Heliyon 9 (2023) e19939

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Cassava production in africa: A panel analysis of the drivers and trends

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A R T I C L E I N F O

Keywords:
Africa
Agriculture
Cassava
Smallholder farmers
Sustainable crop intensification
Yield gap

A B S T R A C T

Cassava is Africa's most important tuberous crop. It is an all-year-round cheap and reliable staple food for millions of Africans, making it vital for food security on the continent. However, cassava production in Africa is hindered by a persistent problem of low yield per hectare. This study addresses the dearth of research on the specific influences of area harvested and yield per hectare on cassava production in Africa. This work uses panel data from 37 African countries from 1961 to 2020 and sheds light on three key aspects. Firstly, it investigates the extent and nature of the low yield per hectare problem, offering insights into its underlying causes and implications. Secondly, it examines the interplay between area harvested and yield per hectare, revealing the factors driving the observed trends in cassava yields on the continent. Lastly, this study contributes to the achievement of Sustainable Development Goals, particularly Goal 15: Life on Land and Goal 2: Zero Hunger, by providing valuable information to enhance cassava production sustainability. The findings indicate that approximately 95.6% of the variability in production can be explained by changes in the area harvested, around 1.1% by yield variability, about 27.6% by consumer price index and 1.8% by temperature changes. Notably, the study observes a significant increase in the area harvested by 16.8 million hectares and average yield levels varied between 5.7 and 9.6 tonnes per hectare. The analysis also reveals a disparity in translating gains from disease eradication and introducing high-yield, disease-resistant varieties into smallholder cassava farming. In conclusion, the study highlights the potential for sustainable intensification of cassava production as a viable pathway to enhance absolute and per-hectare yields while promoting farmers' income and mitigating cassava cultivation-related deforestation. Understanding and addressing the low yield per hectare problem in cassava production are crucial steps toward ensuring food security and achieving sustainable agricultural practices in Africa.

1. Introduction

Cassava is the world's fourth most important staple food behind rice, wheat and maize and forms part of the diet of more than a billion people worldwide. Given its resistance to drought and depleted soils and the possibility of planting and harvesting it almost throughout the year, cassava is crucial to food security, especially in areas prone to drought and poor soils. However, it thrives best on rich, sandy-clay soils [1]. Jansz & Uluwaduge [2] posit that cassava yields can be as high as 50–82 metric tons per hectare, making it the highest-producing starchy staple. Also, it can be produced on marginal soil when other crops cannot have an economically viable yield. Compared to staples like rice 176×10^3 calories/ha/day, rice 176×10^3, wheat 110×10^3 for wheat, maize 200×10^3 and

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https://doi.org/10.1016/j.heliyon.2023.e19939
Received 3 October 2022; Received in revised form 5 September 2023; Accepted 6 September 2023
Available online 7 September 2023

sorghum 114 × 10^3 for sorghum, cassava 250 × 10^3 calories/ha/day is more efficient in generating carbohydrates [3,4]. Its starchy tuberous roots are a great all-year-round source of cheap calories in developing countries [5], where calorie deficit and malnutrition are prevalent [1].

Cassava is Sub-Saharan Africa (SSA)'s second most crucial staple food crop [6]. Its highest per capita consumption, around 800g per person/day, occurs in sub-Saharan Africa, where it is the primary energy source for almost 40% of the population [7]. Humans eat cassava leaves and tender shoots in several regions of the African continent [8,9]. The boiled or fried cassava tuber is one of the main dishes in the Democratic Republic of the Congo, the Republic of the Congo and Tanzania, and the leaves are condiments for making soup [10]. According to Nweke [11], cassava consumption provides 1000 calories per person/day in DR Congo, where many families eat it for breakfast, lunch and supper. Cassava is consumed with sauces containing protein, vitamins, and minerals. Gari – toasted cassava flake, is a foremost staple food in Nigeria, Sierra Leone, Ghana, Guinea, Benin, and Togo [5],[12],[13]. Other traditional processed products from cassava tubers are attieke, lafun, fufu, tapioca, and dumby [4],[5],[13]. High-quality cassava starch (HQCF), ethanol [5], and sorbitol are new high-end cassava products. Cassava flour is gluten-free [14–16] and viable as a healthy standalone flour for making bread and other pastries [16] and as a mixture with wheat flour to reduce the gluten content of the final product [14, 15].

The phenomenal expansion of cassava production in Africa is well documented [5],[17–21]. Since the 1960s, the continent has experienced the most significant cassava production increase globally. Its total cassava output has grown at an increasing rate, eclipsing output gains in the other continents in the past decades. However, in the same period, average cassava yields per hectare on the continent have been below the world's average per hectare yield and below that of frontline cassava-producing continents like Asia and the Americas [22]. Researchers, policymakers, and important stakeholders continue to mention that Africa's cassava production suffers from a low yield/ha problem. Nyirakanani [23] posited that cassava yield in tropical countries is nowhere near the potential yields obtainable. According to De Souza et al. [24], Africa's average cassava yield on smallholder farms is 2.51 tonnes of dry matter yield (t DM ha −1) and approximately 7.2 tonnes/ha of fresh roots. This yield is 2.5 times lower than those attained in Asia. In Nigeria and the Democratic Republic of Congo, the world's two biggest cassava producers, the 2017 average cassava yield was 8.75 tons/ha and 8.14 tons/ha, respectively. These yields are below the world's average of 11.08 tonnes per hectare. Dr Simon Gichuki, a senior advisor at the VIRCA Plus Project, observes that East Africa and Kenya cassava yields are meagre compared to those documented in Asia and South America. The yields in Kenya seldom get to 10 tons per hectare, whereas in Asia and South America, yields of around 50 tons per hectare have been recorded [25,26].

There is a dearth of research focused on the specific impact of area harvested and yield/ha on increasing production on the continent. Hence, with a focus on Africa, this paper examines the specific influence of area harvested and yields/ha on annual cassava production. It uses panel data on production, yield variability, consumer price index, temperature and area harvested for 37 African countries obtained from FAOSTAT for 1961–2020. The data were analysed using descriptive statistics, Spearman correlation, and random effects regression. This paper further extant literature by providing useful insight on (1) whether there is a low yield/ha problem and its nature and extent, (2) the area harvested and yield/ha mix driving increasing yields on the continent, (3) contributes to the discussion towards achieving Sustainable Development Goals15-Life on Land. Africa would be on the right track to a sustainable long-term increase in production if the increases in total production resulted mainly from increases in yields per hectare or a good combination of increases in yields per hectare and area harvested. However, suppose the increases occurred solely or primarily due to the increasing land allocation to cassava cultivation. In that case, there is a cause for concern as this is unsustainable in the long run. Clearing virgin lands for agricultural purposes promotes deforestation, aggravates climate change, and leads to soil erosion, flooding and droughts, and loss of soil nutrients and biodiversity [27]. Amongst other things, restoration and fighting against desertification, land degradation and biodiversity loss are some key focuses of SDG Goals15-Life on Land [28]. The following research questions guide his papers: i) To what degree did increases in average yields per hectare affect the total output of Cassava in Africa from 1961 to 2020? ii) To what degree did increases in area harvested affect the total cassava output of Cassava in Africa from 1961 to 2020?

This paper comprises five sections. This current section introduces the work, and the second section provides an overview of the literature. Section three contains the sources and description of the data, the methodology and the econometric model. Section four contains the results and discussions, and section five concludes the paper.

2. Cassava production trends, issues and production function

2.1. Cassava production trend in Africa

Cassava is both a subsistence and cash crop and is well adapted to African farming systems [29]. According to Balagopalan et al.[4], tuberous crops are a critical category of crops in the tropics, and cassava is one of the most frequently farmed tuber crops, serving as the primary staple food for more than 300 million people in the tropics. Approximately 65% of the overall output is consumed, with the remainder used in the feed and industrial sectors. Africa is the biggest cassava-producing continent in the world. It produced around 40% of the world's cassava output in the 1960s. Three decades later, in the early 1990s, its production has grown to half of the world's total production [19]. Between 1965 and 1995, Africa's cassava production grew annually by 2.9% and added 45 million tonnes, moving from 35 million in 1965 to more than 80 million tonnes in 1995. During the period, cassava and population growth rates on the continent were similar; hence, the average per capita production remained the same. However, production grew by around 3.8% in the decade after this, driving up per capita production [17]. The crop is grown in about 99 countries globally [22] and in 40 countries on the African continent [30]. The main cassava-producing countries in Africa, from the biggest to smallest producers, and their percentages of African and World production for 2019 are shown in Table 1.

2.2. Cassava production issues in africa

Crop production in Africa is predominantly carried out by smallholder farmers [31,32]. This group of farmers continue to operate in agricultural systems characterised by low inputs and low outputs. The most significant factor affecting the profitability and competitiveness of smallholder producers is their low yield. In addition, many smallholder producers do not have the capabilities suited to the complexities of the agricultural industry. Many lack the necessary talents and resources for commercial agriculture. Over eighty percent of smallholder producers continue to produce at subsistence levels [32].

Cassava production in Africa is currently characterised by a wide gap between potential and actual cassava yields per hectare and portrays an inability to embrace sustainable intensification of cassava production. The crop's potential yield where high yield, pest, and disease-resistant varieties have been grown coupled with good agronomy practices is six times the actual yield. Under optimal conditions, the potential cassava yields per hectare could be as high as 80 tons/ha [33]. Smallholder farmers predominantly grow cassava in Africa [5],[33]. Over ninety percent of output occurs on small farms. As such, its production is plagued by low yields caused, amongst other things, by farming on marginal lands, lack of access to finance, lack of proper crop management skills, dependence on rainfeed farming, and an underdeveloped value chain [5]. Studies and researchers continue to reflect on Africa's cassava yield situation. Kollo [34] posited that Africa's low cassava productivity reflects the use of rudimentary farming tools and equipment, the near lack of mechanisation, and the lack of market options. Philip et al. [35] argue that continuing low yield can be attributed, amongst other things, to low soil fertility and lack of interventions like applying organic and or inorganic fertilisers to boost yields. Also, critical factors like soil heat levels, humidity, soil erosion, poor soil nutrients, and poor cultural practices affect cassava yield negatively [36]. Poor stem quality, pests and diseases are also obstacles to yield improvement [18]. Despite breakthroughs in cassava disease management and new high-yield cassava varieties development, yields per hectare have not increased substantially. The average cassava yield in Africa is 8.9 tons/ha, ranging between 5.7 and 10.5 tonnes from 1961 to 2019 [22].

Table 1
List of Cassava Producing Countries in Africa from biggest to smallest producer and their percentage of African and World production for 2019.

Position	Country	*Output (tonnes)*	% of Africa Prod.	% of world Prod.
1	Nigeria	59,411,510	30.8137	19.4993
2	The Democratic Republic of the Congo	40,050,112	20.8483	13.1931
3	Ghana	22,447,635	11.6853	7.3946
4	Angola	9,000,432	4.6852	2.9649
5	United Republic of Tanzania	8,184,093	4.2603	2.6960
6	Cameroon	6,092,549	3.1715	2.0070
7	Malawi	5,667,887	2.9505	1.8671
8	Côte d'Ivoire	5,238,244	2.7268	1.7256
9	Sierra Leone	4,588,612	2.3886	1.5116
10	Zambia	4,036,584	2.1013	1.3297
11	Mozambique	3,987,446	2.0757	1.3135
12	Benin	3,894,777	2.0275	1.2830
13	Madagascar	2,913,862	1.5168	0.9599
14	Uganda	2,841,625	1.4792	0.9361
15	Burundi	2,408,958	1.2540	0.7935
16	Guinea	2,145,484	1.1168	0.7068
17	Congo	1,457,028	0.7585	0.4800
18	Rwanda	1,181,825	0.6152	0.3893
19	Togo	1,117,880	0.5819	0.3682
20	Senegal	1,030,592	0.5365	0.3395
21	Kenya	970,587	0.5052	0.3197
22	Central African Republic	730,362	0.3802	0.2406
23	South Sudan	572,531	0.2980	0.1886
24	Liberia	558,222	0.2906	0.1839
25	Niger	513,671	0.2674	0.1692
26	Gabon	337,209	0.1755	0.1111
27	Chad	296,976	0.1546	0.0978
28	Zimbabwe	253,835	0.1321	0.0836
29	Somalia	93,717	0.0488	0.0309
30	Equatorial Guinea	79,646	0.0415	0.0262
31	Mali	70,312	0.0366	0.0232
32	Comoros	65,071	0.0339	0.0214
33	Guinea-Bissau	56,073	0.0292	0.0185
34	Gambia	13,174	0.0069	0.0043
35	Cabo Verde	5124	0.0027	0.0017
36	Burkina Faso	4046	0.0021	0.0013
37	Sao Tome and Principe	1384	0.0007	0.0005
38	Mauritius	715	0.0004	0.0002
39	Seychelles	236	0.0001	0.0001

Source: FAO [22] – FAOSTAT: Data, Table author's construction

2.3. Analysis of the cassava production function in Africa

Crop production is contingent on the availability of arable land and influenced by yields, macroeconomic uncertainties, and consumption habits; it also significantly impacts agricultural commodities' pricing. The significance of agricultural production is proportional to harvested areas, returns per hectare (yields), and output volumes [37]. The quantity produced of any crop depends on the area harvested and yield per hectare; the two factors are the drivers of any movement in agricultural output [37–41]. In most instances, yield numbers are generated by dividing the production data by the harvested area data. The yield harvested on a farm relies on various variables, including the crop's genetic potential, the quantity of sunshine, water, and nutrients taken by the crop, and the presence of pests. Crop yield is quantified in tonnes per hectare, thousand hectares, and thousands of tonnes [37]. The area harvested is the share of the cultivated land where matured crops are gathered. It is calculated as the cultivated area minus the area not harvested. The area not harvested is the area planted but where matured crops were not gathered due to crop loss for various reasons [42]. Pfeiffer [43] posited that aggregate productivity is the quantity of output that can be achieved from a given level of inputs in a sector or economy. As a result, gains in productivity occur when output from a given level of inputs rises. This tendency may be attributed to advances in the technical efficiency with which inputs are employed, additional human capital, and technological advancements that enable more output to be created. Per FAO [44], elements like water, seed types, fertiliser usage, usage of pesticides and insecticides, mechanisation and labour inputs are embedded in the area harvested, and yields mix.

3. Data and methodology

3.1. Data source and description

The information for the study is based on secondary data obtained from FAOSTAT - the United Nations' Food and Agriculture Organisation (FAO) data website. The data consists of annual cassava data for the 60 years 1961–2020 on total output, yield variability, area harvested, consumer price index and temperature changes for 37 African countries. There are no missing data, and the data is in panel form. The data was analysed using tables, charts, Spearman's correlation, and random effects regression to examine the nature of the relationship between the variables of interest. The dependent variable is the total cassava produced (tonnes) in the relevant country. The independent variables are the annual area harvested (hectares) and yield variability per hectare (tonnes), consumer price index (percentage), and temperature changes (degree centigrade) in the relevant countries from 1961 to 2020. Yield variability is a variable that is obtained from the departure from the mean cassava yield per hectare. Variability in agricultural yields from one growing season to the next or from one section of a farm to another is measured by yield variability. It is estimated as the standard variation of crop production per hectare across various agricultural regions or growing seasons [45,46]. The variables were selected based on the objectives of the work to investigate the specific influence of area harvested and variability of average yield per hectare on cassava production increases in the period under focus. To answer the research questions of (i) what is the contribution of increases in average yields per hectare to increases in cassava production in Africa from 1961 to 2020? (ii) what is the contribution of increases in area harvested to increases in cassava production in Africa?

3.2. Methodology

3.2.1. Preliminary statistics and model selection

This work uses Spearson's coefficient correlation, as some variables are skewed and nonlinear, as shown by the skewness test and scatterplot. Spearman's coefficient examines the monotonic relationships between variables. It is suitable in situations with extreme outliers and where one or both variables are skewed or ordinal [47–50].

To select the model best suited to this work between the pooled ordinary least squares (POLS), the random and fixed effects regression models. I first perform the Breusch and Pagan test [51], then the Chow test [51,55] and lastly, the Hausmann test [52]. Step 1, I perform the Breusch and Pagan Lagrangian multiplier test for random effects. The test is used to determine whether the model contains random effects. The Breusch–Pagan test checks for heteroskedasticity in a regression model [53,54]. The presence of heteroskedasticity indicates that the residual or error term variance is constant in a regression model. In such a situation, the error term exhibits a slight variation in response to changes in the independent variables. Here, the null hypothesis is that there are no random effects, and the alternative hypothesis is that there are random effects. The random effects regression model is selected where the p-value of chi2 is significant <0.05, and the simple pooled OLS is selected where the null hypothesis is not rejected [53]. The result returned a chi2 of 10673.14 and a significant p-value of 0.0000. Hence, we reject the null hypothesis and temporarily conclude that the random-effects model is the more appropriate model for our regression (see Table 2).

Table 2
Breusch and Pagan (1979) LM test for random effects estimates results.

	Coef.
Chi-square test value	10673.14
P-value	0.0000

Table 3
Chow, G.C. (1960) Chow's structural change test results.

	Coef.
Chow Test	2.51
P > F(294, 1877) =	0.0000

Table 4
Hausman (1978) specification test.

	Coef.
Chi-square test value	0.55
P-value	0.9073

Table 5
Variance inflation factor (VIF).

Variable VIF	1/VIF	
area harvested	1.02	0.977814
yield variability	1.1	0.907572
consumer price index	1.19	0.843251
temperature changes	1.1	0.907731
Mean VIF	1.1	

In step 2, I perform the Chow test to check test for structural change or not in the relationship between the dependent and independent variables [55,56]. The Chow test compares the sum of squared residuals from the two models to determine whether a structural break in the data justifies using the fixed effects regression instead of the pooled OLS regression [56]. See the Chow test result in Table 3.

Based on the Chow test results, the null hypothesis (Ho) is that there is no structural change in the data. However, the p-value of the Chow test is less than the significance level (0.05), which means we can reject the null hypothesis and conclude that there is evidence of a structural change in the data. In this case, we choose the fixed effect regression instead of the pooled OLS regression because the fixed effect model accounts for unobserved heterogeneity across countries, which may be an important source of the structural change detected by the Chow test.

Step 3: Here, I performed the Hausman test to select the more appropriate regression method between the fixed and random effects regression. The random-effects regression is the choice model (null hypothesis): it specifies that the model's unique errors and regressors are not correlated. The fixed-effects model is the alternative hypothesis and indicates a correlation between the model's unique errors and regressors [52],[57],[58]. The Hausman test returned a chi2 of 0.55 and a p-value of 0.9073 (see Table 4). Hence, we fail to reject the null hypothesis that the model's unique errors and regressors are not correlated. Consequently, we provisionally select the random-effects model.

Furthermore, the variance inflation factor (VIF) was used to test for multicollinearity in multiple regression analysis by measuring how much the variance of the estimated regression coefficient increases when the predictor variables are highly correlated. The results show no significant multicollinearity among the independent variables in the regression model. The VIF values for all the variables are close to 1, which suggests that there is little to no correlation among them. Overall, the mean VIF for all the variables is 1.10, confirming no significant multicollinearity among the predictors in the regression model. See Table 5.

3.2.2. Specification of the model

The model for the empirical analysis is shown in equation (1)

$$Y_{it} = \varphi + \psi X'_{it} + e, i = 1, 2, ..., I; \ t = 1, 2, ..., T \tag{1}$$

Where Y is the dependent variable (annual cassava output), φ is the constant term, X' is the covariate of the independent variables with the coefficient ψ, e is the error term that captures other independent variables not included in the analysis. Similarly, in the model, ($i =$ 1,2,...,I) *and* $t(t = 1, 2, ..., T)$, capture the entities and time dimension of the study. Entity ($i = (1, \ldots, I)$ captures the 37 African countries included in the model.

Table 6
Descriptive statistics – Africa.

N = 2220					
Variables	Obs.	Min	Max	Mean	SD
Production (tonnes)	2220	75	60,001,531	2,294,115	6,178,857
Area harvested (ha)	2220	3	7,737,846	283,704	691,075
Yield variability (per ha)	2220	−5.08	28.52	2.92	4.03
Consumer price index	2220	0.99	6818.69	306.12	543.04
Temperature Changes ^{0}C	2176	−0.75	2.71	0.51	0.52

4. Results and discussion

4.1. Descriptive statistics

4.1.1. Summary statistics – overview of Africa

Table 6 contains the summary statistics for the variables for the 37 African countries under investigation. Nigeria accounted for the largest maximum yield of around 60 million tonnes and the largest area harvested of 7.7 million hectares in the continent in the 60 years 1961–2020 [22]. Zambia achieved the highest yield of 34.85 tonnes/ha achieved in the same period. Mauritius had the lowest yield and area harvested for the period of 75 tonnes and 3 ha, respectively. The mean production and standard deviation of around 2.29 million and 6.18 million for the period show that cassava production in most African countries is either below the mean or a couple of million tonnes above the mean. Outlier countries like Nigeria, DR Congo, Ghana, Angola, and Tanzania, with production levels far above the mean production, account for the majority of the production on the continent [22,59]. These countries were responsible for over 72% of the cassava produced in Africa in 2019 [22].

A maximum and minimum yield variability of 28.5 and −5.1 tonnes occurred in Zambia and Burkina Faso. This indicates a wide yield per hectare variation amongst the countries with the highest and lowest yield variability. Additionally, the minimum yield variability indicates that Burkina Faso had the highest fall in yield per hectare in a year during the period under review. The mean and standard deviation of yield variability was 2.92 and 4.03 tonnes, indicating that the average change in yield/ha was 2.92 tonnes. The yield variability in many countries is clustered just above the mean yield. The consumer price index ranged from 0.99% in Burkina Faso to 6818.69% in Sierra Leone. The mean CPI and standard deviation of 306% and 543% show that the CPI in many other countries is low and clusters around the mean compared to that obtained in Sierra Leone. The maximum temperature change on the continent was about 2.71° centigrade recorded in Niger Republic, and the minimum is −0.75 in Nigeria. The mean temperature change is 0.51, and the standard deviation is 0.52° centigrade. These values revealed relatively small temperature fluctuations and a relatively stable temperature pattern.

4.1.2. Summary statistics – cassava-producing regions Within Africa

Table 7 contains the descriptive statistics for the three cassava-growing regions in Africa: East, Middle, and West Africa. East Africa had the smallest maximum output of the three subregions in the 60 years under review. Tanzania's output of 8.3 m tonnes in 2018 is the largest ever recorded in East Africa. Amongst the subregions, West Africa has the highest production output in a country in a particular year in the period under review – produced by Nigeria. The country's cassava output for 2020 was around 60 million tonnes, making it the largest cassava output achieved in the world by any country [17]. Also, the country is the biggest cassava producer in the

Table 7
Descriptive statistics for East, Middle and West Africa.

	Obs	Min	Max	Mean	SD
East Africa					
Production (tonnes)	840	75	8,372,217	1,355,964	1,853,759
Area harvested (ha)	840	3	2,094,501	206,450	300,046
Yield variability (per ha)	840	−3.35	28.52	3.43	4.27
Consumer price index	840	24.51	3985.54	294.83	471.04
Temperature changes ^{0}C	807	0.4	0.5	−0.67	1.94
Middle Africa					
Production (tonnes)	540	1200	41,014,256	2,913,890	6,408,544
Area harvested (ha)	540	138	5,036,492	388,896	786,763
Yield variability (per ha)	540	−3.53	12.1	1.65	3.21
Consumer price index	540	60	2481.26	263.25	279.07
Temperature changes ^{0}C	533	−0.42	1.98	0.46	0.49
West Africa					
Production (tonnes)	840	235	60,001,531	2,833,838	8,345,248
Area harvested (ha)	840	50	7,737,846	293,334	872,388
Yield variability (per ha)	840	−5.079	23.49	3.24	4.1
Consumer price index	840	0.99	6818.69	344.96	710.35
Temperature changes ^{0}C	836	−75	2.7	0.64	0.57

world [5],[21],[22]. Middle Africa is the subregion with the second-largest maximum output. During the review period, DR Congo's output of 41 million tonnes in 2020 was the largest cassava ever recorded in Middle Africa [22].

Cassava production has benefitted from government and private sector intervention in several African countries, especially Ghana and Nigeria. The Presidential Initiative on Cassava (PIC) in Ghana started in 2001, and Nigeria's PIC started in 2002. The main aspect of both PICs was to develop the cassava value chain by expanding cassava production, processing and marketing and creating a market for processed products [60]. The PICs stimulated the development and introduction of improved high-yield and pest and disease-resistant cassava varieties. Also, it encouraged private sector participation, especially in the aspect of the local fabrication of cassava processing machines and equipment [60],[61]. According to Donkor et al. [61], Nigeria's PCI led to increased cassava output in the country. Furthermore, research has shown that the adoption rate of improved varieties of cassava is slow but improving in Sub-Saharan African countries like Nigeria, Ghana, Zambia, Tanzania, Uganda and Sierra Leone [62–69]. However, the adoption rate in Nigeria is higher than observed in these other countries [61]. Kollo [34] opines that West Africa's cassava output forms a significant portion of the world's total production, although yield per hectare is one of the lowest at 10–12 tonnes per hectare.

There is also the Cassava: Adding Value for Africa (C: AVA) project that was aimed at High Quality Cassava Flour (HQCF) value chain development in Ghana, Tanzania, Uganda, Nigeria and Malawi. The project was funded by a grant from the Bill & Melinda Gates Foundation through the University of Greenwich [70]. The first phase of the project took place from 2008 to 2014, and the second phase started in 2015 and ended in 2019. The project involved the training of farmers on farming techniques, the introduction of new cassava varieties, the development of local technology and equipment for cassava processing, training on how to ensure quality control, identifying markets, and connecting value chain actors, and business support [70–72]. The programs were highly successful, and the countries benefitted immensely [70],[71],[73].

West Africa had the highest amount of cassava area harvested in a country in a year in the period under review of 7.7 million hectares; it was around 5 million hectares in middle Africa and 2.1 million hectares in East Africa. Also, the minimum area harvested in a year in a country in the period was 3, 138 and 50 ha, respectively, for East, Middle and West Africa. East Africa's mean and standard deviation of area harvested of 206,45 and 300,046 indicates a cluster around the mean, while those of Middle Africa (388,896 and 786,763) and West Africa (293,334 and 872,388) are more dispersed in comparison. This means that the cassava area harvested in East Africa is smaller compared to the two other regions.

East Africa has a greater yield variability compared to the other two regions, with a minimum of −3.35 and a maximum of 28.52. The minimum and maximum yield variability in Middle and West Africa are (−3.5 and 12.1) and (−5.1 and 23.5). The biggest positive change in yield happened in East Africa, followed by West Africa, and the increase in yield ever recorded in the period under review Middle Africa Here, the highest is in East Africa, followed by West Africa, and Middle Africa has the lowest maximum yield achieved in a country in a particular year. Also, compared to the other regions, West Africa has the biggest minimum yield variability. This is indicative of a higher yield level compared to the other two regions.

The maximum consumer price index in West Africa of 6818.69 is higher than those of the other two regions: it was 3985.54 for East Africa and 2481.26 for Middle Africa. This indicates that the biggest price change occurred in West Africa compared to Middle and East Africa. The minimum CPI in West Africa is 0.99, in Middle Africa 60 and in East Africa 24.51, showing that the smallest change in price occurred in West Africa in the period. The mean and standard deviation are West Africa (344.96 and 710.35), Middle Africa (263.25 and 279.07) and East Africa (294.83 and 471.04). This shows that West Africa has the highest price change on average compared to the other regions in the period. The ruling market price and expectation of future rise or deep in price are critical to the level of demand and supply.

Compared to the other two regions, West Africa has the highest maximum temperature change in the period under review of 2.7 °C. East and Middle Africa's maximum temperature change was 0.5 °C and 1.98 °C. The maximum temperature change in West Africa is four times higher compared to the maximum temperature change in East Africa and is around 36% higher than the maximum temperature change in Middle Africa in the period under review. Cassava grows well in temperate regions of the world because it grows well where there is moderate rain and there is ample sunshine [74].

Interestingly, East Africa has the highest variability per hectare in a country in a particular year, followed by West Africa, while Middle Africa trails. East Africa seems to be doing better than the other two regions, looking at the production, area harvested, and yield variability per hectare mix.

See a list of African cassava-producing countries and their respective regions within the continent in Appendix 1.

4.1.3. *Descriptive statistics - cassava production in Africa*

World and Regional Cassava Production 2000 to 2019.

Table 8 presents the world and regional cassava production from 2000 to 2019. It shows the regional percentage contribution to the world's output and the percentage change in production between 2000 and 2019. The world's cassava production grew by around 128 million tonnes between 2000 and 2019. Africa's cassava output grew by approximately 97 million tonnes in the same period. The implication is that 75.8% of the increases in world cassava output for the period occurred in Africa. The world's cassava production increased by 72.6% during the period, and Africa's production increased by 101.3%. Furthermore, it was only Africa's percentage share of the world's production that increased among the regions looking at 2000 and 2019. According to Clayton [33], the world's cassava output has increased tremendously since the year 2000. The expanding market for dried cassava chips, animal feeds, industrial use in Asia and rising urban demand for cassava derivatives in Africa drove the production increases.

Table 9 presents the cassava production in Nigeria, the Democratic Republic of Congo, and Ghana for 2000 and 2019 and details the increase/decrease in output and the percentage change in output between 2000 and 2019.

Interestingly, the worldwide increases in cassava production between 2000 and 2019 were driven by a remarkable increase in

Table 8
Regional and World Cassava production in 2000 and 2019 and their % Contribution to World's Production and % Change in Prod. Between 2000 and 2019.

Regions	Production (tonnes) *2000 (A)*	% of World Production 2000	Production (tonnes) *2019 (B)*	% of World Production 2019	*Increase/Decrease in Prod. (2000–2019)* (B-A)	*% Change in Prod.*
Africa	95,410,925	54.26	192,102,224	63.28	96,691,299	101.3
Americas	30,793,002	17.51	26,108,349	8.60	−4,684,653	−15.2
Caribbean	910,756	0.52	1,511,759	0.50	601,003	66.0
Asia	49,458,536	28.13	85,102,568	28.03	35,644,032	72.1
Oceania	182,275	0.10	255,673	0.08	73,398	40.3
World	175,844,738		303,568,814		127,724,076	72.6

Source: Computed by the author using FAOSTAT Data
Major Cassava Production Changes in Africa (2000–2019)

Table 9
Cassava production in Nigeria, Democratic Republic of Congo, and Ghana for 2000 and 2019, the increase/decrease in production and the percentage change in output between 2000 and 2019.

Country	*Production (tonnes) 2000 (A)*	*Production (tonnes) 2019 (B)*	*Increase/Decrease in Prod. (2000–2019) (B) – (A)*	*% Change in Prod.*	*% Contribution to Africa's increase in production (2000–2019)*
Nigeria	32,010,000	59,193,708	27,183,708	184.9	28.3
Congo, Dem. Rep.	15,959,000	40,050,112	24,091,112	250.9	25.1
Ghana	8,106,800	22,447,635	14,340,835	276.8	14.9

Source: Computed by the author using FAOSTAT Data

output in Nigeria, the Democratic Republic of Congo, and Ghana. In the 19 years from 2000 to 2019, Ghana's cassava production increased by around 277%, the Democratic Republic of Congo's output increased by about 251%, and Nigeria's production increased by an estimated 185% [22]. The three countries accounted for 68.3% of the total increase in cassava production in Africa and 51.3% of the total increase in world cassava production. During the period, the Democratic Republic of Congo's cassava production increased from 15.96 million to 40.05 million tonnes, and Ghana's output increased from 8.1 million to 22.45 million. Nigeria's production grew from 32 million in 2000 to 59.19 million tonnes in 2019. Among these countries, Nigeria's increase in production was phenomenal. It expanded its production by 27,465,202 tonnes, a whopping 36.9% of the gains in Africa and 26.8% of the rise in world output [22].

Other countries like Sierra Leone, Senegal, Zambia, Mali, Mauritius, Burundi, Cameroon, Niger, Guinea, Cote d'Ivoire, Kenya, Angola, and Malawi increased their cassava production by more than 200% between 2000 and 2019. See Table 10.

Nweke [19]argues that two factors drive the significant increases in cassava production in Africa. The first is the increasing demand for and consumption of cheap, high-calorie foods. The second is that, especially in Ghana and Nigeria, the availability of improved high-yield cassava and good farming practices has led to improved yields. Also, Balagopalan et al. [4] posited that the typical traditional yield of cassava is between 5 and 12 tons/ha. However, where high-yield

varieties are cultivated with good agronomy practice; yields could rise to between 40 and 60 tons/ha. Fig. 1 below reflects how

Table 10
African countries with production increases of more than 200% between 2000 and 2019.

	Country	*Production (tonnes) 2000 (A)*	*Production (tonnes) 2019 (B)*	*Increase/Decrease in Prod. (2000–2019) (B) – (A)*	*% Change in Prod.*	*% Contribution to Africa's increase in production (2000–2019)*
1	Sierra Leone	314,400	4,588,612	4,274,212	1459.5	4.44
2	Senegal	132,859	1,030,592	897,733	775.7	0.93
3	Zambia	815,248	4,036,584	3,221,336	495.1	3.35
4	Mali	14,787	70,312	55,525	475.5	0.06
5	Mauritius	151	715	564	473.5	0.00
6	Burundi	656,656	2,408,958	1,752,302	366.9	1.82
7	Cameroon	1,918,300	6,092,549	4,174,249	317.6	4.34
8	Niger	164,515	513,671	349,156	312.2	0.36
9	Guinea	845,488	2,145,484	1,299,996	253.8	1.35
10	Cote d'Ivoire	2,100,354	5,238,244	3,137,890	249.4	3.27
11	Kenya	418,621	970,587	551,966	231.9	0.57
12	Angola	4,433,026	9,000,432	4,567,406	203.0	4.75
13	Malawi	2,794,617	5,667,887	2,873,270	202.8	2.99

Source: Computed by the author using FAOSTAT Data

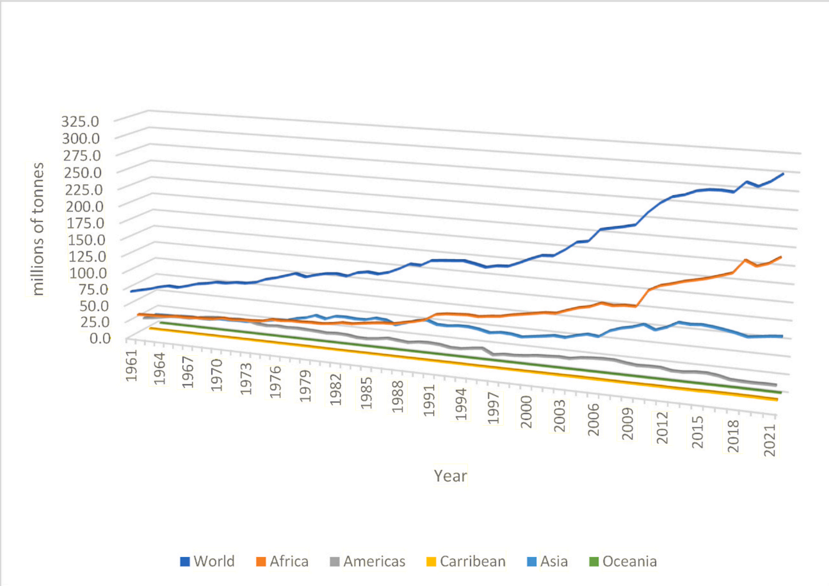

Fig. 1. World and regional cassava production in tonnes (1961–2020). Source: Computed by the author using FAOSTAT Data

growth in African cassava output has majorly propelled worldwide increases in cassava production.

4.1.4. *Descriptive statistics - cassava area harvested in Africa*

Fig. 2 presents the world and regional cassava area harvested in millions of hectares from 1961 to 2020. The world and Africa area harvested followed the same trajectory, indicating that increases in the area harvested in Africa are a major driver of the increases in the world area harvested for cassava. The continent's cassava harvested area was 5.6 million hectares in 1961. It grew to 7.1 million in 1980 and 11 million hectares in 2010. By 2019, it stood at 21.6 million hectares. Consequently, the harvested area on the continent grew at an average of 6.6% yearly from 1961 to 2019. Per Spencer [20], Africa's cassava area harvested has grown significantly since the 1960s. For example, with an annual growth rate of 2.9%, the area on the continent grew from 35 million tonnes in 1965 to more than 80 million tonnes in 1995. This increase mostly drove the tremendous increase in production witnessed worldwide. Improvement in yield had a lesser impact on total production [20].

Africa has witnessed the highest increase in its area harvested compared to other continents. The cassava area harvested in Africa increased by 16,072,494 ha between 1961 and 2019, whereas the area harvested in the Americas, Caribbean, Asia, and Oceania increased by 181,164, 1,637,205, and 6,004, respectively [22]. Since the 1960s, most of the additional land allocated to cassava production worldwide has been in Africa. Low cassava yields per hectare might be synonymous with the dominance of cassava farming in Africa by smallholder farmers who are constrained by many factors and have very little incentive to venture into large-scale production.

Key takeaways from Table 11 are that between 1961 and 2019, the world cassava area harvested increased by 17,896,910 ha, with Africa contributing (16,072,494 ha, 89.81%) of the increase and the Americas (181,164 ha, 1.01%), the Caribbean (153,543 ha, 0.86%), Asia (1,637,205 ha, 9.15%), Oceania (6047 ha, 0.03%). This indicates that growing area harvested in Africa has been instrumental in driving world increases in area harvested (see Table 12).

4.1.5. *Cassava yields in Africa*

Yield levels have improved in other continents over the years compared to the situation in Africa presently. For example, in 1984, the yield in Asia fluctuated around 8 tons/ha. It was just above 16 tons/ha in India, and in Africa and South America, it was between 5 and 9 tons/ha and 10–15 tons/ha [4]. However, Africa's 2020 yield of 8.6 tons/ha is below the world's average of 11.3 tons/ha. Also, it is below the average yield recorded in other top cassava-producing continents, like Asia and the Americas [22]. The average yield per hectare in countries on the continent is divergent. While some countries have been able to drive up yields per hectare, others have not significantly improved. Zambia, with an average 28 tons/ha yield in 2020, is the African country with the highest cassava per hectare yield. From 1961 to 2013, the country's top yield was 6.32 tons/ha, achieved in 1965. However, it was able to drive up yields per hectare from 9.7 tons/ha in 2014 to a peak of 38.4 tons/ha in 2018 [22]. Field research in Zambia reveals a 7–12 tons/ha yield much less than the attainable average between 30 and 50 tons/ha. Furthermore, farm yields vary considerably as the availability of labour, rich soil, proper and timely management, and well-timed harvesting lead to high yields [75]. In 2020, countries like Niger (29.8 tons/ha), Malawi (24.2 tons/ha), Ghana (23 tons/ha), Malawi (24.2 tons/ha), Mali (15.6 tons/ha), Cameroon (14.8 tons/ha) and Mauritius (12.4 tons/ha) were some of the countries with highest per hectare yields of cassava on the continent [22]. Top cassava-producing countries on the continent like Nigeria (7.8 tons/ha), DR Congo (8.1 tons/ha), Angola (9.6 tons/ha), and the United

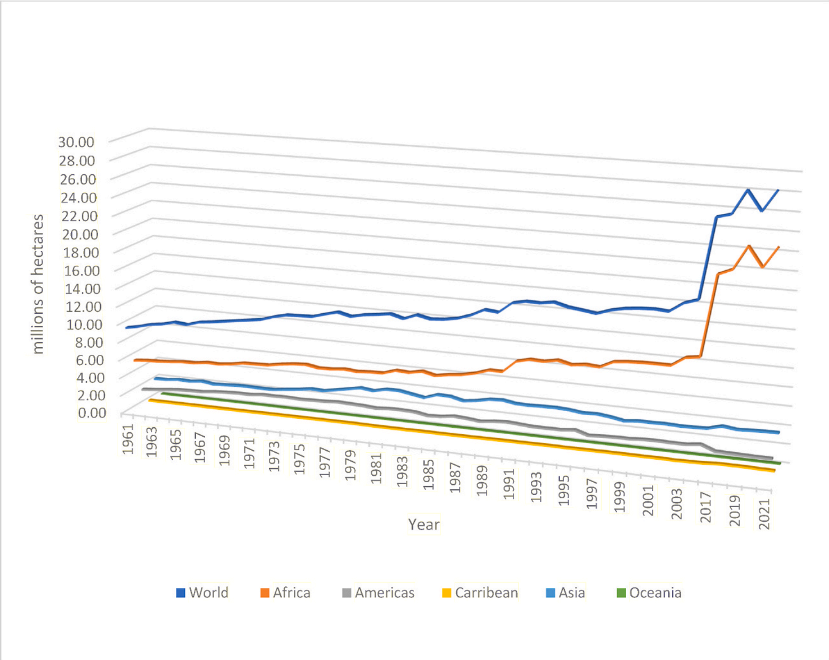

Fig. 2. World and regional cassava area harvested in millions of hectares (1961–2020). Source: Computed by the author using FAOSTAT Data

Table 11
Cassava Area Harvested in regions of the world for 1961and 2019 and their % of World Harvested Area and % Change in Harvested area.

	World	Africa	Americas	Caribbean	Asia	Oceania
Harvested Area (1961) - (a)	9,623,133	5,564,040	1,815,514	118,701	2,228,843	14,736
% Contribution to Worlds Harvested Area (1961)	–	57.82	18.87	1.23	23.16	0.15
Harvested area (2019) - (b)	27,520,043	21,636,534	1,996,678	272,244	3,866,048	20,783
% Contribution to the world's Harvested Area (2019)	–	78.62	7.26	0.99	14.05	0.08
Increase/Decrease in H. Area Prod. (1961–2019) (b) – (a)	17,896,910	16,072,494	181,164	153,543	1,637,205	6047

Source: Computed by the author using FAOSTAT Data

Table 12
Spearman's rank correlation coefficients.

Key
- rho
- Sig. level
- R^2

Variables	(1)	(2)	(3)	(4)	(5)
(1) production	1.000				
(2) area harvested	0.978***	1.000			
	0.000				
	0.956				
(3) yield variability	0.105***	−0.063***	1.000		
	0.000	0.000			
	0.011	0.003			
(4) consumer price index	0.525***	0.456***	0.251***	1.000	
	0.000	0.000	0.000		
	0.276	0.208	0.063		
(5) Temperature Changes	0.134***	0.09***	0.07***	0.402***	1.000
	0.000	0.000	0.011	0.000	
	0.018	0.008	0.005	0.162	

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ indicate 5%,1%, 0.01% significance level.

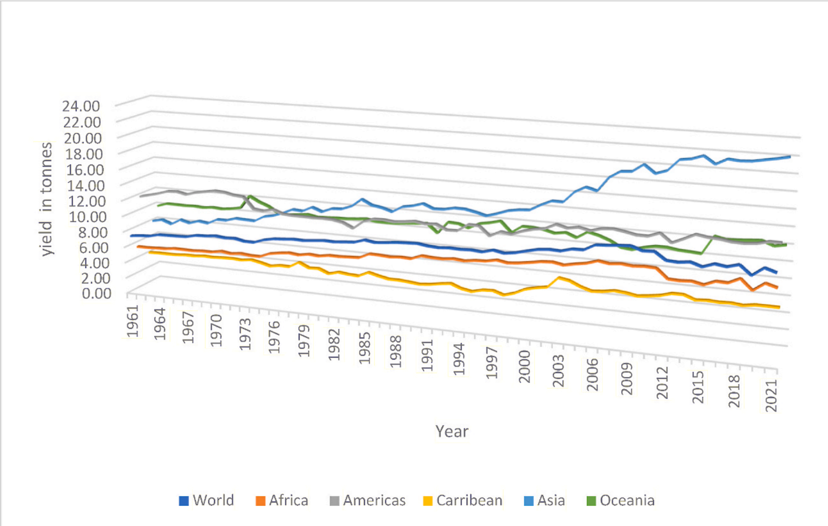

Fig. 3. Yield per hectare - world and the continental trends (1961–2020). Source: Computed by the author using FAOSTAT Data

Republic of Tanzania (7.3 tons/ha) - 2020 are still battling with yields low yields [22]. See Fig. 3 for details of the world and regional average yield per hectare from 1961 to 2020.

Spencer [78] explained that smallholder farms produce more than 90% of Africa's cassava. Small farmers use small, imported hand tools, and medium and large-scale farms use machinery like tractors and chemical fertilisers and herbicides.

4.2. Results of Spearson's correlation Africa

The link between production, area harvested, yield variability, consumer price index and temperature changes was evaluated using Spearman's correlation analysis (Table 12). The results revealed a statistically significant positive association between production and area harvested area (rho = 0.978, p = 0.000). The size of this association is large, and the square of the correlation coefficients showed that 95.6% of the variance in total output over the 60 years 1961–2020 was explained by increases in harvested area. The relationship between total production and yield variability was statistically significant as rho = 0.105, p = 0.000. The correlation coefficient indicated that only 1.1% of the variance in the total production could be attributed to changes in yields per hectare in the period under review. The relationship between total production and consumer price index is statistically significant as rho = 0.525, p = 0.000. The correlation coefficient indicated that about 27.6% of the variance in the total production could be attributed to changes in prices. Also, the relationship between total production and temperature changes is statistically significant as rho = 0.134, p = 0.000. The correlation coefficient indicated that around 1.8% of the variance in the total production could be attributed to changes in temperature.

In summary, the above results showed a positive relationship between production and all independent variables. The variation in output over the period under review can be largely attributable to increases in the area harvested. As the area harvested increases, total output has been growing in Africa. Yield variability per hectare had but a slight influence on the variation in production. Price changes also had some significant influence on production, while temperature change has but a little influence on production. The analysis suggests strong positive correlations between production and both the area harvested and the consumer price index. Hence, there is the possibility that, to some extent, price changes could explain why cassava production has been increasing, driven by increases in the area harvested without a corresponding increase in yield variability [76]. Also, temperature changes have some significant positive correlation with price changes. The takeaway is that cassava prices have always fluctuated with weather conditions. Prices are lower in the rainy season because many farmers harvest their cassava to give way for the cultivation of new crops. Also, it is easier to harvest the crop in the rainy because the soil is moist and softer compared to the dry season when it is much more difficult and costlier to harvest.

4.3. Regression model result - Africa

Based on the results from the Breusch and Pagan test, the Chow test and the Hausman specification test, the study made use of the random effect regression analysis, and the result is presented in Table 13.

The regression output above indicates that the coefficients of the independent variables (area harvested, yield variability, consumer price index and temperature changes) are statistically significant. The implication is that production is projected to increase by around 8.5 tonnes when the area harvested increases by 1 ha. Also, production is expected to increase by 176,056 tonnes when yield variability per hectare increases by 1 tonne. Furthermore, production is expected to increase by 231.6 tonnes when the consumer price index increases by 1%. Production will increase by 218,080 tonnes when temperature changes by 1°.

Table 13
Random effect estimates and results.

VARIABLES	Production
area_harvested	8.457***
	(0.0609)
yield_variability	176,056***
	(8640)
Consumer_price_index	231.6***
	(58.83)
Temperature_changes	218,080***
	(49,704)
Constant	−802,129***
	(159,065)
Observations	2176
Number of Countries	37
Chi-square	22,356.08
Prob > chi2	0.000
Goodness of fit statistics	
R-sq within	0.9089
R-sq between	0.9685
R-sq overall	0.9493

Standard errors in parentheses.
Note: *p < 0.05, **p < 0.01, ***p < 0.001 indicate 5%,1%, 0.01% significance level.

4.4. Regression model dummy result – Africa

Table 14 displays the regression results with dummy variables at area harvested, yield variability per hectare, consumer price index and temperature changes level above the respective mean level. Here, this work examines activities outside of the standard deviation of the variables. The slope for the area harvested dummy variable (ah_gtm) is positive and significant as (b = 1,425,728, s.e. = 395,411, p = 0.000). This implies that a 1-ha increase in the area harvested would lead to a greater increase in production in countries with more than the mean area harvested compared to those with mean and below the mean area harvested. Also, the slope for the yield variability dummy variable (yv_gtm) is positive and significant as (b = 1,122,808, s.e. = 74,376, p = 0.000). This implies that a 1-ha increase in yield variability would lead to a greater increase in production in countries with more than mean yield variability per hectare compared to those with mean and below the mean yield variability. The slope of the consumer price index dummy variable (cpi_gtm) is also positive and significant as (b = 517,524, s.e. = 81,279, p = 0.000). This implies a greater increase in production for countries with above CPI mean compared to their counterpart with mean and below mean CPI when a percentage point increase in the consumer price index occurs. The temperature changes dummy variable's (TemCC_gtm) slope is positive and significant as (b = 196,834, s.e. = 49,551, p = 0.000). This indicates a significant positive increase in production in countries with above mean temperature changes compared to

Table 14
Regression model dummy result – Africa.

VARIABLES	ah_gtm (1)	yv_gtm (2)	cpi_gtm (3)	TemCC_gtm (4)
area_harvested		8.445***	8.373***	8.475***
		(0.0633)	(0.0628)	(0.0598)
yield_variability	17,732		175,420***	177,034***
	(26,727)		(8116)	(8509)
consumer_price_index	1429***	496.7***		245.0***
	(187.7)	(57.60)		(57.70)
Temperature_changes	1,542,484***	199,573***	146,157***	
	(151,959)	(51,675)	(51,472)	
ah_gtm (1)	1,425,728 ***			
	(395,411)			
yv_gtm (2)		1,122,808 ***		
		(74,376)		
cpi_gtm (3)			517,524***	
			(81,279)	
TemCC_gtm (4)				196,834***
				(49,551)
Constant	708,575	−807,257***	−783,252***	−798,732***
	(631,017)	(155,504)	(155,983)	(156,452)
Observations	2176	2176	2176	2220
Number of countries	37	37	37	37

Standard errors in parentheses.
Note: *p < 0.05, **p < 0.01, ***p < 0.001 indicate 5%,1%, 0.01% significance level.

Table 15
Regression output for sub-regions within Africa.

VARIABLES	East Africa	Middle Africa	West Africa
area_harvested	3.149***	8.445***	8.640***
	(0.186)	(0.0767)	(0.0921)
yield_variability	107,287***	179,911***	164,270***
	(8080)	(15,339)	(17,423)
consumer_price_index	700.0***	1284***	232.1**
	(71.21)	(189.9)	(90.64)
Temperature_changes	198,202***	263,705***	268,832***
	(47,316)	(69,321)	(98,086)
Constant	40,254	−1.124e+06***	−485,354**
	(149,518)	(125,035)	(201,252)
Observations	807	533	836
Number of Countries	14	9	14
Chi-square	1528	15,584	9929
Prob > chi2	0.000	0.000	0.000
Goodness of fit statistics			
R-sq within	0.655	0.965	0.915
R-sq between	0.858	0.996	0.992
R-sq overall	0.745	0.985	0.962

Standard errors in parentheses.
Note: *p < 0.05, **p < 0.01, ***p < 0.001 indicate 5%,1%, 0.01% significance level.

their counterpart with mean and below mean temperature changes.

4.5. Regression output for sub-regions Within Africa

The sub-regions within Africa regression Table 15 examines heterogeneity in area harvested, yield variability, consumer price index and temperature changes among Africa's three main cassava-producing sub-regions. These are East, Middle and West Africa. West Africa (8.64 tonnes) makes better use of 1 additional hectare of area harvested than Middle Africa (8.45 tonnes) and East Africa (3.15 tonnes). Juxtaposing these coefficients of area harvested with the mean area harvested of the three subregions in Table 7, Middle Africa (388,896), East Africa (206,450) and West Africa (293,334). Suggests that changes in the area harvested have a stronger effect on cassava production in Middle Africa than in West and East Africa.

In terms of an increase in yield variability of 1 tonne per hectare - Middle Africa has the highest expected increase in total output of 179,911 tonnes, followed by West Africa's 164,270 tonnes. There is something amiss in East Africa, 107,287 tonnes, as the coefficient of area harvested is low compared to that of Middle and West Africa. Dr. Gichuki [26] observes that cassava yields in East Africa and Kenya are particularly low and rarely reach 10 tons/ha, not because of poor farm practices but due to the prevalence of Cassava Brown Streak Disease (CBSD) and Cassava Mosaic disease [25,26]. Fermont et al. [75,77], in their study involving 99 on-farm and 6 on-station trials in the East African countries of Uganda and Kenya, find that factors affecting cassava output differ greatly based on location and years. The primary stumbling block to high cassava yields is cassava cultivation on infertile soil, early water stress and sub-optimal weed management.

Middle Africa has the most significant change in production of 1284 tonnes when a one percent increase in consumer price index occurs; for East and West Africa, it is 700 and 232 tonnes, respectively. This implies that production is more price elastic in Middle Africa compared to the two other subregions. Cassava production/supply follows a normal supply curve; as such, as price rises, production increases. However, cassava production is plagued by seasonal price instability; for example, in Nigeria, price instability leads to a three to four-year cycle of production glut. Excess production drives down prices for around two years; in the third year, prices shoot up due to supply shortages [76]. Finally, a temperature change of 0.1° would lead to a 268,832-tonne increase in production in West Africa and a 263,705 and 198,202-tonne increase in production in Middle and East Africa.

4.6. Limitations of the study

This study has some limitations. First, the analysis relies on the accuracy and robustness of data that was obtained from FAOSTAT. The data on FAOSTAT is gathered from multiple sources using rigorous quality control procedures; however, its accuracy and consistency may be affected by differences in measurement and reporting practices across countries and other factors. Secondly, another limitation is that the work focuses explicitly on the interplay between area harvested and yield per hectare driving cassava production in Africa. However, I have endeavoured to identify and control for some key factors that may influence cassava production, like temperature and price changes; however, other unmeasured factors may contribute to yield changes. For example, the level of adoption of new cassava varieties, farming practices, pest and disease prevalence or changes in land use patterns could influence yield but are difficult to quantify and control for in this analysis. Thirdly, the study is limited by the availability of data over time. While there is data on cassava output, yield per hectare and area harvested from 1961 to 2020, there has been a lack of adequate and reliable data for many years regarding other variables that may influence cassava yields. These variables were not included, affecting the ability to discuss issues relating to these variables extensively and track trends relating to them. This creates opportunities for further study of these variables in relation to their effect on crop yield at the micro and country levels.

5. Conclusion and recommendation

The results suggest that the sustained increases in the area harvested was a major driver of the continued upsurges in cassava production between 1961 and 2020. During the period, land allocated to cassava production in Africa grew significantly and drove the worldwide increase in area harvested and total production. Interestingly, the production increases were driven majorly by cassava production activities in a few African countries. Also, price changes were an important driver of fluctuations in cassava production and area harvested as such price changes could explain to some extent why cassava production has been increasing, driven by increases in the area harvested without a corresponding increase in yield variability. Improvements in cassava yield induced by other factors were small and had a negligible effect on production growth. The yearly yield per hectare graph for the period shows modest growth. Compared to yield growth per hectare in other prominent cassava-growing regions worldwide, the per hectare yield in Africa is discouraging. However, this does not account for cases of significant in-country and across-country improvement in yield per hectare that have also driven significant increases in production in specific areas and countries.

Furthermore, there is no clear picture of a steady rise or fall in yields; instead, gains in certain years have been wiped out by deeps in other years. In contrast, output continued to increase due to the increasing allocation of land to cassava cultivation. In the long run, a sustained increasing allocation of land to cassava cultivation is unsustainable. It promotes deforestation, aggravates climate change, and leads to soil erosion, flooding, droughts, and loss of soil nutrients and biodiversity. Due to agricultural development, once tree- and thickly bush-covered landscapes in the South-West of Nigeria have become open fields, as was observed during recent fieldwork.

Also, East Africa has something amiss as its area harvested coefficient is lower than that of Middle and West Africa. The disparity could result from any combination of factors, including climate conditions, soil fertility, water quality, agronomy practices, crop diseases, insects, and weeds. However, it should be noted that the cassava value chain is more developed in certain countries and regions than in others.

Whereas potential cassava yields could be up to 80 tonnes per hectare, the average yield of 7.7 tonnes per hectare from 1961 to 2020 gives a cause for concern. This indicates a gap in translating gains made via the eradication of major cassava diseases and the production of new high-yield, disease, and pest-resistant varieties into smallholder cassava farming. Some smallholder cassava growers have adopted new high-yield varieties in some African countries, but yields have remained low and unencouraging. A further area for research could be why the adoption of new high-yield varieties by some farmers has not led to a significant per-hectare yield increase. Reasons for the persistent low yield could be poor farm practices, lack of finances, lack of a ready market, or risk; these areas need to be looked at critically.

The sustainable intensification of cassava production offers a pathway to increase absolute and per-hectare yields and farmers' income within current cassava lands while slowing down cassava cultivation-related deforestation. The government, research institutes, cassava farmers, processors, and other important players along the cassava value chain should come together to discuss issues affecting cassava yields. Insights from the relevant stakeholders will help identify the real issues that militate the increase in cassava yields per hectare. Farmers who are at the centre of the low-yield problem should be listened to, and their views and insights should be taken seriously.

Author contribution statement

Waidi Gbenro Adebayo: Conceived and designed the experiments; Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The author acknowledges the support of the Linkage Research Grant [REF 3.4–1147508-NGA-IP] awarded by the Alexander von Humboldt Foundation (AvH) for the research linkage project titled "Access to Land and Agricultural Value Chain: Female and Youth Engagement Discourse in Nigeria". Particular thanks go to the Centre for Economic Policy and Development Research (CEPDeR), Covenant University, for their support during the research stay abroad, where some of the groundwork for this paper was conducted. Special gratitude goes to Prof. Magdalene Silberberger and Prof. Evans Osabuohien for their invaluable guidance, insightful comments, and assistance in reviewing this work. Their expertise significantly enhanced this study, though any remaining errors are solely the author's responsibility.

Appendix

Appendix 1
Cassava-producing countries and their respective regions within Africa

S/No	East Africa	Middle Africa	West Africa
1	Burundi	1. Angola	1. Benin
2	Comoros	2. Cameroon	2. Burkina Faso
3	Kenya	3. The Central African Republic	3. Cabo Verde
4	Madagascar	4. Chad	4. Côte d'Ivoire
5	Malawi	5. Congo	5. The Gambia
6	Mauritius	6. DR Congo	6. Ghana
7	Mozambique	7. Equatorial Guinea	7. Guinea
8	Rwanda	8. Gabon	8. Liberia
9	Seychelles	9. Sao Tome and Principe	9. Mali
10	Somalia		10. Niger
11	Uganda		11. Nigeria
12	United Republic of Tanzania		12. Senegal
13	Zambia		13. Sierra Leone
14	Zimbabwe		14. Togo

Table constructed by the author.

References

[1] FAO & IFAD, The World Cassava Economy: Facts, Trends and Outlook, Food & Agriculture Organisation, Rome, 2000.
[2] E.R. Jansz, I. Uluwaduge, Biochemical aspects of cassava (Manihot esculenta Crantz) with special emphasis on cyanogenic glucosides-A review, J. Natl. Sci. Found. Sri Lanka 25 (1) (1997).
[3] B.N. Okigbo, Nutritional implications of projects giving high priority to the production of staples of low nutritive quality. In the case for cassava (Manihot esculenta, Crantz) in the humid tropics of West Africa, Food Nutr. Bull. 2 (1980).
[4] C. Balagopalan, G. Padmaja, S.K. Nanda, S.N. Moorthy, Cassava in Food, Feed, and Industry, CRC Press, 2018.
[5] W.G. Adebayo, M. Silberberger, Poverty reduction in Nigeria: can improving and the cassava value chain help?, in: The Palgrave Handbook of Agricultural and Rural Development in Africa Palgrave Macmillan, Geneva, 2020.
[6] S.H. Katz, W.W. Weaver, Cassava, in: Encyclopedia of Food and Culture, Schribner, New York, 2020. ISBN 0684805685, https://www.newworldencyclopedia.org/p/index.php?title=Cassava&oldid=1030031.
[7] A. Burns, R. Gleadow, J. Cliff, A. Zacarias, T. Cavagnaro, Cassava: the drought, war and famine crop in a changing world, Sustainability 2 (11) (2010) 3572–3607.
[8] IITA, Cassava in Tropical Africa: a Reference Manual, International Institute of Tropical Agriculture(IITA), Ibadan, 1990.
[9] W.O. Jones, Manioc in Africa, Manioc in Africa., 1959 ix + 315.
[10] C.E. Boyer, "A taste of cassava in Tanzania," NextGen , 14 10 [Online]. Available: https://www.nextgencassava.org/2019/09/26/a-taste-of-cassava-in-tanzania, 2019. (Accessed 16 March 2023).
[11] F.I. Nweke, "New Challenges in the Cassava Transformation in Nigeria and Ghana," in *Conference Paper No. 8. Paper Presented at the INVENT, IFPRI, NEPAD, CTA Conference*. Successes in African Agriculture, December 1 and 3, Pretoria, 2004.
[12] R. Bayitse, F. Tornyie, A.B. Bjerre, Cassava Cultivation, Processing and Potential Uses in Ghana. Handbook on Cassava, Nova Science Publishers, Inc, 2017, pp. 313–333.
[13] E.A. Duah, E. Parkes, R.O. Baah, A. Acquatey-Mensah, A.O. Danquah, P. Kirscht, M. Steiner-Asiedu, Consumption Trends of White Cassava and Consumer Perceptions of Yellow Cassava in Ghana, 2016.
[14] T. Sigüenza-Andrés, C. Gallego, M. Gómez, Can cassava improve the quality of gluten free breads? LWT 149 (2021), 111923.
[15] C. Dini, M.C. Doporto, S.Z. Viña, M.A. García, Cassava Flour and Starch as Differentiated Ingredients for Gluten Free Products. Cassava: Production, Nutritional Properties, and Health Effects, July 2017, 87-114,", 2014.
[16] A. Pasqualone, F. Caponio, C. Summo, V.M. Paradiso, G. Bottega, M.A. Pagani, Gluten-free bread making trials from cassava (Manihot esculenta Crantz) flour and sensory evaluation of the final product, Int. J. Food Prop. 13 (3) (2010) 562–573.
[17] R.J. Hillocks, Cassava in Africa, in: Cassava: Biology, Production and Utilization, CABI, Wallingford, 2002, p. 14.
[18] IITA, Cassava," 12 05 2021. [Online]. Available: https://www.iita.org/cropsnew/cassava/.
[19] F.I. Nweke, The cassava transformation in Africa, in: A Review of Cassava in Africa with Country Case Studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin, FAO and IFAD, Rome, 2005, pp. 1–66.
[20] D. Spencer, Cassava in Africa: past, present and future, in: Proceedings of the Validation Forum on the Global Cassava Development Strategy, 2005.
[21] E.S. Ikuemonisan, T.E. Mafimisebi, I. Ajibefun, K. Adenegan, Cassava production in Nigeria: trends, instability and decomposition analysis (1970–2018), Heliyon 6 (2020), e05089, 1-9, 2020.
[22] FAO, FAOSTAT (Crops), Food and Agricultural Organization of the United Nations, 2023.
[23] C. Nyirakanani, J.P. Bizimana, Y. Kwibuka, A. Nduwumuremyi, V.D. Bigirimana, C. Bucagu, L. Lassois, E. Malice, N. Gengler, S. Massart, C. Bragard, M. Habtu, Y. Brostaux, C. Thonar, H. Vanderschuren, Farmer and field survey in cassava-growing districts of Rwanda reveals key factors associated with cassava Brown Streak disease incidence and cassava productivity, Front. Sustain. Food Syst. 5 (2021), 699655.
[24] A.P. De Souza, L.N. Massenburg, D. Jaiswal, S. Cheng, R. Shekar, S.P. Long, Rooting for cassava: insights into photosynthesis and associated physiology as a route to improve yield potential, New Phytol. 213 (1) (2017) 50–65.
[25] S. Gichuki, Kenya Approves Disease-Resistant GMO Cassava, 25 06 2021 [Online]. Available: https://geneticliteracyproject.org/2021/06/25/kenya-approves-disease-resistant-gmo-cassava/.
[26] S. Gichuki, Interviewee, *Why We Need Disease Resistant Cassava Varieties*, 2020 *[Video]. YouTube.* [Interview]. 25 05.
[27] H.K. Gibbs, A.S. Ruesch, F. Achard, M. Clayton, P. Holmgren, N. Ramankutty, J. Foley, Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s, in: Proceedings of the National Academy of Sciences Sep 2010, 2010.

[28] United Nations, Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly on 6 July 2017, United Nations Organisation, 2017.
[29] S.K. Hahn, E.R. Terry, K. Leuschner, I.O. Akobundu, C. Okali, R. Lal, Cassava improvement in Africa, Field Crops Res. 2 (1979) 193–226.
[30] M.B. Solh, Preface, in: A Review of Cassava in Africa with Country Case Studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin, Rome, Italy, 2005, p. 66.
[31] B. Valk, "4 Ways Africa's Small Farmers Can Double Their Yield," 28 04, 2017 [Online]. Available: https://www.weforum.org/agenda/2017/04/4-ways-africa-farmers-can-double-yields/.
[32] B. Oyewole, Boosting Smallholder Farmers' Productivity to Feed Africa against the Looming Food Crisis.Keynote Address by Dr. Babafemi Oyewole CEO, Pan African Farmers Organization, Kigali, Rwanda.at AfDB Virtual Evaluation Week, 28-29 September 2022, African Development Bank, 2022.
[33] C. Clayton, "Foreward", in *Save And Grow: Cassava: a Guide to Sustainable Production Intensification*, Food and Agriculture Organization of the United Nations, Rome, 2013, p. 129.
[34] A. Kollo, Expert Says Africa Is Largest Producer of Cassava, but Lowest in Yields, TheGuardian, TheGuardian, 2016.
[35] T. Philip, D. Taylor, L. Sanni, R. Okechukwu, C. Ezedinma, M. Akoroda, J. Lemchi, P. Ilona, F. Ogbe, E. Okoro, A. Dixon, The Nigerian Cassava Industry Statistical Handbook, International Institute of Tropical Agriculture (IITA), Ibadan, 2005.
[36] IITA, Cassava in Tropical Africa: A Reference Manual, Ibadan, Nigeria, International Institute for Tropical Agriculture (IITA), 1990.
[37] OECD, Crop Production (Indicator), 2023, https://doi.org/10.1787/49a4e677-en. (Accessed 16 January 2023).
[38] E.E. Rezaei, G. Ghazaryan, R. Moradi, O. Dubovyk, S. Siebert, Crop harvested area, not yield, drives variability in crop production in Iran, Environ. Res. Lett. 16 (6) (2021), 064058.
[39] PWC, Transforming Nigeria's Agricultural Value Chain-A Case Study of the Cocoa, PricewaterhouseCoopers, 2017.
[40] T. Masuda, P.D. Goldsmith, World soybean production: area harvested, yield, and long-term projections, Int. Food Agribus. Manag. Rev. 12 (4) (2009) 143–161.
[41] A.C. Allem, Manihot esculenta is a native of the neotropics 71 (1987) 22–24.
[42] FAO, Indicators Definitions | CountrySTAT, 2023 [Online]. Available: https://www.fao.org/in-action/countrystat/news-and-events/events/training-material/indicators-definitions/en/. (Accessed 25 February 2023).
[43] L. Pfeiffer, Agricultural Productivity Growth in the Andean Community, 2004, pp. 4–21. No. 318-2016-9574.
[44] FAO, Estimation of Crop Area and Yield in Agricultural Statistics, 1982.
[45] T. Iizumi, N. Ramankutty, Changes in yield variability of major crops for 1981–2010 explained by climate change, Environ. Res. Lett. 11 (3) (2016), 034003.
[46] M.S. Kukal, S. Irmak, Climate-driven crop yield and yield variability and climate change impacts on the US Great Plains agricultural production, Sci. Rep. 8 (1) (2018) 1–18.
[47] P. Schober, C. Boer, L.A. Schwarte, Correlation coefficients: appropriate use and interpretation, Anesth. Analg. 126 (5) (2018) 1763–1768.
[48] N. O'Rourke, L. Hatcher, E.J. Stepanski, A Step-by-step Approach to Using SAS for Univariate & Multivariate Statistics, SAS institute, 2005.
[49] M. Bland, An Introduction to Medical Statistics, fourth ed., Oxford University Press, 2015, p. 427.
[50] A. Lehman, JMP for Basic Univariate and Multivariate Statistics: A Step-by-step Guide, Sas Inst., 2005.
[51] B. Baltagi, Econometric Analysis of Panel Data, third ed., John Wiley & Sons, Toronto, 2005.
[52] J. Hausman, Specification tests in econometrics, Econometrica 46 (1978) 1251–1272.
[53] T.S. Breusch, A.R. Pagan, A simple test for heteroscedasticity and random coefficient variation, Econometrica 47 (5) (1979) 1287–1294.
[54] B.H. Baltagi, L. Q, A Lagrange multiplier test for the error components model with incomplete panels, Econom. Rev. 9 (1990) 103–107.
[55] G. Chow, Tests of equality between sets of coefficients in two linear regressions, Econometrica 28 (1960) 591–605.
[56] D.N. Gujarati, Basic Econometrics, fourth ed., McGraw Hill, 2003.
[57] W.H. Greene, Econometric Analysis, sixth ed., Prentice-Hall, Upper Saddle River, N.J., 2008.
[58] O. Torres-Reyna, Panel Data Analysis Fixed and Random Effects Using Stata, Princeton University., 2007.
[59] Robb C., Ranking of countries that produce the most cassava (FAO), Beef2Live, 28 04 [Online]. Available: 2023. https://beef2live.com/story-ranking-countries-produce-cassava-fao-352-215805. (Accessed 1 April 2023).
[60] D. A, O. Sanogo, Presidential Initiatives on Cassava in Africa: Case Studies of Ghana and Nigeria, Malawi: IITANEPAD, 2008, p. 73.
[61] E. Donkor, S. Onakuse, J. Bogue, I. de Los Rios Carmenado, The impact of the presidential cassava initiative on cassava productivity in Nigeria: implication for sustainable food supply and food security, Cogent Food Agric. 3 (1) (2017), 13688.
[62] T. Abdoulaye, A. Abass, B. Maziya-Dixon, G. Tarawali, R. Okechukwu, J. Rusike, B. Ayedun, Awareness and adoption of improved cassava varieties and processing technologies in Nigeria, J. Dev. Agric. Econ. 6 (2) (2014) 67–75.
[63] T. Abdoulaye, A.S. Bamire, A. Oparinde, A.A. Akinola, Determinants of Adoption of Improved Cassava Varieties Among Farming Households in Oyo, Benue, and Akwa Ibom States of Nigeria, HarvestPlus Working, 2015. Paper No. 20).
[64] P.P. Acheampong, V. Owusu, Impact of Improved Cassava Varieties' Adoption on Farmers' Incomes in Rural Ghana (No. 1008-2016-79888), 2015.
[65] E. Donkor, V. Owusu, E. Owusu-Sekyere, Assessing the determinants of adoption of improved cassava varieties in Ashanti of Ghana, Africa Development and Resource Research Institute Journal 5 (2014) 92–104.
[66] M. Khonje, P. Mkandawire, J. Manda, A.D. Alene, Analysis of adoption and impacts of improved cassava varieties in Zambia, in: 29th Triennial Conference of the International Association of Agricultural Economists (IAAE) in Milan Italy from 8th, 2015.
[67] F.Y. Kavia, C.C. Mushongi, G.B. Sonda, Factors affecting adoption of cassava varieties: a case of Cassava Mosaic Disease tolerant varieties in Lake Zone Regions – Tanzania, African Crop Science Conference Proceedings 8 (2007) 1875–1878.
[68] S. Abele, E. Twine, P. Ntawuruhunga, Y. Baguma, C. Kanobe, A. Bua, Development and dissemination of improved cassava varieties in Uganda: analysis of adoption rates, variety attributes and speed of adoption, AAAE Conference Proceedings 479 (2007).
[69] S.C. Margao, D.S. Fornah, I.S. Barrie, Determinants of Farmers' Adoption of Improved Cassava and Sweet Potato Varieties in Sierra Leone. Proceedings of the 13th ISTRC Symposium, 2007, 2007, pp. 593–600.
[70] Natural Resources Institute, Cassava: Adding Value for Africa (C:AVA) Project [Video], YouTube, 2013.
[71] African Innovation Institute, Cassava Adding Value for Africa Phase Two (CAVA II) -Project Fact Sheet, 2019.
[72] P. Abdulsalam-Saghir, L. Sanni, B. Siwoku, K. Adebayo, A.M. Martin, A. Westby, Cassava : adding value for Africa - startegic market initiatives that support wealth creation for women along the cassava value chain in South west Nigeria, Journal of Agricultural Science and Environment 12 (2) (2012) 70–82.
[73] O. Ogunyinka, V. Guwelamgomba, L. Kaitira, A. Oguntuase, D. Otim, K. Otim, Transforming Rural Livelihoods through Cassava Value Addition, a Case Study of Cassava Adding Value for Africa Project (C: AVA), African Journal of Food, Agriculture, 2018.
[74] CIAT, Improving Cassava for the Developing World - Annual Report 2006, Centro Internacional de Agricultura, 2006.
[75] A.M. Fermont, Cassava and Soil Fertility in Intensifying Smallholder Farming Systems of East Africa (PhD Thesis Unplublished), Wageningen University and Research, 2009.
[76] PWC, Harnessing the Economic Potential of Cassava Production in Nigeria, PriceWaterCooper, 2020.
[77] A.M. Fermont, P.J. Van Asten, P. Tittonell, M.T. Van Wijk, K.E. Giller, Closing the cassava yield gap: an analysis from smallholder farms in East Africa, Field Crops Res. 112 (1) (2009) 24–36.
[78] D. Spencer, Cassava cultivation in sub-Saharan Africa, Achieving Sustainable Cultivation of Cassava, Burleigh Dodds Science Publishing (2017) 141–157.