British Biotechnology Journal
6(4): 146-153, 2015, Article no.BBJ.2015.037
ISSN: 2231–2927

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Assesment of Cocoa Genotypes for Quantitative Pod Traits

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Authors' contributions

This work was carried out in collaboration between all authors. Author OIS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors BOA and DBA managed the analyses of the study. Author OIS managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BBJ/2015/15266
Editor(s):
(1) Yan Juan, Doctorate of Horticultural Crop Biotechnology Breeding, Sichuan Agricultural University, Ya'an, China.
(2) Kuo-Kau Lee, Department of Aquaculture, National Taiwan Ocean University, Taiwan.
Reviewers:
(1) Anonymous, Brazil.
(2) Anonymous, South Africa.
(3) Anonymous, China.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1028&id=11&aid=8287

Original Research Article

Received 17th November 2014
Accepted 3rd February 2015
Published 27th February 2015

ABSTRACT

Yield related traits in 20 cocoa genotypes were investigated to determine suitable parental genotypes for yield improvement programmes in cocoa. Fifteen uniformly ripe pods were collected for pod and bean characteristic assessment from twenty genotypes in an existing cocoa hybrid trial research plot laid out in a randomized complete block design with six replications at the Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria. Seven quantitative data on the pods were subjected to statistical analysis. The 20 genotypes differed significantly ($P < 0.001$) for the seven traits. Performances of the genotypes ranged as: pod weight (175.40 – 620.50 g), pod length (11.30 – 20.10 cm), pod width (6.37 – 8.90 cm), pod thickness (0.73 – 1.65 cm), number of beans per pod (20 - 52), weight of beans per pod (27.33–119.67 g) and dry weight of hundred beans

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(52.33 – 115 g). Positive and significant (P < 0.001) correlation existed between pod weight and length, pod width, pod thickness and weight of beans per pod. The range of broad sense heritability was between 56.13 (number of beans per pod) to 81.76 (dry weight of hundred beans). About 86% of the total variation was explained by the first three principal component axes and four distinct groups emerged from the clustering technique. Results show significant (P<0.05) intra-cluster variability of the seven traits and that choosing genotypes G3 (T65/7 x T9/15), G5 (P7 x T60/887), G6 (P7 x PA150), G15 (T86/2 x T22/28) and G16 (T82/27 x T12/11) as parents in future yield improvement programmes will enhance cocoa productivity in Nigeria.

Keywords: Cocoa yield; parental genotypes; broad sense heritability; eigenvector; eigenvalue; principal component analysis.

1. INTRODUCTION

Agriculture has continued to play an important role in the provision of food, raw material for industries, employment of people and foreign exchange earnings in West Africa. Rural developmental activities have been greatly enhances by this sector of the economy. Industrial tree crops, notably cocoa, coffee, oil palm, and rubber, have dominated agricultural exports. Cocoa, especially have been of particular interest for some countries in the West Africa sub region and the global chocolate industries. West African countries, including Cote d'Ivoire, Ghana, Nigeria, Cameroon, Togo and others together accounted for more than 70% of total world cocoa production in 2006 [1]. Cocoa has historically been a key cash crop of very high economic value in the Nigerian agricultural system; providing the lead in quantity of foreign exchange to the nation. It is therefore remarked as the highest non-oil economic crop in Nigeria.

Cocoa (*Theobroma cacao* L.) is an under-storey tree crop of Amazonian origin, planted almost exclusively by smallholders in the tropics. Cocoa is among the major perennial crops worldwide and has enormous economic importance for developing countries in the humid tropics [2]. The major raw material from cocoa is the dried cocoa bean [3]. Sustainability of life has been dependent on this product, especially in some remote cocoa growing communities [4].

The utmost challenge to crop production is the maintenance of sustainable and productive yield; hence, improvement of yield is one of the major objectives of plant breeding. In Brazil, according to Dias et al. [5], the use of superior cocoa hybrids has contributed significantly to enhance cocoa productivity. For long, Nigeria cocoa production target has been increased productivity per hectare [3]. Identification of high quality and superior hybrids from the germplasm for further breeding programme could lead to a boost in tonnage from cocoa hectares of the country.

The pod and bean characteristics of cocoa have very significant descriptive and discriminatory properties that guide selection of good cocoa genetic materials for breeding advancement [6]. Information on the potentials of cocoa genotypes is critical to selection. This study carried out field evaluation of 20 cocoa genotypes that were developed as hybrids. As a follow-up to the recent work by Adewale et al. [6], it would be necessary to have basic information on the pod and bean characteristics of the twenty genotypes. The information will be used to infer an opinion about the comparative advantages of each genotype and hence about the interrelationship among the studied traits. From the information, the distinctive potential of each genotype will also be determined for a guided selection programme.

2. MATERIALS AND METHODS

The experiment was carried out in an existing hybrid trial plot of Cocoa Research Institute of Nigeria (CRIN) Ibadan, Nigeria. The experimental design in the plot was Randomized Completely Block Design with six replications. The plot size was ten trees per genotypes. Planting was done at a spacing of 3 m by 3 m. Table 1 has the list of the 20 cocoa genotypes considered in the study. Data were collected from fifteen uniformly matured and ripe pods from each genotype, following the procedure of Adewale et al. [6]. Data was collected on the metric distance of the proximal to the distal end of the pod i.e. pod length (PdLT), pods were weighed and the weights were recorded as pod weight (PdWT), the circumferential length around the widest width of the pod were recorded as the pod width (PdWidth), pod thickness (PdThick) was determined as the difference between the inner and the outer diameter of the pod.

Moreover, the number of beans per pod (NoBP) was counted and the weight of all beans from a pod was recorded as weight of bean per pod (WtBP). The weight of one hundred dried beans was recorded as 100 beans (DW100B). All the data were subjected to the statistical analysis using the Statistical Analysis Software (SAS), version 9.2 [7]. The analysis of variance (ANOVA) was calculated using the PROC GLM procedure in SAS and means were separated using the Duncan multiple range test. Broad sense heritability was estimated as the ratio of genetic variance to the phenotypic variance from the component of the ANOVA and expressed in percentage following Toker [8], as

Broad Sense Heritability

$$(H) = \sigma^2 g/\sigma^2 p \times 100$$
$$\sigma^2 p = \sigma^2 g + \sigma^2 e$$

Where

$\sigma^2 g$ = genotypic variance
$\sigma^2 p$ = phenotypic variance
$\sigma^2 e$ = environmental variance

Heritability percentages were categorized as low, moderate and high as indicated by Elrod and Stanfield [9],

0 - 10% - Low
20 - 50% - Moderate
≥50% - High

Pearson Correlation among the seven studied traits was done using the Analyst option in SAS. Data matrix containing the means of each genotype with each respective trait were subjected to principal component analysis (PCA) and a three dimensional figure showing the spatial display of the twenty genotypes was generated.

3. RESULTS

The twenty genotypes differed significantly (P < 0.01) from each other for five (PdWT, PdLT, PdWidth, PdThick, and DW100B) out of the seven studied traits (Table 2). The mean of the twenty genotypes for the traits are: PdWT (384.18 g), PdLT (15.20 cm), PdWidth (7.75 cm), PdThick (1.20 cm) and DW100B (83.63 g). The coefficients of variation for the seven traits ranged between 8.15 (PdWidth) and 33.48 (WtBP).

From Table 3, G10 gave the highest mean value for pod weight (620.50 g), pod length (20.10 cm), pod width (8.90 cm), pod thickness (1.65 cm) and number of bean per pod (46.67). The highest weight of bean per pod (119.67 g) was by G15. G22 which gave the highest value for 100 dry bean weight (115 g), however, had the least mean value for pod weight, pod width, number of beans per pod and weight of bean per pod. G11, G2, and G24 gave the least mean for pod length, pod thickness and dry weight of hundred beans respectively (Table 3).

Table 1. Description of the twenty genotypes used in the study

S/N	Code	Pedigree
1	G2	T12/11 x N38
2	G3	T65/7 x T9/15
3	G4	PA150 x T60/887
4	G5	P7 x T60/887
5	G6	P7 x PA150
6	G7	T65/7 x T57/22
7	G8	T53/5 x N38
8	G9	T65/7 x N38
9	G10	T53/5 x T12/11
10	G11	T65/35 x T30/13
11	G12	T86/2 x T9/15
12	G13	T9/15 x T57/22
13	G15	T86/2 x T22/28
14	G16	T82/27 x T12/11
15	G17	T86/2 x T16/17
16	G18	T65/7 x T53/8
17	G19	T65/7 x T101/15
18	G22	T101/15 x N38
19	G23	T82/27 x T16/17
20	G24	T86/2 x T57/22

In this study, broad sense heritability ranged from 56.13 (NoBP) to 81.76 (DW100B). Most of the traits, had very high (>70%) heritability (Table 4).

The relationship among the seven traits was presented in Table 5. The pod weight had positive and significant (P<0.001) correlation with pod length (r = 0.732), pod width (r = 0.875), pod thickness (r = 0.677) and WtBP (r = 0.733). On the other hand, significant (P≤0.05) and positive correlation existed between PdLT and PdWidth, PdThick and WtBP at r = 0.704, 0.673 and 0.476 respectively (Table 5). Other significant correlation was observed between width of pod and its thickness (r = 0.668), podwidth and WtBP (r = 0.616) and the number of beans with WtBP (r = 0.694).

From Table 6, the total genetic variation among the 20 cocoa genotypes was accounted for by seven Principal Component (PC) axes, with variance proportions ranging from 55.62% (PC1) to 0.84% (PC6). The eigenvalues for each axes followed the descending trend as the variance proportion. The total variation (85.61%) among the twenty genotypes as explained by the first three PC axes were 55.62%, 15.8% and 14.18% respectively. By magnitude prominent traits with high eigenvector loadings in PC1 were: pod weight (0.47), length (0.43) and width (0.45) were most prominent in PC1. Number of beans per pod (0.65) and weight of beans per pod (0.51) were most discriminatory in PC2 while dry weight of hundred beans had the highest eigenvector (0.98) in PC3.

The display of the twenty genotypes in the tri-dimensional plane was presented in Fig. 1. Four distinct clusters were identifiable. The population of genotypes in each cluster was: I (5), II (2), III (3) and IV (4). G2, G10, G12, G17, G22 and G24 were loosely separated in the plane as nearer neighbours to the four simple clusters. G10 had highest mean performance for five (pod weight, pod length, pod width, pod thickness and number of beans per pod) out of the seven studied traits. With respect to the five traits, G12 and G24 had quite high and closer performance to G10. The least mean for pod weight, pod width, number of beans per pod and weight of beans per pod occurred in G22 while the same had the highest mean for an hundred dry bean weight. G2 had the least mean for pod thickness.

Table 7 presents the intra cluster information of each cluster with respect to the seven traits. The genotypes in cluster I had the highest mean for pod weight (479.83 g), length (16.61 cm), width (8.16 cm) and thickness (1.13 cm). The genotypes in cluster III had higher mean number of beans per pod (48), weight of beans per pod (110 g) and 100 bean weight (94 g). The least pod thickness (0.87 cm) also occurred in the cluster (Table 7). In this study, cluster IV was prominent for: lowest PdWT (321.42 g), PdLT (14.54 cm), PdWidth (7.53 cm), NoBP (36), WtBP (67.25 g) and DW100B (75.34 g).

4. DISCUSSION

The cocoa genotypes considered in this study exhibited significant variation for the studied pod characteristics. This proffers possibilities for subsequent breeding programme and opportunities. Vodouhe et al. [10] remarked that plant genetic resources are the most valuable resource to the world. Available variations within genetic resources offer the needed materials to tackle emerging agro-ecological problems, forms basis for parental selection and guarantees subsequent breeding success. Breeding progress is dependent on the proportion of the total variation that is genetic. The high heritability observed for the seven traits in this study indicates that there was high influence of the genetic component of variance on the phenotypic expression of the traits by the twenty genotypes. Genetic parameters and character associations provide information about expected response of various characters; this information is important for selection and development of breeding procedures [11]. Knowledge of the simple, phenotypic and genotypic correlations between important characters with breeding values is necessary for planning; it will facilitate simultaneous breeding for inheritance and aids understanding of trait association [12,13]. Simultaneous trait selection could be facilitated by the observed positive relationship of the pod weight with its length, width, thickness and the weight of bean per pod, whereby the selection of genotypes with heavier pods equally means a selection for genotypes with higher bean weight. An initial study [6] observed strong and significant positive correlation among some of the traits in the present study. In this study, pod length, width, thickness and the weight of the wet beans are indices for pod weight determination. G10 positively and remarkably demonstrated this

Table 2. Analysis of variance for the yield characters

Source of variation	DF	PdWT	PdLT	PdWidth	PdThick	NoBP	WtBP	DW100B
Genotype	19	38419.85***	15.21**	1.30***	0.12***	153.89	1274.85	687.05***
Error	38	8416.32	5.37	0.40	0.03	93.00	778.94	78.70
Mean		384.18	15.20	7.75	1.06	38.42	83.36	83.63
CV%		23.88	15.25	8.15	15.38	25.10	33.48	10.61

PdLT-Pod length, PdWT-Pod weight, PdWidth- Pod width, PdThick-Pod thickness, NoBP- Number of beans per pod, WtBP- Weight of bean per pod, and DW100B- Dry weight of hundred beans

Table 3. Mean performance of twenty genotypes for seven characters

Genotypes	PdWT	PdLT	PdWidth	PdThick	DW100B
G2	306.83^{fgh}	14.13^{bcde}	7.03^{def}	0.73^{f}	62.00^{gh}
G3	407.00^{bcdef}	17.40^{abc}	8.17^{abcd}	1.20^{bc}	94.67^{bc}
G4	341.83^{defgh}	15.90^{abcd}	7.60^{bcde}	1.03^{bcdef}	74.00^{efg}
G5	506.50^{abcd}	15.33^{bcde}	8.30^{abc}	1.00^{bcdef}	100.67^{ab}
G6	437.33^{bcdef}	17.20^{abc}	8.33^{abc}	1.07^{bcde}	93.33^{bcd}
G7	317.67^{efgh}	15.37^{bcde}	7.17^{cdef}	1.03^{bcdef}	72.67^{fg}
G8	294.50^{fgh}	13.43^{cde}	7.40^{cdef}	1.20^{bc}	78.00^{cdefg}
G9	331.67^{defgh}	13.47^{cde}	7.93^{abcd}	1.13^{bcd}	76.67^{defg}
G10	620.50^{a}	20.10^{a}	8.90^{a}	1.65^{a}	74.00^{efg}
G11	352.17^{cdefg}	11.30^{e}	7.90^{abcd}	1.03^{bcdef}	89.33^{bcdef}
G12	394.67^{bcdef}	17.60^{abc}	7.73^{abcd}	1.23^{b}	75.33^{efg}
G13	363.83^{cdefg}	14.07^{bcde}	7.70^{abcd}	0.83^{def}	94.67^{bc}
G15	555.67^{ab}	14.70^{bcde}	7.80^{abcd}	1.20^{bc}	82.67^{cdef}
G16	492.67^{abcde}	18.43^{ab}	8.20^{abcd}	1.17^{bc}	100.00^{ab}
G17	213.67^{gh}	12.23^{de}	6.47^{ef}	0.80^{ef}	64.67^{gh}
G18	371.83^{cdefg}	15.03^{bcde}	7.90^{abcd}	0.97^{bcdef}	88.00^{bcdef}
G19	289.17^{fgh}	14.70^{bcde}	7.57^{cde}	0.97^{bcdef}	90.67^{bcde}
G22	175.40^{h}	12.00^{de}	6.37^{f}	0.93^{bcdef}	115.00^{a}
G23	382.83^{bcdefg}	14.70^{bcde}	7.60^{bcde}	0.90^{cdef}	94.00^{bc}
G24	529.83^{abc}	16.97^{abc}	8.83^{ab}	1.20^{bc}	52.33^{h}

Means followed by the same letter(s) are not significantly different according to DMRT (P<0.05)
NB: PdLT-Pod length, PdWT-Pod weight, PdWidth- Pod width, PdThick-Pod thickness, NoBP- Number of beans per pod, WtBP- Weight of bean per pod, and DW100B- Dry weight of hundred beans

Table 4. Heritability for the seven characters in *T. cacao*

Characters	Heritability
PdWT	72.17
PdLT	71.03
PdWidth	73.00
PdThick	75.00
NoBP	56.13
WtBP	56.89
DW100B	81.76

NB: PdLT-Pod length, PdWT-Pod weight, PdWidth- Pod width, PdThick-Pod thickness, NoBP- Number of beans per pod, WtBP- Weight of bean per pod, and DW100B- Dry weight of hundred beans

for pod weight, length, thickness and the number of beans per pod. Adewale et al. [14] recently stated that heavier cocoa pods in most cases contain many beans and or few bigger beans. Moreover, the weight of the wet beans is a function of the number of beans, the length and width of the pods. The mode of contribution of the component traits to pod weight and wet bean weight deserves investigation through path coefficient analysis, to ascertain direct or indirect contribution.

The dry bean is the most economic part of cocoa [3]. Selection focused on genotypes with higher wet and dry bean weight will enhance greater production of cocoa. From this study, the significantly higher 100 dry bean weight value for G22 (T101/15 x N38); despite the fairly low pod weight, pod width, number and weight of beans per pod, must have been due to higher individual bean weight arising from low moisture but high dry matter content. One of the major goals of cocoa breeding is to increase the number of beans per pod and the bean weight. G10 (T53/5 x T12/11) and G22 (T101/15 x N38) positively offer these two desirable traits. A hybridization programme between the two may produce some outstanding results. An outstanding significant quality in G2 (T12/11 x N38) is the low pod thickness. Except for the importance of pod husk utilization for organic manure composting [15] for soil fertility enhancement; thinner rind of the pod husk is a desirable trait in cocoa breeding programme. Selection of genotypes with such quality in a hybridization programme may lead to physiological and genetic advances in appropriate assimilate distribution of the sink to the most economic component of the pod (i.e. the beans). Moreover, intra-cluster selection of parents and hybridization within cluster III could lead to the generation of heterotic hybrids with high quality (number and weight) bean traits.

Table 5. Pearson correlation coefficient of the seven yield trait

	PdWT	PdLT	PdWidth	PdThick	NoBP	WtBP
PdLT	0.732***					
PdWidth	0.875***	0.704***				
PdThick	0.677***	0.673***	0.668***			
NoBP	0.389^{ns}	0.389^{ns}	0.328^{ns}	0.236^{ns}		
WtBP	0.733***	0.476*	0.616**	0.234^{ns}	0.694***	
DW100B	-0.099^{ns}	-0.116^{ns}	-0.078^{ns}	-0.129^{ns}	-0.126^{ns}	-0.065^{ns}

NB: PdLT-Pod length, PdWT-Pod weight, PdWidth- Pod width, PdThick-Pod thickness, NoBP- Number of beans per pod, WtBP- Weight of bean per pod, and DW100B- Dry weight of hundred beans

Table 6. Eigenvalues, variance proportions and eigenvectors showing the prominence of each trait to each PC axes

				Eigenvectors of seven yield traits						
PC-Axes	**Eigenvalue**	**Variance proportion**	**Cumulative**	**PdWT**	**PdLT**	**Pdwidth**	**PdThick**	**NoBP**	**WtBP**	**DW100B**
PC1	3.89	55.62	55.62	0.47	0.43	0.45	0.37	0.30	0.39	-0.08
PC2	1.11	15.80	71.43	-0.93	-0.21	-0.19	-0.48	0.65	0.51	-0.04
PC3	0.99	14.18	85.61	0.08	-0.01	0.09	-0.07	-0.05	0.12	0.98
PC4	0.50	7.14	92.74	-0.34	0.30	-0.34	0.45	0.57	-0.36	0.16
PC5	0.30	4.27	97.01	0.09	-0.83	0.14	0.52	0.16	0.01	0.02
PC6	0.15	2.16	99.16	0.37	0.03	-0.78	0.26	-0.25	0.36	0.01
PC7	0.06	0.84	100.00	-0.71	0.08	0.11	0.30	-0.27	0.56	-0.01

Table 7. Cluster means showing intra-cluster variability of the seven traits

	PdWT	PdLT	PdWidth	PdThick	NoBP	WtBP	DW100B
Cluster I	479.83	16.61	8.16	1.13	38.53	98.10	94.27
Cluster II	337.72	13.68	7.79	0.99	40.33	78.00	89.33
Cluster III	373.33	14.39	7.65	0.87	47.67	110.08	94.34
Cluster IV	321.42	14.54	7.53	1.10	35.83	67.25	75.34

NB: PdLT-Pod length, PdWT-Pod weight, PdWidth- Pod width, PdThick-Pod thickness, NoBP- Number of beans per pod, WtBP- Weight of bean per pod, and DW100B- Dry weight of hundred beans

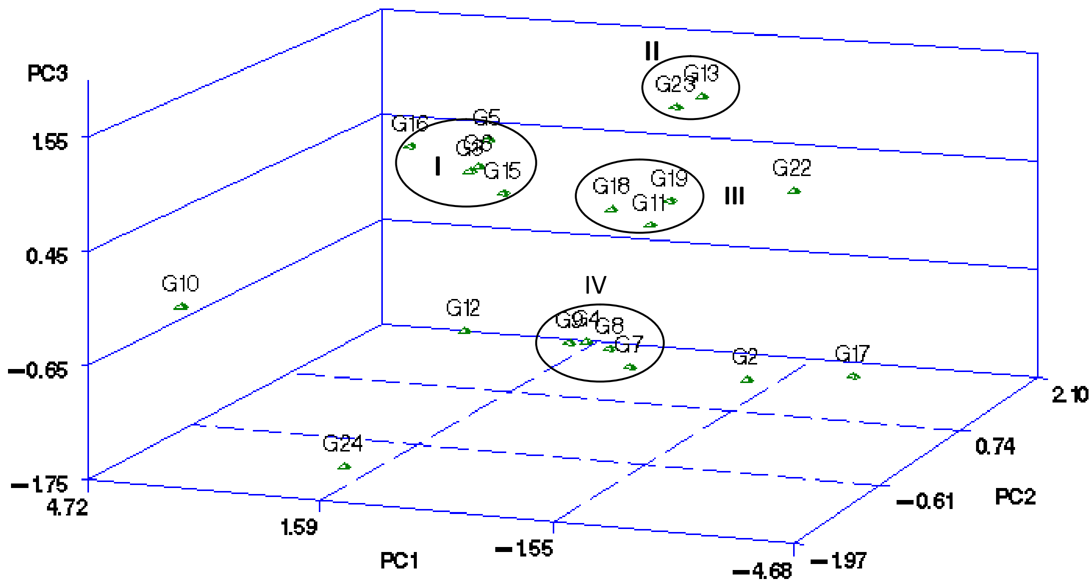

Fig. 1. Three dimensional representation revealing similarities among the twenty genotypes of cocoa

Furthermore, genotypes with comparative advantage for the economic trait (100 dry bean weight) are: G5 (P7 x T60/887), G13 (T9/15 x T57/22), G16 (T82/27 x T12/11), G22 (T101/15 x N38) and G23 (T82/27 x T16/17). Owing to the long protocol of varietal development, selection of these genotypes for further evaluation over years and locations as sexual or clonal planting material may eventually lead to their release to farmers in a short term breeding programme. In conclusion, the use of the above identified genotypes as parents in future breeding programmes will enhance the productivity of cocoa in Nigeria.

5. CONCLUSION

The findings of this study identified five cocoa genotypes (G5, G13, G16, G22 and G23) with significant dry bean quality. Their selection as parents for subsequent hybrid development may result in the generation of progenies with higher and significant heterotic quality for dry bean weight.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1028&id=11&aid=8287