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Research article

DIVERSITY AND STABILITY OF GROWTH AND YIELD TRAITS OF SOME COCOA GENOTYPES

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ABSTRACT

The agronomic and yield related characteristics of twenty Cocoa genotypes established and laid out in randomized complete block design (RCBD) with six replications were studied for two years at the Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria to understand their diversity and stability. Data were collected quarterly in each year on tree circumference (TC), jorquette height (JH), number of ripe fruits (NRF) and number of wilted fruits (NWF). The data were subjected to analysis of variance (ANOVA), correlation and clustering using (SAS), version 9.2. The genotypes differed significantly ($P \leq 0.05$) in the four traits for each year and for the two years. Genotype by quarter interaction was significant ($P \leq 0.05$) for N RF and NWF in 2013 and for the two years. Year by quarter interaction was significant ($P \leq 0.001$). The total variation among the twenty genotypes were explained by the first three principal component axes at 97.7%, 93.9% and 97.3% in 2012, 2013 and combined years. Three clusters were generated in the clustering pattern in each case.T65/7xT57/22 gave the highest pod yield (25.16). Pod yield stability estimate by Wricke ecovalence of T65/7xT57/22 was 100.788. The genotype ranked poorly in terms of stability. However, T65/7xN38,T12/11xN38, PA150xT60/887,T82/27xT12/11 and T65/7xT53/8 were identified in this study as the genotypes with high pod productivity and with good genetic stability.

Keywords: Diversity, stability, agronomic and yield traits, principal component analysis, cocoa genotypes.

INTRODUCTION

Cocoa (*Theobroma cacao L.*) is native to Amazon region of South America. There are over 20 species of the genus. Cacao is the most economic species and it is widely cultivated for its bean. It is considered one of the most important perennial crops with an estimated world output of 3.5 million tons in 2006 (ICCO, 2007). Cocoa has become a major commodity crop and, by value, it is now the seventh largest food commodity traded globally (Wood, 2010). It is predominantly grown in the tropical areas of Central and South America, Asia and Africa . The bulk of cocoa production comes from the tropics of West Africa. In West Africa, cocoa production is predominantly a small holder's enterprise with several hundreds of thousand families depending on it for their livelihood (Rice and Greenberg, 2000). In the 2003/2004 cocoa year (1st October, 2003 to 30th September, 2004), West Africa produced two and a half million tonnes, representing 72.4% of the world's total output of 3.45 million metric tonnes (ICCO, 2007). Cocoa, in comparison with other agricultural commodities makes the largest contribution to economic development of producing countries. In Nigeria, cocoa has been the only significant non-oil foreign exchange earning export commodities since 1975 when petroleum became the major commodity of export. The cocoa bean is Nigeria's leading agricultural export commodity and in 2001 it accounted for 65% of total agricultural export (CBN, 2004). It is a major source of income to the farmers and governments of producing states. Cocoa has become a major commodity crop and, by value, it is now the seventh largest food commodity traded globally (Wood, 2010).

Crop diversity is the variance in genetic and phenotypic characteristics of plants used in agriculture (Nigel *et al*, 2010). To develop viable crop varieties for a particular region, plant breeders usually collect data at various representative locations over a number of seasons; the genotype × environment data are used to provide an unbiased estimate of yield and other agronomic characteristics and to determine yield stability or ability to withstand both predictable and unpredictable environmental variation. Assessment of diversity, stability as well as performance of genotypes are important to plant breeders and agronomists as tools for selecting superior cultivars. The success of crop improvement activities largely depends on identification of superior genotype for cultivation. This is made possible by assessing stability performance of genotypes. The understanding of diversity among numerous genotypes has remained a guide for selection of the right cultivar for targeted breeding programme. Stability of performances of the genotypes with respect to various traits equally augments the criteria for the selection process. This study was carried out to determine the diversity among twenty cocoa hybrid genotypes and to identify the most stable genotype with respect to pod yield. The attendant information will serve as a guide for selection of superior genotypes for the development of new varieties in future cocoa breeding programmes in Nigeria.

MATERIALS AND METHODS

The experiment was carried out in an already established hybrid trial plot of Cocoa Research Institute of Nigeria (CRIN) Ibadan, Nigeria. The experimental design adopted was Randomized Complete Block Design with six replications. There were ten trees per block for each of the hybrids at a spacing of 3m by 3m. Table 1 shows the list of the 20 cocoa genotypes considered in the study. Data were collected from the ten cocoa trees of each of the twenty genotypes for each replicate on quarterly basis for 2years in the hybrid trial plots. Data collected include agronomic characteristics, namely jorquette height (JH) and tree circumference (TC); yield characteristics, namely number of ripe fruits (NRF) and number of wilted fruits (NWF).

All the data were subjected to the statistical analysis using the Statistical Analysis Software (SAS), version 9.2, (SAS, 2007). The analysis of variance (ANOVA) was calculated using the PROC GLM procedure in SAS and means separated using Duncan Multiple Range Test (DMRT). Correlation among the studied traits was done using the Analyst option in SAS.

The significance of the genotype by quarter, genotype by year, and year by quarter interaction for four trait components (Jorquette Height, Tree Circumference, Number of ripe fruit, Number of wilted fruit) in the ANOVA demanded further investigation. This was done using Wricke's ecovalence,Wi (Wricke, 1962). i.e.

$$Wi = (Yij - Yi. - Y.j + Y.)^2$$

Where; Wi = ecovalence of the i-th cultivar, σi^2 = Shukla stability variance of the i-th cultivar

Yij = the observed phenotypic value of the i-th cultivar in the j-th environment, Yi. = mean of i-th cultivar across the entire environment, Y.j = mean of j-th environment, Y. = grand mean, g = number of genotypes or cultivar and e = number of environments.

The principal component analysis (PCA) was estimated. The principal component analysis produced vector loading for the variables on principal component (PC) axes. The PCA examined the interrelationship among the set of variables and identified the characters which contribute significantly to the variability among the 20 genotypes based on the eigenvector loading assigned to the original variables.

RESULTS

Table 2 shows the analysis of variance of twenty genotypes of cacao in four environments (quarters) in 2012, 2013 and two years combination. The twenty genotypes differed significantly ($P < 0.01$) from one another in 2012 in respect of the studied traits. The four quarters also differed significantly ($P < 0.001$) for TC, NRF and NWF in 2012. The least (9.20) and the highest (81.22) coefficient of variation in 2012 was observed in TC and NWF respectively.

In 2013, as revealed in Table 2, the twenty genotypes differed significantly ($P \leq 0.05$) from one another for the four studied traits. Quarter effect was only significant ($P \leq 0.001$) for NRF and NWF. Genotype by Quarter interaction was identified to be significant ($P < 0.01$) for NRF and NWF. TC had the lowest (10.61) coefficient of variation. The highest (107.84) coefficient of variation was observed in NWF. Across the two years, the twenty genotypes differed significantly ($P \leq 0.05$) from one another based on the main effect of genotypes and year. The effect of quarter as a main effect was only significant ($P < 0.001$) on TC, NRF and NWF. The interaction effect of the genotype by year and genotype by quarters was significant ($P \leq 0.05$) on NRF and NWF. However, the interaction of year by quarter was significant ($P < 0.001$) on TC, NRF and NWF. The coefficient of variation of TC was the least (9.91), while that of NWF was the highest (125.95).

Mean performances of the twenty cocoa genotypes with respect to the four phenotypic traits for 2012 are shown in Table 3. G9 had the highest (184.57cm) jorquette height. The least (139.89cm) occurred in G15. The same genotype (i.e. G15) had the least number of ripe fruits (15.98). The widest (55.68cm) tree circumference occurred in G24, while the least (45.93cm) was observed in G18. In all, G7 had the highest number of ripe fruits (37.89) and G13 had the highest number of wilted fruit (6.44).

The genotype with the highest jorquette height in 2013 is G9 (189.13cm) followed by G3 (184.05cm) as shown in Table 4 while the least height (142.44cm) was observed in G15. Also, G15 had the least performance for tree circumference (50.21cm), number of ripe fruit (8.09) and number of wilted fruit (7.66). The widest circumference occurred in G24 (60.35cm) followed by G12 (59.73cm). The highest number of ripe fruits (14.28) was observed in G13. Four genotypes: G8, G15, G23, and G24 all had small number of wilted fruits.

The mean performances of the twenty genotypes for the two years combined are presented in Table 5. G3, one of the genotypes with high jorquette height along with G9 had the least tree circumference of 48.8cm. Other genotypes with short tree circumference include G7, G15, G16 and G18. The longest tree circumference (58.01cm) was observed in G24 followed by G12 (56.96cm). The genotype G7 with the highest number of ripe fruits equally had the highest number of wilted fruits. Genotype G23 had the lowest number of wilted fruits followed by Genotype G8.

Tables 6, 7, 8, and 9 presented the stability statistics (Wi) and ranks of four phenotypic traits in twenty genotypes of cocoa. For jorquette height and number of wilted pods G18 is the most stable genotype with Wi of 0.300 and 1.404 respectively (Table 6 and 9). For jorquette height, G4 had the highest Wi value of 4.311, making it the most unstable genotype for the trait. G22 had the smallest Wi of 0.115 for tree circumference. The most unstable genotype for tree circumference was G6 with Wricke ecovalence value of 2.845 (Table 7). For number of ripe fruits, the most stable genotype was G9 with Wi = 3.092 and the most unstable G13 with Wi = 171.29 (Table 8). Genotype G7 was the least stable genotype in terms of number of wilted fruit while the most stable genotype G18 (Table 9).

Positive and significant ($P \leq 0.001$) correlation existed between number of ripe fruits and the number of wilted fruits in 2012, r = 0.9018 (Table 10), in 2013, r = 0.7033 (Table 11) and in the combined years, r = 0.8946, (Table 12). In 2013, jorquette height and the number of ripe fruits also had positive and significant ($P < 0.05$) correlation, r = 0.4283 (Table 11). The eigenvalues, variance proportion of four principal component (PC) axes for 2012 and the eigenvectors of the agronomic and yield traits are presented in Table 13. Only two of the four PC axes had eigenvalues greater than 1. The percentage variance reduces progressively from PC1 to PC4 and the percentages of the four PC axes were 49.15, 32.04, 16.56, and 2.25 respectively. The first three PC axes accounted for 97.75% of the total genetic variation among the twenty cocoa genotypes.

Agronomic and yield traits with eigenvectors greater than 0.3 were significant in their contribution to loading each PC axis. Two characters relating to yield NRF and NWF loaded PC1. Agronomic traits JH and TC were most important in PC2 while TC and NWF were loaded in PC3 and PC4. The total genetic variation among the twenty genotypes was accounted for by the four PC axes in 2013 with variance proportion ranging from 47.87% (PC1) to 6.06% (PC4). The eigenvalues for each axis followed the descending trend as the variance proportion. Each of the four traits had higher (> 0.3) but varied magnitude of vector loading in the first three PC axes which accounted for 93.94% of the total genetic variation among the twenty cocoa genotypes. By the magnitude of the eigenvector loadings, JH (0.45), NRF (0.66) and NWF (0.58) were most prominent in PC1. TC and NWF had the highest loading for PC3 and PC4 respectively. TC had the highest vector loading (0.76) in PC 2 (Table 14).

From table 15, the total genetic variation among the twenty genotypes was accounted for by the four PC axes in 2012, 2013 Combined with variance proportion ranging from 48.17% (PC1) to 2.17% (PC4). Two PC axes had eigenvalues greater than1. The total variation (97.83%) among the twenty genotypes is explained by the first three PC axes 48.17%, 33.52% and 16.13% respectively. By the magnitude of the eigenvectors loading, NRF and NWF were the most prominent in PC1, TC and NWF had the highest eigenvector loading in PC3and PC4 while JH had the highest eigenvector in PC2.

In 2012, at 0.15 point of inflection, the twenty genotypes were classified into three clusters. The genotypes in each of the clusters, I, II, and III are shown in figure 1. The seven genotypes in cluster I had the highest number of ripe fruits and number of wilted fruits with a mean of 30.98 and 3.85 respectively (Table 16). Genotypes in cluster II were evident for the highest jorquette height and tree circumference with a mean of 170.76cm and 51.96cm respectively (Table 16).

In 2013, the twenty genotypes were classified into three clusters. The genotypes in each clusters, I, II, and III are shown in figure 2. In cluster I, seven genotypes had the highest number of ripe fruits and eight genotypes had the highest number of wilted fruits with a mean of 12.46 and 18.14 respectively (Table 17). Genotypes in cluster II were evident for the highest jorquette height and tree circumference with a mean of 176.02cm and 56.86cm respectively (Table 17).

For the combined year, the twenty genotypes were classified into three clusters at the point of inflection as shown in figure 3. The eight genotypes in cluster I had the highest number of ripe fruits and number of wilted fruits with a mean 21.07 and 10.56 respectively (Table 18). Genotypes in cluster II were evident for the highest jorquette height and tree circumference with a mean of 174.16cm and 54.40cm respectively (Table 18).

DISCUSSION

The observed decline in the fruit yield from 2012 to 2013 may be attributed to the high loss of pods to wilt and Phytophtora pod rot. Pod loss was higher in 2013 compared to 2012. Bowers et al. (2001) reported that yield loss due to Phytophtora pod rot can be as high as 70% if unchecked. High rainfall correlates with high humidity which aids a high buildup of the Phytophtora spores in cocoa plantation (Bowers et al., 20001). This may be an explanation for the high loss of cocoa pods in 2013. Genotypes which have low number of wilted fruits are likely to be tolerant to the disease.

Growth in plant is progressive before the peak of production. In this study the growth parameters namely jorquette height and tree circumference steadily increased from 158.95cm and 49.82cm in 2012 to 161.31cm and 53.99cm respectively in 2013. According to Galun (2007), plants exhibit active division of cells for growth during the developing stage.

Higher jorquette height depicts tallness of the cocoa tree. This is economically a disadvantage because harvesting pods from the tree will have to be aided by the use of long sickle. Therefore, genotypes with shorter jorquette height such as G15 (T86/2 x T22/28) would be most desirable during selection for cocoa plantation establishment for ease of pod harvest. Cocoa is a cash crop and having widetrunk may not be necessary as observed in G24 except if all the surface of the trunk can initiate cushion for flowering and better fruiting. Shorter height and slim girth of G15 offer it a desirable mother parent for a composite breeding programme for high yield and shorter storey cocoa plants. This study identifies G15 and G7 for such a breeding programme. Stability status of jorquette height and tree circumference may be of importance to the cocoa agronomist who may be interested in modelling the stable genotypes for the growth traits in terms of its architecture.

Cacao is an economic species, widely cultivated for its beans. Genotype G7 (T65/7 x T57/22) with the highest value in terms of pod production is one of the most unstable genotype. This result is consistent with the finding of Kamdi (2001), Asfaw (2007) and Jandong et al (2011) that most high yielding genotypes are usually unstable. Their performance for specific trait is environmentally specific. The genotypes identified to be stable with high number of pods (14.36 – 20.85) were G9, G2, G4, G16 and G18. They are, therefore, the most suitable parental genotypes for yield improvement programmes in cocoa producing ecologies in Nigeria.

Genetic diversity is important for sustainable production in crop species. The twenty genotypes have unique genetic constitution and they differ from one another in the phenotypic expression of the four traits. The general rule is that cluster formation depends on similarities among sets of genotypes for specific phenotypic traits. In this study, diversity existed among the twenty genotypes. Significant clustering system provides platform for intra and inter cluster selection. Inherent genetic potential is feasible within the observed three clusters for subsequent breeding programme. A wide genetic variability provides raw material for breeding new and improved varieties to achieve a more economically sustainable cocoa production system. The observed diversity among the 20 cocoa genotypes in this study indicates that there is possibility for selection of genetic materials for further breeding programme.

Principal component analysis (PCA) is a very important multivariate statistical technique for classification of species (Ariyo, 1993; Morris 2007; Vadivel and Janardhnan, 2005). It highlights similarities and differences among variables, identifies the data pattern and assesses the relative contribution of different variables to each principal component (PC). The resultant estimate from PCA include eigenvalues, the proportion of variance explained by a particular principal component and eigenvectors. In this study, different character contributed differently to the total variation as indicated by their eigenvectors, weight and loading in the four PC axes. All the four characteristics studied, namely jorquette height, tree circumference, number of ripe fruits and number of wilted fruits, have contributed effectively to the total variation within the 20 cocoa genotypes, implying that the four traits are very important in the classification of the genotypes.

CONCLUSION

The twenty cocoa genotypes investigated differed in jorquette height, tree circumference, number of ripe pods and number of wilted fruits. Cocoa genotypes with short jorquette height, slim girth and high pod yield are most desirable for economic cocoa production. This study identified genotypes T86/2xT22/28, T65/7xT57/22, T82/27xT12/11 and P7xPA150 as candidates with the above characteristics. Genotype G15 (T86/2xT22/28) has shorter jorquette height and slim girth while G7 (T65/7xT57/22) was a prolific pod producer..The yield capacity and stability of genotypes G9 (T65/7xN38), G2 (T12/11xN38), G4 (PA150xT60/887), G16 (T82/27xT12/11) and G18 (T65/7xT53/8) make them promising genotypes for selection for further cocoa breeding programme to enhance cocoa production in Nigeria.

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Tables and Figures

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

Table 2: Analysis of variance of twenty genotypes of cacao in four environments (quarters) in 2012, 2013 and two years combination.

		2012			
Source of Variation	**DF**	**JH**	**TC**	**NRF**	**NWF**
Genotypes	19	2682.87***	165.53***	833.91***	20.43***
Quarters	3	620.94	581.83***	21795.82***	26.14**
Genotype*Quarter	57	36.92	9.00	218.47	7.30
Error	395	285.78	20.20	184.45	6.94
Mean		158.95	49.82	24.71	3.24
CV%		10.64	9.20	54.96	81.22
		2013			
Genotypes	19	2847.83***	209.62***	75.58**	789.37***
Quarters	3	111.26	77.45	2028.45***	14484.18***
Genotype*Quarter	57	14.99	11.75	56.57**	280.77*
Error	395	312.19	32.82	33.69	198.36
Mean		161.31	53.99	10.88	13.06
CV%		10.95	10.61	53.35	107.84
		Combined			
Genotypes	19	5495.97***	368.02***	642.13***	462.58***
Years	1	1331.09*	4170.43***	45896.11***	23132.81***
Quarters	3	149.79	373.80***	9833.98***	7169.51***
Genotypes*Years	19	34.74	7.12	267.37***	347.21***
Genotype*Quarter	57	33.10	10.93	167.81*	149.04*
Years*Quarters	3	582.41	285.48***	13990.29***	7340.81***
Genotypes*Years* Quarters	57	18.81	9.82	107.23	139.04
Error	795	298.94	26.47	114.01	105.39
Mean		160.13	51.90	17.79	8.15
CV%		10.79	9.91	59.99	125.95

NB: *, **, ***- Significance at 0.05, 0.01, and 0.001 respectively. The value without any asterisk are not significant
NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 3: Mean performances of the twenty cocoa genotypes with respect to four phenotypic traits for 2012

Genotypes	**JH**	**TC**	**NRF**	**NWF**
G2	170.77^{bc}	53.41^{abc}	24.09^{defghi}	3.40^{bc}
G3	179.91^{ab}	46.22^{hi}	$22.94^{defghij}$	2.56^{c}
G4	154.06^{fg}	49.77^{def}	20.74^{fghij}	2.17^{c}
G5	150.43^{g}	50.19^{de}	27.07^{bcdefg}	3.54^{bc}
G6	157.00^{defg}	50.11^{de}	21.11^{fghij}	2.54^{c}
G7	150.00^{g}	46.77^{ghi}	37.89^{a}	3.51^{bc}
G8	156.84^{defg}	50.53^{de}	16.42^{ij}	2.68^{bc}
G9	184.57^{a}	50.28^{de}	28.02^{bcdef}	4.13^{b}
G10	157.97^{defg}	50.54^{de}	28.89^{bcde}	4.10^{b}
G11	148.45^{gh}	49.63^{def}	33.74^{ab}	3.21^{bc}
G12	162.51^{cdef}	54.19^{ab}	25.23^{cdefgh}	3.29^{bc}
G13	161.38^{cdef}	48.59^{efgh}	31.93^{abc}	6.44^{a}
G15	139.89^{h}	46.69^{ghi}	15.98^{j}	3.35^{bc}

G16	150.49[g]	47.28[ghi]	19.94[ghij]	2.29[c]
G17	165.15[cde]	51.89[bcd]	21.79[efghij]	2.77[bc]
G18	156.41[efg]	45.93[i]	23.37[defghij]	3.14[bc]
G19	157.95[defg]	48.51[efgh]	26.82[bcdefg]	3.15[bc]
G22	155.57[efg]	50.99[cde]	30.54[abcd]	2.98[bc]
G23	153.52[fg]	49.11[efg]	18.04[hij]	2.49[c]
G24	166.23[cd]	55.68[a]	19.68[ghij]	3.09[bc]
Means	158.955	49.816	24.712	3.242

Means followed by the same letter(s) are not significantly different according to DMRT (P<0.05)
NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit.

Table 4: Mean performances of the twenty cocoa genotypes with respect to four phenotypic traits for 2013

Genotypes	JH	TC	NRF	NWF
G2	171.27[b]	58.51[ab]	10.82[bcdefg]	11.78[bcd]
G3	184.05[a]	51.39[fgh]	11.18[abcdefg]	9.72[cd]
G4	158.17[defg]	53.69[cdefg]	9.13[fg]	9.29[cd]
G5	151.35[fgh]	53.69[cdefg]	11.68[abcdef]	13.79[bcd]
G6	157.39[defg]	55.08[cd]	9.62[cdefg]	8.29[d]
G7	153.59[efg]	50.51[gh]	12.43[abcd]	32.40[a]
G8	159.52[cdefg]	54.79[cdef]	9.51[cdefg]	7.81[d]
G9	189.13[a]	54.29[cdef]	13.68[ab]	15.04[bcd]
G10	162.66[bcde]	54.51[cdef]	12.38[abcde]	14.01[bcd]
G11	153.73[efg]	53.50[cdefg]	10.56[bcdefg]	17.21[bc]
G12	164.99[bcd]	59.73[a]	10.65[bcdefg]	13.55[bcd]
G13	159.64[cdef]	51.54[fgh]	14.28[a]	19.10[b]
G15	142.44[h]	50.21[h]	8.09[g]	7.66[d]
G16	149.60[gh]	51.69[efgh]	8.78[fg]	9.72[cd]
G17	165.24[bcd]	56.03[bc]	9.05[fg]	11.91[bcd]
G18	158.39[cdefg]	50.97[gh]	9.68[cdefg]	11.89[bcd]
G19	159.64[cdef]	51.87[defgh]	13.25[ab]	11.71[bcd]
G22	158.17[defg]	55.57[bc]	12.61[abc]	18.75[b]
G23	156.33[defg]	51.78[efgh]	9.22[defg]	8.36[d]
G24	168.28[bc]	60.35[a]	11.08[abcdefg]	9.19[d]
Means	161.179	53.985	10.884	13.059

Means followed by the same letter(s) are not significantly different according to DMRT (P<0.05)
NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit

Table 5: Mean performances of the twenty genotypes with respect to four phenotypic traits for 2012, 2013 combined

Genotypes	JH	TC	NRF	NWF
G2	171.02[b]	55.96[ab]	17.45[defghi]	7.59[cdef]
G3	181.98[a]	48.80[g]	17.06[efghij]	6.14[def]
G4	156.11[fghi]	51.73[def]	14.93[hijk]	5.73[ef]
G5	150.89[hi]	51.94[cdef]	19.37[bcdefg]	8.67[bcdef]
G6	157.19[efgh]	52.59[cd]	15.36[ghijk]	5.42[f]
G7	151.80[ghi]	48.64[g]	25.16[a]	17.96[a]
G8	158.18[efg]	52.66[cd]	12.96[jk]	5.25[f]
G9	186.85[a]	52.28[cde]	20.85[bcde]	9.59[bcde]
G10	160.31[def]	52.53[bc]	20.64[bcdef]	9.06[bcdef]
G11	151.09[hi]	51.57[def]	22.15[abc]	10.21[bcd]
G12	163.75[cde]	56.96[a]	17.94[cdefgh]	8.42[cdef]
G13	161.80[cdef]	50.07[fg]	23.10[ab]	12.77[b]

G15	141.17^{j}	48.45^{g}	12.03^{k}	5.51^{ef}
G16	150.05^{i}	49.49^{g}	14.36^{hijk}	6.01^{ef}
G17	165.19^{bcd}	53.97^{bc}	15.42^{ghijk}	7.34^{cdef}
G18	157.19^{efg}	48.45^{g}	16.52^{fghij}	7.52^{cdef}
G19	158.80^{def}	50.19^{fg}	20.04^{bcdef}	7.43^{cdef}
G22	156.86^{efghi}	53.28^{cd}	21.57^{abcd}	10.87^{bc}
G23	154.92^{fghi}	50.44^{efg}	13.63^{ijk}	5.43^{f}
G24	167.25^{bc}	58.01^{a}	15.38^{ghijk}	6.15^{def}
Means	160.12	51.901	17.796	8.154

Means followed by the same letter(s) are not significantly different according to DMRT ($P<0.05$)
NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit

Table 6: Wrickeecovalence stability estimate of Jorquette Height measured in the twenty cocoa genotypes

Genotype	Combined Mean	Rank	Wi	Rank
G2	171.02^{b}	3	3.136	18
G3	181.98^{a}	2	2.726	17
G4	156.11^{fghi}	14	4.311	20
G5	150.89^{hi}	18	0.947	5
G6	157.19^{efgh}	12	2.083	12
G7	151.80^{ghi}	16	0.845	4
G8	158.18^{efg}	10	1.519	9
G9	186.85^{a}	1	2.598	15
G10	160.31^{def}	8	3.224	19
G11	151.09^{hi}	17	2.100	13
G12	163.75^{cde}	6	2.635	16
G13	161.80^{cdef}	7	1.092	8
G15	141.17^{j}	20	0.609	2
G16	150.05^{i}	19	0.984	6
G17	165.19^{bcd}	5	1.061	7
G18	157.19^{efg}	11	0.300	1
G19	158.80^{def}	9	1.998	11
G22	156.86^{efghi}	13	0.828	3
G23	154.92^{fghi}	15	2.397	14
G24	167.25^{bc}	4	1.642	10

Table 7: Wrickeecovalence stability estimate of Tree Circumference measured in the twenty cocoa genotypes

Genotypes	Combined Mean	Rank	Wi	Rank
G2	55.96^{ab}	3	1.295	18
G3	48.80^{g}	17	0.296	6
G4	51.73^{def}	11	0.986	13
G5	51.94^{cdef}	10	0.713	11
G6	52.59^{cd}	7	2.845	20
G7	48.64^{g}	18	0.638	10
G8	52.66^{cd}	6	1.024	15
G9	52.28^{cde}	9	1.179	16
G10	52.53^{bc}	8	1.259	17
G11	51.57^{def}	12	1.496	19
G12	56.96^{a}	2	0.988	14
G13	50.07^{fg}	15	0.164	2
G15	48.45^{g}	19	0.251	4
G16	49.49^{g}	16	0.290	5

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G17	53.97^{bc}	4	0.787	12
G18	48.45^{g}	20	0.209	3
G19	50.19^{fg}	14	0.369	9
G22	53.28^{cd}	5	0.115	1
G23	50.44^{efg}	13	0.346	8
G24	58.01^{a}	1	0.323	7

Table 8: Wrickeecovalence stability estimate of Number of ripe fruits measured in the twenty cocoa genotypes

Genotypes	Combined Mean	Rank	Wi	Rank
G2	17.45^{defghi}	10	3.334	2
G3	17.06^{efghij}	11	15.713	6
G4	14.93^{hijk}	16	5.625	3
G5	19.37^{bcdefg}	8	34.607	12
G6	15.36^{ghijk}	15	48.534	14
G7	25.16^{a}	1	100.788	19
G8	12.96^{jk}	19	21.944	9
G9	20.85^{bcde}	5	3.092	1
G10	20.64^{bcdef}	6	43.055	13
G11	22.15^{abc}	3	93.453	18
G12	17.94^{cdefgh}	9	52.978	15
G13	23.10^{ab}	2	171.297	20
G15	12.03^{k}	20	58.539	16
G16	14.36^{hijk}	17	8.313	4
G17	15.42^{ghijk}	13	21.242	7
G18	16.52^{fghij}	12	10.367	5
G19	20.04^{bcdef}	7	21.937	8
G22	21.57^{abcd}	4	26.460	10
G23	13.63^{ijk}	18	79.699	17
G24	15.38^{ghijk}	14	32.452	11

Table 9: Wrickeecovalence stability estimate of Number of wilted fruits measured in the twenty cocoa genotypes

Genotypes	Combined Mean	Rank	Wi	Rank
G2	7.59^{cdef}	9	5.045	6
G3	6.14^{def}	14	9.359	10
G4	5.73^{ef}	16	5.297	7
G5	8.67^{bcdef}	7	1.696	2
G6	5.42^{f}	18	15.735	15
G7	17.96^{a}	1	491.385	20
G8	5.25^{f}	20	25.504	18
G9	9.59^{bcde}	5	1.738	3
G10	9.06^{bcdef}	6	7.614	8
G11	10.21^{bcd}	4	7.775	9
G12	8.42^{cdef}	8	12.421	12
G13	12.77^{b}	2	23.281	17
G15	5.51^{ef}	17	33.936	19
G16	6.01^{ef}	15	10.150	11
G17	7.34^{cdef}	12	4.213	4
G18	7.52^{cdef}	10	1.404	1
G19	7.43^{cdef}	11	4.894	5
G22	10.87^{bc}	3	13.522	13
G23	5.43^{f}	19	13.528	14

G24	6.15^{def}	13	19.794	16

Table 10: Correlation coefficient of four agronomic traits of cocoa for 2012

	JH	TC	NRF	NWF
JH		0.3086^{ns}	0.03104^{ns}	-0.0914^{ns}
TC			-0.0944^{ns}	-0.1483^{ns}
NRF				0.9018***
NWF				

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 11: Correlation coefficient of four agronomic traits of cocoa for 2013

	JH	TC	NRF	NWF
JH		0.3454^{ns}	0.4283*	0.1508^{ns}
TC			0.0129^{ns}	-0.0894^{ns}
NRF				0.7033***
NWF				

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 12: Correlation coefficient of four agronomic traits of cocoa for 2012, 2013 combined

	JH	TC	NRF	NWF
JH		0.3333^{ns}	0.1464^{ns}	-0.0365^{ns}
TC			-0.0788^{ns}	-0.1648^{ns}
NRF				0.8946***
NWF				

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 13: Eigenvalues, variance proportions of PC axes and eigenvectors of traits (4) used in the study for 2012

	PC1	PC2	PC3	PC4
Eigenvalue	1.97	1.28	0.66	0.09
Percent Variance	49.15	32.04	16.56	2.25
Cumulative Variance	49.15	81.19	97.75	100.00
	Eigenvectors (scores)			
JH	-0.1184	**0.7227**	-0.6757	0.0844
TC	-0.2586	**0.6361**	**0.7269**	0.0104
NRF	**0.6707**	0.2334	0.0444	-0.7026
NWF	**0.6850**	0.1365	0.1141	**0.7065**

NB: PC – Principal Components, JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 14: Eigenvalues, variance proportions of PC axes and eigenvectors of traits (4)used in the study for 2013.

	PC1	PC2	PC3	PC4
Eigenvalue	1.92	1.25	0.59	0.24
Percent Variance	47.87	31.23	14.84	6.06
Cumulative Variance	47.87	79.10	93.94	100.00
	Eigenvectors (scores)			

JH	**0.4580**	**0.4946**	-0.6759	0.2978
TC	0.1262	**0.7675**	**0.6268**	-0.0459
NRF	**0.6615**	-0.1596	0.0083	-0.7327
NWF	**0.5802**	-0.3753	0.3875	**0.6102**

NB: PC – Principal Components, JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

Table 15: Eigenvalues, variance proportions of PC axes and eigenvectors of trait (4) used in the study for 2012, 2013 combined.

	PC1	PC2	PC3	PC4
Eigenvalue	1.92	1.34	0.64	0.87
Percent Variance	48.17	33.52	16.13	2.17
Cumulative Variance	48.17	81.70	97.83	100.00
	Eigenvectors (scores)			
JH	0.0184	**0.7238**	-0.6764	0.1349
TC	-0.1766	**0.6728**	**0.7183**	0.0159
NRF	**0.6926**	0.1531	0.0424	-0.7036
NWF	**0.6991**	-0.0008	0.1572	**0.6975**

NB: PC – Principal Components, JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruits and NWF-Number of wilted fruits

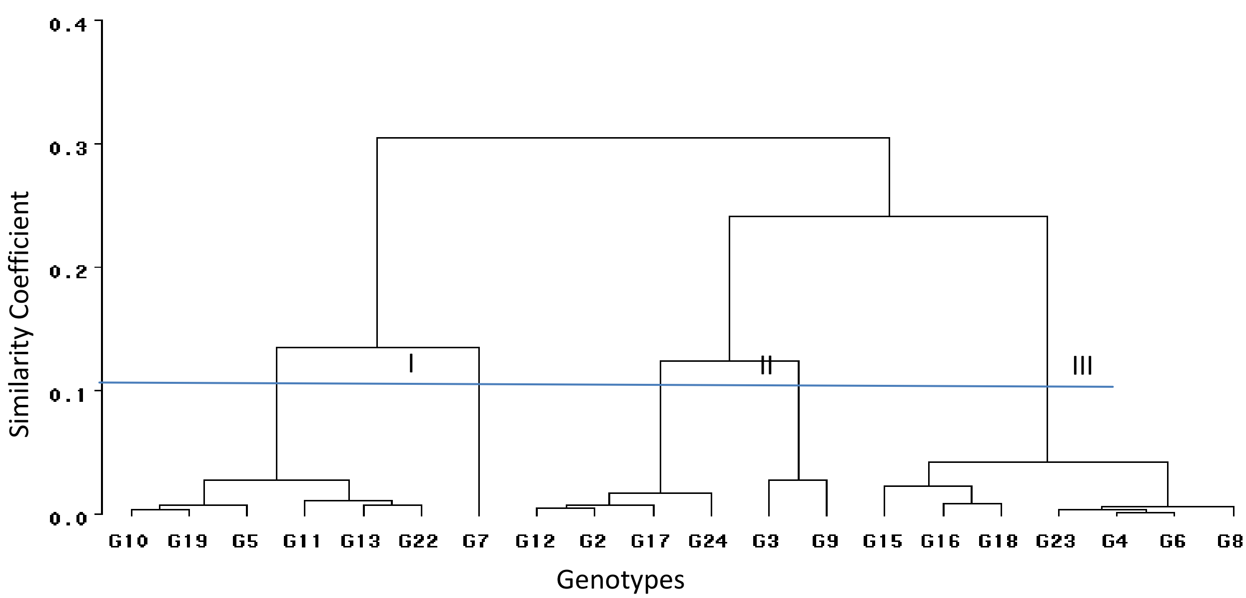

Figure 1: Dendrogram revealing similarities among the twenty genotypes of cocoa for 2012

Table 16: Intra-cluster variability of the four traits for 2012

	JH	TC	NRF	NWF
Cluster I	153.76	49.06	30.98	3.85
Cluster II	170.76	51.94	23.63	3.30
Cluster III	151.95	48.39	19.37	2.68

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit

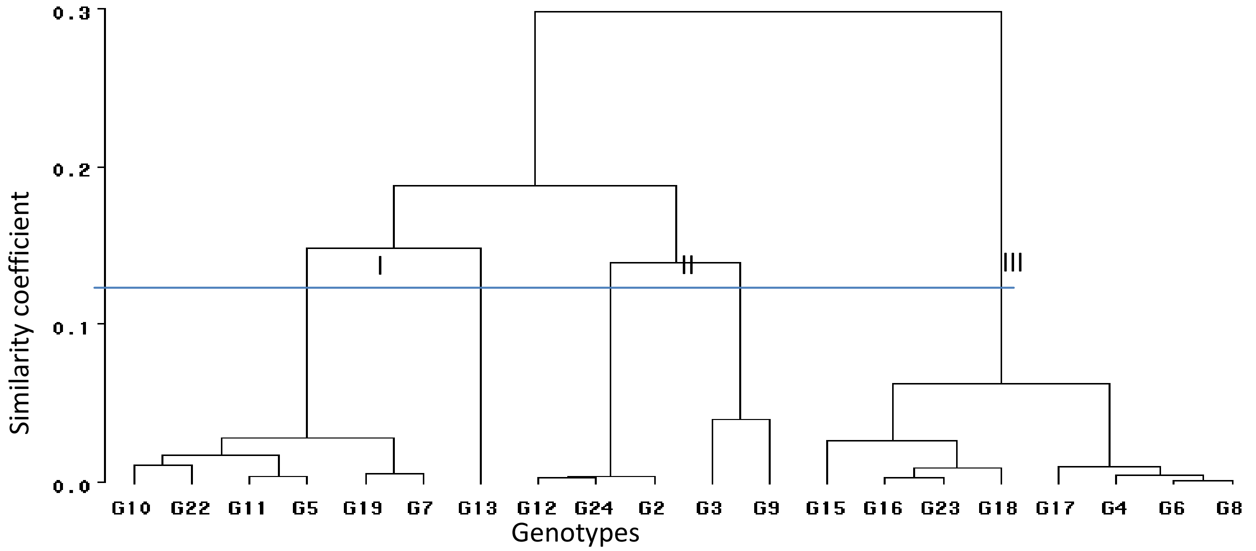

Figure 2: Dendrogram revealing similarities among the twenty genotypes of cocoa for 2013

Table 17: Intra-cluster variability of the four traits for 2013

	JH	TC	NRF	NWF
Cluster I	158.11	53.28	12.46	18.14
Cluster II	176.02	56.86	11.48	11.87
Cluster III	156.73	53.11	9.13	9.01

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit

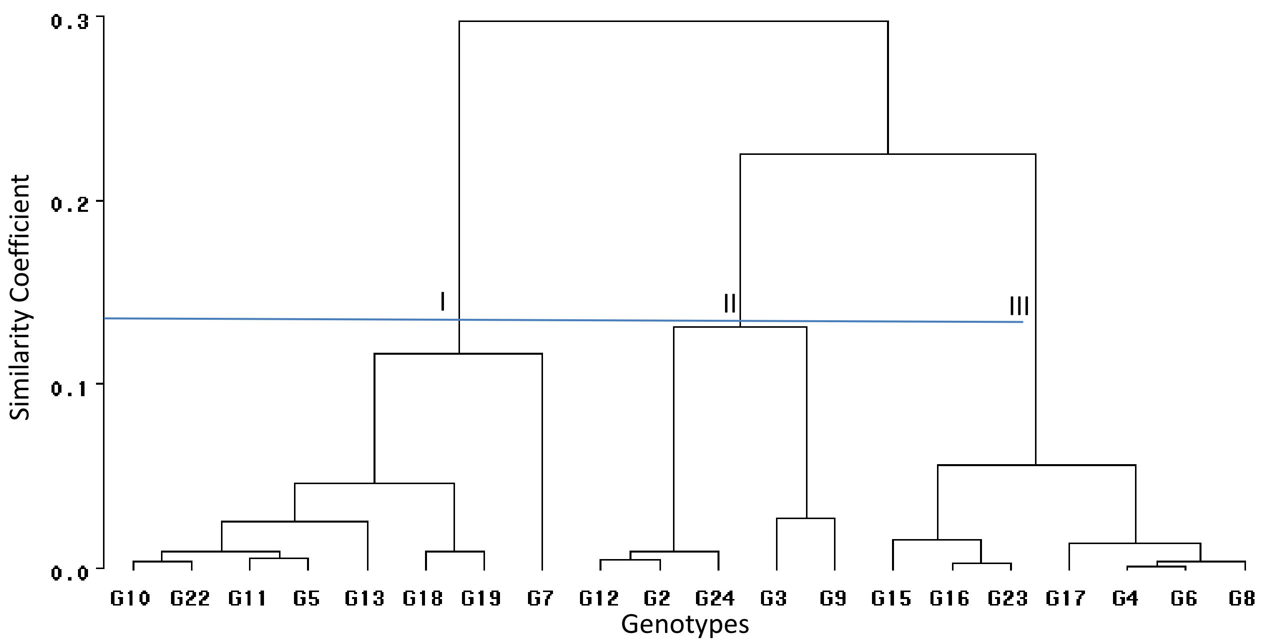

Figure 3: Dendrogram revealing similarities among the twenty genotypes of cocoa for 2012, 2013combined

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Table 18: Intra-cluster variability of the four traits for 2012, 2013 combined

	JH	TC	NRF	NWF
Cluster I	156.11	50.83	21.07	10.56
Cluster II	174.16	54.40	17.73	7.58
Cluster III	154.69	51.33	14.10	5.81

NB: JH- Jorquette Height, TC – Tree Circumference, NRF –Number of ripe fruit and NWF-Number of wilted fruit