (Researcher)

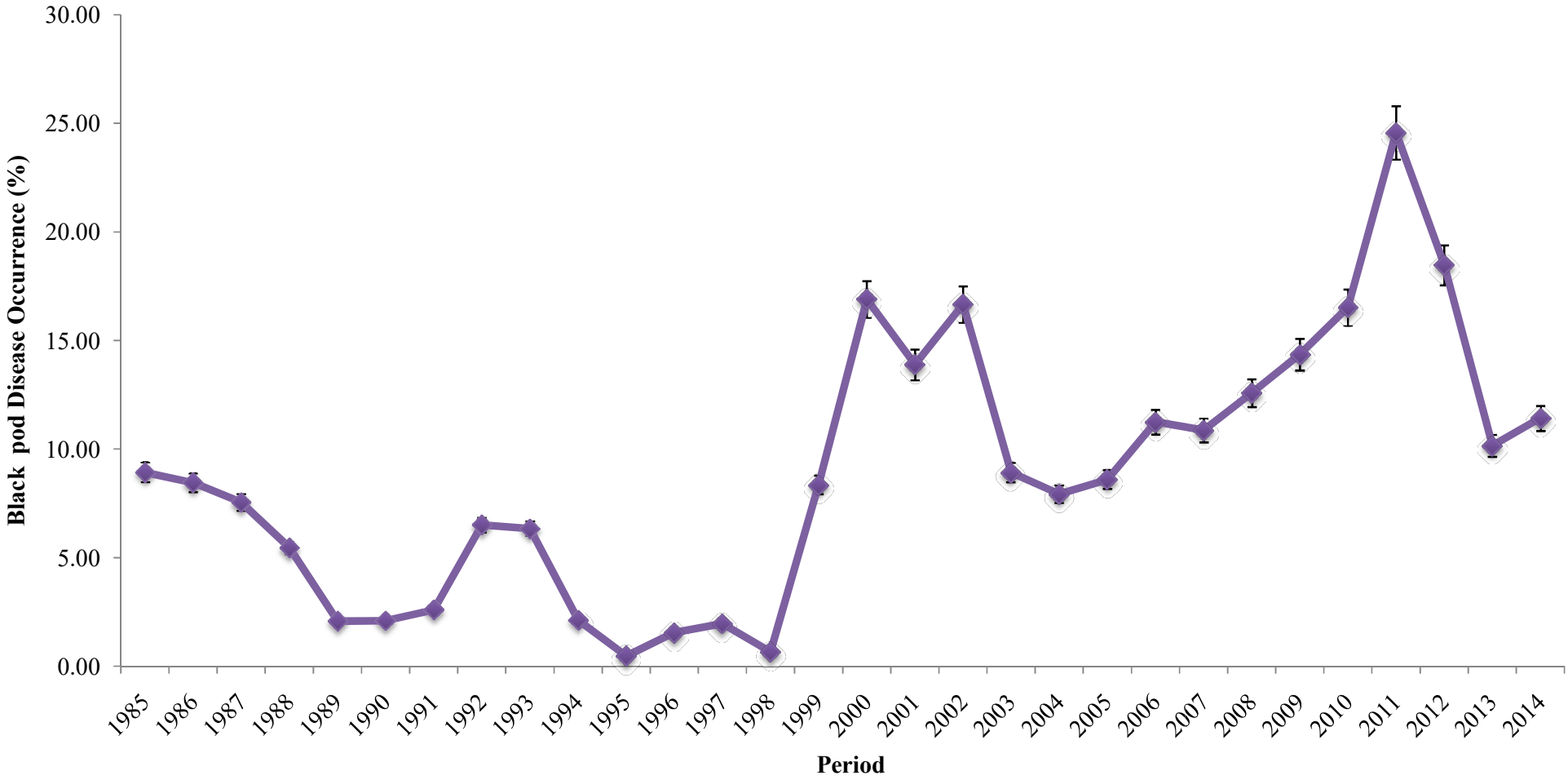


Fig A1.Black pod disease pestilence in Southwest, Nigeria

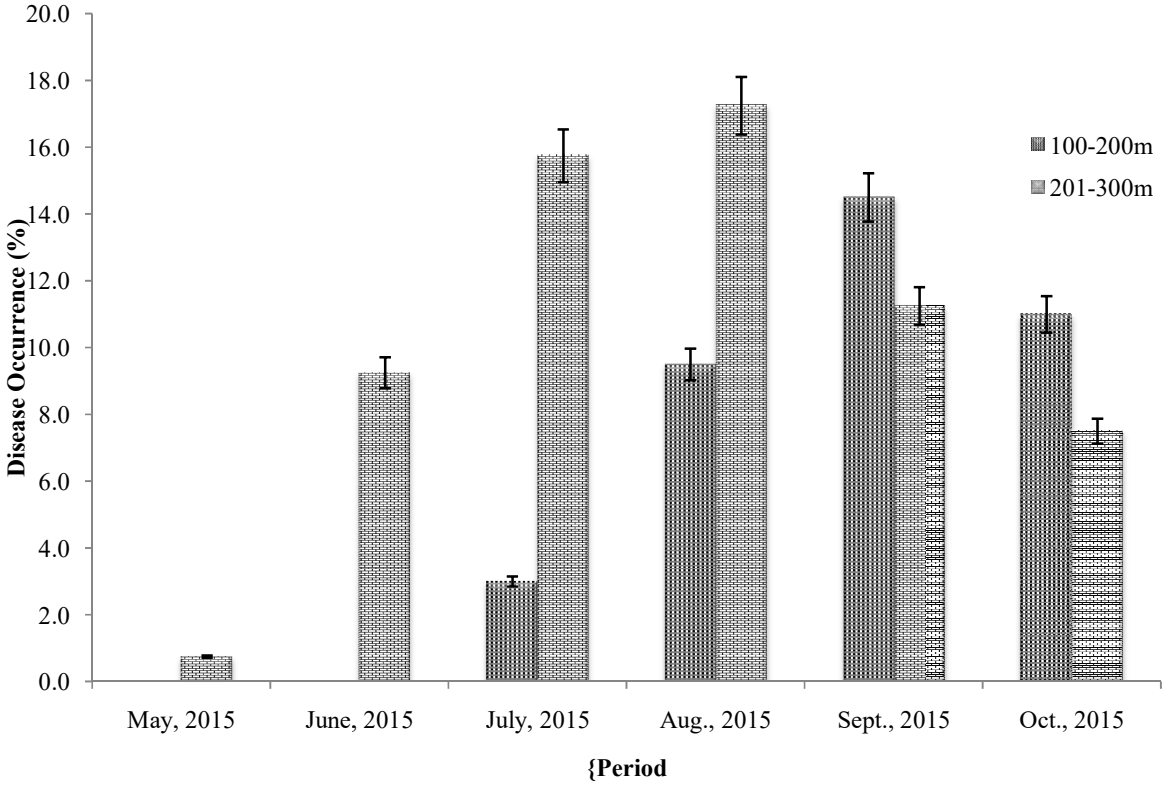


Fig A2.Altitudinal effects of black pod disease occurrence within the Southwest of Nigeria