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**Research Article**

# Estimation of variability parameters for certain quantitative traits in cocoa (*Theobroma cacao* L.) genotypes

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**Abstract**
Cocoa (*Theobroma cacao* L.) is an important plantation crop of Malvaceae family and its center of origin is Upper Amazon basin of South America. In India, it is grown as an intercrop in coconut and arecanut gardens especially in South India. Morpho-agronomic characters of pods and seeds can be used to evaluate the relationship between cocoa genotypes. In the present study, significant variations inthe mean performance of 20 genotypes for 13 traits were observed which revealed that the germplasm collections being maintained have high breeding value. The GCV and PCV ranged from moderate to high. Traits like plant height, first branching height, canopy area, leaf area, pod weight and single dry bean weight recorded high PCV and GCV indicating the high variability. High heritability ranging from 52.81 per cent for number of beans per pod to 99.84 per cent for first branching height was recorded. High genetic advance as per cent of mean was recorded for canopy area (89.33 per cent). High heritability coupled with high genetic advance for all the traits except pod girth, bean length and pod value indicated that all these traits are controlled by additive gene action and has least environmental influence. Further, correlation analysis revealed association of various traits which can be used as selection criteria for efficient planning of cocoa breeding program.

**Key words**
Cocoa, PCV, GCV, heritability, growth parameter, pod and bean traits, correlation

## Introduction

Cocoa (*Theobroma cacao* L.) is an important plantation crop grown in humid tropical regions around the world and belongs to Malvaceae family. The crop is a native of South America, and Upper Amazon basin is considered as the centre of origin (Cheesman, 1944) with greatest morphological diversity. There are 22 species of *Theobroma*, out of which *T.cacao* is widely cultivated and is of commercial importance. Two main genetic groups of cocoa namely 'Criollo' and 'Forastero', are classified based on morphological traits and geographical origin. 'Trinitario' is a natural hybrid of Criollo and Forastero.

In India, cocoa is an introduced crop and widely grown as an intercrop in coconut and arecanut gardens of South India *viz.,* Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Andhra Pradesh leads in production (7700 MT) and productivity (800 kg/ha). Tamil Nadu ranks first in area covering about 29,205 hectares with a production and productivity of 1650 MT and 320 kg/ha respectively. The national productivity of cocoa is 580 kg/ha (DCCD, 2018).

Cocoa, being a highly cross pollinated and self-incompatible crop shows greater diversity. Cocoa germplasm, the "raw material" for plant breeding, is a vital resource for the improvement and sustainability of cocoa production. Access to a genetically diverse range of germplasm is essential for plant breeders to select material with stress resistance and good agronomic and quality characteristics (Bekele *et al.,* 2006). Morpho-agronomic characteristics of pods, seeds and flowers can be used to evaluate the relationship between cocoa genotypes (Bekele and Bekele, 1996). Variability in a population is either due to differences in genetic constitution or in the environment in which they are grown.Efficiency of selection in any crop largely depends on the potential of various yield contributing traits being inherited to succeeding generations irrespective of its growing environment.

Thus, estimation of genetic parameters such as phenotypic coefficient of variation, genotypic coefficient of variation, heritability and genetic advance as mean elucidates the response of various traits to selection and important consideration to further crop improvement program.

Further, knowledge on association between traits enable the breeder to analyze the effect of selection pressure exerted on one trait and it's response on other traits, thereby helping in establishing selection index for the crop. Correlation analysis quantifies the relationship between any pair of traits (Draper and Smith, 1967). The study was taken up to elucidate the potential of cocoa genotypes at early growth phase and to estimate correlation between various agronomic traits.

**Material and Methods**

Cocoa field gene bank was established at Tamil Nadu Agricultural University, Coimbatore with grafted planting material collected from Central Plantation Crop Research Institute, Regional Station, Vittal, Karnataka during 2015-2016. Twenty genotypes which have started yielding were selected for the present study. Thirteen characters *viz.*, Plant height (cm), Stem girth (cm), First branching height (cm), Canopy area ($cm^2$), Leaf area ($cm^2$), Pod length (cm), Pod girth (cm), Pod weight (g), Number of beans per pod, Bean length (cm), Bean girth (cm), Single dry bean weight (g) and Pod value (No. of pods required to produce 1 kg wet beans) were subjected to analysis for understanding the variability present.

Phenotypic and genotypic coefficients of variation were calculated using the formula given by Burton, 1952. The range of PCV and GCV values were classified as suggested by Siva Subramanian and Madhava Menon (1973).

Heritability in the broad sense was estimated by the method described by Lush (1940) and expressed in per cent.The range of heritability was categorized as suggested by Johnson *et al*. (1955).

Genetic advance was expressed as per cent of mean by using the following formula and categorized as suggested by Johnson *et al*., 1955.

Simple correlation was calculated using the following formula

$$r_{xy} = \frac{\sum xy - \frac{\sum x \sum y}{N}}{\sqrt{\sum x^2 - \frac{(\sum x)^2}{N} \cdot \sum y^2 - \frac{(\sum y)^2}{N}}}$$

Where, N is the number of observations on variable x and y. The calculated r can be tested for significance comparing with table r value at N-2 degrees of freedom.

**Results and Discussion**

Analysis of variance revealed that significant differences exist among the 20 cocoa genotypes for all the 13 traits studied. The mean performance of the genotypes for 13 traits is given in Table 1. Plant height was highest in ICS-6 (254.07 cm) while the lowest was recorded in TRIN-2 (109.30 cm). The average plant height was 184.54 cm. Stem girth ranged from 10.33 cm in TRIN-3 to 18.63 cm in NC-42. The average first branching height of 20 genotypes was 74.02 cm. Canopy area was maximum in ICS-6 (729.29 $cm^2$) while the least was recorded in NC-26 (164.59 $cm^2$). The genotype W-1 recorded the highest values for pod length (25.00 cm), pod girth (28.73 cm) and pod weight (521.33 g). The bean characters showed variation among the genotypes and the highest number of beans per pod (45.67) and bean length (2.73 cm) were recorded in NC-42. Single dry bean weight was highest in W-5 (0.87 g) closely followed by W-4 (0.81 g) and ICS-6 (0.80 g) with an average of 0.55 g. Pod value ranged from 6.89 in NC-42 to 13.40 in TRIN-1. Pod value less than 15 is very desirable trait of selection (Pound, 1932).Similarly, in the present study, low pod value was observed for all the 20 cocoa genotypes. The presence of significant variations among the germplasm collections indicates their importance in breeding programs (Bekele *et al.,* 2006). Differences in phenotypic values among the genotypes across various environment provide measures of GXE interactions (DuVal *et al.,* 2017).

The phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability ($h^2$) and genetic advance as per cent mean of thirteen characters are presented in Table 2. In the present study, variability observed among the 20 cocoa genotypes ranged from moderate to high. The highest PCV and GCV were recorded for canopy area (44.10 per cent and 43.73 per cent respectively) while minimum PCV and GCV were recorded for pod girth (12.27 per cent and 10.17 per cent respectively). Based on the scale suggested by Siva Subramanian and Madhava Menon (1973), characters like plant height, first branching height, canopy area, leaf area,

pod weight and single dry bean weight were observed to have high PCV and GCV (more than 20%) and hence these characters showed high variability among the genotypes. The PCV and GCV of stem girth, pod length, pod girth, number of beans per pod, bean length, bean girth and pod value ranged from 10-20 per cent which suggests that variability was moderate for these traits. Variability in these characters indicate that these can be considered as morphological descriptors for selection of cocoa genotypes with superior performance (Lachen and Oliver, 2005). Wide variability in vegetative and pod characters was also reported by Thondaiman *et al.* (2013).

Heritability is the proportion of total variability due to genetic cause and it is an index of transmission of characters from parents to their off-springs (Falconer, 1960). In the present study, based on the heritability categories suggested by Johnson *et al*. (1955), high heritability (52.81 to 99.84 per cent) was recorded for all the traits except bean length and pod value which recorded moderate heritability (33.92 and 36.28 per cent respectively). Similarly, genetic advance as per cent of mean was high (20.37 to 89.33 per cent) for all traits except pod girth, bean length and pod value. High heritability accompanied by high genetic advance revealed that heritability of these traitswas due to additive gene action and selection of genotypes based on these characters can be effective. Characters which showed moderate heritability and genetic advance explains that these have some extent of environmental influence. Knowledge on genetic stability of a quantitative trait across various environmentsis important for selection of a genotype for further breeding program (Engles, 1993). Pod value exhibited the highest heritability of all other traits studied and can be used as a good indicator of stability and additive gene action during selection process (Du Val *et al.,* 2017).

Correlation analysis for the 13 traits is presented in Table 3. The results revealed that plant height had highly significant positive correlation with first branching height (0.645**) and canopy area (0.893**). In the present study, increase in plant height results in significant increase in other vegetative parameters such as first branching height and canopy area suggesting that plant height has positive influence on plant vigor. The trait stem girth was significantly correlated with bean girth (0.676**). First branching height was significantly correlated to canopy area (0.51*). Positive and significant correlation was recorded for canopy area with bean girth (0.495*) and single dry bean weight (0.497*). Increase in canopy area indicates higher photosynthetic area and higher production of assimilates, thereby effective partitioning of assimilates which might be the reason for the positive correlation of canopy area with stem girth and single dry bean weight.Pod length recorded highly significant correlation with pod girth (0.713**), pod weight (0.761**) and number of beans per pod (0.652**) whereas significant negative correlation was recorded with pod value (-0.617*). Pod girth was positively correlated with pod weight (0.534*). Increase in pod length and girth indicates the larger size of the pod which eventually contributes to the pod weight and number of beans per pod. Positive and significant correlation was observed for pod weight with number of beans per pod (0.785**) whereas it showed highly significant negative correlation with pod value (-.0752**). Pod weight in cocoa is a combination of husk weight and bean weight, as the pod weight and bean weight are directly proportional, increase in pod weight eventually decreases the number of pods required to produce 1 kg of wet beans (pod value), hence the estimates are negatively correlated. Efombagn *et al.* (2009) reported that cocoa genotype with higher bean size and bean weight recorded lower pod value. Bean length recorded positive significant correlation with bean girth and single dry bean weight while negatively correlated with pod value. Correlation analysis described the traits like pod weight, pod length, dry bean weight and bean length as important descriptors to characterize germplasm while rejecting traits of least importance (Bekele *et al.,* 1994).

Thus, the twenty cocoa genotypes exhibited high variability in their mean performance for vegetative, pod and bean characters. High PCV and GCV for most of the traits studied indicate good breeding value of the germplasm material. Traits with high heritability coupled with high genetic advance as per cent of mean can be used as selection criteria as they are least influenced by environmental variation. Correlation analysis further revealed the association of various traits and determined the component characters on which selection can be relied upon for genetic improvement of yield.

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**Table 1. Mean performance of cocoa genotypes for thirteen morphological, pod and bean characters**

| Cocoa genotypes | PH | SG | FBH | CA | LA | PL | PG | PW | NBP | BL | BG | SDBW | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NC-26 | 109.73 | 10.37 | 46.37 | 164.59 | 137.39 | 18.13 | 26.07 | 286.19 | 33.67 | 1.98 | 2.17 | 0.40 | 10.47 |
| NC-27 | 142.17 | 11.73 | 48.13 | 189.59 | 254.80 | 23.67 | 28.13 | 331.58 | 41.00 | 2.01 | 3.12 | 0.42 | 9.00 |
| NC-31 | 192.73 | 16.03 | 89.97 | 389.51 | 258.97 | 20.76 | 22.56 | 269.29 | 40.00 | 2.33 | 3.03 | 0.37 | 8.79 |
| NC-36 | 237.00 | 15.83 | 86.10 | 701.47 | 189.71 | 20.60 | 24.73 | 236.53 | 29.33 | 2.17 | 3.47 | 0.62 | 11.24 |
| NC-37 | 176.97 | 13.23 | 68.13 | 373.43 | 152.91 | 20.27 | 21.69 | 408.40 | 42.33 | 2.20 | 3.06 | 0.44 | 8.61 |
| NC-42 | 162.17 | 18.63 | 91.07 | 323.57 | 96.24 | 23.80 | 28.23 | 477.59 | 45.67 | 2.73 | 3.77 | 0.58 | 6.89 |
| NC-49 | 157.10 | 12.30 | 72.13 | 297.83 | 132.37 | 23.87 | 28.30 | 412.70 | 44.33 | 2.57 | 2.93 | 0.51 | 7.79 |
| ICS-6 | 254.07 | 15.07 | 75.30 | 729.29 | 157.92 | 16.90 | 26.07 | 214.74 | 36.67 | 2.63 | 3.83 | 0.80 | 8.28 |
| TRIN-1 | 182.93 | 12.30 | 54.27 | 286.09 | 121.73 | 16.67 | 22.93 | 258.07 | 28.33 | 1.87 | 2.83 | 0.36 | 13.40 |
| TRIN-2 | 109.30 | 11.13 | 69.07 | 165.10 | 111.21 | 18.00 | 25.40 | 269.14 | 34.67 | 2.30 | 2.23 | 0.41 | 10.41 |
| TRIN-3 | 182.13 | 10.33 | 78.97 | 323.89 | 156.33 | 19.43 | 27.30 | 251.25 | 33.33 | 2.37 | 2.77 | 0.45 | 11.66 |
| TRIN-5 | 229.83 | 12.47 | 94.97 | 378.53 | 293.95 | 20.77 | 26.13 | 195.29 | 27.67 | 1.68 | 2.30 | 0.50 | 13.28 |
| TRIN-10 | 163.70 | 13.43 | 61.10 | 353.52 | 202.05 | 16.90 | 20.70 | 229.67 | 28.67 | 2.13 | 2.90 | 0.51 | 10.93 |
| TRIN-11 | 180.57 | 14.23 | 67.67 | 301.47 | 202.84 | 17.07 | 20.70 | 207.60 | 30.00 | 2.00 | 2.87 | 0.47 | 11.50 |
| W-1 | 237.27 | 12.83 | 78.63 | 634.70 | 240.60 | 25.00 | 28.73 | 521.33 | 38.00 | 2.23 | 2.67 | 0.62 | 8.54 |
| W-2 | 159.80 | 14.17 | 55.08 | 289.47 | 218.75 | 22.37 | 26.87 | 297.27 | 37.33 | 2.65 | 3.40 | 0.64 | 9.52 |
| W-3 | 199.53 | 12.47 | 96.10 | 400.51 | 225.77 | 22.80 | 26.80 | 346.17 | 44.00 | 2.35 | 3.23 | 0.45 | 8.85 |
| W-4 | 250.27 | 14.13 | 93.13 | 563.91 | 217.62 | 19.37 | 24.13 | 267.57 | 35.67 | 2.63 | 3.67 | 0.81 | 11.03 |
| W-5 | 160.83 | 12.13 | 66.13 | 260.44 | 299.74 | 16.53 | 23.47 | 198.22 | 36.33 | 2.70 | 3.27 | 0.87 | 11.46 |
| W-6 | 202.70 | 12.30 | 88.17 | 322.17 | 246.22 | 18.10 | 20.63 | 221.89 | 34.33 | 2.63 | 3.30 | 0.71 | 11.03 |
| **G. Mean** | **184.54** | **13.26** | **74.02** | **372.45** | **195.86** | **20.05** | **24.97** | **295.02** | **36.07** | **2.31** | **3.04** | **0.55** | **10.13** |
| **Mini** | **109.30** | **10.33** | **46.37** | **164.59** | **96.24** | **16.53** | **20.63** | **195.29** | **27.67** | **1.68** | **2.17** | **0.36** | **6.89** |
| **Maxi** | **254.07** | **18.63** | **96.10** | **729.29** | **299.74** | **25.00** | **28.73** | **521.33** | **45.67** | **2.73** | **3.83** | **0.87** | **13.40** |
| **S.E.** | **5.79** | **0.24** | **0.36** | **12.28** | **15.56** | **1.07** | **1.40** | **22.92** | **2.68** | **0.27** | **0.22** | **0.05** | **1.08** |
| **C.D.(5%)** | **16.45** | **0.67** | **1.03** | **34.91** | **44.24** | **2.17** | **2.84** | **65.16** | **7.61** | **0.55** | **0.45** | **0.14** | **3.06** |
| **CV(%)** | **5.43** | **3.07** | **0.85** | **5.71** | **13.76** | **13.46** | **10.64** | **13.46** | **12.86** | **12.93** | **15.25** | **15.92** | **18.39** |

**PH**- Plant height (cm) **SG**- Stem girth (cm) **FBH**- First Branching height (cm) **CA**- Canopy Area ($cm^2$) **PV**- Pod value
**LA**- Leaf Area ($cm^2$) **PL**- Pod length (cm) **PG**- Pod girth (cm) **PW**- Pod weight (g)
**NBP**- Number of beans per pod **BL**- Bean length (cm) **BG**- Bean girth (cm) **SDBW**- Single dry bean weight (g)

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**Table 2. Variability parameters, heritability and genetic advance as per cent mean of 13 traits of cocoa genotypes**

| Characters | Mean | Range | | PCV (%) | GCV (%) | $h^2$(%) | Genetic Advance as per cent mean |
|---|---|---|---|---|---|---|---|
| | | Minimum | Maximum | | | | |
| Plant height (cm) | 184.54 | 109.30 | 254.07 | 23.13 | 22.49 | 94.48 | 45.03 |
| Stem girth (cm) | 13.26 | 10.33 | 18.63 | 15.52 | 15.21 | 96.08 | 30.71 |
| First branching height (cm) | 74.02 | 46.37 | 96.10 | 21.36 | 21.34 | 99.84 | 43.94 |
| Canopy area ($cm^2$) | 372.45 | 164.59 | 729.29 | 44.10 | 43.73 | 98.32 | 89.33 |
| Leaf area ($cm^2$) | 195.86 | 96.24 | 299.74 | 32.82 | 29.80 | 82.42 | 55.72 |
| Pod length (cm) | 20.05 | 16.53 | 25.00 | 14.81 | 13.28 | 80.41 | 24.53 |
| Pod girth (cm) | 24.98 | 20.63 | 28.73 | 12.27 | 10.17 | 68.59 | 17.34 |
| Pod weight (g) | 295.02 | 195.29 | 521.33 | 33.63 | 30.82 | 83.99 | 58.19 |
| No. of beans per pod | 36.07 | 27.67 | 45.67 | 18.72 | 13.61 | 52.81 | 20.37 |
| Bean length (cm) | 2.31 | 1.68 | 2.73 | 17.75 | 10.34 | 33.92 | 12.40 |
| Bean girth (cm) | 3.04 | 2.17 | 3.83 | 17.30 | 14.75 | 72.75 | 25.92 |
| Single dry bean weight (g) | 0.55 | 0.36 | 0.87 | 31.06 | 26.65 | 73.65 | 47.12 |
| Pod value | 10.13 | 6.89 | 13.40 | 23.04 | 13.88 | 36.28 | 17.22 |

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**Table 3. Simple correlation analysis**

| | PH | SG | FBH | CA | LA | PL | PG | PW | NBP | BL | BG | SDBW | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PH** | 1 | 0.375 | 0.645** | 0.893** | 0.356 | 0.061 | -0.049 | -0.208 | -0.169 | 0.085 | 0.456 | 0.492* | 0.096 |
| **SG** | | 1 | 0.42 | 0.468 | -0.074 | 0.212 | -0.064 | 0.175 | 0.234 | 0.34 | 0.676** | 0.264 | -0.414 |
| **FBH** | | | 1 | 0.51* | 0.23 | 0.246 | 0.036 | 0.031 | 0.156 | 0.274 | 0.311 | 0.27 | -0.091 |
| **CA** | | | | 1 | 0.126 | 0.105 | 0.062 | -0.069 | -0.069 | 0.175 | 0.495* | 0.497* | -0.142 |
| **LA** | | | | | 1 | 0.076 | -0.158 | -0.415 | -0.145 | -0.09 | 0.032 | 0.312 | 0.254 |
| **PL** | | | | | | 1 | 0.713** | 0.761** | 0.652** | 0.114 | 0.109 | -0.14 | -0.617* |
| **PG** | | | | | | | 1 | 0.534* | 0.457 | 0.138 | -0.017 | -0.026 | -0.44 |
| **PW** | | | | | | | | 1 | 0.785** | 0.248 | 0.094 | -0.202 | -0.752** |
| **NBP** | | | | | | | | | 1 | 0.547* | 0.369 | 0.016 | -0.884** |
| **BL** | | | | | | | | | | 1 | 0.686** | 0.664** | -0.515* |
| **BG** | | | | | | | | | | | 1 | 0.63* | -0.391 |
| **SDBW** | | | | | | | | | | | | 1 | -0.045 |
| **PV** | | | | | | | | | | | | | 1 |

***Significant , **Highly significant**

**PH**- Plant height **SG**- Stem girth **FBH**- First Branching height **CA**- Canopy Area
**LA**- Leaf Area **PL**- Pod length **PG**- Pod girth **PW**- Pod weight
**NBP**- Number of beans per pod **BL**- Bean length **BG**- Bean girth **SDBW**- Single dry bean weight
**PV**- Pod value