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Assessment of variability and stability of pod productivity in cocoa hybrids after a decade of pod production in Nigeria

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Abstract

Understanding the trend and stability of continuous productivity of the economic product of tree genotypes after years of establishment is key to their recommendation to farmers. Attention to this area in Cocoa is low in Nigeria. The present study was conducted in a hybrid trial plot established from beans whose pod productivity commenced in 2001. Pod yield of ten trees per plot of twenty genotypes laid out in randomized complete block design of five replications were monitored for four quarters in three consecutive years after a decade of continuous fruiting. A mixed model approach was employed for the data analysis; genotypes were random but quarters and years were fixed. The levels of the three factors differed significantly ($P<0.001$) from the analysis of variance. The environment had the largest (87.01%) portion of the total variance. Only genotype by year and year by quarter interactions were significant ($P\leq0.05$) in the experiment. Pod yield of the twenty cocoa genotypes ranged between 40 to 53 quarterly and between 161 to 213 annually; the corresponding least and highest occurred in T53/5 x N38 and T65/7 x T57/22 respectively. The first quarter (running from January to March) and 2012 mostly supported pod yields of the 20 genotypes. Regression coefficient (bi) and Shukla stability variance (σ_i^2) differently and respectively identified T53/5 x T12/11 and T12/11 x N38 as the most stable genotype in the experiment. Pod production varied in the different quarters and years, but the production potential of the 20 hybrids was all-round the year. Production trend of the genotypes for the three years of study was linear; suggesting that few years beyond a decade of cocoa establishment is still within the active productive years.

Key words: cacao, heterosis, genotype x environment interaction, productive age, variance components

Introduction

Demand for chocolate increases steadily at a rate of ∼3% per year, while supply has been characterized by wide fluctuations (CacaoNet, 2012). Meeting this demand has been the recurrent annual objective of the cocoa community. From the cocoa breeding stand-point, increasing the yield has remained largely unchanged in the past 80 years (DuVal *et al.*, 2017). In sequence, improvement of yield, resistance/tolerance to pests and diseases and the improvement of bean quality have been the prominent cocoa breeding goals. Average yield from farmers' field in West Africa which supplies 75% of the global production has been about 300kg/ha, with a mean range of 150 – 800kg/ha. About 90% of the farm holdings providing the above are smaller than 5hectares (DuVal et al., 2017). Low cocoa productivity is due to several causes: poor performance of traditional cocoa fields, low-yielding planting material and high vulnerability to disease (Amores *et al.*, 2011).

The estimated global production of cacao was ∼4 million tons in 2011–2012, with an estimated market value of between 8 and 10 billion USD (CacaoNet, 2012). Despite the increased global demand for the economic product of cocoa, poor productivity has been responsible for low attraction of the youth to cocoa farming in Nigeria. Since high productivity with commensurate economic returns is the essence of any production system (Amores *et al.*, 2011), the supply of genetically improved cocoa cultivars, equipped with a high-yielding potential and less vulnerability to diseases is therefore key to solving the problem of the low average cocoa yield in West Africa. Obtainable estimated yield potential of 2.7tonnes/ha have been reported in research plots for cultivated improved clonal materials and hybrids (Schnell *et al.*, 2005; Laliberté and End, 2015).

For breeding efforts to meet the primary objective of continued production to meet global demand and buffer fluctuations in supply, generation and dissemination of improved genetic material in the form of high-yielding clones and hybrids with resistance to a range of pests and diseases must constitute a vital component of the cocoa breeding programme (Eskes, 2006; Phillips *et al.*, 2009). Less than 40% of world cocoa comes from varieties selected at research stations. Hybrids varieties have been widely distributed to growers and today occupy about 35% of total cocoa acreage (Eskes, 2006).

The introduction and the use of improved varieties is therefore one of the most cost-effective and environmentally friendly changes in technology that can be proposed to overcome the major cocoa production constraints (Eskes, 2006; Kingsbury, 2011). Owing from the CFC/ICCO/IPGRI funded project on "Cocoa Gerplasm Utilization and Conservation: a Global Approach" some cocoa hybrids were generated and evaluated. The Cocoa Research Institute of Nigeria released eight (high yielding and well adapted varieties) of some of the hybrids to the Nigerian farmers in 2011 (CRIN, 2011).

The economic lifespan of a cocoa plantation according to Eskes (2006) was estimated to be 20 to 30 years. Variation from this range could substantially be a factor of the environment especially, diseases and pests, inherent soil fertility and management. Glendinning (1972) identified two main period of ripening of cocoa to be period of the minor crop (mid-May to mid-July) and the main crop, which may extends from September till February. We obtained ripe pods all-round the year from these cocoa hybrids; therefore, we divided each of the three years of our investigation to four quarters running from January to December. The essences of the research therefore were to identify: variability among the 20 hybrid cocoa genotypes for pod productivity, effects of quarter and year on the number of pods produced by genotypes, assess possible and meaningful interaction and pod productive stability of the different genotypes after a decade of pod productivity within the plantation.

Materials and Methods

A global Cocoa improvement programme on: cocoa germplasm utilization and conservation: a global approach was initiated by CFC/ICCO/IPGRI in Nigeria in 1997. The programme involved selection of some proven genetic materials; crosses were made among them to generate hybrids in 1998 (IPGRI, 1998). Twenty-three hybrids were generated through hand pollination. Seedlings were raised from the hybrid pods along with seedlings of F3 Amazon (a check). The same were established in the Hybrid Trial plot at the Cocoa Research Institute of Nigeria, Ibadan, Nigeria in June/July, 1999. The 24 genotypes were laid out in a randomized complete block design (RCBD) of six replications. The seedlings were planted at a spacing of 3metres x 3metres. Plant population per plot was 10 trees. Annually, the usual management practices in the plantation includes: manual weeding, pruning and pest and diseases control. Fruit bearing commenced in 2001 for almost all the genotypes and fruiting of the genotypes reached a decade in 2010.

From January 2011, data on the number of harvestable and matured ripe pod per tree, per plot were recorded for twenty selected genotypes from the first five replications where the number of trees per plot was ≥ 80%. See Table 2 for the pedigree and codes of the 20 genotypes. Pod yield/plot/month was cumulated for each quarter every year. The investigation lasted for three consecutive years from 2011 to 2013. With the three factors (genotypes (random), years (fixed) and quarters (fixed)), the experimental design became a factorial in RCBD. A mixed model analysis of variance for the number of pods was employed to partition the various sources of variations using PROC GLM in SAS (version 9.3, 2011).

Genotype x year and year x quarter interaction was observed to be significant ($P \leq 0.05$). Genotype by year interaction was further partitioned by regression coefficient (*bi*) of Eberhart and Russsel (1966) and variance stability statistics (σ_i^2) of Shukla (1972). PROC GLM generated mean and standard deviation for the interaction between years and quarters. Mean of the twelve year by quarter combinations were separated using least significant difference (LSD) at $P = 0.05$ following the method of Adewale and Odoh (2017).

Results

The summary of the analysis of variance for the factorial in RCBD experiment is presented in Table 1. Highly significant ($P \leq 0.05$) variation existed among the levels of the three (Genotypes, Years and Quarters) factors which constitute the main effects in the experiment. Interaction between genotypes and year was significant ($P \leq 0.05$), while years by quarters interaction was highly significant ($P \leq 0.001$). Moreover from Table 1, variance proportion accrued to the environment was 87.01%. The proportion contributed by the genotype to total variance was 3.07. Interaction involving the genotype and other environmental components had a total variance of 7.79%. From Table 2, quarterly pod production ranged between 40 and 53, while the annual pod production was between 161 and 213. Among the twenty genotypes, T65/7 x T57/22 (G7) with a corresponding 53.31 and 213.24 quarterly and annual mean pod yield, consistently had the highest pod production (Table 2). Pod production by G8 and G15 were significantly ($P \leq 0.05$) least (Table 2).

Pod production by the genotypes characteristically and significantly ($P \leq 0.05$) differed in the three years; the highest (230 pods) was recorded in 2012. Mean pod production in 2011 and 2013 was 169 and 153 pods respectively (Table 3). Moreover, the highest quantity of pods was recorded in the first (52) then the third (46) quarter of each year. Lowest pod production occurred at the second and the fourth quarters. Pod production within the two quarters were significantly ($P \leq 0.05$) the same (Table 3). Significant ($P \leq 0.05$) differences in mean pod production were observed among the four quarters in each of the years and vice versa (Table 4). Among twelve year x quarter combinations in Table 4, the highest (96) mean pod production was in the first quarter of 2012, but the least (29 pods) was obtained in the second quarter of 2011. For the four quarters across the three years, highest quantity of pods (58) was recorded in the first quarter. However, across the four quarters, highest pod production (63) was obtained in 2012 (Table 4).

From Table 5, T65/7 x T57/22 in this study produced the highest (213) annual pods; by ranking among others for the mean, it came first. However, the ranking of the same by the two parametric stability statistics were: $bi = 20$ and $\sigma_i^2 = 20$. The twentieth by mean ranking for pod production was T53/5 x N38 with a value of 161 pods; the b and σ_i^2 ranking for the same were: 1 and 16 respectively (Table 5). The regression coefficient identified T53/5 x T12/11 (whose mean annual pod yield was 198) to be the most stable genotype. Stability variance by Shukla identified T12/11 x N38 to be most stable. Meanwhile, the annual mean pod yield of T12/11 x N38 was 192 and the regression coefficient of the same was 0.97 (approximately 1.0). Other genotypes with fairy high yield, b estimates nearing 1.0 and lower stability variance include: T65/7 x T53/8, T65/7 x T101/15 and T65/7 x N38 (Table 5).

Discussion

Our present result concur with the report of Aikpokpodion *et al.* (2011) which revealed highly significant ($P<0.001$) main and interaction effects of genotype, season and year on pod production among the 24 genotypes at the eighth year of establishment. They further added that productivity of some the hybrids including T65/7xN38, T101/15xN38 and P7xPA150 reached 1tonne/ha in 5 years of establishment (2004-05). Year effect is a function of the climate; the present study identified its role in the influence of the 20 genotypes in their pattern of pod production for the three years. In the present study (three year after a decade of pod production), the positional placement of the first five highly productive genotypes were: T65/7 x T57/22, T53/5 x T12/11, T65/35 x T30/13, T9/15 x T57/22 and T12/11 x N38.

The variation in positional ranking of the genotypes at the eighth (Aikpokpodion *et al.*, 2011) and three post-decade years (in the present study) revealed the exhibition of cross-over genotype by environment interaction pattern by the genotypes; featuring non-consistent lead in pod productivity by the same genotype over the years. The two parametric statistic model used in this study identified stable genotype(s) with significant disparity. Through a harmonious consensus of the two parametric stability statistics, T12/11 x N38 was identified to be most stable, meaning that the annual abiotic and biotic fluctuations did not or fairly affect the pod productivity potential of the genotype.

T65/7 x T57/22 whose pod production was significantly highest in the study was released as an improved variety to the Nigerian farmer as CRIN Tc4 (CRIN, 2011). Its high quarterly and annual productivity is worthwhile, hence its recommendation for public use. Moreover, its continuous linear productive potential after a decade of fruiting is significant: investment in its cultivation is promising and may equally enhance national planning for cocoa production improvement. Amores *et al.* (2011) hinted that good genetic base of cocoa genotypes with respect to high yield and disease resistance is key to promising investment. The eight released hybrids characteristically possess these attributes (CRIN, 2011).

The 20 genotypes produced pod all-round the year. This negates the earlier report of Glendinning (1972) who identified two main cocoa production periods; although, he further added that under a very favourable or uniform weather condition cropping may be almost continuous. Apart from the environmental support, the significance of the round-the-year production potentials of the different genotypes may be a reflection of genetic advancement reported by Dias et al., (2003) for cocoa genotypes. They identified high pod productivity with significant stability owing to their wide adaptability with reduced year effect on agronomic and pod yield. No clear-cut production trend was observed, depicting that yield decline may not become observable few years beyond a decade of cocoa establishment.

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Tables

Table1: Variance components, proportions and significance of the different sources of variation

Sources of variation	DF	Variance proportion (%)	Mean Square
Rep	4	2.12	2321.73***
Genotypes	19	3.07	708.15***
Years	2	19.15	41993.88***
Quarters	3	3.33	4876.57***
Genotypes x Years	38	2.30	266.01*
Genotypes x Quarters	57	1.54	118.76
Years x Quarters	6	24.79	18127.01***
Genotypes x Years x Quarters	114	3.95	152.05
Experimental Error	956	39.74	182.372

Table 2: Quarterly and annual mean pod production by the twenty cocoa hybrids

Pedigree	Genotypes codes	Quarterly mean yield	Annual mean yield
T12/11 x N38	G2	47.88abcd	191.54ab

T65/7 x T9/15	G3	42.50de	169.99bc
PA150 x T60/887	G4	43.60bcde	174.41bc
P7 x T60/887	G5	45.20bcde	180.80bc
P7 x PA150	G6	43.29cde	173.19bc
T65/7 x T57/22	G7	53.31a	213.24a
T53/5 x N38	G8	40.30e	161.19c
T65/7 x N38	G9	48.75abc	194.99ab
T53/5 x T12/11	G10	49.38ab	197.54ab
T65/35 x T30/13	G11	49.38ab	197.51ab
T86/2 x T9/15	G12	44.95bcde	179.91bc
T9/15 x T57/22	G13	49.19ab	196.77ab
T86/2 x T22/28	G15	40.41e	161.65c
T82/27 x T12/11	G16	43.85bcde	175.39bc
T86/2 x T16/17	G17	45.38bcde	181.51bc
T65/7 x T53/8	G18	47.27bcd	189.08abc
T65/7 x T101/15	G19	49.41ab	197.63ab
T101/15 x N38	G22	47.86abcd	191.46ab
T82/27 x T16/17	G23	42.28de	169.12bc
T86/2 x T57/22	G24	45.41bcde	181.64bc

Means with the same letter are not significantly different at P≤0.05; mean comparison for quarterly and annual pod production is along the column

Table 3: Mean of the year and quarter main effects on pod production

S/N	Years	Means

1	2011	168.70b
2	2012	230.35a
3	2013	152.73c
	Quarters	Means
1	1	51.54a
2	2	42.65c
3	3	46.32b
4	4	43.42c

Means with the same letter are not significantly different at $P \leq 0.05$; mean comparison for years and quarters is along the column

Table 4: Interaction between years and quarters for mean pod production

Years	Quarters	Years Mean	$LSD_{0.05}$

	1	2	3	4		
2011	38.82	28.59	52.29	50.50	42.55	2.26
2012	95.91	66.62	42.41	45.90	62.71	4.09
2013	37.66	35.45	44.76	34.86	38.18	1.15
Quarters Mean	57.46	43.56	46.49	43.75		
$LSD_{0.05}$	3.47	1.73	2.30	2.50		

Significant means comparison exist if the difference (by substitution) between two means is higher than the corresponding LSD value at $P \leq 0.05$. Mean comparison for years across the quarters and quarters across the years is along the rows and column respectively.

Table 5: Annual mean pod production, stability statistics and ranked performances of each genotype in three years

Genotypes	Code	Mean	Mean_Rank	*b*	*b*_Rank	Shukla (σ_i^2)	Shukla (σ_i^2)_Rank
T12/11 x N38	G2	191.54	7	0.97	12	-0.43	1
T65/7 x T9/15	G3	169.99	17	0.78	9	2.41	6
PA150 x T60/887	G4	174.41	15	0.77	8	2.84	8
P7 x T60/887	G5	180.80	12	1.18	15	2.81	7
P7 x PA150	G6	173.19	16	0.66	4	7.47	13
T65/7 x T57/22	G7	213.24	1	2.23	20	94.88	20
T53/5 x N38	G8	161.19	20	0.44	1	19.70	16
T65/7 x N38	G9	194.99	6	1.11	14	1.59	5
T53/5 x T12/11	G10	197.54	3	1.00	13	1.43	4
T65/35 x T30/13	G11	197.51	4	1.58	19	20.55	18
T86/2 x T9/15	G12	179.91	13	1.23	16	3.63	10
T9/15 x T57/22	G13	196.77	5	1.53	17	19.71	17
T86/2 x T22/28	G15	161.65	19	0.47	2	19.27	15
T82/27 x T12/11	G16	175.39	14	0.76	7	3.16	9
T86/2 x T16/17	G17	181.51	11	0.74	6	7.00	12
T65/7 x T53/8	G18	189.08	9	0.88	11	0.59	2
T65/7 x T101/15	G19	197.63	2	0.84	10	0.99	3
T101/15 x N38	G22	191.46	8	1.55	18	22.24	19
T82/27 x T16/17	G23	169.12	18	0.60	3	9.82	14
T86/2 x T57/22	G24	181.64	10	0.68	5	6.26	11

*Ranking of the mean pod yield is based on magnitude in a descending order. Nearness to unitary value is a measure of stability of a genotype regression coefficient (***b***) while lower Shukla stability variance (σ_i^2) estimate signifies high stability for specific genotype.