



Some Identifiable Factors Responsible for the Variation in Cocoa Production in Nigeria and Other Cocoa Producing Nations, Adjudicated by Their Contributions to the Global Market

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The increasing human population is indeed responsible for the upsurge in the demand for cocoa products and the saddling pressure on the global cocoa market. Sadly, the contributions of some major producers like Nigeria, Brazil, Ghana, to the global cocoa market is dwindling (while others are appreciating). Climate change, diseases and poor farm management have been identified as major factors affecting global cocoa production. Nigeria, was the major focus of this research. Cocoa farms were investigated (Nigeria only), black pod disease (BPD) pressure was described by ETAPOD (a model for black pod disease prediction), while climate and cocoa production data were obtained from the relevant databases. On the global scene, Ghana, Nigeria, Cameroon, Brazil, Ecuador and Colombia experienced shortfall in their contribution to global cocoa production from 26.15, 20.55, 7.45, 12.14, 4.07, and 1.40%, respectively (1970s), to 16.99, 6.31, 5.67, 4.54, 3.96, and 1.09%, respectively (2000s). Cross River State, Nigeria's leading producer of cocoa (1970–1990s) is currently ranked 3rd in the nation. Unfortunately, cocoa farmers in Nigeria are completely dependent on pesticide application (100%) to save their crops. A prognosis of global BPD outbreak showed that Honduras (15.1%) and Lagos, Nigeria (14.4%) are foremost hotspots for BPD invasion. Hopefully, scientific advancement in cocoa production might be the key to these problems.

Keywords: climate change, poor farm management, integrated pest and disease management, Nigeria, scientific advancement, global cocoa market

INTRODUCTION

Cocoa (*Theobroma cacao*) is exclusively cultivated between latitude 20°N and 20°S of the equator (Voora et al., 2019; Obiakara et al., 2020), where the atmosphere is humid (>65%), rainfall is abundant (1,000 mm ≤ precipitation ≤ 3,000 mm), the altitude is low (<400 m above sea level) and there is plenty of sunshine, with ambient temperature of 18°C ≤ temperature ≤ 32°C, i.e., from the densely populated rainforest of Africa to the lowlands and mixed forest of Asia, and the

Atlantic forest of Latin (South) America (International Trade Centre UNCTAD CNUCED/WTO OMC, 2001). Sadly, this beneficial climate also favor the survival and proliferation of cocoa pests and pathogens (Etaware, 2019a), for example, witches' broom (WB) caused by *Moniliophthora* (syn. *Crinipellis*) *perniciosa*, black pod disease "BPD" (Supplementary Figure S1) caused by several species of *Phytophthora* (Etaware, 2019a,b, 2021; Etaware and Adedeji, 2019; Etaware et al., 2020; Obiakara et al., 2020), frosty pod rot (FPR) caused by *Moniliophthora roreri*, cocoa swollen shoot disease (CSSD) caused by CSSV (CSSV), and the vascular streak dieback (VSD) caused by *Oncobasidium* (syn. *Thanatephorus*) *theobromae*, while pests such as arboreal rodents and insects, insect larvae and epiphytic parasitic plants abound. The most influential disease of cocoa is BPD (Opoku et al., 2000; Akrofi, 2015; Etaware, 2019a; Etaware and Adedeji, 2019).

Most pests and diseases of cocoa can be managed, to some extent, by the application of chemicals. Pesticides (fungicides) have been used extensively to control BPD globally (International Trade Centre UNCTAD CNUCED/WTO OMC, 2001), for example, copper-based fungicides are still commonly used in West Africa, in countries like Nigeria and Togo (Agbeniyi and Oni, 2014), Zambia and Zaire (Mabbett, 1997), Ghana, Cote D'Ivoire, Cameroon. However, chemical application to control BPD outbreak is no longer ecologically acceptable because of its health implications (International Trade Centre UNCTAD CNUCED/WTO OMC, 2001). The underlying decision to totally or partially ban chemical control is not only because of its health implications, but also, its lethal nature, non-degradable potential(s) and tendency to slowly build-up (bio-accumulate) and stored in plant tissues and cells for years. Accumulation of toxic or heavy metals in cocoa might be harmful to the consumers of cocoa products. Therefore, under the phase-out plan mandated by the Montreal Protocol and adopted by the US Government in 2001, methyl bromide (CH₃Br) may no longer be manufactured in, imported into or exported from the US. Also, phosphine, a broad-base pesticide for insects, may no longer be in supply because it is highly inflammable and potentially destructive to delicate electronics. This is the major reason why its use is restricted or totally banned in some countries. Also, organophosphate have been demonstrated to be harmless to mammals, still the US environmental protection agency (EPA) is determined to ban the use of dichlorvos (DDVP) in locations where it may come in contact with children. DDVP is very expensive and currently, it is being used as a fogging agent in cocoa warehouses, it may eventually be prohibited by EPA in future (International Trade Centre UNCTAD CNUCED/WTO OMC, 2001). These are some of the limitations to the use of pesticides in the control of cocoa pests and pathogens. It is very obvious that more countries will join in the race to monitor or checkmate the use of chemicals in farmlands. This can help minimize the dependence of farmers on the use of chemical control only.

The African economy was altered by colonial masters in dear need of suppliers of agricultural raw materials. Long after their exit from Africa, their landmark is still well-established in the continent, in countries like Niger (the Office

du Niger set up for cotton export), Senegal and Nigeria (the famous groundnut pyramids), and other countries where cotton basins, cocoa plantations, rubber trees and oil palm plantations were established. Their landmarks were responsible for shaping the rural landscape, fostering the development of towns, redistribution of indigenous populations and ultimately, defining borders of future zones, nations or states of our dearly beloved continent (International Trade Centre UNCTAD CNUCED/WTO OMC, 2001). Africa, particularly West Africa is the largest producer of cocoa, accounting for ≤75% of global cocoa production (Shahbandeh, 2020; Etaware, 2021), Ironically, Europe and America jointly account for consumption of over 60% of the world's cocoa produce (Etaware, 2021). In the early 1970s the foremost cocoa producing countries were Ghana (400,000 tons), Nigeria (250,000 tons), Côte d'Ivoire (200,000 tons) and Brazil (200,000 tons), occupying 1st, 2nd, 3rd and 4th positions, respectively, based on their contributions to the global cocoa market. Presently, Nigeria with a production capacity of 328,263 tons (7%) is ranked 4th behind Côte d'Ivoire, ranked 1st in the world, with 2,034,000 tons (40%), Ghana, ranked 2nd, with 883,652 tons (18%) and Indonesia, ranked 3rd, with 659,776 tons (13%), followed closely by Cameroon, ranked 5th, with 295,028 tons (6%), Brazil, ranked 6th, with 235,809 tons (5%), Ecuador, ranked 7th, with 205,955 tons (4%), and Peru, ranked 8th, with 121,825 tons (3%), while the rest of the world account for ≥4% of global cocoa production (WorldAtlas, 2020). The variation in cocoa production in Nigeria was the rationale behind the selection of the country as a case study for this research.

METHODOLOGY

Case Study

Nigeria is located on Latitude 9.0820°N and Longitude 8.6753°E of the equator. The "giant of Africa" (Nigeria) is a member of the ECOWAS countries of Africa. The country is bounded in the east by Cameroon, in the west by the Republic of Benin, in the north by Niger and Chad, and in the South by the Gulf of Guinea and Atlantic Ocean. The largest vegetation belt in Nigeria is the savannah vegetation, interspersed by tropical rainforest, mangrove swamp, montane and desert vegetation situated at the periphery. The elevation of the Nigerian plain is <2,000 m above sea level, with an annual precipitation of 1,100–4,870 mm, and an ambient temperature ranging from 18 to 36°C. Nigeria consists of 36 States and the Federal Capital Territory (Abuja) with a population of 211,400,708, a population density of 229 persons per Sq. Km. (as at 2021), and a landmass of 923,769 Sq. km. (Climates to Travel, 2021; Wikipedia, 2021).

Annual Yield Loss to Black Pod Disease Estimated by ETAPOD

The computer model "ETAPOD," developed by Etaware and his research team, was used to identify hotspots for black pod disease in Nigeria and other cocoa producing communities around the world. The forecast model was effective, in the past, in quantifying black pod disease pressure on cocoa farms in Nigeria (Etaware, 2019b; Etaware et al., 2020). Therefore, it was used in this research to estimate yield loss by cocoa farmers to BPD, both

in Nigeria and around the world. The model statistics for the computer model “ETAPOD” is briefly described below:

$$Y_{(BPD-Outbreak)} = -\alpha_{(BPD-Outbreak)} - \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \xi_{(BPD-Outbreak)}$$

$$Y_{(BPD-Outbreak)} = -\alpha_{(BPD-Outbreak)} - \beta_1 (\text{Rainfall}) + \beta_2 (\text{Relative Humidity}) + \beta_3 (\text{Temperature}) + \xi_{(BPD-Outbreak)}$$

Therefore,

$$Y_{(BPD-Outbreak)} = -20.4 - 0.004 (\text{Rainfall}) + 0.272 (\text{Relative Humidity}) + 0.511 (\text{Temperature}) + 0$$

Climate Data

Climate data for all the cocoa producing communities/States in Nigeria and around the world were obtained from Department of Meteorology (2016), Britannica (2021), Climate-Data (2021) database, Climates to Travel (2021), Current Results (2021), Nations Encyclopedia (2021), Travelonline (2021), USAID/USGS (2021), Weather Climate (2021), Weather Costa Rica (2021), Weather Spark (2021), Wikipedia (2021), Wonderful Indonesia (2021), WorldData (2021), and World Travel Guide (2021). The information used for this research were collected mostly from curated online sources. The list of data source provided here are all-inclusive and all-exhaustive.

Nigeria and Global Cocoa Production Statistics

The data for Nigeria and global cocoa production was obtained from Akiyama and Duncan (1984), the International Trade Centre UNCTAD CNUCED/WTO OMC (2001), MAFAP/SPAAA (2013), Igwenagu (2020), Mfonobong (2020), WorldAtlas (2020) database, Emerging Young Entrepreneur (2021), NationMaster (2021), and World Population Review (2021).

General Statistics on Farm Management

The primary data generated for pesticide application and usage among indigenous cocoa farmers in Nigeria was obtained from the doctoral research work of Peter M. Etaware (Ph.D. Thesis, 2019–Department of Botany, Faculty of Science, University of Ibadan, Ibadan, Oyo State, Nigeria), conducted within the South-western region of Nigeria during the 2015/2016 cocoa production season. The location and coordinates of the cocoa farms were obtained from Etaware (2019a,b), Etaware and Adedeji (2019), and Etaware et al. (2020).

Statistical Analysis

The use of data mining and cleansing techniques facilitated the detection of misrepresented values, outliers and ambiguous datasets. Minitab 16.0, Costat 6.451 and SPSS 20.0 software were used for data analysis. Graphs and figures were generated from Microsoft Office (2016), Minitab 16.0 and SPSS 20.0 software.

RESULTS

Global Statistics on Cocoa Production Between 1970 and 2020

Cote D’Ivoire (Ivory Coast) ranked 4th in its contribution to global cocoa production in the early ‘70s, with a production capacity of 180,000 tons then (accounting for just 12% of world cocoa production). Currently, Ivory Coast is at the top of the chart (1st position), contributing nearly 40% of cocoa beans and other raw materials from cocoa to the global market, with a net production capacity close to 2.1 million tons per annum (Table 1). Sadly, Ghana, Nigeria, and Brazil which were the famous “Trio,” once referenced in the past as the world powers of cocoa, with a joint total contribution of about 60% of cocoa beans, cocoa butter and cocoa oil available within the global market in the early ‘70s, i.e., Ghana (26%), Nigeria (21%), and Brazil (12%), respectively, with a combined output capacity of nearly one (1) million tons then (Ranked 1st, 2nd, and 3rd, respectively), are now relegated to 2nd, 4th, and 6th positions with a disappointing output capacity of about 28% contribution to global cocoa production in 2021 (Table 1). The researcher intends to determine and describe major factors responsible for the decline in the individual contributions of these countries to global cocoa production and how they can be effectively managed using Nigeria as a case study. Cameroon, Ecuador and Colombia experienced a decline in their contribution to global cocoa production too, i.e., from 7.5 to 5.7% (Cameroon), 4.1 to 3.96% (Ecuador), and 1.4 to 1.1% (Colombia). Indonesia had a positive increase from <1% to 12.69% (Currently ranked 3rd) and finally, the cocoa production capacity of the Dominican Republic was unaffected either by climate change, pests and diseases or other cocoa production limiting factors (Table 1).

The increase or decline in cocoa production in all the countries involved is not necessarily reflected in their current production capacities per annum, i.e., Cote D’Ivoire (2,034,000 tons), Ghana (883,000 tons), Indonesia (659,776 tons), Nigeria (328,263 tons), Cameroon (295,028 tons), Brazil (235,809 tons), Ecuador (205,955 tons), Dominican Republic (86,599 tons), Colombia (56,808 tons), compared to their previous production output capacities, i.e., between 21,000 and 392,000 tons from the least (Colombia) to the greatest (Ghana), rather, it is reflected in their contribution to world cocoa production. For example, the total contribution of Cote D’Ivoire and Indonesia increased from 12% and <1% (in the ‘70s) to almost 40% and 13% (in the early ‘20s), whereas, countries like Ghana, Nigeria, Cameroon, Brazil, Ecuador and Colombia offered less to the global market, with a drastic decline in their contribution to global cocoa production from 26.15, 20.55, 7.45, 12.14, 4.07 and 1.40%, respectively, in the ‘70s, to 16.99, 6.31, 5.67, 4.54, 3.96, and 1.09%, respectively, in the ‘20s (Table 1). What could possibly be the reason for such a drastic decline in cocoa production within these countries?

Cocoa Production in Nigeria

Currently, Ondo State is ranked 1st in Nigeria with a production capacity of about 79,000 tons per annum, contributing 24% to Nigeria’s net national cocoa production. Osun State, ranked 2nd, contributes about 73,000 tons (22%) to the Nigerian cocoa

TABLE 1 | Global ranking based on countries' contributions to global cocoa production (past and present).

Location and position		Cocoa production (tons)		Global input (%)	
Rank	Country	1970s	2020s	1970s	2020s
1st	Cote D' Ivoire	180,000	2,034,000	12.01	39.12
2nd	Ghana	392,000	883,652	26.15	16.99
3rd	Indonesia	Below 10,000	659,776	<1	12.69
4th	Nigeria	308,000	328,263	20.55	6.31
5th	Cameroon	112,000	295,028	7.47	5.67
6th	Brazil	182,000	235,809	12.14	4.54
7th	Ecuador	61,000	205,955	4.07	3.96
8th	Peru	Below 10,000	121,825	<1	2.34
9th	Dominican Republic	25,000	86,599	1.67	1.67
10th	Colombia	21,000	56,808	1.40	1.09
11th	Papua New Guinea	Below 10,000	44,504	<1	0.86
12th	Uganda	Below 10,000	31,312	<1	0.60
13th	Mexico	Below 10,000	27,287	<1	0.52
14th	Venezuela	Below 10,000	23,349	<1	0.45
15th	Togo	Below 10,000	22,522	<1	0.43
16th	India	Below 10,000	19,000	<1	0.37
17th	Sierra Leone	Below 10,000	14,670	<1	0.28
18th	Haiti	Below 10,000	14,173	<1	0.27
19th	Guatemala	Below 10,000	11,803	<1	0.23
20th	Madagascar	Below 10,000	11,010	<1	0.21
21st	Guinea	Below 10,000	10,638	<1	0.20
22nd	Liberia	Below 10,000	8,552	<1	0.16
23rd	Tanzania	Below 10,000	8,548	<1	0.16
24th	Philippines	Below 10,000	7,009	<1	0.13
25th	Nicaragua	Below 10,000	6,600	<1	0.13
26th	Bolivia	Below 10,000	5,518	<1	0.11
27th	Solomon Islands	Below 10,000	4,940	<1	0.10
28th	Republic of Congo	Below 10,000	4,000	<1	0.08
29th	DR Congo	Below 10,000	3,758	<1	0.07
30th	Sao Tome and Principe	Below 10,000	2,778	<1	0.05
31st	Vanuatu	Below 10,000	1,813	<1	0.03
32nd	Sri Lanka	Below 10,000	1,291	<1	0.02
33rd	Malaysia	Below 10,000	1,029	<1	0.02
34th	Grenada	Below 10,000	800	<1	0.02
35th	Honduras	Below 10,000	751	<1	0.01
36th	Panama	Below 10,000	662	<1	0.01
37th	Costa Rica	Below 10,000	545	<1	0.01
38th	Samoa	Below 10,000	479	<1	0.01
39th	Angola	Below 10,000	442	<1	0.01
40th	Guyana	Below 10,000	429	<1	0.01
41st	Equatorial Guinea	Below 10,000	413	<1	0.01
42nd	El Salvador	Below 10,000	357	<1	0.01
43rd	Trinidad and Tobago	Below 10,000	320	<1	0.01
44th	Dominica	Below 10,000	312	<1	0.01
45th	Jamaica	Below 10,000	305	<1	0.01
Global production		1,499,000	5,199,634	100	100

market, while Cross River State which was initially ranked 1st in the early '70s, 80s and 90s is now 3rd with a production capacity of 59,087 tons per annum, with a contribution of 18% to the cocoa market in Nigeria (**Table 2**). Oyo and Ogun States jointly contribute a little <20% to Nigeria's cocoa production, with production capacities of about 33,000 (Oyo State) and 30,000 (Ogun State), respectively. Other cocoa producing States in Nigeria jointly account for the remaining 17% (with the exception of Lagos and Rivers States) as Stated in **Table 2**. What is indeed responsible for the setback in cocoa production in Nigeria?

The Climate of Cocoa Producing Countries Around the World

Majority of the countries where cocoa is being produced (in massive proportions) have an average annual minimum temperature of 20–25°C, in places like Cote D'Ivoire (20.8°C), Ghana (24°C), Indonesia (23°C), Nigeria and Peru (21°C), Cameroon and Brazil (22°C), with the exception of Mexico (13°C), Sierra Leone (18°C), and Costa Rica (12°C) where the average annual minimum temperature is well below 20°C. Also, the average annual humidity of the surrounding environment within these countries was between 70 and 90% (**Supplementary Table S1**), the all-year-round average level of humidity was pertinent for optimal production of cocoa, as seen in all the countries mentioned above including Ecuador (80%), Dominican Republic (78%), Colombia (79%), Papua New Guinea (77%), with exception of countries like Mexico (59.3%), Togo (69%), Bolivia (59.8%), and Dominica (62.5%), where the annual average land humidity was well below 70% (**Supplementary Table S1**). Finally, the average annual rainfall (precipitation) values optimal for cocoa production was within the range of 1,000–5,000 mm from Cote D'Ivoire to Jamaica (**Supplementary Table S1**), with few exceptions like Mexico (800 mm) and Sri Lanka (400 mm), respectively. This could be a possible explanation to the irregular changes in cocoa production within some of these countries observed along the years.

The Nigerian Climate

The climate of Nigeria is synonymous to that of the global climate for cocoa producing regions and countries all around the world, with average monthly minimum temperature of between 22°C (Ekiti, Kwara, Ondo, and Osun States) and 25°C (Lagos State). The average monthly rainfall was a little above 50 mm (Taraba State) and well below 300 mm (Cross River State) as shown in **Supplementary Table S1**. The average humidity was between 70 and 90% with exception of places like Adamawa (46%), Kogi (65%), Kwara (64%), and Taraba (53%) with all-time values well below 70% (**Supplementary Table S2**). The optimal sunshine duration was between 5 and 7 h (on the average) with exception of places like Adamawa (10 h) and Taraba (9 h) where there is excessive elongation of sunshine duration. The optimal recurrence of rain was well between 12- and 20-days average duration, except for places like Adamawa and Taraba with only 6 days of rainfall on the average, alongside Kogi and Kwara with just 8 days of rainfall on the average (**Supplementary Table S2**).

Global Estimation of Black Pod Disease and the Causal Agents

The pathogens responsible for inciting BPD on cocoa are *Phytophthora megakarya* Brasier & M.J. Griffin, *P. palmivora* (E.J. Butler) E.J. Butler, *P. capsici* Leonian, *P. theobromicola* (R.E. Sm. & E.H. Sm.) Leonian, *P. megasperma* Drechsler, *P. castaneae* Katsura & K. Uchida, *P. tropicalis* Aragaki & J.Y. Uchida (Declouement et al., 2021; Index Fungorum, 2021). The annual black pod disease outbreak was estimated to be highest in Honduras (15.1%) and lowest in Mexico (2.1%) as shown in **Table 3**. The annual BPD outbreak was estimated to be a fraction above 14% in places like Ghana and Sri Lanka, 13% in countries like Cote D'Ivoire, Indonesia, Cameroon, Dominican Republic, and Uganda, respectively (**Supplementary Figure S2** and **Table 3**), 12% in areas like Nigeria, Colombia, Haiti, Guatemala, Sao Tome and Principe, Equatorial Guinea, Trinidad and Tobago, respectively (**Table 3**), 11% in places like Brazil, Ecuador, Papua New Guinea, Venezuela, India, Madagascar, Liberia, Democratic Republic of Congo, Malaysia, Grenada, Samoa, and Angola, respectively (**Table 3**). Finally, countries with annual BPD outbreak estimated to be $\leq 10\%$ include Peru, Togo, Sierra Leone, Guinea, Tanzania, Philippines, Nicaragua, Bolivia, Solomon Islands, Vanuatu, Panama, Costa Rica, Guyana, El Salvador, Dominica and Jamaica, respectively (**Table 3**).

BPD Outbreak in Nigeria

The highest level of annual BPD outbreak in Nigeria was estimated in places like Lagos (14.4%), Ogun (14.1%), and Rivers (14.3%) States, while the lowest BPD outbreak in Nigeria was estimated to be in Adamawa State (4.2%) as shown in **Table 4**. Areas with BPD outbreak just above 13% were Abia, Akwa Ibom, Cross River, and Edo States (**Table 4**). Delta, Imo, and Oyo States had their BPD outbreak values estimated as $\geq 12\%$, while BPD outbreak in Ebonyi, Ekiti, Ondo, and Osun States were estimated to be a fraction above 11% (**Table 4**). Finally, the BPD outbreak level in Kogi, Kwara, and Taraba States were estimated to be below 10% (**Table 4**).

Current BPD Management Strategies in Some Parts of Nigeria

Cocoa farmers in some parts of Nigeria totally depend on the use of fungicides or pesticides (100%), which is basically a chemical form of treatment for the management of black pod disease in the field, rather than exploiting other possibilities such as biological treatment (0.0%) involving the use of antagonists (bacteria or fungi), treatment with herbal mixtures, decoctions, or extracts, and physical treatment (0.0%) of infected pods, for example, heat treatment, UV-, Infrared- or gamma radiation, stratification, scarification, if and where possible. These indigenous cocoa farmers (63.6%) apply fungicide (pesticides) monthly as their normal routine, with or without the emergence of the disease, as shown in **Table 5**, while the 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 (**Table 5**). It

TABLE 2 | The Independent cocoa producing States of Nigeria, GPS location and total output.

S/N	Cocoa farm location			GPS coordinates		Cocoa production	
	State	Local Govt. area	Community	Latitude	Longitude	Tons	Output (%)
1	Abia	Ikwuano	Ikwuano	5.4093°N	7.5897°E	Below 10,000	<5
2	Adamawa	Toungo	Toungo	8.1177°N	12.0441°E	Below 10,000	<5
3	Akwa Ibom	Ini	Odoro Ikpe	5.2826°N	7.7634°E	Below 10,000	<5
4	Cross River	Ikom	Ikom	5.9624°N	8.7082°E	59,087	18
5	Delta	Aniocha South	Nsukwa	6.0167°N	6.4500°E	Below 10,000	<5
6	Ebonyi	Afikpo South	Edda	5.7839°N	7.8368°E	Below 10,000	<5
7	Edo	Owan West	Sabongida-Ora	6.8988°N	5.9372°E	Below 10,000	<5
8	Ekiti	Ikere-Ekiti	Atoka	7.4991°N	5.2319°E	Below 10,000	<5
9	Imo	Owerri	New Owerri	5.4999°N	6.9853°E	Below 10,000	<5
10	Kogi	Lokoja	Lokoja	7.8023°N	6.7333°E	Below 10,000	<5
11	Kwara	Isin	Oke Onigbin	8.2218°N	4.9987°E	Below 10,000	<5
12	Lagos	Ikeja	Agege	6.6154°N	3.3238°E	0.0000	00
13	Ogun	Odeda	Odeda	7.2328°N	3.5281°E	29,544	09
14	Ondo	Ifedore	Owena	7.1961°N	5.0195°E	78,783	24
15	Osun	Ife East	Iyanfoworogi	7.3653°N	4.8164°E	72,217	22
16	Oyo	Ido (Ibadan)	daagi logba	7.3900°N	3.7537°E	32,826	10
17	Rivers	Bonny	Bonny	4.4333°N	7.1667°E	Infinitesimal	<1
18	Taraba	Gashaka	Gashaka	7.3667°N	11.4868°E	Below 10,000	<5
Total						328,263	100

is most likely that these farmers adopted other cocoa disease management methods that is best suited for their farms.

A total of 75% of cocoa farmers investigated 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 and 8.3% each of the population of local cocoa growers investigated applied any of these fungicides, i.e., Redfox, Rocket, Benzoepin, Altimax, Super 10, Killer, Tari, Mackecknie-gold, Kocide 2000, at random in the management of BPD outbreak on their farms (Table 5). Cultural practices like farm clearing and proper farm sanitation were done once or twice in a year (27.3%) specifically within periods close to the harvest season, or tri-annually (18.2%), or quarterly (9.1%), or monthly (18.2%). Few cocoa farmers inspect their farms daily (9.1%) while most of the farmers prefer to inspect their farms at least once a week (45.5%). Finally, cocoa husks disposal has been a major problem for local cocoa farmers in Nigeria. All the farmers interviewed heap the husks 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%), composting (0.0%), and other local methods (0.0%) were totally unutilized.

DISCUSSION

The variation in cocoa production around the world can be attributed to several factors, among which climate change and disease have major influence. The shortfall in contribution to global cocoa production by Ghana, Nigeria, Cameroon, Brazil, Ecuador, Colombia, just to mention but a few, is enough

reason to setup an international body, with membership thrown open to renowned scientists, meteorologists, plant disease forecasters, cocoa researchers, experienced extension workers and selected cocoa farmers across the globe, with good knowledge and experience in cocoa farming, for the sole purpose of establishing a global organization for independent disease and pest management of cocoa. The global organization would also be responsible for cocoa genetic resource management, and cocoa disease outbreak forecast, with a view to extend optimal cocoa production, around the world. The development of integrated pests or disease management strategies (IPM or IDM), will be practically useful in managing cocoa diseases around the world. This is in line with the objectives set by WHO as their millennium target to eradicate food scarcity in the world and also, the aforementioned recommendation is in agreement with the suggestions made by Etaware (2019a,b), Etaware and Adedeji (2019), and Etaware et al. (2020). For now, there is no much impact of BPD, witches’ broom disease and other notable cocoa diseases on global cocoa production due to the cushion effects of other countries that have increased cocoa productivity over the years. Still, it is pertinent to investigate some of these causes so as to balance the shift in global cocoa production. Increasing the functionality of the subunits of cocoa production around the world can help boost, sustain and improve the supply capacity of the global cocoa market.

In Nigeria, cocoa farming has gone into extinction in places like Lagos State and Bonny (Rivers State), while a rapid phase-off is currently experienced in Kwara and Kogi States. The remaining fourteen (14) active cocoa producing States are seriously affected by poor farm management, lack of improved materials for

TABLE 3 | Global estimation of BPD outbreak in countries renowned for cocoa production.

Rank	Country	Mean annual BPD outbreak (%)
1st	Cote D' Ivoire	13.2
2nd	Ghana	14.6
3rd	Indonesia	13.0
4th	Nigeria	12.9
5th	Cameroon	13.4
6th	Brazil	11.6
7th	Ecuador	11.2
8th	Peru	10.2
9th	Dominican Republic	13.1
10th	Colombia	12.2
11th	Papua New Guinea	11.4
12th	Uganda	13.3
13th	Mexico	02.1
14th	Venezuela	11.4
15th	Togo	08.0
16th	India	11.1
17th	Sierra Leone	09.9
18th	Haiti	12.0
19th	Guatemala	12.2
20th	Madagascar	11.1
21st	Guinea	10.9
22nd	Liberia	11.9
23rd	Tanzania	10.1
24th	Philippines	10.7
25th	Nicaragua	08.3
26th	Bolivia	07.1
27th	Solomon Islands	09.3
28th	Republic of Congo	12.1
29th	DR Congo	11.0
30th	Sao Tome and Principe	12.0
31st	Vanuatu	10.6
32nd	Sri Lanka	14.7
33rd	Malaysia	11.3
34th	Grenada	11.0
35th	Honduras	15.1
36th	Panama	10.2
37th	Costa Rica	07.2
38th	Samoa	11.6
39th	Angola	11.5
40th	Guyana	09.6
41st	Equatorial Guinea	12.1
42nd	El Salvador	10.0
43rd	Trinidad and Tobago	12.6
44th	Dominica	07.2
45th	Jamaica	10.5

See attached information on **Supplementary Figure S2** and **Supplementary Table S1** for climate data.

planting and replacement of old trees, poor financial aid to farmers, diseases, poor processing and storage facilities, bad roads. It is important to note at this point that cocoa farming

TABLE 4 | An estimate of BPD outbreak in Nigeria.

S/N	State	Mean annual BPD outbreak (%)
1	Abia	13.6
2	Adamawa	04.2
3	Akwa Ibom	13.5
4	Cross River	13.9
5	Delta	12.4
6	Ebonyi	11.7
7	Edo	13.7
8	Ekiti	11.0
9	Imo	12.9
10	Kogi	09.3
11	Kwara	08.0
12	Lagos	14.4
13	Ogun	14.1
14	Ondo	11.8
15	Osun	11.8
16	Oyo	12.4
17	Rivers	14.3
18	Taraba	05.6
Average BPD Outbreak		11.6

See attached information on **Supplementary Figure S2** and **Supplementary Table S2** for climate data.

might one day become a myth, folklore or folktale to the future generation of Nigerian farmers, if important steps are not taken to improve the situation. The findings were in agreement with the suggestions made by Opoku et al. (2000) and Akrofi (2015), who noted that diseases, poor farm management, aging of cocoa trees and other factors are indeed responsible for the total abandonment or lack of renovation of old cocoa farms, the unwillingness of new investors or stakeholders to invest in cocoa farming in areas with good prospects for cocoa production but with high risk of disease infection, the indisposition of financial operatives to grant loans to cocoa farmers, and the decadence in the cocoa sector in Ghana, Nigeria, and Africa at large.

Black pod disease outbreak was estimated to be higher in places where the cocoa tree is more adapted for optimum production. The development of a unified system for BPD control around the world will encourage farmers across the world to show more interest in cocoa farming, and possibly instigate the renovation of cocoa farms in areas where such farms have been abandoned or totally overhauled for the production of other profitable crops. Cocoa farmers around the world should be advised and encouraged to apply other forms of plant disease control other than the indiscriminate use pesticides alone, as the effects might be long lasting and hazardous. This was in line with the research conducted by Opoku et al. (2007) and the warning of WHO and some government agencies like the National Agency for Food and Drugs Administration and Control (NAFDAC) in Nigeria, to farmers and producers of crops to minimize the exposure of their products to chemicals, as this might be lethal to human health.

TABLE 5 | Management practices adopted by some cocoa farmers in Nigeria.

Subscription	Cultural practices		Chemical treatment		
	Tree inspection (%)	Farm sanitation (%)	Freq. of chemical application (%)	Type	Usage (%)
Daily	9.1	0	0	Ridomil	75
Weekly	45.5	0	0	Redfox	8.3
Monthly	18.2	18.2	63.6	Rocket	8.3
Quarterly	0	9.1	0	Benzoepin	8.3
Tri-Annually	0	18.2	0	Altimax	8.3
Bi-Annually	0	27.3	9.1	Super 10	8.3
Annually	27.3	27.3	18.2	Killer	8.3
None	0	0	9.1	Tari	8.3
				Mackeeknie-gold	8.3
				Kocide 2000	8.3
				None	16.7
Survey statistics					
Commercial farms	11	11	11	12	12

Note: The names of the chemicals (fungicides) listed in **Table 5** are indeed representations used by indigenous cocoa farmers of Southwestern Nigeria to identify or describe the type(s) of fungicide(s) used during fumigation. As such, the names were adapted for use in this article to avoid loss of useful research information, sustain the precision of the observations noted in the field and also promote research credibility through factual and logical conclusions drawn from the analyzed data set. Therefore, these names are solely used in this article for "identification purposes only," regardless of the fact that they may or may not be linked to any commercial brand. The percentage usage of each fungicide presented in **Table 5** was actually influenced by several factors (disclosed in confidentiality to the author) and as such, it is noteworthy to state that the values recorded are not a "true" reflection of the level of acceptability, neither are they a benchmark for accessing the quality or efficacy of each fungicide. The percentage usage described here was a matter of choice among the indigenous sect of cocoa farmers in Nigeria.

Communication/Language barrier was identified as one of the most important factors that play a key role in cocoa farm survey within rural areas of Nigeria, as it is sometimes difficult for the third party (translator) to effectively translate and convey the real meaning of the question asked or answers given, leading to the loss of important research information, i.e., due to poor communication skills mostly as a result of low educational background of the translator. Another factor is the unavailability of cocoa farmers for interview, i.e., it is very difficult to access indigenous cocoa farmers for research survey in Nigeria as majority of them operate more than one farm at a time, or have a variety of menial jobs they do for a living aside cocoa farming. The third factor is negligible though but still noteworthy of mentioning; few indigenous cocoa farmers shy away from research survey based on the fact that they receive little or no incentives (financial or material) from researchers before or after survey, and most importantly, the fear of researchers exposing some of their lapses or sharp farm practices. Nonetheless, some of these farmers were highly cooperative, hospitable, receptive and totally in support of researchers working to improve their farms. These are some of the strong points, setbacks and limitations to effective farm survey in Nigeria.

Also, the BPD prediction efficiency of ETAPOD was 100% affected by the accuracy of the data fed into the system (primary and secondary data). Climate data was used as both primary (in conjunction with past BPD data) and secondary data, so it is the major data used for modeling ETAPOD. As such, the limitations associated with climate data directly influenced the prediction accuracy of ETAPOD. Some of the readily observable limitations of climate data used in this research include (but not limited to): the credibility of weather (climate) data source, the proximity

of the weather forecast office to the cocoa farm location (i.e., the closer the range the better the result), inaccurate forecast results due to poor forecast equipment or facilities in some cocoa producing regions, lack of functional weather forecast facilities in some rural and sub-urban communities where cocoa are mostly produced (for example, in rural regions like Kiama (Kwara State), Iyánfoworogi, Adaàgbà, Owódé-Igàngán (Osun State), Ọbáfemi-Owódé, Ọdèdá (Ogun State), Ọmi-Adió, Mòyè and Olórò villages (Oyo State), Ọwẹnà, Wáàsìmi (Ondo State), using Nigeria as a case study). Also, the quality of the forecast equipment used for weather data collection, the frequency of the weather data generated per station (i.e., seconds/minutes/hours/daily), the errors in calculation of data averages (mean), subtotal, or total (daily or monthly or biannually or tri-annually or annually), are some limitations that can affect the accuracy of weather or climate dataset used in most researches. In Nigeria, the most important limiting factor to climate or weather data collection is the commercialization or "huge price tag" associated with acquisition of the data from accredited private and government forecast stations. The limitations of the BPD data used as primary data for modeling ETAPOD include: the methodology for disease investigation adopted by the investigator in the field, disease classification and quantification techniques used, the accuracy of data generated and collected by the researcher. In all, there is still room for modifications and improvement of ETAPOD for optimum prediction of BPD anywhere in the world.

The use of cultural methods like effective farm management strategies, frequent weed removal, elimination or effective disposition of infected pods, regular removal of epiphytes, the use of traps and nets to control arboreal rodents and the dislodgement of ant nests, which might be possible propagators

or inoculants of BPD from pod to pod, can help minimize BPD outbreak in cocoa farms around the world. Also, the problem of cocoa husks disposal in Nigeria requires urgent attention. Cocoa husks heaped on the surface of the farmland serve as a breeding ground for most noxious pathogens of cocoa. Also, rodents and insects take advantage of the heaps to setup their nests for breeding, or forage for food. Proper disposal of these husks, piled on the soil surface as waste, can help reduce the outbreak of some economically important diseases of cocoa like black pod disease responsible for poor yield in Africa (in countries like Ghana, Nigeria, Cameroon), witches' broom disease responsible for massive crop loss in Brazil and some Latin American countries too. In any case, the husks can be put into good use either as feeds for animals like sheep, pigs, cattle or goats, or converted into biological fertilizers for plant growth or even processed to produce other finish products that can be useful in construction or other areas of engineering. Currently, in Nigeria, civil engineers are trying to convert these husks into low, medium and high-quality bricks that can be useful in the construction of low-cost buildings and other much smaller facilities.

CONCLUSION

Climate change, poor farm management, and diseases are the major limiting factors to bountiful cocoa production around the world. The development of a unified system for climate and weather survey, integrated pests and disease management, will help alleviate these problems. In the meantime, cocoa farmers around the world are advised to minimize the use of pesticides in their farms as this might result in the development of deadly

infections or diseases like cancer, cardiovascular dysfunction, stroke, nephrotoxicity, and hepatotoxicity, in humans and other animals that consume the treated products based on bio-absorption and bioaccumulation of toxic elements in the body. The use of biological or other environmentally friendly approach to curtail the development and spread of BPD within cocoa farms is highly recommended.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fagro.2022.731019/full#supplementary-material>

Supplementary Figure S1 | Cocoa pod infestation by *Phytophthora* spp. causing black pod disease.

Supplementary Figure S2 | BPD outbreak evaluation for cocoa producing countries around the world.

Supplementary Table S1 | The climate of some cocoa growing countries of the world.

Supplementary Table S2 | The climate of cocoa producing States in Nigeria.

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