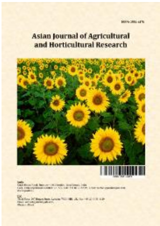

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Surface Temperature Changes and Effects on Cocoa Yield in the Top Four Cocoa Producing Countries of Africa: A Comparative Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Cocoa is a leading export crop to the world market and Cote D'Ivoire, Ghana, Nigeria and Cameroon in Africa, accounts for about 70% of the global supply. However, increasing global warming with attendant high ambient temperature had affected yields in the tropical regions of Africa. The data of 61 years (1961 – 2021), area harvested (ha), yield (kg/ha) and temperature (^{O}C) were sourced from the database of Food and Agricultural Organisation Corporate Statistical (FAOSTAT). Least squares regression and correlation analysis models were used for data analysis. Results showed that mean ambient temperature in Cote D'Ivoire, Ghana, Nigeria and Cameroon have increased by 0.7661, 0.7507, 0.7333 and 0.6400 ^{O}C for a total of 51, 51, 50 and 49 years

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respectively, while mean decreases were 0.1541, 0.1693, 0.1710, 0.1392ºC for 10, 10, 11 and 12 years respectively. Annual average temperature increase was highest (0.0243ºC) in Cote D'Ivoire with regression coefficient (R^2) of 0.7232 and least (0.0200ºC) in Nigeria at R^2 of 0.6380. However, in both countries, annual temperature decreased by 0.0012º and 0.0007º with R^2 of 0.0052 and 0.0014 respectively. The mean annual temperature increase in Ghana and Cameroon were 0.023º and 0.0204º with R^2 of 0.7364 and 0.6965 respectively, while the decreases were 0.0019º and -0.0011º with R^2 of 0.0152 and 0.0431 respectively. The cocoa cumulative yield (kg/ha) reduced by 105.8, 90.8 and 75.0kg/ha respectively in Cote D'Ivoire, Ghana and Cameroon when temperature decreased, but increased by 12.5kg/ha in Nigeria during same temperature decreasing trend. In Ghana and Cameroon, cocoa annual yield was higher in the years of temperature increase, while decreased ambient temperature enhanced cocoa yield in Nigeria and Cote D'Ivoire. Hence, to enhance cocoa yield in the top four cocoa producing countries of Africa, the ambient temperatures should be controlled through the adoption of Good Agricultural Practices (GAP).

Keywords: Ambient temperature; cocoa yield; FAOSTAT; good agricultural practices; West Africa.

1. INTRODUCTION

The global cocoa production of 4,645 thousand tonnes for 2017/2018 placed it among the world leading export crops [1]. In November 2023 Quarterly Bulletin on Cocoa Statistics, the 2022/2023 cocoa balance sheet showed global production of 4.953 million tonnes [2], which amounted to 2.6% change in the year-on-year in world cocoa production. The global cocoa market value will be worth US$14.572 billion by 2026, due to rising demand and inclination of younger consumers toward chocolate across the globe [3]. Thus globally, there is strong and growing demand for cocoa, most especially in Eastern Europe and Latin America [4].

Cocoa beans are produced in tropical zones around the Equator, where climatic conditions are well suited for growing cocoa trees [5, 6]. Although cocoa beans originate from South America, most of the world's cocoa bean production is attributed to Africa [7] with total production amounting to 3.5 million tons in 2019/2020. According to [8], Africa accounts for 75.9% of the world cocoa production, and remains the largest cocoa producing region globally, and this is followed by America (17%), Asia and Oceania (7.1%). Interestingly, about 70% of the world's cocoa beans are supplied by four African countries which are Cote D'Ivoire, Ghana, Nigeria and Cameroon. The Cote D'Ivoire and Ghana are by far the two largest producers of cocoa in the world, accounting for more than 50% of the world´s cocoa supply. In 2021, the Ivory Coast alone produced approximately 2.1 million metric tons of cocoa beans [5]. The economy of Cote D'Ivoire is highly dependent on cocoa production, which accounts for 40% of the national income. Ghana is the second largest exporter of cocoa beans to the world market with estimated produce of 1 million metric tons in 2020/2021 [6]. However, Nigeria ranked as the third largest cocoa producer in West Africa, but witnessed a drastic reduction in cocoa production with output ranging between 250,000 and 280,000 tonnes [9], while Cameroon, which had a production level of between 230,000 and 290,000 tonnes per year, is the fourth world largest cocoa producer [6]. Among the most limiting factor to cocoa production is climate change. The effects of climate change is more pronounced in African societies because of its geography, its sole dependence on Agriculture and its generalized incapacity to cope and adapt to climate extreme [10]. According to the AFDB [11], Africa is the most vulnerable continent to climate change impacts under all climate scenarios above 1.5 degrees Celsius. Despite having contributed the least to global warming and having the lowest emissions, Africa faces exponential collateral damage, posing systemic risks to its economies, infrastructure investments, water and food systems, public health, agriculture, and livelihoods, threatening to undo its modest development gains and slip into higher levels of extreme poverty. Developing countries are currently at a double disadvantage, because the tropical areas stand to experience some of the most severe impacts of climate change, and agriculture which is a sector most sensitive to climate change, is expected to be seriously impacted. Whereas increasing global temperature is likely to boost agricultural production in the temperate regions, it is expected to reduce on same in the tropical regions [12]. According to the IPCC report [13], it is projected that many regions of Africa will suffer from droughts and floods with greater frequency and intensity in the nearest future and that the rise in average temperature between 1980/1999 and 2080/2099 would be in the range of 3 - 4°C across the entire African continent; this would be 1.5 times more than the global level. It is pertinent to know that, every stage of cocoa production requires adequate weather conditions [14]. However, a number of factors have interrelated impacts on the growth of cocoa plants. These ranged from weather elements of rainfall, temperature, sunlight and humidity, along with others such as soil nutrient status, pest and diseases, farmers planting practices and management techniques [15]. Cocoa is known to produce well with minimal but sustained water availability throughout the year [16]. Good Agricultural Practices like weeding, pruning, applying fertilizer and pest disease control are essential for cocoa tree to thrive [17]. There is a concern that the projected global temperature increase and concomitant increase in potential evapotranspiration (ETP) and plant water demand may result in increased drought stress during the dry season and a further deterioration of the climatic conditions for cocoa [18]. The cocoa plant respond well at temperatures with maximum annual average of 30 to 32°C and a minimum average of 18 to 21°C [19]; Very high and very low temperatures are associated with decreased photosynthesis. High temperatures decrease the life span of leaves, increase the speed of pod ripening, which in turn increases the hardness of cocoa butter. Moreover, temperature changes raise seedling mortality rates, may negatively affect yields, and decrease the quality and size of cocoa beans. Pests that thrive under the new temperature conditions may pose an additional threat to yields [20]. According to Ajewole and Iyanda [21], rainfall of 900-1000mm, with increased temperature are very important for cocoa production and better yield. Climate change could alter the stages and rates of cocoa growth, development of cocoa pests and pathogens, as well as modify host resistance and result in changes in the physiology of host-pathogen/pest interaction. Cocoa seedling mortality is encouraged by drought, and in like manner, water deficit in cocoa plant results in low yield and increase in the level of capsid damage. Cocoa is highly sensitive to changes in climate, particularly to temperature due to its effects on evapotranspiration [22]. This study was aimed to determine the impact of ambient temperature changes on cocoa production in the four major cocoa producing countries of Africa.

2. MATERIALS AND METHODS

2.1 Characteristics of the Study Locations

Cote d'Ivoire is located in the transition zone between the humid equatorial climate that characterizes the southern part of the country, and the dry tropical climate of the north. The country generally experiences a rainy season from June to October and average annual temperatures range from 24-28°C [23]. The climate of Ghana is tropical and strongly influenced by the West Africa monsoon winds. It is generally warm with variable temperatures masked by seasons and elevation. The country enjoys a high temperature while the average annual temperature is between 24°C and 30°C. In the Southern and Northern parts of Ghana, temperatures may lie between 18°C and 40°C [24, 25]. Three distinct climate zones, a tropical monsoon climate in the south, a tropical savannah climate for most of the central regions and a Sahelian hot and semi-arid climate in the north characterise Nigeria. The Mean annual temperature for Nigeria is 26.9°C, with average monthly temperatures ranging between 24°C and 30°C [26]. The humid and equatorial climate characterise the southern part of Cameroon with temperatures, which depends on the altitude, ranging from 20-25°C; the Northern Cameroon is semi-arid and dry with temperatures ranging from 25-30°C [27].

2.2 Source of Data

The data on area harvested (ha), yield (kg/ha) and temperature (^{O}C) in Ivory Coast, Ghana, Nigeria and Cameroon over 61 years (1961 - 2021) were obtained from the database of Food and Agricultural Organisation Corporate Statistical (FAOSTAT), (FAO, 2024). The FAOSTAT database provided temperature variations and the corresponding annual cocoa yield data for the 61 years (1961 - 2021) duration.

2.3 Data Analysis

The data were analysed using least squares regression and correlation analysis model. To approximate a given set of data, (x_1,y_1), (x_2,y_2), … , (x_n,y_n), where $n \geq 2$ the least squares straight line method used is

$Y = a + bx$

Implicitly, the model can be represented as follows:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \ldots\ldots\ldots\ldots + b_nX_n + e_i$$

Where:

Y = Dependent variable,

Xs = Independent variables,

e = Random error term.

a and b are as defined below.

$$a = \frac{\sum y - m\sum x}{N}$$

$$b = \frac{N\sum(xy) - \sum x \sum y}{N\sum(x^2) - \left(\sum x\right)^2}$$

Where 'a' stands for the intercept and 'b' stands for the slope; x and y are the coordinates of the data points that represent variables. The slope is equivalent to variation in measured variables per annum [28].

To quantify the strength of relationship between the measured variables, correlation coefficient was also computed. Correlation coefficient values close to +1 indicates a strong positive linear relationship while values close to -1 indicate a strong negative linear relationship, while generally, values close to 0 indicates absence of linear relationship.

3. RESULTS AND DISCUSSION

3.1 Ambient Temperature Variations in the Countries

The ambient temperature for the 61 years of observation showed that there was 10 years of decrease in temperature (^{0}C) in Cote D'Ivoire with a 51year temperature increase. However, in Ghana, Nigeria and Cameroon, temperature decreased for 10, 11 and 12 years respectively and increased for 51, 50 and 49 years respectively. The ambient temperature for Cote D'Ivoire (Table 1) increased by a range of 0.1033 – 1.7387^{o}C with mean of 0.7661^{o}C, while temperature decrease ranged from 0.0013 - 0.3231^{o}C with mean of 0.1541^{o}C (Table 2). In Ghana and Nigeria, ambient temperature range was 0.1095 - 1.6988^{o}C with mean of 0.7507^{o}C for Ghana, and 0.0004 – 1.4368^{o}C with mean of 0.7333^{o}C for Nigeria (Table 1). The decrease in surface temperature in both countries ranged from 0.0523 - 0.3348^{o}C with mean of 0.1693^{o}C and 0.0136 - 0.4743^{o}C with mean of 0.1710^{o}C respectively (Table 2).

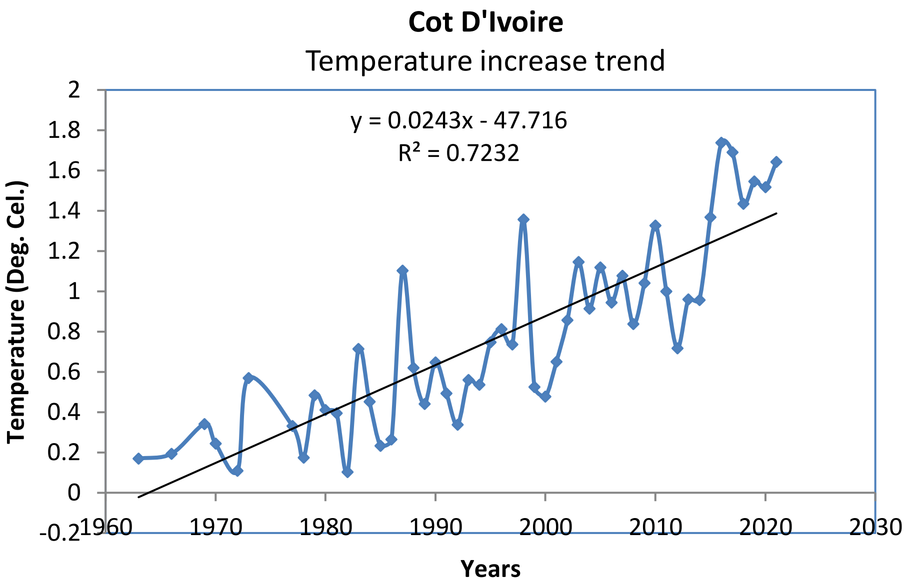
The increase in ambient temperature for Cameroon ranged from 0.0344 - 1.4381^{o}C with mean of 0.6400^{o}C while decrease in temperature ranged from 0.0651 – 0.2568^{o}C with mean value of 0.1392^{o}C (Tables 1 and 2). The temperature trend analysis for the 61 years (Fig. 1) showed that mean temperature increase per annum was highest (0.0243^{o}C) in Cote D'Ivoire with regression coefficient (R^2) of 0.7232 and was least (0.0200^{o}C) in Nigeria with R^2 value of 0.6380, while the temperature decreased (Fig. 2) for both countries was 0.0012^{o}C for Cote D'Ivoire and 0.0007^{o}C for Nigeria with R^2 values of 0.0052 and 0.0014 respectively. The annual mean temperature increase (Fig. 1) for Ghana and Cameroon were 0.0231 and 0.0204^{o}C with R^2 values of 0.7364 and 0.6965 respectively, while decrease in temperature (Fig. 2) was 0.0019 for Ghana and -0.0011^{o}C for Cameroon with R^2 values of 0.0152 and 0.0431 respectively. Therefore, with the exception of Cameroon that had negative annual temperature decrease for 12 years, it was a positive trend for the other three countries.

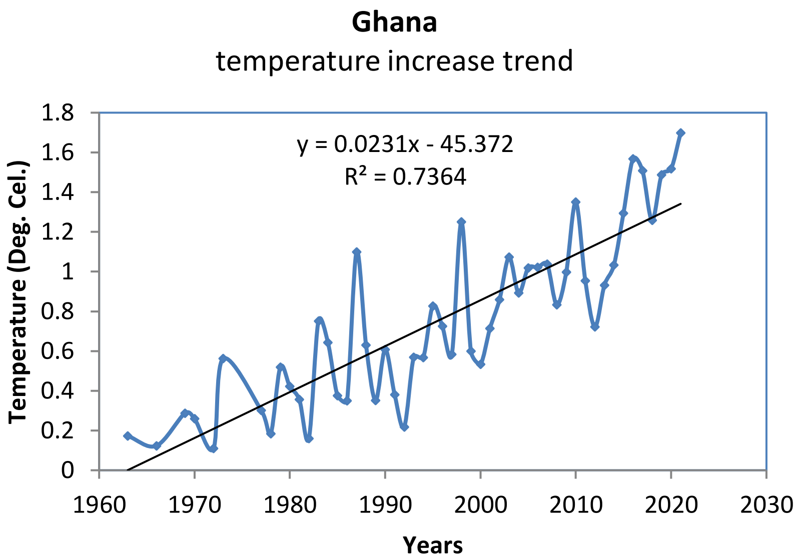
Table 1. Cocoa cumulative yield as influenced by temperature increase in 61 years

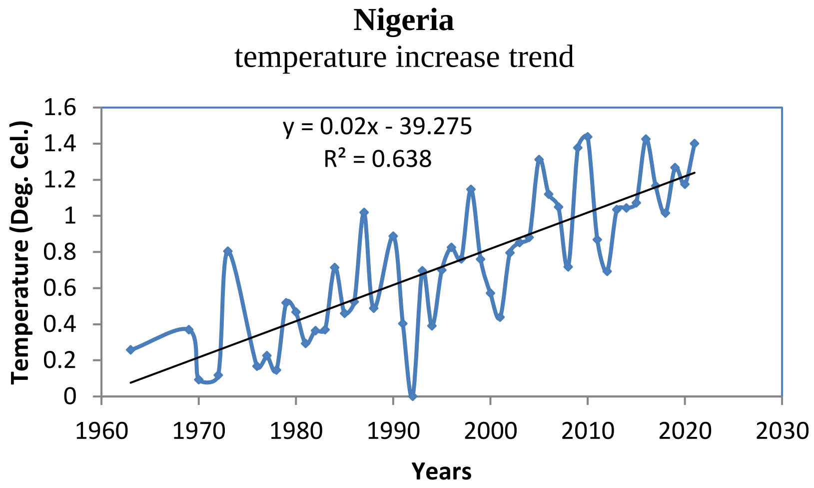
Variables	Yield as temperature increases							
	Cot D'Ivoire		Ghana		Nigeria		Cameroon	
	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)
Minimum	0.1033	378.2	0.1095	205.4	0.0004	200.0	0.0344	219.0
Maximum	1.7387	700.6	1.6988	563.9	1.4368	498.0	1.4381	412.3
Mean	0.7661	535.8	0.7507	359.1	0.7333	312.0	0.6400	336.2
Standard deviation	0.4514	78.7	0.1811	111.0	0.3918	73.0	0.3927	55.0
Correlation analysis	0.282		0.703		0.022		0.756	

Table 2. Cocoa cumulative yield as influenced by temperature decrease in 61 years

Variables	Yield as temperature decreases							
	Cot D'Ivoire		Ghana		Nigeria		Cameroon	
	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)	Temp. (^{0}C)	Yield (kg/ha)
Minimum	0.0013	326.9	0.0523	227.2	0.0136	260.0	0.0651	197.6
Maximum	0.3231	534.1	0.3348	314.1	0.4743	426.1	0.2568	355.4
Mean	0.1541	430.0	0.1693	268.3	0.1710	324.5	0.1392	261.2
Standard deviation	0.0936	63.7	0.0844	31.9	0.1380	54.6	0.0516	55.7
Correlation analysis	0.039		0.179		0.030		0.114	







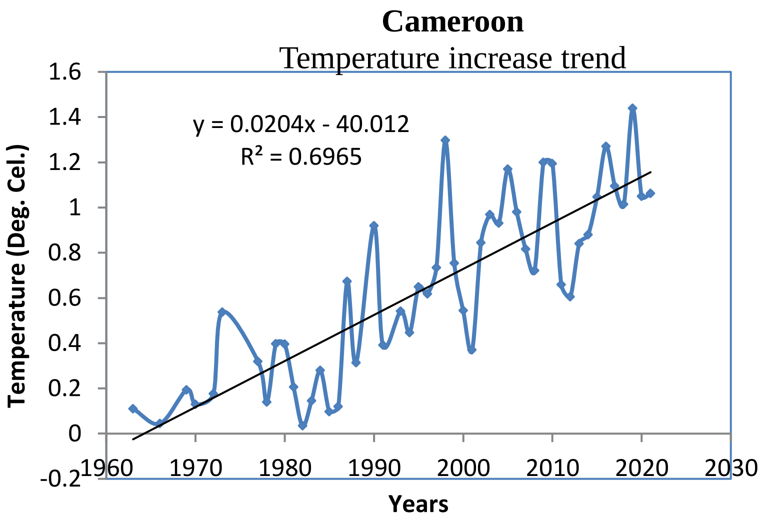
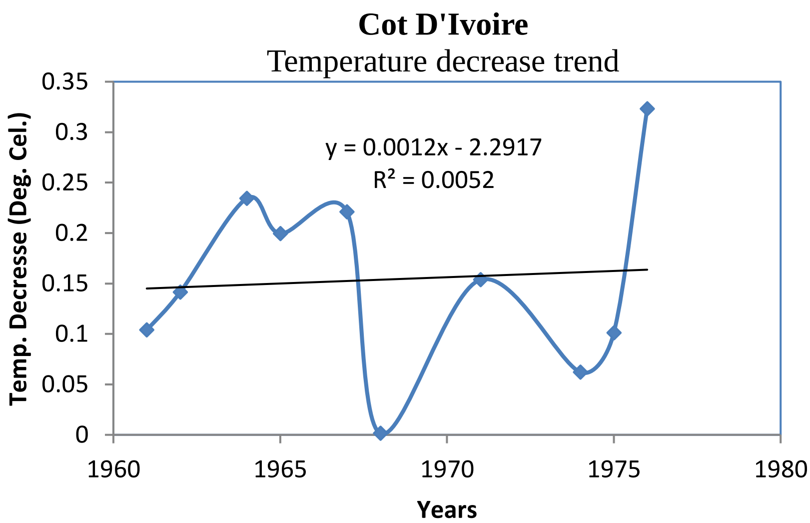


Fig. 1. Temperature increase trend in Cote D'lvore, Ghana, Nigeria and Cameroon



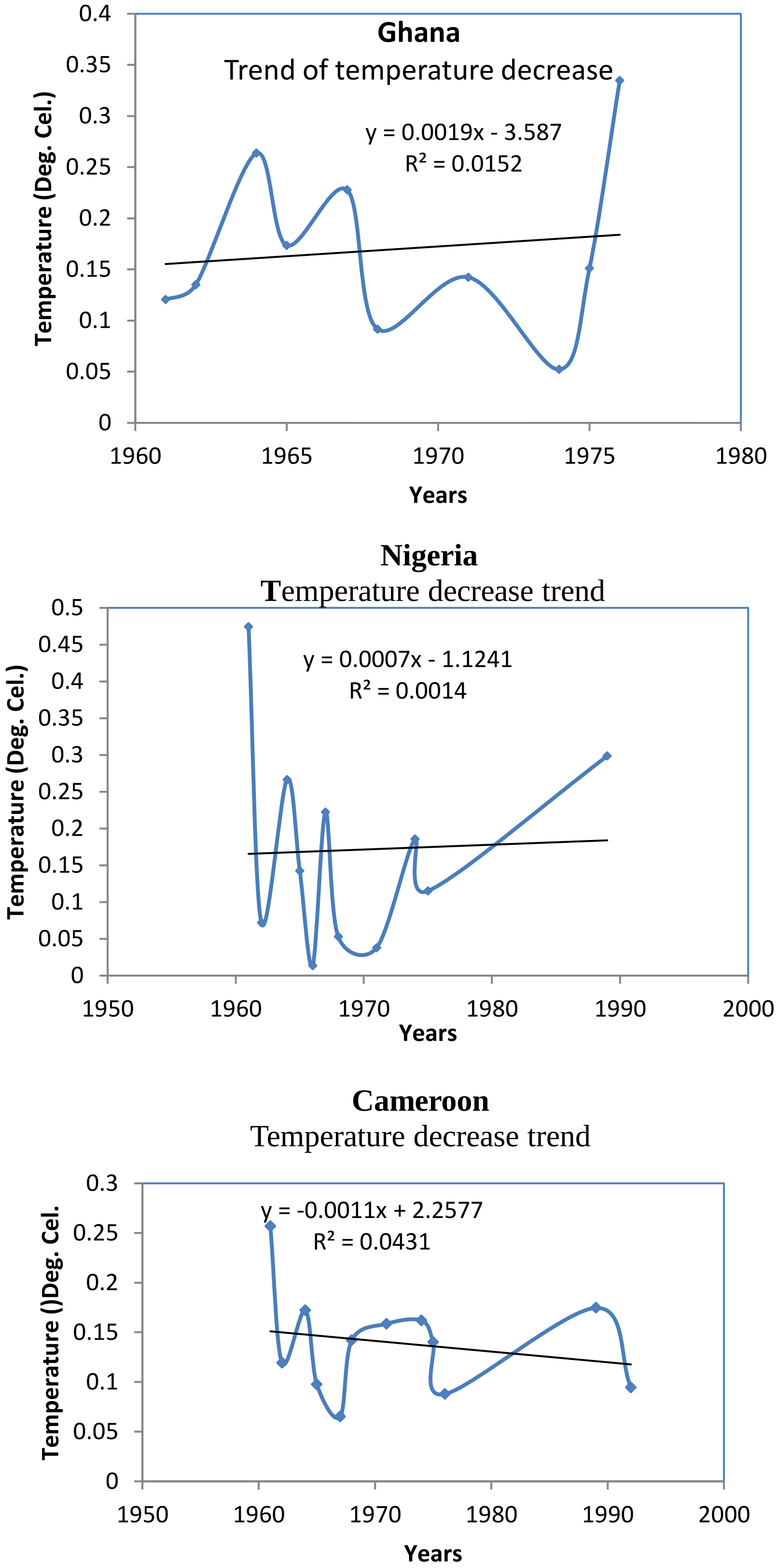


Fig. 2. Temperature decrease trend in Cote D'lvore, Ghana, Nigeria and Cameroon

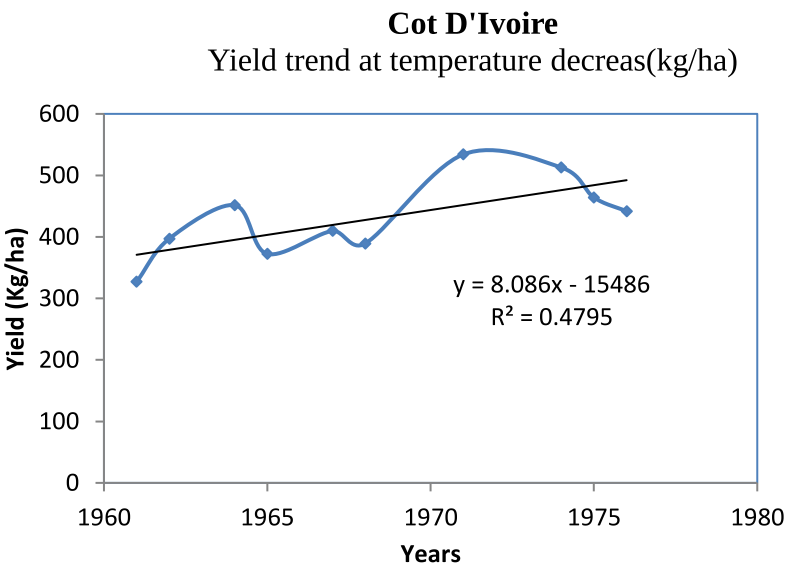
3.2 Temperature Variations and Cocoa Cumulative Yield

Cocoa cumulative yield in the four largest cocoa producin g countries in Africa as influenced by temperature variations during the 61 years of this study is shown in Tables 1 and 2. The mean cocoa yield per hectare during temperature increase (Table 1) in Cote D'Ivoire was 535.8 kg with a standard deviation of 78.7; In Ghana and Cameroon the mean yields were 359.1kg and 336.2kg at standard deviation of 111.0 and 55.0 respectively. During the 10 years decrease in temperature in Cote D'Ivoire (Table 2), the mean yield of cocoa reduced to 430.0 kg with a 63.7 standard deviation, also, In Ghana and Cameroon, as the temperature decreased for 10 and 12 years duration, the mean yields reduced to 268.3kg and 261.2kg per hectare at standard deviations of 31.9 and 55.7 respectively. However, in Nigeria, the yield of cocoa during the 50 years temperature increase was 312.0kg/ha with 73.0 standard deviation; the yield increased to 324.5kg/ha with a standard deviation of 54.6, when the temperature reduced for 10 years.

The correlation analysis between temperature and cocoa yield across the four countries was positive for both periods of increase and decrease in temperature; this deduction aligns with International Cocoa Organization [2] that average temperature positively impacts cocoa in the long and short run. However, for the 61 years investigated, with the exception of Nigeria that had increase in mean yield by about 12.5kg/ha during the period of temperature decrease, cocoa yield per hectare reduced by 105.8, 90.8 and 75.0kg/ha for Cote D'Ivoire, Ghana and Cameroon respectively. The cocoa yield for Nigeria ranked the least among the four countries during period of increase in the ambient temperature, while the yield per hectare for the country ranked next to Cot D'Ivoire when temperature decreased for 11 years. This corroborates the deduction by Bomdzele and Molua [24] that despite Africa's comparative advantage of 65.7% in cocoa production, climatic variables such as disruption of seasonal patterns, inconsistent rainfall, rising temperatures and draughts [29] severely impact the continent.

3.3 Trend Analysis of Yield

The trend analysis to show annual variations in cocoa yield as temperature varies (Fig. 4) revealed that within the 10 years of decrease in temperature in Cote D'Ivoire, annual cocoa yield actually increased by 8.086kg/ha with regression coefficient (R^2) of 0.48, while during the 51 years of temperature increase, cocoa yield increased annually by 2.2624kg with R^2 value of 0.21 [30]. Hence, the 105.8kg/ha reduction in yield as the temperature varied for Cote D'Ivoire was a cumulative difference, hence, within the 10 years of temperature decrease, the annual yield actually increased.



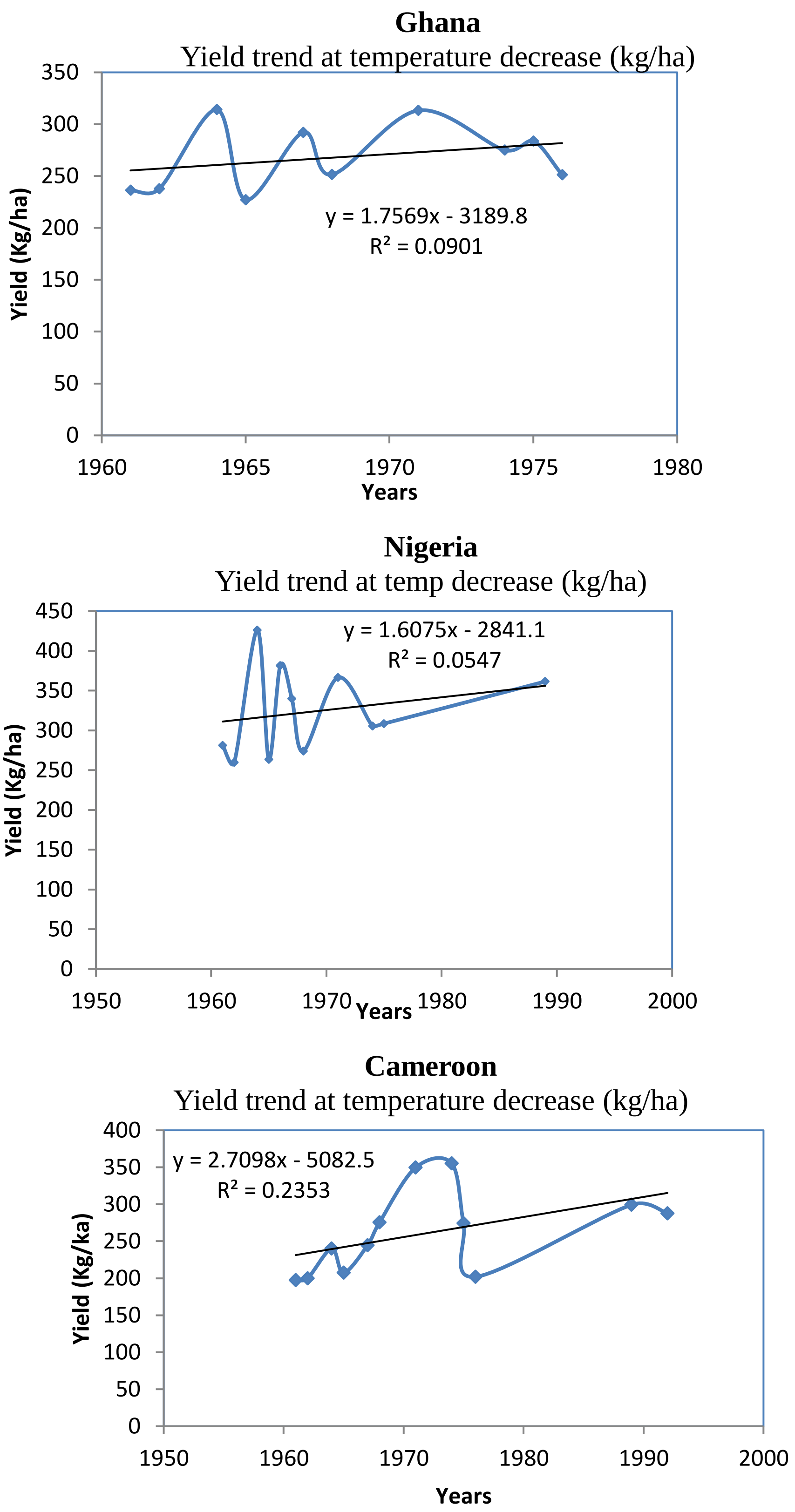
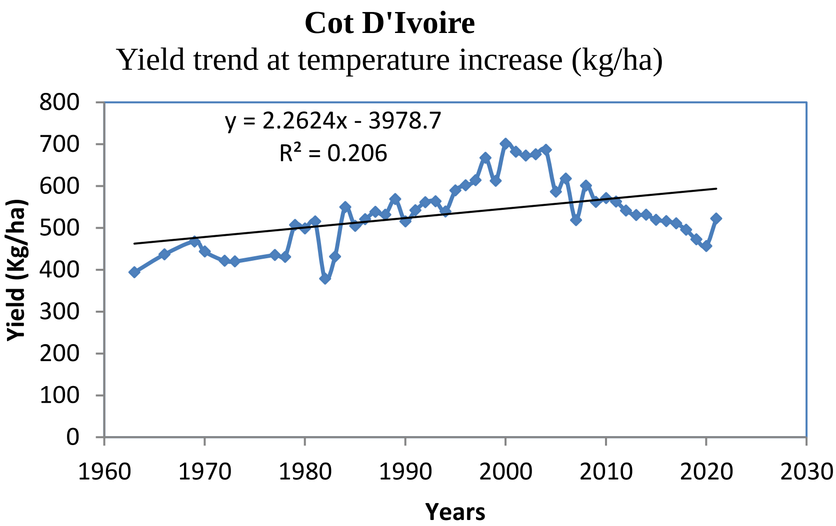
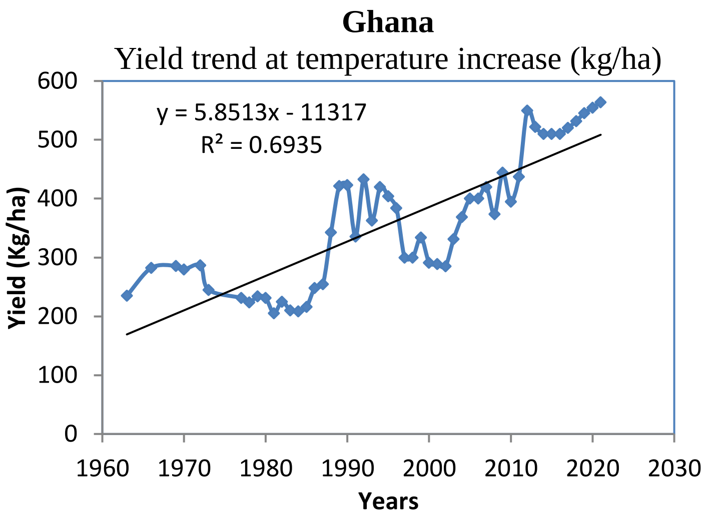
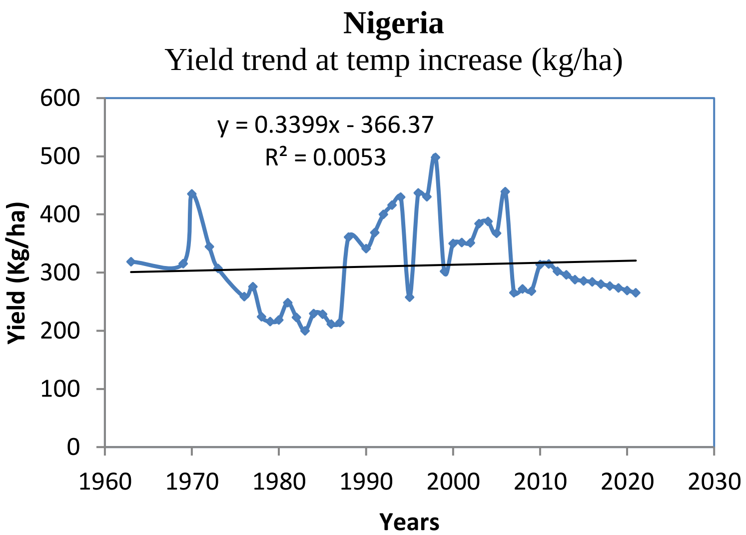


Fig. 3. Cocoa yield trend as temperature decreases across the four topmost cocoa producing countries of Africa


Cot D'Ivoire
Yield trend at temperature increase (kg/ha)
y = 2.2624x - 3978.7
R² = 0.206
Yield (Kg/ha)
0
100
200
300
400
500
600
700
800
1960
1970
1980
1990
2000
2010
2020
2030
Years


Ghana
Yield trend at temperature increase (kg/ha)
y = 5.8513x - 11317
R² = 0.6935
Yield (Kg/ha)
0
100
200
300
400
500
600
1960
1970
1980
1990
2000
2010
2020
2030
Years


Nigeria
Yield trend at temp increase (kg/ha)
y = 0.3399x - 366.37
R² = 0.0053
Yield (Kg/ha)
0
100
200
300
400
500
600
1960
1970
1980
1990
2000
2010
2020
2030
Years

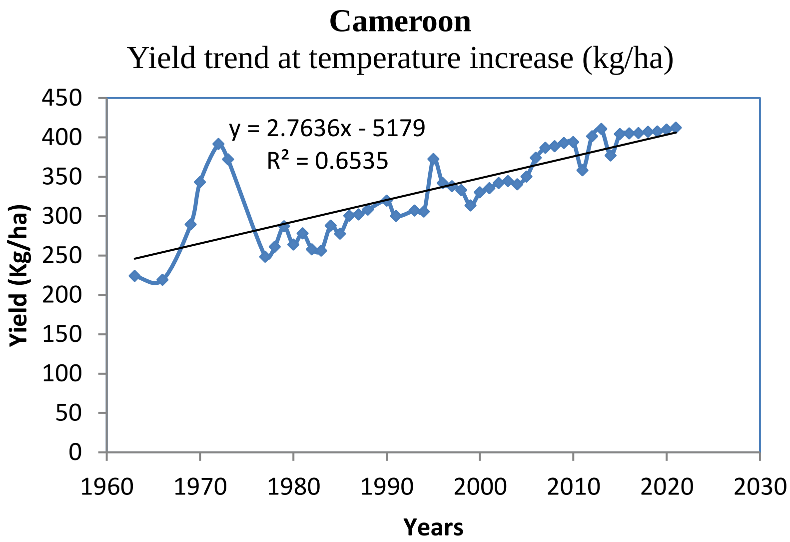


Fig. 4. Cocoa yield trend as temperature increases across the four topmost cocoa producing countries of Africa

The cocoa yield per hectare in Nigeria increased at 1.6075kg/ha per annum during the period of temperature decrease with R^2 value of 0.05 but the production decreased by 0.3399kg per annum at R^2 of 0.01, when the temperature increased. In Ghana and Cameroon on the other hand, the cocoa yield when the temperature increased was higher (5.8513 and 2.7636kg/ha) with R^2 values of 0.69 and 0.65 respectively and became lower (1.7569 and 2.7098kg/ha) when the temperature decreased, with regression coefficients of 0.09 and 0.24 respectively. These results revealed that decrease in surface temperature enhanced cocoa yield in Nigeria and Cote D'Ivoire while temperature increase enhanced higher cocoa yield per hectare in Ghana and Cameroon [31].

4. CONCLUSION

The study was conducted to reveal the temperature variations and its effects on yield of cocoa per hectare in each of the four major cocoa producing countries of Africa. The results obtained revealed that in the 61 years coverage, there was temperature decrease by 16.39% for 10 years in Cote D'Ivoire and with increase by 83.61% in 51 years while in Ghana, Nigeria and Cameroon, the temperature decreased by 16.39%, 18.03% and 19.67% (10, 11 and 12 years) respectively and increased by 83.61%, 81.97% and 80.33% (51, 50 and 49 years) respectively. The cumulative mean yield results obtained across all the years of temperature increase and decrease in the countries showed that with the exception of Nigeria with increase in cumulative mean yield by 12.5kg/ha during temperature decrease, the yield per hectare of cocoa reduced by 105.8, 90.8 and 75.0kg/ha respectively in Cot D'Ivoire, Ghana and Cameroon when temperature decreased. Also, the yield in Nigeria ranked least among the top four cocoa producing countries during increase in surface temperature, while the rank was next to Cot D'Ivoire when temperature decreased. The annual yield trend analysis showed that the 105.8kg/ha reduction in yield as temperature varied in Cote D'Ivoire is a cumulative difference but within the 10 years of temperature decrease, the annual yield was higher than the 51 years of increase. In Ghana and Cameroon, the annual yield was higher during the years of increase in temperature. The decrease in surface temperature enhanced cocoa yield per hectare in Nigeria and Cote D'Ivoire while the increase enhanced yield in Ghana and Cameroon. These may be unconnected with the lower temperature threshold which is higher throughout Cote D'Ivoire and Nigeria (24ºC) than Ghana (18ºC) and Cameroon (20ºC). Furthermore, To enhance cocoa yield in the top four cocoa producing countries of Africa, the surface temperatures should be kept within the limit of optimal yield through the adoption of Good Agricultural Practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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