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ARTICLE

Correlation and Path Coefficient Analyses of Yield in Cacao (*Theobroma cacao* L.)

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ABSTRACT

Cacao (*Theobroma cacao* L.) is an important commodity tree crop which produces the cocoa bean, a major source of income for most West African countries and many smallholder farmers. Declining yield of cacao is a major limitation to cocoa production in Nigeria. This study aimed at determining the correlations of the phenotypic traits that were related in the yield of the cacao genotypes. Nine cacao hybrids produced from some high-yielding parents in the research farm of Cocoa Research Institute of Nigeria, Ibadan, Nigeria were evaluated from 2012 through 2017 in Owena (7°11' N, 5°1' E), Ondo state, Nigeria. Character Correlations and Path Coefficient Analysis were used in the description of the performance of the genotypes. The study concluded that significant genotypic and phenotypic correlations existed among many of the pairs of the fruit and bean characters with one another and with pod index, suggesting a complex contribution of these characters either positively or negatively to growth and yield in cacao, and that fruit and bean traits are determinants of yield in cacao.

1. Introduction

The importance of the cacao crop is very enormous to farmers and government in the producing countries. Cocoa bean, the main ingredient used in the manufacture of chocolate, other beverages and confectionery products, is the major product obtained from the cacao tree. Declining yield is, however, a limiting factor in cacao cropping in Nigeria [1]. The cocoa bean yield is the primary focus of any cacao farming venture, and is indicated essentially in the "pod index", which refers to the number of cocoa pods (fruit) required to produce one kilogramme (1kg) of dry cocoa beans. Among other factors, cocoa bean yield is influenced by variety and age of plant [2]. A number of

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factors are, therefore, observed to be correlated with pod index in cacao. Understanding the magnitude and direction of the association of the traits that influence yield, as a complex trait, is paramount in selection for improved yield [3].

Correlation is a measure of the degree of relationship between variables and a plant breeder should know whether the improvement of one character will result in simultaneous change in other characters through estimates of inter character correlations [4]. Estimates of genotypic, phenotypic and environmental correlations among characters can provide the basis of planning of more efficient breeding programmes. A positive genetic correlation between two desirable traits simplifies the breeder's job of crop improvement. As yield, being a complex and polygenic trait, is influenced even by fluctuations in environmental factors, a knowledge of the nature and magnitude of the traits that influence yield in cacao can provide a basis for genotype selection. Beyond the influence of climate, an often complex inter-relationship of plant traits is an important determinant of yield in cacao [1]. Therefore this study was carried out to understand the association among yield and the related traits in cacao so as to enhance further selection for the improved yield of the crop.

2. Materials and Methods

Nine new early-bearing cacao hybrids produced at the Cocoa Research Institute of Nigeria which fruited at the Owena sub-station (7° 11'N, 5° 1'E) of the Institute, with harvest period ranging from 104 through 124 weeks after field ploanting (Table 1) were used this study. Thirty (30) individual seedlings were established per genotype as ten (10) seedlings per plot in three (3) replications in a Randomized Complete Block Design (RCBD). Prior to fruit harvest, data were collected (at three months interval) on plant height, stem diameter, number of leaves, time to jorquette, jorquette height, tree circumference, fruiting and cherelle wilt. Five uniformly matured and ripe cocoa pods were harvested per genotype in each of three replications, giving a total of fifteen pods (fruits) per genotype. The time to fruit harvest (being the time of fruit maturation) was recorded in weeks. Each fruit was weighed, and the fruit length and width measured using a vernier calliper. The fruits were carefully broken and pod husk thickness was estimated as the difference between the outer (ridge to ridge) and the inner diameter of the fresh pod husk using the venier calliper. The number of rows, number of beans per row and number of beans per pod was counted and the weight of the beans was recorded per fruit, while the weight of one bean was recorded as the average of the weight of ten beans randomly selected per fruit. The beans from each fruit were extracted and fermented in trays. The beans were weighed after fermentation and the weight recorded per fruit and per individual bean as the average of ten fermented beans weighed. The fermented beans were sun-dried, and the pod value recorded as the weight of the total dried beans obtained per fruit. The weight of one dried bean was also recorded as the average of the weight of ten dried bean per fruit. Dried bean length and width were recorded by as an average of the values of ten dried beans using the vernier calliper.

Table 1. List of nine cacao genotypes used in the study

S/N	Genotypes	Pedigree	Weeks to Harvest
1	$P_1 \times P_{10}$	$(T_{82/27} \times T_{12/11}) \times (T_{65/7} \times T_{57/22})$	122
2	$P_1 \times P_{11}$	$(T_{82/27} \times T_{12/11}) \times (T_{53/5} \times {}_{N38})$	117
3	$P_2 \times P_{10}$	$(P_7 \times T_{60/887}) \times (T_{65/7} \times T_{57/22})$	124
4	$P_3 \times P_{10}$	$(T_{86/2} \times T_{9/15}) \times (T_{65/7} \times T_{57/22})$	114
5	$P_3 \times P_{11}$	$(T_{86/2} \times T_{9/15}) \times (T_{53/5} \times {}_{N38})$	105
6	$P_5 \times P_9$	$(T_{86/2} \times T_{22/28}) \times (T_{65/7} \times T_{22/28})$	117
7	$P_6 \times P_{10}$	$(T_{65/7} \times T_{9/15}) \times (T_{65/7} \times T_{57/22})$	104
8	$P_7 \times P_8$	$(P_7 \times P_{A150}) \times (T_{101/15} \times N_{38})$	117
9	$P_7 \times P_{10}$	$(P_7 \times P_{A150}) \times (T_{65/7} \times T_{57/22})$	114

Pod index was calculated from the weight of dried beans from each pod as the number of pods required to produce one kilogramme of dry cocoa beans. In all, a total of fourteen quantitative traits were used to assess the nine genotypes. The characters measured in cocoa pod and bean metrics and their units are presented in Table 2. The means from the sampling unit per genotype were used to estimate the phenotypic, genotypic and environmental correlation coefficients using the formula: of Miller *et al.* [5] thus:

$$r(x,y) = \frac{Cov(xy)}{\sqrt{(\delta x)^2.(\delta y)^2}}$$

where $r_{(x,y)}$ is either genotypic or phenotypic or environmental correlation between variables x and y;
$Cov_{(xy)}$ is the covariance of variables x and y;
$(\delta_x)^2$ is either the genotypic or phenotypic or environmental variance of variable x;
$(\delta_y)^2$ is either the genotypic or phenotypic or environmental variance of variable y.

The significance of the correlation coefficients was tested using the non-directional probability in the software of Lowry [6].

The traits which had significant genotypic correlation coefficients with Pod Index (the yield parameter) were subjected to Path Coefficient analysis by dissecting the correlations so as to understand the direct path of relationships between each trait and Pod Index, as well as the indirect path of relationship of each trait through other traits with Pod Index. The direct and indirect Path Coefficients were calculated to reveal the strength of the relationship among Pod Index and the yield-related traits by solving a series of simultaneous equations as suggested by Dewey and Lu [7].

Figure 1 shows the cause and effect system between independent and dependent variables. It reveals that pod index (X_{13}) was determined by Plant height (X_1), Stem diameter (X_2), Time to joruette (X_3), Jorquette height (X_4), Tree circumference (X_5), Presence of fruit (X_6), Cherelle wilt (X_7), Time to fruit harvest (X_8), Fruit weight (X_9), Fruit length (X_{10}), Fruit width (X_{11}), Number of Beans per row (X_{12}) and a composite variable (residual effect = U) that include all other factors affecting dry bean yield but not accounted for in this study.

Table 2. Characters measured in cocoa pod and bean metrics and their units

S/N	Character	Unit
1.	Time to fruit harvest	Weeks
2.	Fruit weight	Grammes
3.	Fruit Length	Millimetres
4.	Fruit Width	Millimetres
5.	Pod Thickness	Millimetres
6.	Number of rows	Nil
7.	Number of beans per row	Nil
8.	Number of beans per fruit	Nil
9.	Weight of beans per fruit	Grammes
10.	Weight of 1 bean	Grammes
11.	Weight of beans per fruit after fermentation	Grammes
12.	Weight of 1 bean after fermentation	Grammes
13.	Pod value (Total weight of dry beans per pod)	Grammes
14.	Weight of 1 dry bean	Grammes
15.	Dry bean length	Millimetres
16.	Dry bean width	Millimetres
17.	Pod index	Nil

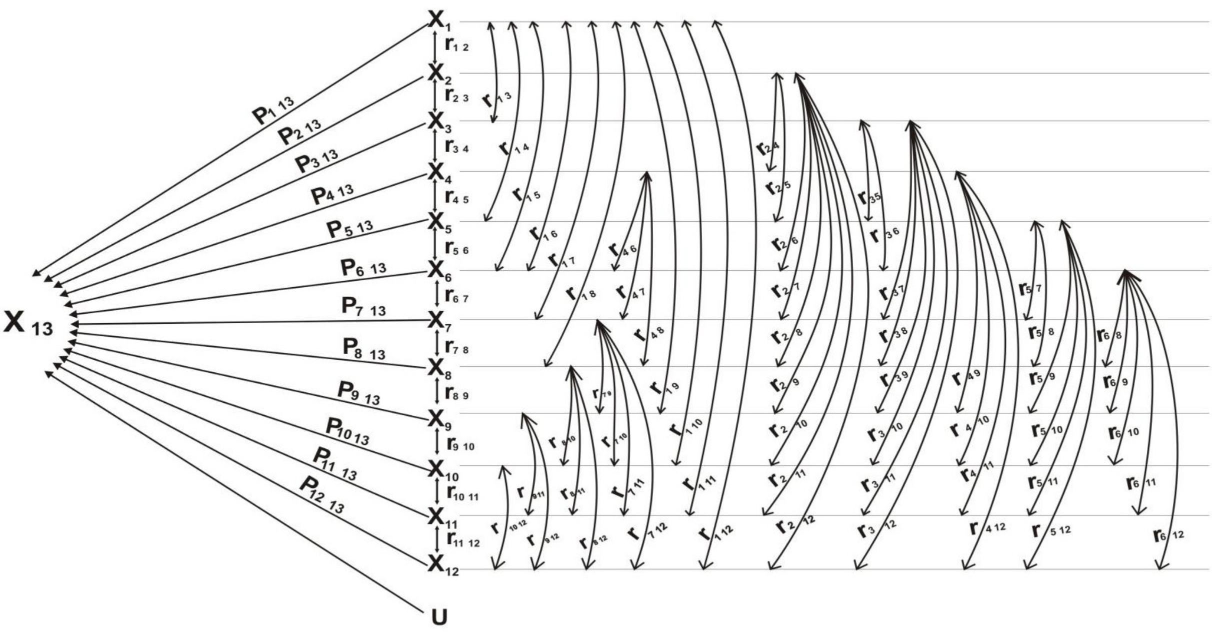

Figure 1. Causation diagram indicating the relationship between pod index and yield-related traits

From this figure,

$$r_{1\,13} = P_{1\,13} + r_{1\,2}P_{2\,13} + r_{1\,3}P_{3\,13} + r_{1\,4}P_{4\,13} + r_{1\,5}P_{5\,13} + r_{1\,6}P_{6\,13} + r_{1\,7}P_{7\,13} + r_{1\,8}P_{8\,13} + r_{1\,9}P_{9\,13} + r_{1\,10}P_{10\,13} + r_{1\,11}P_{11\,13} + r_{1\,12}P_{12\,13}$$

$$r_{2\,13} = r_{1\,2}P_{1\,13} + P_{2\,13} + r_{2\,3}P_{3\,13} + r_{2\,4}P_{4\,13} + r_{2\,5}P_{5\,13} + r_{2\,6}P_{6\,13} + r_{2\,7}P_{7\,13} + r_{2\,8}P_{8\,13} + r_{2\,9}P_{9\,13} + r_{2\,10}P_{10\,13} + r_{2\,11}P_{11\,13} + r_{2\,12}P_{12\,13}$$

$$r_{3\,13} = r_{1\,3}P_{1\,13} + r_{2\,3}P_{2\,13} + P_{3\,13} + r_{3\,4}P_{4\,13} + r_{3\,5}P_{5\,13} + r_{3\,6}P_{6\,13} + r_{3\,7}P_{7\,13} + r_{3\,8}P_{8\,13} + r_{3\,9}P_{9\,13} + r_{3\,10}P_{10\,13} + r_{3\,11}P_{11\,13} + r_{3\,12}P_{12\,13}$$

$$r_{4\,13} = r_{1\,4}P_{1\,13} + r_{2\,4}P_{2\,13} + r_{3\,4}P_{3\,13} + P_{4\,13} + r_{4\,5}P_{5\,13} + r_{4\,6}P_{6\,13} + r_{4\,7}P_{7\,13} + r_{4\,8}P_{8\,13} + r_{4\,9}P_{9\,13} + r_{4\,10}P_{10\,13} + r_{4\,11}P_{11\,13} + r_{4\,12}P_{12\,13}$$

$$r_{5\,13} = r_{1\,5}P_{1\,13} + r_{2\,5}P_{2\,13} + r_{3\,5}P_{3\,13} + r_{4\,5}P_{4\,13} + P_{5\,13} + r_{5\,6}P_{6\,13} + r_{5\,7}P_{7\,13} + r_{5\,8}P_{8\,13} + r_{5\,9}P_{9\,13} + r_{5\,10}P_{10\,13} + r_{5\,11}P_{11\,13} + r_{5\,12}P_{12\,13}$$

$$r_{6\,13} = r_{1\,6}P_{1\,13} + r_{2\,6}P_{2\,13} + r_{3\,6}P_{3\,13} + r_{4\,6}P_{4\,13} + r_{5\,6}P_{5\,13} + P_{6\,13} + r_{6\,7}P_{7\,13} + r_{6\,8}P_{8\,13} + r_{6\,9}P_{9\,13} + r_{6\,10}P_{10\,13} + r_{6\,11}P_{11\,13} + r_{6\,12}P_{12\,13}$$

$$r_{7\,13} = r_{1\,7}P_{1\,13} + r_{2\,7}P_{2\,13} + r_{3\,7}P_{3\,13} + r_{4\,7}P_{4\,13} + r_{5\,7}P_{5\,13} + r_{6\,7}P_{6\,13} + P_{7\,13} + r_{7\,8}P_{8\,13} + r_{7\,9}P_{9\,13} + r_{7\,10}P_{10\,13} + r_{7\,11}P_{11\,13} + r_{7\,12}P_{12\,13}$$

$$r_{8\,13} = r_{1\,8}P_{1\,13} + r_{2\,8}P_{2\,13} + r_{3\,8}P_{3\,13} + r_{4\,8}P_{4\,13} + r_{5\,8}P_{5\,13} + r_{6\,8}P_{6\,13} + r_{7\,8}P_{7\,13} + P_{8\,13} + r_{8\,9}P_{9\,13} + r_{8\,10}P_{10\,13} + r_{8\,11}P_{11\,13} + r_{8\,12}P_{12\,13}$$

$$r_{9\,13} = r_{1\,9}P_{1\,13} + r_{2\,9}P_{2\,13} + r_{3\,9}P_{3\,13} + r_{4\,9}P_{4\,13} + r_{5\,9}P_{5\,13} + r_{6\,9}P_{6\,13} + r_{7\,9}P_{7\,13} + r_{8\,9}P_{8\,13} + P_{9\,13} + r_{9\,10}P_{10\,13} + r_{9\,11}P_{11\,13} + r_{9\,12}P_{12\,13}$$

$$r_{10\,13} = r_{1\,10}P_{1\,13} + r_{2\,10}P_{2\,13} + r_{3\,10}P_{3\,13} + r_{4\,10}P_{4\,13} + r_{5\,10}P_{5\,13} + r_{6\,10}P_{6\,13} + r_{7\,10}P_{7\,13} + r_{8\,10}P_{8\,13} + r_{9\,10}P_{9\,13} + P_{10\,13} + r_{10\,11}P_{11\,13} + r_{10\,12}P_{12\,13}$$

$$r_{11\,13} = r_{1\,11}P_{1\,13} + r_{2\,11}P_{2\,13} + r_{3\,11}P_{3\,13} + r_{4\,11}P_{4\,13} + r_{5\,11}P_{5\,13} + r_{6\,11}P_{6\,13} + r_{7\,11}P_{7\,13} + r_{8\,11}P_{8\,13} + r_{9\,11}P_{9\,13} + r_{10\,11}P_{10\,13} + P_{11\,13} + r_{11\,12}P_{12\,13}$$

$$r_{12\,13} = r_{1\,12}P_{1\,13} + r_{2\,12}P_{2\,13} + r_{3\,12}P_{3\,13} + r_{4\,12}P_{4\,13} + r_{5\,12}P_{5\,13} + r_{6\,12}P_{6\,13} + r_{7\,12}P_{7\,13} + r_{8\,12}P_{8\,13} + r_{9\,12}P_{9\,13} + r_{10\,12}P_{10\,13} + r_{11\,12}P_{11\,13} + P_{12\,13}$$

where: r_{ij} represents correlation coefficient between the i^{th} and j^{th} trait (i = 1 to 12 and j = 2 to 13) and P_{i13} represents direct effect of the i^{th} trait on trait number 13.

3. Results

The phenotypic correlation coefficients among fourteen vegetative and fruit characters of the nine cacao hybrids are presented in Table 3. Plant height was positively and significantly correlated with stem diameter (0.83), tree circumference (0.60), presence of fruits (0.46), fruit width (0.41) and pod index (0.56), but negatively correlated with time to fruit harvest (–0.47). Time to jorquette was positively (P≤0.05) correlated with time to fruit harvest, (0.43) and fruit weight (0.53) but negatively correlated with pod index (–0.40). Presence of fruit was positively significantly correlated with cherelle wilt (0.57) and pod thickness (0.96). Cherelle wilt was positively significantly correlated with pod thickness (0.55). Time to fruit harvest was positively significantly correlated with fruit weight (0.41), fruit length (0.71), but negatively correlated with fruit width (–0.91) and pod index (–0.83). Number of beans per row was negatively correlated with pod index (–0.71).

The genotypic correlation coefficients among fourteen vegetative and fruit characters of the nine cacao hybrids are presented in Table 4. Plant height was positively significantly (P≤0.01) correlated with stem diameter (2.84), time to jorquette (1.29), tree circumference (2.29), presence of fruit (2.24), fruit width (27.68), pod thickness (19.82), and pod index (4.27) but negatively correlated with number of leaves (–1.62), jorquette height (–1.06),

Table 3. Phenotypic correlation coefficients among fourteen vegetative and fruit characters of nine cacao hybrids used in the study

Character	S D	N L	TTJ	JH	TC	FRT	WLT	TFH	Frt Wt	Frt Lt	Frt Wth	P T	Rows	P. I.
P H	0.83**	0.25	0.10	0.21	0.60**	0.46*	–0.06	–0.47**	–0.09	–0.27	0.41*	0.36	–0.01	0.56**
S D		0.40*	–0.09	0.37*	0.55**	–0.06	–0.41*	–0.45*	–0.01	–0.09	0.48**	–0.17	–0.05	0.36
N L			–0.17	0.09	0.35	–0.09	–0.16	–0.09	–0.23	0.05	0.13	–0.18	0.33	0.06
TTJ				0.11	–0.10	0.25	0.30	0.43*	0.53**	0.29	–0.69**	0.30	–0.27	–0.40*
JH					0.14	–0.32	–0.28	–0.36	0.19	–0.07	0.27	–0.33	–0.30	0.09
TC						0.23	0.01	–0.25	–0.05	–0.08	0.30	0.15	–0.08	0.29
FRT							0.57**	0.03	–0.15	–0.26	–0.10	0.96**	0.25	0.25
WLT								0.30	0.21	–0.15	–0.32	0.55**	0.01	–0.12
TFH									0.41*	0.71**	–0.91**	0.10	–0.05	–0.83**
Frt Wt										0.18	–0.35	–0.17	–0.64**	–0.62**
Frt Lt											–0.66**	–0.11	–0.29	–0.63**
Frt Wth												–0.19	0.04	0.73**
P T													0.14	0.21
Rows														0.15
Bns/Row														–0.71**

NB: df= 25; * and ** = Significance at 0.05 and 0.01 respectively. The values without asterisk are not significant

PH= Plant Height; SD= Stem Diameter; NL= Number of Leaves; TTJ= Time to Jorquette; JH=jorquette Height; TC= Tree Circumference; FRT= Presence of Fruit; WLT= Cherelle Wilt; TFH= Time to fruit harvest; Frt Wt= Fruit Weight; Frt Lt= Fruit Length; Frt Wth = Fruit Width; PT= Pod Thickness; Bns/Row= Number of Beans per row; P. I. = Pod Index cherelle wilt (–4.09), time to fruit harvest (–2.19), fruit weight (–1.07), fruit length (–0.47) and number of rows (–0.82). Time to jorquette was also highly significantly (P≤0.01) correlated with the rest of the characters except jorquette height. The highly significant correlations of time to jorquette with these characters was however negative with fruit width (–9.98), number of rows (–0.53) and pod index (–0.99). Jorquette height was significantly (P≤0.05) correlated with the rest of the characters except fruit weight, fruit length and pod thickness. The highly significant correlations of jorquette height with these characters was however negative with presence of fruit (–0.68), Cherelle wilt (–1.42), time to fruit harvest (–0.41) and number of rows (–0.41). Tree circumference was positively significantly (P≤0.01) correlated with fruit width (7.96), pod thickness (1.84) and pod index (0.72) but negatively correlated with cherelle wilt (–1.27), time to fruit harvest (-0.42) and number of rows (–0.37). Presence of fruit was positively significantly (P≤0.01) correlated with cherelle wilt (0.57), pod thickness (10.60), and pod index (0.47) but negatively correlated with fruit length (–0.47). Cherelle wilt was also positively significantly (P≤0.01) correlated with time to fruit harvest (0.54), pod thickness (9.52) and pod index (0.54) but negatively correlated with fruit width (–3.76). The correlation of pod index was negative with each of time to fruit harvest (–1.09), fruit weight (–0.75), fruit length (–0.92) and number of beans per row (–0.56). Fruit width was positively correlated with pod index (12.26).

The environmental correlation coefficients among fourteen vegetative and fruit characters of the hybrids are presented in Table 5. Plant height showed positively significant (P≤0.05) correlations with stem diameter (0.65), number of leaves (0.63), jorquette height (0.54), tree circumference (0.42) and cherelle wilt (0.60). Stem diameter showed positively significant (P≤0.05) correlations with number of leaves (1.13), tree circumference (0.98) and cherelle wilt (0.64). Time to jorquette was negatively significantly (P≤0.01) correlated with tree circumference (–0.86) and cherelle wilt (–0.44). Jorquette height was positively significantly correlated with cherelle wilt (0.73) but negatively correlated with time to fruit harvest (–0.55). Tree circumference had positively significant correlations only with the presence of fruit (0.37) and cherelle wilt (0.91). Presence of fruits had positively significant correlation only with cherelle wilt (0.63), but a negative correlation with pod thickness (–0.92). Cherelle wilt was positively significantly (P≤0.01) correlated with the number of rows (0.40) but negative correlations with pod thickness (–0.58) and pod index (–0.79). Time to fruit harvest was negatively significantly correlated with number of rows (–0.43). Fruit weight was negatively correlated with number of rows (–0.78). Fruit width and number of beans per row were negatively significant with pod index (–0.39 and –0.90 respectively).

Table 4. Genotypic correlation coefficients among fourteen vegetative and fruit characters of nine cacao hybrids used in the study

Character	S D	N L	TTJ	JH	TC	FRT	WLT	TFH	Frt Wt	Frt Lt	Frt Wth	P T	Rows	P. I.
P H	2.84**	–1.62**	1.29**	–1.06**	2.29**	2.24**	–4.09**	–2.19**	–1.07**	–0.47**	27.68**	19.82**	–0.82**	4.27**
S D		–0.93**	0.49**	0.70**	–0.23	–0.49**	–2.51**	–0.90**	–0.02	0.27	14.46**	0.88**	–0.48**	0.96**
N L			0.11	0.42	–0.72**	–0.52	–1.34**	–0.25	–0.46*	0.21	5.06**	1.13**	0.42*	0.24
TTJ				0.15	1.25**	0.84**	1.70**	0.78**	1.21**	0.56**	–9.98**	2.39**	–0.53**	–0.99**
JH					0.75**	–0.68**	–1.42**	–0.41*	0.15	0.09	1.57**	0.12	–0.41*	0.78*
TC						0.14	–1.27**	–0.42**	–0.08	–0.14	7.96**	1.84**	–0.37*	0.72*
FRT							0.57*	0.03	–0.25	–0.47**	–0.05	10.60**	0.30	0.47**
WLT								0.54**	0.31	–0.28	–3.76**	9.52**	–0.33	0.54**
TFH									0.44*	0.89**	–9.17**	0.66**	–0.02	–1.09**
Frt Wt										0.24	–4.85**	–0.42	–0.61**	–0.75*
Frt Lt											–9.89**	–1.21**	–0.30	–0.92**
Frt Wth												–17.20**	2.56**	12.26**
P T													1.37**	0.38
Rows														0.11
Bns/Row														–0.56**

NB: df= 25; * and ** = Significance at 0.05 and 0.01 respectively. The values without asterisk are not significant

PH= Plant Height; SD= Stem Diameter; NL= Number of Leaves; TTJ= Time to Jorquette; JH=jorquette Height; TC= Tree Circumference; FRT= Presence of Fruit; WLT= Cherelle Wilt; TFH= Time to fruit harvest; Frt Wt= Fruit Weight; Frt Lt= Fruit Length; Frt Wth = Fruit Width; PT= Pod Thickness; Bns/Row= Number of Beans per row; P. I. = Pod Index

Table 5. Environmental correlation coefficients among fourteen vegetative and fruit characters of nine cacao hybrids used in the study

Character	S D	N L	TTJ	JH	TC	FRT	WLT	TFH	Frt Wt	Frt Lt	Frt Wth	P T	Rows	P. I.
P H	0.65**	0.63**	–0.04	0.54**	0.42*	0.18	0.60**	–0.25	0.24	–0.32	–0.15	–0.29	0.22	–0.16
S D		1.13**	–0.32	0.17	0.98**	0.33	0.64**	0.13	0.00	–0.38	–0.35	–0.30	0.33	–0.07
N L			–0.33	–0.22	1.17**	0.48**	0.69**	0.61**	0.15	–0.14	–0.29	–0.41	0.24	–0.14
TTJ				0.09	–0.86**	–0.28	–0.44**	0.06	–0.18	0.09	–0.17	0.10	–0.06	0.04
JH					–0.44	0.26	0.73**	–0.55**	0.33	–0.29	0.22	–0.51	–0.14	–0.84
TC						0.37*	0.91**	0.16	0.01	–0.02	–0.30	–0.06	0.30	–0.16
FRT							0.63**	0.11	0.16	0.13	–0.18	–0.92**	0.12	–0.14
WLT								–0.31	0.09	–0.03	–0.10	–0.58**	0.40*	–0.79**
TFH									0.29	0.22	0.09	–0.07	–0.43*	0.02
Frt Wt										0.02	0.23	–0.27	–0.78**	–0.35
Frt Lt											0.22	0.07	–0.27	–0.17
Frt Wth												0.10	–0.31	–0.39*
P T													–0.09	0.26
Rows														0.24
Bns/Row														–0.90**

NB: df= 25; * and ** = Significance at 0.05 and 0.01 respectively. The values without asterisk are not significant
PH= Plant Height; SD= Stem Diameter; NL= Number of Leaves; TTJ= Time to Jorquette; JH=jorquette Height; TC= Tree Circumference; FRT= Presence of Fruit; WLT= Cherelle Wilt; TFH= Time to fruit harvest; Frt Wt= Fruit Weight; Frt Lt= Fruit Length; Frt Wth = Fruit Width; PT= Pod Thickness; Bns/Row= Number of Beans per row; P. I. = Pod Index

The direct and indirect path coefficients that estimate the strength of the relationship between pod index and the vegetative and fruit characters using the genotypic correlation values is presented in table 6. Fruit length had the largest positive direct effect (4.5487) on pod index, with its largest indirect effect through time to jorquette (1.6755). The largest negative indirect effect of fruit length on pod index is through time to fruit harvest (–7.5772). Cherelle wilt also had a notably large positive direct effect (3.5830) 0n pod index, with its largest indirect effect also through time to jorquette (5.0864). The largest negative indirect effect of cherelle wilt on pod index is through time to fruit harvest (–4.5974). Time to fruit harvest had the largest negative direct effect (–8.5137) on pod index, with its largest indirect effect through fruit length (4.0484). The negative direct effects of jorquette height (–0.4375), and plant height (–0.2087) on pod index are also noteworthy. Jorquette height had its largest indirect effect also through time to fruit harvest (3.4906). Though the number of characters used in the path coefficient analysis was large, the residual factor was 1.7558.

Table 6. Direct and indirect path coefficients between pod index and twelve vegetative and fruit characters of nine cacao hybrids

		Indirect effects through other plant characters												
	Direct effect	PH	SD	TTJ	JH	TC	FRT	WLT	TFH	Frt Wt	Frt Lt	Frt Wth	Bns/Row	Corr with Pod index
PH	**–0.2087**		1.4382	3.8597	0.4637	0.6822	–6.3551	–14.6547	18.645	4.4176	–2.1379	–2.7851	0.9052	4.27
SD	**0.5064**	–0.5928		1.4661	–0.3062	–0.0685	1.3902	–8.9934	7.6623	0.0826	1.2282	–1.4549	0.0402	0.96
TTJ	**2.992**	–0.2693	0.2481		–0.0656	0.3724	–2.3832	6.0912	–6.6407	–4.9956	2.5473	1.0042	0.1092	–0.99
JH	**–0.4375**	0.2212	0.3545	0.4488		0.2234	1.9292	–5.0879	3.4906	–0.6193	0.4094	–0.158	0.0055	0.78
TC	**0.2979**	–0.4780	–0.1165	3.7400	–0.3281		–0.3972	–4.5505	3.5758	0.3303	–0.6368	–0.8009	0.084	0.72
FRT	**–2.8371**	–0.4675	–0.2481	2.5133	0.2975	0.0417		2.0423	–0.2554	1.0321	–2.1379	0.005	0.4841	0.47
WLT	**3.583**	0.8537	–1.2711	5.0864	0.6212	–0.3783	–1.6171		–4.5974	–1.2799	–1.2736	0.3783	0.4348	0.54
TFH	**–8.5137**	0.4571	–0.4558	2.3338	0.1794	–0.1251	–0.0851	1.9348		–1.8166	4.0484	0.9227	0.0301	–1.09
Frt Wt	**–4.1286**	0.2233	–0.0101	3.6203	–0.0656	–0.0238	0.7093	1.1107	–3.7460		1.0917	0.4880	–0.0192	–0.75
Frt Lt	**4.5487**	0.0981	0.1367	1.6755	–0.0394	–0.0417	1.3334	–1.0033	–7.5772	–0.9909		0.9951	–0.0553	–0.92
Frt Wth	**–0.1006**	–5.7774	7.3226	–29.8601	–0.6868	2.3711	0.1419	–13.4723	78.0706	20.0236	–44.987		–0.7855	12.26
Bns/Row	**0.0457**	–4.1369	0.4456	7.1509	–0.0525	0.5481	–30.0732	34.1106	–5.619	1.734	–5.504	1.7306		–0.56

PH= Plant Height; SD= Stem Diameter; TTJ= Time to Jorquette; JH=jorquette Height; TC= Tree Circumference; FRT= Presence of Fruit; WLT= Cherelle Wilt; TFH= Time to fruit harvest; Frt Wt= Fruit Weight; Frt Lt= Fruit Length; Frt Wth= Fruit Width; Bns/Row= Number of Beans per row
Residual effect = 1.7558

4. Discussion

The mutual association among characters is often expressed by the phenotypic, genotypic and environmental correlations [8,9]. Phenotypic correlation is a composite of genotypic and environmental correlations. In this study, the genotypic correlation coefficients were in most cases higher than the corresponding phenotypic correlation coefficients and the environmental correlation coefficients. This has been ascribed to reduced values of environmental correlations between the corresponding characters implying reduced influence by the environment [8]. This implies that the genotypic factor had a greater contribution in the development of the character association [10]. The low values of the environmental correlation coefficients imply that the phenotypic correlation coefficients would be good indicators of genotypic correlation coefficients. This is supported by the findings of Kalambe *et al* on cowpea [11].

Selection of the genotypes based only on inter-character associations which are genotypically correlated but not phenotypically correlated may not be of practical value since selection is mostly based on the phenotypes of the characters. Such a selection will be unrepeatable and unreliable [1]. This applies to the pairs of characters that exhibited this kind of relationship in the study, such as stem diameter, fruiting and wilted fruits with pod index.

The significant genotypic and phenotypic correlations of many of the pairs of the vegetative and fruit characters with one another and with pod index suggested that these characters contributed either positively or negatively to growth and yield in the cacao genotypes. Such inter-character associations can therefore be used as criteria for selection of the genotypes that particularly exhibit good yield. This relationship applies to plant height, time to jorquette, time to fruit harvest, fruit length and fruit width with pod index. Significant correlations of yield-related characters in young cacao plants were reported by Santos *et al.* [12].

The direct and indirect relationships between pod index and the vegetative and fruit characters of the nine cacao genotypes indicated that plant height, jorquette height, fruiting, time to fruit harvest, fruit weight and fruit width all had a negative direct effects on pod index. These relationships are very desirable. It implies that an inverse relationship exists between each of these traits and pod index, i.e. an increase in the value of each of these results in a corresponding reduction in the pod index. Since pod index refers to the number of cocoa pods required to produce 1.0 kg of dry cocoa beans [13], the lower the value, the more desirable the genotype. Any character whose incremental value will reduce the numerical value of pod index is therefore of utmost importance. Thondaiman and Rajamani [14] reported similar findings in cacao.

The valuable negative indirect effects of these plant traits on pod index include their effects through fruiting, cherelle wilt, fruit length and fruit width (for plant height); fruit wilt, fruit weight and fruit width (for jorquette height); plant height, stem diameter, time to fruit harvest and fruit length (for fruiting); stem diameter, tree circumference, fruiting and fruit weight (for time to fruit harvest); stem diameter, jorquette height, tree circumference, time to fruit harvest and pod thickness (for fruit weight); and plant height, time to jorquette, cherelle wilt, fruit length and pod thickness (for fruit width). Each of plant height, jorquette height, fruiting, time to fruit harvest, fruit weight and fruit width can therefore be considered along with any or all of each of the other traits that enhance their negative expression in the screening or selection of these cacao genotypes for desirable pod index. Initial increase in the tree circumference can result in better yield (pod index), when tree circumference is considered in association with jorquette height, fruiting, cherelle wilt, fruit length and fruit width, which all had negative indirect correlations with pod index. The other traits such as stem diameter, time to jorquette, cherelle wilt, fruit length and pod thickness which had positive direct effect on pod index (which is not desirable in this context) can also be considered in conjunction with the traits which had negative indirect effect on pod index. Thondaiman and Rajamani [14] also reported findings similar to these. The significant value of the residual factor in spite of the large number of characters used in the path coefficient analysis may be due to the fact that correlations are mere estimates, and may also be due to rounding-off errors.

5. Conclusions

Significant association existed among most traits under consideration, and such traits significantly determined yield as indicated by pod index in cacao. These traits, therefore, are important for consideration in further yield improvement procedures in cacao.

Conflict of Interest

There exists no conflict of interest with respect to the entire process leading to the submission of this article for publication.

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