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Heterosis and Heritability Estimates of Some Yield Traits in Eight Hybrids of Cocoa (*Theobroma cacao)*

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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, ACO, DBA and AAM managed the analyses of the study. Author OIS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The quest to understand the inheritance pattern of some traits in generated progenies of some parental clones of cocoa lead to this study. Hybridization was carried out to generate progenies from eleven parental clones. The hybrids were established in a randomized complete block design of six replications in a hybrid evaluation trial plot at the Cocoa Research Institute of Nigeria (CRIN), Ibadan in 1999. Data were collected on some yield parameters from the parents and the hybrids.

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Heritability, component of genetic variation and heterosis were estimated for the traits. The collected data were subjected to analysis of variance (ANOVA). There were significant variation (P<0.05) among the nineteen genotypes for all the studied traits except the placental weight and bean weight per pod respectively. Among the parents, Pound 7 had the highest pod weight. However, P7xPA150 had the highest number of bean per pod. Some of the hybrids exhibited significant heterosis for most of the yield traits. Their inclusion in commercial cocoa production can lead to the improvement of the national cocoa productivity.

Keywords: Parent; yield; heterosis; heritability and productivity.

1. INTRODUCTION

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 [1]. Cocoa trees grow in tropical environments, within 15 to 20 degrees latitude from the equator. The ideal climate for growing cocoa is hot, rainy, and tropical, with lush vegetation to provide shade for the cocoa trees. The primary growing regions are Africa, Asia, and Latin America [2]. Its seeds, called cocoa beans, are processed into cocoa powder, cocoa butter, and chocolate [3].

The largest producers of cocoa are Cote d'ivoire, Ghana, Indonesia and Nigeria and Côte d'Ivoire produces 33% of global supply [4,2]. 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 [5]. It is a major source of income to the farmers and government of producing states. Nigeria still produces 300,000 to 350,000 tonns of cocoa a year, most of which is consumed abroad [6].

In West Africa most farmers establish their cacao plantation from seeds. Some farmers have access to seeds resulting from bi-parental crosses (sometimes called "hybrid" crosses) carried out in seed gardens, and some farmers use seeds from their own or neighbours trees for new plantings [7].

The use of improved planting materials with good yield and quality potentials is necessary for a sustainable cocoa production system. This should guarantee good yield per unit area, timeliness in fruiting and the profitability of the venture. This has been a long term target in Nigeria [8].

One of the aims of plant breeding is to improve the yield and quality of crops. Economically important part of the cocoa plant is the bean and improvement of the cocoa bean in terms of the size and quality is an important aspect of cocoa breeding research at the Cocoa Research Institute of Nigeria (CRIN).

Heterosis has been one of the most important contributions of genetics to scientific agriculture in providing hybrid and vigorous and high yielding hybrids in plants.

Heterosis is exploited through the development of hybrid. It is commercially exploited in seed production of cross pollinated crops. The presence of sufficient hybrid vigour is an important prerequisite for successful production of hybrid varieties. Therefore, the heterotic studies can provide the basis for the exploitation of valuable hybrid combinations in the future breeding programmes and their commercial utilization [9].

Heritability is the proportion of variation in a phenotype that is caused by genetic variation among individuals. It estimate and enable the breeder decide which method should be used for selection and it construct selection index, it also decide minimum population required to carry out selection effectively and know response of various traits to selection [10].

Hybridization is an important method of crop improvement and it involves the generation of hybrids from selected parent of proven agronomic characteristic.

Of utmost importance is the evaluation of the generated hybrids to understand their genetic potentials in terms heritability, heterosis and the collection of the studied agronomic and yield parameters to enhance subsequent selection for use of the proven progenies.

This study was carried out to estimate the broad sense heritability of the cocoa hybrids for yield traits in cacao and to estimate expressed level of heterosis for some yield and yield related traits in some cocoa hybrids accessions and some of their hybrids.

2. MATERIALS AND METHODS

The project was carried out at the local clone and hybrid trial plots of the Cocoa Research Institute of Nigeria (CRIN) Ibadan. The experimental design was laid out in a randomized completely block design with six replications of ten trees per block for each parent and hybrids at a spacing of 3m x 3m. Table 1 show the list of the eight cocoa hybrids (CRIN TC1 to CRIN TC8 releases to Nigeria farmers) considered in the study. Data were collected from fifteen uniformly matured and ripe cocoa pods from each parent and hybrid in the local clone and hybrid trial plots respectively. Data collected includes; pod weight (PdWT), pod length (PdLT), pod girth (PdGth), inner pod diameter (InPdD), outer pod diameter (OutPdD), weight of beans per pod (WtPD), placental length (PLL), number of beans per pod (NoBP), placental weight (PLWT), and hundred beans weight (HBWT). All the data were subjected to the statistical analysis using the Statistical Analysis Software (SAS), version 9.2 [11]. The analysis of variance (ANOVA) was calculated using the PROC GLM procedure in SAS.

Table 1. Description of the eight hybrids used in the study

S/N	Code	Pedigree
1	CRIN TC1	T65/7xN38
2	CRIN TC2	T101/15xN38
3	CRIN TC3	P7xPA150
4	CRIN TC4	T65/7xT57/22
5	CRIN TC5	T82/27xT12/11
6	CRIN TC6	PA150xT60/887
7	CRIN TC7	T82/27xT16/17
8	CRIN TC8	T65/7xT9/15

The variance components such as genotypic variance (σ^2g), phenotypic variance (σ^2p), and environmental variance (σ^2e), were computed according to Singh and Chaudhary [12] as follows;

Genotypic coefficient of variation $GCV=\frac{\sqrt{\sigma^2 g}}{X}x100$

Phenotypic coefficient of variation $PCV=\frac{\sqrt{\sigma^2 p}}{X}x100$

σ^2g = genotypic variance
σ^2p = phenotypic variance
X = Sample means of the character

GCV and PCV values were categorized as low, moderate and high as indicated by Siva Subramanian and Manon [13],

0-10%; low
10-20%; moderate
20% and above; high

Broad sense heritability was estimated as the ratio of the genetic variance to the phenotypic variance and expressed in percentage following Toker [14] as

Broad Sense Heritability

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

Where

σ^2g = genotypic variance
σ^2p = phenotypic variance
σ^2e = environmental variance

Heritability percentages were categorized as low, moderate and high as indicated by Elrod and Stanfield [15].

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

Genetic advance (GA) and Expected Genetic Gain were computed according to the formula by Johnson et al. [16].

$$GA = \frac{\sigma^2 g \times K}{\sqrt{\sigma^2 p}}$$

Where k = 2.06 (selection differential at 10%)

σ^2g = genotypic variance
σ^2p = phenotypic variance

Expected genetic gain was determined from genetic advance as a percentage of population mean *x*

Expected genetic gain = $\frac{GA}{x}\ x\ 100$

Where *x* –sample mean of the character

Heterosis was computed according to formula given by Nuruzzaman et al. [17].

Mid parent heterosis (%) = $\frac{\text{F1}-\text{Mid Parent}}{\text{Mid parent}}$x100

Better parent heterosis (%) = $\frac{\text{F1}-\text{Better Parent}}{\text{Better parent}}$x100

3. RESULTS

The mean performances of the eleven cocoa parents and eight hybrids are presented in Table 2; among the cocoa parent, P7 recorded the highest mean for pod weight, inner pod diameter, weight of beans per pod and placental weight and was significantly different from other parents. It has the least mean pod length, pod girth, outer pod diameter, number of beans per pod, and placental length. T9/15 gave the highest mean value for pod length, pod girth, outer pod diameter and placental length; T101/15 gave the highest value for number of beans per pod while T82/27 and T12/11 gave a higher value for hundred beans weight.

Among the eight cocoa hybrids for ten characters as revealed Table 2, T82/27xT16/17 gave the highest mean value for pod weight and placental weight, P7xPA150 gave the highest mean value for pod length, weight of beans per pod, number of beans per pod and hundred beans weight and it has the least mean value for inner pod diameter and outer diameter. T101/15xN38 recorded the highest mean value for the placental length and the least value for pod weight, weight of beans per pod, placental weight, and hundred beans weight. T65/7xT9/15 recorded the highest mean value for pod girth, inner pod diameter, outer pod diameter.

From Table 2 for both parents and hybrids, P7 recorded the highest mean value for pod weight, inner pod diameter, weight of beans per pod, placental weight and has the least mean value for placental length, pod length, number of beans per pod, and hundred beans weight, T9/15 gave the highest mean value for pod length and has the least mean value pod weight, T65/7xT9/15 gave the highest mean value for pod girth, and outer pod diameter, T101/15xN38 gave the highest mean value for placental length, P7xPA150 gave the highest mean value for number of beans per pod, for hundred beans weight, T82/27 and T12/11 gave the highest mean value and T82/27 has the least mean value for placental length.

Table 3 shows the mean phenotypic and genotypic coefficient of variation, heritability and expected genetic gain in the genotypes included in the present studies. Generally, phenotypic coefficient of variation was higher than genotypic coefficient of variation for all the characters. Pod weight has the highest value for phenotypic and genotypic coefficient of variation followed by placental weight for phenotypic coefficient of variation and inner pod diameter for genotypic coefficient of variation.

The heritability was high in all characters except for weight of beans per pod, placental weight and hundred beans weight; the expected genetic gain is very high in pod weight followed by inner pod diameter.

Mid parents heterosis of eight cocoa hybrids for ten characters was shown in Table 4. Heterotic value with negative sign indicated that the hybrids were not better than the average of the two parents while positive heterosis indicated that the hybrids were better than the average of the two parents.

For traits under study, four hybrids (T65/7xN38, T101/15xN38; P7xPA150 and PA150xT60/887) recorded very high negative heterosis for pod weight; other hybrids recorded positive heterotic values. For number of beans per pod, only T65/7x57/22 had counts than the average of their parents. Other hybrids had positive values ranging from 3.9 to 181%. Hundred beans weight showed only three hybrids P7xPA150, T82/27xT16/17, and T65/7xT9/15 recording positive values, the other five were negative. Over all, one had positive heterosis for all character under investigation. However, one of them recorded positive values for all traits except pod length and these are T82/27xT16/17 and T65/7xT9/15 respectively.

Table 4 also shows the better parent heterosis of eight coca hybrids for ten characters, heterotic value with negative sign indicated that the hybrids were not better than the better parent while positive heterosis indicated that the hybrids were better than the better parent. T65/7xN38, T101/15xN38 and T65/7xT57/22 recorded lesser counts than the better parents; other hybrids had positive values ranging from 3.7 to 85.5%. Hundred beans weight showed only one hybrid P7xPA150 recording positive value, other were negative, T65/7xT57/22 and T82/27xT16/17 had positive heterosis for pod weight, other hybrids had negative.

Table 2. Mean performance of the eleven cocoa parents and eight hybrids for ten characters

Parents/Hybrids	PdWT	PdLT	PdGth	InPD	OutPD	WtBP	PLL	NoBP	PLWT	HBWT
Parents										
T16/17	0.42cd	19.80efg	25.66ef	4.12defg	6.47f	0.10 b	8.06e	33.10de	0.10b	0.28abcd
T9/15	0.91c	25.64a	30.10ab	3.46gh	8.64a	0.12 b	11.79ab	36.98bcd	0.10b	0.30abc
T65/7	0.25cd	20.28def	24.11fg	4.25defg	7.49cd	0.11b	10.02cd	36.84bcd	0.10b	0.28abcd
T101/15	0.44cd	22.89b	28.10bcd	4.38def	7.68bcd	0.10 b	10.68bc	40.28bc	0.10b	0.25cd
T82/27	0.56cd	18.63g	28.34bcd	4.67de	7.65bcd	0.11 b	8.38e	32.73def	0.12b	0.35a
T12/11	0.38cd	18.49g	25.34ef	3.45gh	7.08de	0.11 b	8.84de	36.99bcd	0.10b	0.35a
T57/22	0.45cd	19.36fg	25.36ef	3.03h	6.42f	0.09 b	10.64bc	34.59cde	0.05b	0.30abc
PA150	2.38b	21.20cde	27.00de	3.43gh	6.42f	0.12 b	7.84e	24.83g	0.10b	0.30abc
P7	3.50a	13.57h	22.67fg	6.23a	4.17g	0.16 a	0.12f	17.92h	0.17a	0.12e
N38	2.48b	19.20fg	29.60bc	3.75fgh	6.68ef	0.12 b	8.07e	27.40efg	0.12b	0.30abc
T60/887	0.37cd	20.58def	25.42ef	4.12defg	7.14de	0.10 b	8.98de	35.67bcde	0.10b	0.25cd
Hybrids										
T65/7XN38	0.54cd	20.58def	29.43bc	5.75bc	8.11ab	0.11 b	11.07bc	34.72cde	0.05b	0.27bcd
T101/15XN38	0.08d	20.68def	27.96cd	4.71de	8.50a	0.04 b	12.41a	36.11bcd	0.02b	0.22d
P7XPA150	0.65cd	22.57bc	29.25bc	3.42gh	7.18de	0.14 b	10.83bc	46.06a	0.10b	0.34ab
T65/7XT57/22	0.45cd	21.01de	27.64cd	5.68bc	7.81bc	0.04 b	10.01cd	30.16efg	0.05b	0.25cd
T82/27XT12/11	0.49cd	19.68efg	27.88cd	4.55def	8.55a	0.11 b	11.29abc	41.17ab	0.05b	0.30abc
PA150XT60/887	0.39cd	18.48g	25.10ef	3.98efg	7.50cd	0.10 b	10.69bc	39.74bc	0.10b	0.27bcd
T82/27XT16/17	0.80c	21.60bcd	29.19bc	5.00cd	8.59a	0.14 b	11.08bc	41.67ab	0.12b	0.33ab
T65/7XT9/15	0.70cd	21.69bcd	31.58a	6.19b	8.71a	0.13 b	11.26abc	38.33bcd	0.11b	0.30abc

Means followed by the same letter(s) are not significantly different according to DMRT ($P<0.05$)

NB: Pod weight (PdWT), Pod length (PdLT), Pod girth (PdGth), Inner pod diameter (InPD), Outer pod diameter (OutPD), Weight of beans per pod (WtBP), Placental length (PLL), Number of beans per pod (NoBP), Placental weight (PLWT) Hundred bean weight (HBWT)

Table 3. Mean phenotypic and genotypic coefficient of variances, heritability and expected genetic gain in *T. cacao*

Characters	Mean	PCV	GCV	Environmental variance	Heritability	Genetic advance	Expected genetic gain
PdWT	0.86	95.52	73.11	0.24	62.44	1.02	119.01
PdLT	19.76	10.61	8.68	1.45	67.04	2.89	14.65
PdGth	27.34	9.13	7.19	2.36	62.06	3.19	11.67
InPD	5.83	18.5	14.48	0.45	61.24	1.36	23.34
OutPD	7.41	12.15	10.43	0.21	73.74	1.37	18.45
WtBP	0.48	21.33	0	0.01	0	0	0
PLL	9.56	17.6	13.96	1.05	62.96	2.18	22.82
NoBP	34.39	18.86	13.68	19.91	52.65	7.03	20.45
PLWT	2.11	36.91	0	0.73	0	0	0
HBWT	0.28	21.01	10.13	0.00	23.24	0.03	10.06

NB: Pod weight (PdWT), Pod length (PdLT), Pod girth (PdGth), Inner pod diameter (InPD), Outer pod diameter (OutPD), Weight of beans per pod (WtBP), Placental length (PLL), Number of beans per pod (NoBP), Placental weight (PLWT) Hundred bean weight (HBWT)

Table 4. Mid and high parent heterosis of eight cocoa hybrids for ten characters

	PdWT	PdLT	PdGth	InPD	OutPD	WtBP	PLL	NoBP	PLWT	HBWT
Mid parent heterosis										
T65/7XN38	-60.2	4.3	9.6	43.8	14.5	-8.2	22.5	8.1	-56.9	-7.4
T101/15XN38	-94.9	-1.7	-3.1	15.7	18.4	-64.5	32.4	6.7	-80.0	-18.8
P7XPA150	-78.0	82.2	17.8	2.8	35.0	11.4	172.0	181.2	-25.9	13.3
T65/7XT57/22	29.8	6.0	11.7	55.9	12.4	-14.7	-2.3	-15.6	-46.7	-14.3
T82/27XT12/11	3.5	6.0	3.9	12.2	16.0	-4.4	31.1	18.1	-50.8	-13.8
PA150XT60/887	-71.9	-11.6	-4.2	5.4	10.1	-9.1	27.1	31.4	1.7	-1.8
T82/27XT16/17	62.5	12.4	8.1	13.7	21.7	32.8	34.8	26.6	7.7	4.2
T65/7XT9/15	20.9	-5.5	16.5	60.7	8.0	15.5	3.3	3.9	8.3	1.7
High parent heterosis										
T65/7XN38	-78.2	1.5	-0.6	35.4	8.3	-13.0	10.5	-5.8	-60.0	-10.0
T101/15XN38	-97.0	-9.6	-5.6	7.4	10.7	-67.5	16.2	-10.3	-81.4	-25.6
P7XPA150	-81.5	6.5	8.3	-0.1	11.0	-2.5	38.1	85.5	-41.2	13.3
T65/7XT57/22	0.4	3.6	9.0	33.5	4.3	-20.3	-4.3	-18.1	-46.7	-16.7
T82/27XT12/11	-13.6	5.7	-1.6	-2.5	11.7	-4.4	27.7	11.3	-54.3	-13.8
PA150XT60/887	-83.8	12.9	-7.0	-3.5	4.9	-16.7	19.0	11.4	1.7	-10.0
T82/27XT16/17	42.3	9.1	3.0	7.0	12.3	25.0	32.2	25.9	0.0	-5.7
T65/7XT9/15	-23.3	-15.4	4.9	45.7	0.8	12.3	-4.5	3.7	8.3	-1.1

Means followed by the same letter(s) are not significantly different according to DMRT (P<0.05)

NB: Pod weight (PdWT), Pod length (PdLT), Pod girth (PdGth), Inner pod diameter (InPD), Outer pod diameter (OutPD), Weight of beans per pod (WtBP), Placental length (PLL), Number of beans per pod (NoBP), Placental weight (PLWT) Hundred bean weight (HBWT)

Among the hybrids none had positive heterosis for all characters under investigation; however, T82/27xT16/17 had positive values for all the traits except hundred beans weight.

4. DISCUSSION

The heritability was observed for pod weight, pod length, pod girth, inner pod diameter, outer pod diameter, placental length, and number of bean pod which indicates that there was no influence of the environment on the traits and that the trait is highly heritable and the genetic constituent of the character would be expressed to a greater extent if selection were based on these traits. Moderate heritability was observed in hundred bean weight which indicates that there was influence on the traits.

The expected genetic gain which was calculated explains the predicted magnitude of progress to be made from selection in subsequent generation. For traits with high expected gain such as inner pod diameter, placental length, number of bean per pod implies the progress from selection for improvement base on these traits may be slow. For traits pod length, pod girth, outer pod diameter, hundred bean weight which all recorded low expected genetic gain, progress from selection for improvement based on these traits may require more cycle of selection to achieve desired goal.

According to Johnson et al. [16], heritability and genetic gain estimated are helpful in predicting the resultants effects of selecting the best individual than heritability alone.

The implication of combination of high heritability and high expected genetic gain is that in addition to possible phenotypic selection for the traits, progress from selection made in a cycle will be high for that trait such case is observed in pod weight. The combination of high heritability and moderate expected genetic gain recorded for inner pod diameter, placental length, and number of beans per pod implies that even though phenotypic selection is possible based on this trait, progress from selection made in a cycle will only be moderate for that trait.

However, combination of moderate heritability and low expected genetic gain for traits like hundred bean weight implies that although selection for improvement may be possible based on this trait, progress from selection made in a cycle may be difficult or slow for this trait.

The estimate of percent heterosis for number of bean per pod revealed that seven out of eight hybrids showed hybrid vigour over mid parental values and five out of the eight hybrids surpassed their respective better parental value. Maximum positive heterosis was observed in P7xPA150 (181.2% and 172.0%) for number of bean per pod and placental length respectively.

Four hybrids out of the eight for pod weight showed hybrid vigour over the mid parental values and two out of eight hybrids performed better than their respective better parental value. Estimate percent heterosis for inner pod diameter and outer pod diameter revealed that all the hybrids showed hybrid vigour over mid parental value and all surpassed their better parent for outer pod diameter while five out of eight hybrids surpassed their better parental value for inner pod diameter.

The hybrid with high heterotic effect may offer better chance of identification of desirable pure line in the advance generations as compared to hybrid with low heterosis as reported by Ahmed et al. [18].

5. CONCLUSION

The bean is one of the most important yields in Cocoa. Number of beans per pod is one of the major yield traits in cocoa and from the result the hybrids perform better than the parents in terms of this trait. There is sufficient genetic variability for most of the phenotypic traits among the eleven cocoa varieties. The high variability coupled with high heritability for the phenotypic traits makes most of the parental clones readily available candidates for selection for further improvement through hybridization. The productive capacity of hybrid (P7xP150) qualifies it as a promising genotype for wider distributions to farmers for enhanced cocoa productivity in Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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