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RESEARCH PAPER

Variability in the pod and bean characteristics and their relationship with leaf nutrient content in cocoa (*Theobroma cacao* L.)

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Abstract

Theobroma cacao L., cocoa, produces fruits throughout the year with one or two peaks. The relationship between pod or bean characteristics and leaf nutrient status in cocoa genotypes grown in the humid tropics of India is not well documented. Our investigation found notable differences amongst twenty genotypes of cocoa for pod weight, husk weight, bean count, fresh bean weight pod, single dry bean weight, nib recovery, and shell percentage. Single dry bean weight is an important parameter of the cocoa beans for the industry, and it was significantly associated with the husk weight, pod weight, and nib recovery. The weight of the dry bean was found to be higher in pods with higher pod weight and husk weight. However, it decreased significantly with increased bean count per pod. Higher nib recovery is another important industry trait and was closely associated with single dry bean weight. Pearson's correlation coefficients indicated pod and bean characteristics in different genotypes had no significant association with leaf nutrient status. Even, the nutrient ratios had no tangible influence on the pod/bean traits, except for K/P and Ca/B, which had significant associations with the husk weight and pod count per tree, respectively.

Keywords

Theobroma cacao, bean, pod, nutrient

Introduction

Theobroma cacao L. (Malvaceae), commonly known as the "food of gods," is the most ancient beverage crop grown in tropical countries. It is native to the Amazonian basin (Wood and Lass 2001). It is one of the most economically important perennial tropical crops, cultivated primarily for its beans, which are used in the chocolates and confectioneries. Cocoa is grown in over 10 million ha in more than 58 countries, producing 52,42,000 t dry beans (ICCO 2020). It is grown in agroforestry systems in major cocoa growing countries in South America and Africa but mixed-cropped in Asian countries. In Southern India, cocoa is grown in Karnataka and Kerala states, traditionally as a mixed crop and is gaining importance, and area expansion is observed in other non-traditional

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regions of Tamil Nadu and Andhra Pradesh states. It is grown in an area of 1,03,376 ha, mainly as a component crop in palm based cropping system, with a production of 27,072.15 t of dry beans (DCCD 2021).

Cocoa bear pods throughout the year, depending on the prevailing agro-climatic conditions, with one or two peaks. After pollination, these hard-walled pods take five to six months to mature and contain twenty to forty seeds, which are marketed after being fermented and dried (Toxopeus 1985). The colour of the fruit, bean size, and butter content will vary with the varieties/cultivars (Asna et al. 2014; Elain Apshara 2017), and the quantitative characteristics of the pod and bean have been utilized to evaluate genetic diversity in cocoa (Toxopeus 1985; Ollerton et al. 2011). There is a noticeable variation between the genotypes in the pod's weight, length, breadth, husk:bean ratio, and quantity of beans per pod (Elain Apshara 2017).

Numerous elements, such as size, count, color, acidity, flavor, level of bitterness, polyphenol content, fermentation quality, and nutritional makeup, affect the quality of cocoa beans. The economic part of cocoa is beans, and its size is an important factor in deciding the yield (Soria 1978). Small beans are difficult to process and have a greater shell content, hence bean size is economically important factor for the industry. The processing industries prefer beans weighing one gram or more. The morphological and structural characteristics of beans often exhibit variability among cocoa accessions (Adewale et al. 2010). Great differences exist in the size, shape, color, and quality of the beans between and within cocoa varieties (Enríquez and Soria 1968).

A common method for determining the nutritional state of cocoa trees is leaf nutrient analysis (Paramo et al. 2016; van Vliet and Giller 2017). Nutrient uptake, the process by which nutrients move from the external environment into the plant, is vital for maintaining optimal growth and yield. Pod production in cocoa is primarily influenced by the availability of nutrients within the tree at various stages ranging from flower initiation to pod maturity (Hutcheon 1976). Numerous studies have been conducted on variations in nutrient absorption and use between and among crops (Fageria and Baligar 2005). However, the studies on the relationship between leaf nutrient status and the pod/bean characteristics are very limited in cocoa. Hence, the variability in the pod and bean characteristics in cocoa genotypes, and their relationship with leaf nutrient content was studied in 20 cocoa genotypes.

Material and methods

Experimental location

The experiment was conducted at ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal, India as explained in our earlier study (Bhavishya et al. 2024).

Plant materials

This study used four released hybrids and their parents, one clone planted in 2005, and eight upper Amazon genotypes planted in 2007. Cocoa was grown as a mixed crop with arecanut.

Pod characteristics

The main harvesting season was April – July. The cocoa pods were harvested as and when they ripened.

Average pod weight (g): Five pods were selected randomly and weighed, and the mean value was calculated.

Average husk weight per pod (g): Five ripened pods were harvested randomly, broken using a wooden hammer, and the beans and placenta were removed. The husks of these five pods were weighed, and the mean value was given as average husk weight pod^{-1}.

Average number of beans per pod: The wet beans of five pods used to calculate the average husk weight were counted, and the mean value was given as the average number of beans pod^{-1}.

Average fresh bean weight per pod (g): The wet beans of five pods used to calculate the average husk weight were weighed, and the mean value was given as average fresh bean weight pod^{-1}.

Pod to wet bean ratio: Pod to wet bean ratio was calculated using the formula given by Elain Apshara (2017).

Bean characteristics

The wet beans were fermented in small perforated trays for 6 days, then oven-dried at 55 °C to get the dry beans. The following bean characteristics were recorded.

Single dry bean weight (g): Exactly 100 dry beans were weighed, and the value was divided by 100 to determine the dry weight of a bean.

Nib recovery (%): One hundred dry beans were taken and weighed. The beans were broken to separate the shell and nib. The nib's weight was recorded, and the nib recovery was calculated using the following formula.

$$\text{Nib recovery (\%)} = \frac{\text{Weight of the nib (g)}}{\text{Weight of the dry bean (g)}} \times 100$$

Shell percentage was calculated using the following formula,

$$\text{Shell percentage (\%)} = \frac{\text{Weight of the shell (g)}}{\text{Weight of the dry bean (g)}} \times 100$$

Nutrient estimation

Nutrient analysis was done from mature leaves (the second leaf of the last maturing flush) by following standard methods (Piper 1966; Jackson 1973; Gupta 1979) as explained earlier (Bhavishya et al. 2024).

Data analysis

Data was collected from 20 cocoa genotypes in three replications. The data were analyzed using standard analysis of variance (ANOVA) technique (Gomez and Gomez 1984). The data was subjected to RCBD analysis of variance with three replications using SPSS at a 5 percent significance level.

Results and discussion

Pod characters in cocoa genotypes

Pod characters, i.e., single pod weight, husk weight per pod, fresh bean weight per pod, and bean count, varied significantly among the different cocoa genotypes (Table 1). In 2019, the single pod weight varied from 189 g to 379 g among different genotypes. Cocoa genotype VTLC 66 recorded the highest single pod weight and husk weight per pod (265 g); whereas VTLC 156 registered the lowest single pod weight (189 g) and husk weight per pod (130 g). In 2020, single pod weight was 204–593 g in different cocoa varieties. VTLC 30A stood out with significantly higher single pod weight (593 g) and husk weight (314 g). Variability in pod characters in cocoa was reported by Subramanian and Balasimha (1981), Mallika et al. (1996), and Elain Apshara et al. (2008).

In 2019, VTLCH 3 showcased the highest fresh bean weight of 152 g. However, in 2020, the genotype VTLC 30A recorded a maximum fresh bean weight of 156 g. Genotypic variation in cocoa bean weight can be attributed to the diverse genetic makeup of cocoa plants. Different genotypes possess unique combinations of genes that influence pod development, seed formation, and growth. Environmental factors, including climate and soil conditions, further contribute to this variation. Such variation was also reported by Asna et al. (2014).

Seed count in a pod is a gene controlled character (Glendinning 1963). It also depends on several factors, including environment (De Reffye et al. 1978; Falque et al. 1995; da Silva et al. 2016). These factors include the number of ovules per ovary, the fertility of the ovules, which varies depending on the self-compatibility or self-incompatibility of the cocoa genotype, and natural pollination conditions. In this study, significant variation was observed for bean count. In 2019, the genotypes VTLC 182 and VTLC 185 stood out, with the highest average bean number being 46 per pod. In 2020, VTLC 185 exhibited the highest average bean number of 52.

Table 1. Pod characters in selected cocoa genotypes during 2019 and 2020.

SI No	Genotypes	2019				2020				Mean of 2019 and 2020			
		Single pod weight (g)	Husk weight pod^{-1} (g)	Fresh bean weight pod^{-1} (g)	Average bean number pod^{-1} (g)	Single pod weight (g)	Husk weight pod^{-1} (g)	Fresh bean weight pod^{-1} (g)	Average bean number pod^{-1} (g)	Single pod weight (g)	Husk weight pod^{-1} (g)	Fresh bean weight pod^{-1} (g)	Average bean number pod^{-1} (g)
1	VTLCH 1	350	247	103	35	302	199	103	38	326	223	103	37
2	VTLCH 2	347	231	116	38	204	137	67	38	275	183	91	38
3	VTLCH 3	363	211	152	34	445	304	142	39	404	257	147	38
4	VTLCH 4	284	199	85	36	306	217	90	39	295	208	87	37
5	VTLCC 1	221	134	87	40	322	196	126	42	272	165	107	41
6	VTLC 01	248	162	86	37	449	326	124	41	349	244	105	39
7	VTLC 05	272	173	99	34	332	232	99	37	302	202	99	35
8	VTLC 11	299	219	80	38	345	251	95	40	322	235	87	39
9	VTLC 19A	273	174	99	38	403	266	137	43	338	220	118	41
10	VTLC 30A	328	192	136	35	593	437	156	35	460	314	146	35
11	VTLC 61	320	228	92	36	338	224	115	46	329	226	103	40
12	VTLC 66	379	265	114	40	318	216	102	40	348	240	108	40
13	VTLC 148	331	222	108	33	286	206	81	24	309	214	95	28
14	VTLC 150	301	194	108	41	242	158	84	35	271	175	96	38
15	VTLC 151	370	259	111	37	370	259	111	37	370	259	111	37
16	VTLC 154	363	258	105	36	371	256	115	39	367	257	110	37
17	VTLC 155	319	218	101	37	395	274	122	39	357	246	112	38
18	VTLC 156	189	130	59	41	310	208	102	45	249	169	81	43
19	VTLC 182	261	152	109	46	211	131	81	45	236	142	95	46
20	VTLC 185	300	203	97	46	410	279	131	52	355	241	114	48
	Mean	306	203	102	38	348	239	109	40	327	221	106	39
	CD at 5%	69.9	49.4	31.4	6.5	126.0	91.0	42.0	5.0	77.8	55.2	27.5	3.8

On the other hand, the genotype VTLC 148 had the lowest average bean numbers of 33 and 24 in 2019 and 2020, respectively. Differences in total count of beans pod^{-1} in various cocoa genotypes was reported by Enriquez and Soria (1968) and Lachenaud and Oliver (2005). However, a higher bean count is not an important indicator of good traits because a greater number of beans with small bean sizes is not recommended (Engles 1982). There is a strong relationship between pod weight and bean count (Table 3), which confirms the previous studies (Enriquez and Soria 1968; Cilas et al. 2010). Beans in pods with more beans are a little lighter. It could be due to the competition amongst beans within pods (Doare et al. 2020). However, based on the genotypes, this effect appears to vary.

Bean characteristics in cocoa genotypes

The processing units favor beans weighing one gram or more. Fermented and dried beans were measured for bean traits. Bean characteristics like single dry bean weight (SDB), nib recovery, and shell percentage varied significantly among cocoa genotypes (Table 2). Single dry bean weight is an important trait with high heritability (Cilas et al. 2010). The chocolate industry is interested in two bean size characteristics: uniformity and largeness. Thus, it's essential to consider the average weight of cocoa beans as an important factor in the genetic improvement of cocoa (Doare et al. 2020). According to Enriquez and Soria (1968), the dry weight of beans varies greatly depending on the accession, ranging from 0.5 g to 2.5 g. However, the range seen in this study was 0.69 g to 1.1 g. This could be due to the differences in the accessions used in the present study. Upper Amazon genotype VTLC 151 recorded a higher single dry bean weight of 1.10 and 1.11 g in 2019 and 2020, respectively. In contrast, VTLC 156 (0.62 g) and VTLC 182 (0.63 g) exhibited the lowest single dry bean weight in 2019 and 2020, respectively. Variability in single dry bean weight among cocoa genotypes is well documented (Elain Apshara et al. 2009; Elain Apshara 2015).

Single dry bean weight was significantly associated with the husk weight (r = 0.57) and pod weight (r = 0.53) of cocoa (Fig. 2). This suggests that the weight of the dry beans increases with higher weight of the pod and husk. However, SDB weight decreased significantly with increased bean count per pod (r = -0.63).

Higher nib recovery is also another important trait for the industry. In 2019, the highest nib recovery was obtained in VTLC 11 (85.1%), whereas, the least nib recovery was recorded in VTLC 156 (79.4%). In 2020, VTLC 148 exhibited the highest nib recovery rate (86.3%), while the lowest nib recovery was recorded in VTLC 61 (79.4%). Shell percentage was significantly lower in genotypes with high nib recovery and vice versa. Such variability in nib recovery and shell percentage was observed in the evaluation of cocoa genotypes in the humid tropics of Karnataka (Elain Apshara et al. 2009; Elain Apshara 2015), Gujarat (Bhalerao et al. 2018), and Assam (Singh et al. 2020). Pearson's correlation coefficient indicated that single dry bean weight and nib recovery were significantly associated (r = 0.64). Hence, single dry bean weight is an important bean trait, as the nib recovery is more in bolder beans (Fig. 1).

Table 2. Bean traits in twenty cocoa genotypes.

SI No	Genotypes	2019			2020			Mean of 2019 and 2020		
		Single dry bean weight (g)	Nib recovery (%)	Shell percentage (%)	Single dry bean weight (g)	Nib recovery (%)	Shell percentage (%)	Single dry bean weight (g)	Nib recovery (%)	Shell percentage (%)
1	VTLCH 1	1.04	83.3	16.7	0.97	84.5	15.5	1.00	83.9	16.1
2	VTLCH 2	0.94	83.2	16.8	0.90	83.0	17.0	0.92	83.1	16.9
3	VTLCH 3	0.84	80.9	19.1	1.00	82.8	17.2	0.92	81.9	18.1
4	VTLCH 4	0.97	83.7	16.3	0.91	83.6	16.4	0.94	83.7	16.3
5	VTLCC 1	0.96	83.2	16.8	1.00	84.7	15.3	0.98	84.0	16.0
6	VTLC 01	0.94	83.9	16.1	0.97	85.6	14.4	0.95	84.8	15.3
7	VTLC 05	0.90	80.2	19.8	0.84	80.2	19.8	0.87	80.2	19.8
8	VTLC 11	0.97	85.1	14.9	0.94	83.0	17.0	0.96	84.1	15.9
9	VTLC 19A	0.96	82.7	17.3	0.94	82.0	18.0	0.95	82.4	17.6
10	VTLC 30A	0.98	83.5	16.5	1.06	80.2	19.8	1.02	81.8	18.2
11	VTLC 61	0.90	80.5	19.5	0.67	79.4	20.6	0.79	80.0	20.1
12	VTLC 66	1.01	82.9	17.1	0.87	83.1	16.9	0.94	83.0	17.0
13	VTLC 148	1.04	84.5	15.5	1.00	86.3	13.7	1.02	85.4	14.6
14	VTLC 150	0.75	82.2	17.8	0.65	83.7	16.3	0.70	83.0	17.0
15	VTLC 151	1.11	84.7	15.3	1.10	86.1	13.9	1.10	85.4	14.6
16	VTLC 154	1.00	83.8	16.2	0.95	83.0	17.0	0.98	83.4	16.6
17	VTLC 155	1.05	83.7	16.3	1.02	85.8	14.2	1.04	84.8	15.2
18	VTLC 156	0.62	79.4	20.6	0.76	85.7	14.3	0.69	82.6	17.5
19	VTLC 182	0.76	81.6	18.4	0.63	81.4	18.6	0.70	81.5	18.5
20	VTLC 185	0.77	81.1	18.9	0.65	80.3	19.7	0.71	80.7	19.3
	Mean	0.93	82.7	17.3	0.89	83.2	16.8	0.91	83.0	17.0
	CD at 5%	0.10	3.1	3.1	0.27	3.7	3.7	0.16	2.30	2.30

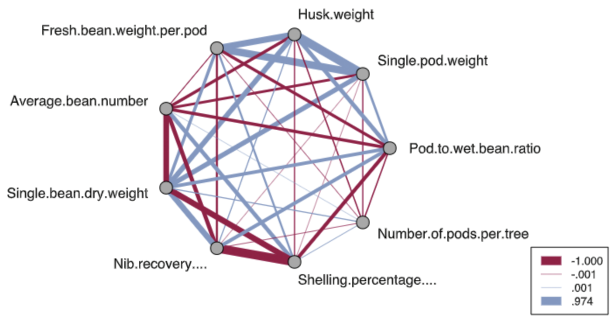

Figure 1. Web plot of the correlation matrix.

Mineral nutrients play a major role in the yield and quality of cocoa (Verlière 1981). Incomplete pod filling appears to result from interactions between nutritional factors and genotypes, and the application of boron was found to increase bean count while decreasing the occurrence of flat beans (Lachenaud 1995). However, the leaf nutrient status had no significant effect on the flowering, fruit set, and cherelle wilt in cocoa, except for calcium which had a significant association with fruit set percentage (Bhavishya et al. 2024). In this study, Pearson's correlation coefficients indicated no tangible association of leaf nutrients with the single dry bean weight, nib recovery, and shell percentage (Table 3). The result is in line with Noordiana et al. (2007), and they observed no significant effect of nutrient treatments on the pod weight, shell weight, bean count and single dry bean weight in two cocoa clones in Malaysia.

The relationship between the leaf mineral nutrient ratios and pod/bean traits was studied (Table 4). The nutrient ratios had no tangible influence on the pod/bean traits, except for K/P and Ca/B, which had significant associations with the husk weight and pod count per tree, respectively.

Conclusion

Cocoa produces fruits throughout the year, with one or two peak seasons. Variability exists for the pod and bean

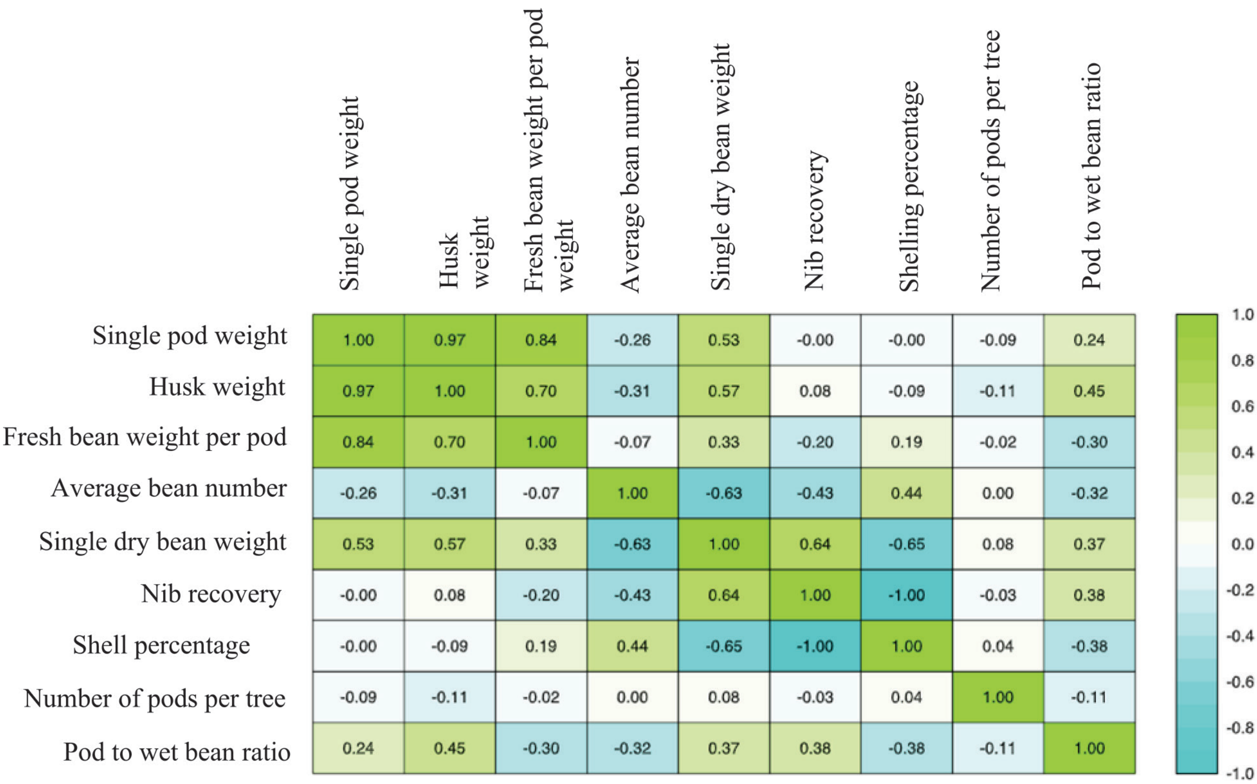

Figure 2. Pearson's correlation coefficients for leaf nutrient status *vs* pod/bean traits.

Table 3. Pearson's correlation coefficients for leaf nutrient status *vs* pod and bean characters in cocoa.

Pod/bean characters	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
Single pod weight	0.19	-0.09	0.15	-0.37	-0.12	-0.13	-0.05	0.04	0.18	-0.22
Husk weight pod^{-1}	0.23	-0.06	0.22	-0.40	-0.09	-0.10	-0.14	-0.07	0.10	-0.22
Fresh bean weight pod^{-1}	0.05	-0.14	-0.03	-0.21	-0.14	-0.19	0.15	0.31	0.33	-0.17
Average bean number pod^{-1}	0.07	0.16	0.10	0.16	-0.02	-0.23	-0.04	0.04	-0.07	-0.05
Single dry bean weight	0.11	0.01	0.17	-0.27	-0.16	0.12	-0.35	-0.21	0.11	-0.33
Nib recovery	-0.12	-0.03	0.07	0.02	0.12	-0.17	-0.04	-0.05	-0.14	-0.38
Shelling percentage	0.13	0.03	-0.07	-0.02	-0.11	0.18	0.04	0.05	0.14	0.38
Number of pods tree^{-1}	0.19	0.19	0.29	-0.23	-0.11	0.39	-0.41	0.12	0.35	0.37

N: Nitrogen; P: Phosphorous; K: Potassium; Ca: Calcium; Mg: Magnesium; Fe: Iron; Mn: Manganese; Cu: Copper; Zn: Zinc; B: Boron.

Table 4. Pearson's correlation coefficients for leaf nutrient ratios *vs* pod and bean characteristics in cocoa.

Pod/bean characters	N/K	N/P	K/P	K/Ca	K/Mg	Ca/Mg	K/Fe	K/Mn	K/Zn	Ca/B	P/Zn
Single pod weight	-0.06	0.40	0.43	0.31	0.20	-0.32	0.28	0.08	-0.06	-0.16	-0.24
Husk weight pod^{-1}	-0.11	0.36	0.44*	0.37	0.25	-0.35	0.31	0.18	0.02	-0.19	-0.18
Fresh bean weight pod^{-1}	0.08	0.39	0.31	0.11	0.04	-0.16	0.18	-0.17	-0.24	-0.06	-0.32
Average bean number pod^{-1}	-0.22	-0.14	-0.06	-0.13	0.00	0.17	0.32	0.01	0.14	0.17	0.18
Single dry bean weight	-0.15	0.14	0.27	0.31	0.26	-0.17	0.01	0.28	-0.03	0.00	-0.16
Nib recovery	-0.23	-0.07	0.13	0.10	0.03	-0.01	0.10	0.08	0.21	0.27	0.11
Shell percentage	0.22	0.06	-0.13	-0.10	-0.03	0.01	-0.10	-0.08	-0.21	-0.28	-0.11
Number of pods tree^{-1}	-0.33	-0.13	0.06	0.26	0.25	-0.11	-0.09	0.35	-0.17	-0.44*	-0.12
Pod to wet bean ratio	-0.18	0.02	0.18	0.31	0.26	-0.24	0.24	0.40	0.23	-0.38	0.09

N: Nitrogen; P: Phosphorous; K: Potassium; Ca: Calcium; Mg: Magnesium; Fe: Iron; Mn: Manganese; Zn: Zinc; B: Boron.

characteristics in different cocoa genotypes. Our study revealed significant variations among twenty cocoa genotypes for pod weight, husk weight, bean count per pod, fresh bean weight per pod, single dry bean weight, nib recovery, and shell percentage. Bean size is an economically important factor for the chocolate industry, and it was significantly associated with husk weight, pod weight, and nib recovery. The weight of the dry bean was found to be higher in pods with higher pod weight and husk weight. However, it decreased significantly with an increase in the bean count per pod. Higher nib recovery was closely associated with single dry bean weight. This indicates that small beans have a higher shell content and are more difficult for the industry to process. Leaf nutrient analysis has been widely used to indicate the nutritional status of cocoa trees. The studies on their relationship with leaf mineral nutrient status are very limited. Pearson's correlation coefficients indicated that pod and bean characteristics in different genotypes had no significant association with leaf nutrient status. Even, the nutrient ratios had no tangible influence on the pod/bean traits, except for K/P and Ca/B, which had significant associations with the husk weight and pod count per tree, respectively.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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