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The identification of yield components, genetic variability, and heritability to determine the superior cocoa trees in West Papua, Indonesia

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Abstract. *Suparno A, Arbianto MA, Prabawardani S, Chadikun P, Tata H, Luhulima FDN. 2024. The identification of yield components, genetic variability, and heritability to determine the superior cocoa trees in West Papua, Indonesia. Biodiversitas 25: 2363-2373.* One of the obstacles to increasing the productivity of cocoa is the existence of superior cocoa clones. This research, therefore, was carried out to select the superior cocoa tree candidates from the existing cocoa plantation populations over 30 years old, using a descriptive method on the yield components of superior cocoa candidates in PT. Cokran Cocoa Plantation, South Manokwari. This research was conducted from May 2020 to May 2022. The initial information on 32 superior cocoa trees was obtained from the farmers who were involved and worked at the PT. Cokran Cocoa Plantation for 30 years. Cocoa was planted on an area of 1,680 ha with a spacing of 2 x 4 m. Data on the 13 quantitative characters of the cocoa pod and cocoa beans were analyzed using ANOVA (SAS V.9 For Window). These 13 quantitative data, including 11 qualitative data of leaves and fruit were used to analyze the relationship of kinship pattern among the accessions using NTSys ver. 2.1. Results of the research show that 8 cocoa accessions had a high production potential of more than 6,000 g per tree annually, namely CKR-02, CKR-03, CKR-04, CKR-09, CKR-12, CKR-26, CKR-28, and CKR-41 accessions. Accessions that produced 1,000 g of dry cocoa beans in less than 20 pods were CKR-03, CKR-04, CKR-07, CKR-09, CKR-12, CKR-15, CKR-22, CKR-26, CKR-40, and CKR-41. Candidate cocoa clones that have the potency to produce dry cocoa beans with grade AA quality were CKR-03, CKR-04, CKR-12, CKR-26, CKR-40, and CKR-41. Wide phenotypic and genotypic coefficients of variations were found among the 32 accessions. High heritability was produced by pod length, pod girth, pod fresh mass, seed number/pod, seed fresh mass, and seed dry mass. The cluster analysis showed a wide morphological diversity of the 32 cocoa accession candidates based on the yield component characters.

Keywords: Genetic parameters, morpho-agronomy, productivity, *Theobroma cacao*

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an important plantation commodity with high economic value in the national and international markets, and the demand is constantly increasing (Cruz Chaustre and Cañas Castillo 2018). Cocoa beans are not only essential in the chocolate industry and confectionery products (Teye et al. 2020), food, cosmetics, and pharmaceutical industries (Lu et al. 2018; dos Santos Silva et al. 2020) but also play an essential role in improving the growth of regions and agro-industry improvement (Wahyudi et al. 2023). Cocoa is an essential commodity that absorbs a lot of labor and is a source of income for farmers (Danial et al. 2015; Onomo et al. 2016; Effendy et al. 2019; Voora et al. 2019; FAO 2020; Tosto et al. 2023). Cocoa is a commercial crop cultivated in wet tropical lowlands (Jaimes-Suárez et al. 2022), with the average price in February 2024 reaching US$6,146/ton (ICCO 2024b), which indicates a good market value. In the 2023/2024, world cocoa production is predicted to reach 4,449,000 tons (ICCO 2024a).

Cocoa has been cultivated in more than 20 tropical countries in Africa, Central America, South America, and some countries in the Asian region (Pereira et al. 2017; Rodriguez-Medina et al. 2019). Indonesia will become the world's sixth cocoa producer, with 692,168 tons produced in 2023 and projected to reach 702,759 tons in 2024 (Kementerian Pertanian 2022). It is estimated that in 2023/ 2024, the main cocoa-producing countries will be the countries in the African region (71.2%), America (23.3%), and Indonesia, combined with Asia-Oceania countries, will contribute 5.6% of world cocoa production (ICCO 2024a).

Cocoa plantations in Indonesia are dominated by the traditional farming system owned by smallholder farmers, comprising more than 90% of Indonesia's cocoa cultivation area of 1.6 million hectares. In managing their plantations, farmers select and develop the local clones by themselves, and thus, variations between clones are mainly found in their physiological adaptations to the local environment (Witjaksono and Asmin 2016; Widyasary and Susandarini 2020).

Cocoa development is not only carried out by the private plantation companies and the state plantations, but small farmers mostly carry it out as a commercial crop, which accounts for 60-90% of family income and contributes 70% of the global cocoa production (Voora et al. 2019). Meanwhile, 99.74% of cocoa production in Indonesia is produced by smallholder plantations (BPS 2021), and about 49.41-60.32% contribute to the farmer's income (Juliatmaja and Helviani 2021; Saputro et al. 2021). As one of the world's cocoa bean-producing countries (Zakiah et al. 2022), Indonesia has conducted various intensification and extensification programs to develop cocoa plantations and to increase export continuation due to the decrease of Indonesian cocoa bean production by 4.5% or only produced 692,168 tons in 2023, with exports of 256,087 tons (January-September 2023) at US$882,707,000 (Kementerian Pertanian 2022; 2023). The development of cocoa plantations is a big opportunity as global demand for cocoa continues to increase and is predicted to increase by more than 7% annually between 2019 and 2025 (Voora et al. 2019; Teye et al. 2020).

The obstacles faced by world cocoa-producing countries, especially Indonesia, are poverty issues and child labor. More than 2/3 of child labor cases occur in the agricultural sector, and more than 70% occur in farming families (ILO 2018). Deforestation due to the expansion of cocoa plantations (Sadhu et al. 2020; Abdullah et al. 2022), poor quality of cocoa beans (Ariningsih 2020), and low cocoa productivity (Muhardi et al. 2020; Zakiah et al. 2022) are additional issues related to the low quality and production in Indonesia, which resulted in an average production of only 700 kg of dry beans/ha/year, while the potential yield is more than 2.75 tons/ha/year. The existence of high-yielding cocoa clones as parent trees is a fundamental key to increasing the productivity and quality of low cocoa beans. The efforts to assemble cocoa clones and in-situ selection of cocoa clones in various regions continue to be carried out to obtain superior cocoa clones that can widely adapt to various environmental conditions. The existence of the PT Coklat Ransiki (Cokran) cocoa plantation in South Manokwari District, West Papua Province, which has existed since 1980, is an important asset as a genetic resource for cocoa that has been adapted to the environment for more than 30 years. Recently, no study has been conducted on cocoa trees that have the potency to become superior cocoa clones in Papua.

Characterization is a useful method for obtaining information on plant yield characteristics. Morphological characterization of yield components is an alternative approach to assess agronomic properties before utilizing germplasm collections (Widyasary and Susandarini 2020). Therefore, this research aimed to select and study the morphological components and yield of cocoa trees with high-yielding potency.

MATERIALS AND METHODS

Study area

The research was carried out at the PT Cocoa Plantation of Cokran, South Manokwari District, West Papua Province, Indonesia, for two years, from May 2020 to May 2022, in a 1,680 ha plantation area (Figure 1). The morphological characteristics, which include 13 quantitative characters of the cocoa pod and beans as well as 11 qualitative characters of leaf and pod color, were conducted at the Agroclimatology Laboratory, Faculty of Agriculture, and the Laboratory of the Agricultural Instrument Standardization Agency, Manokwari, West Papua, Indonesia.

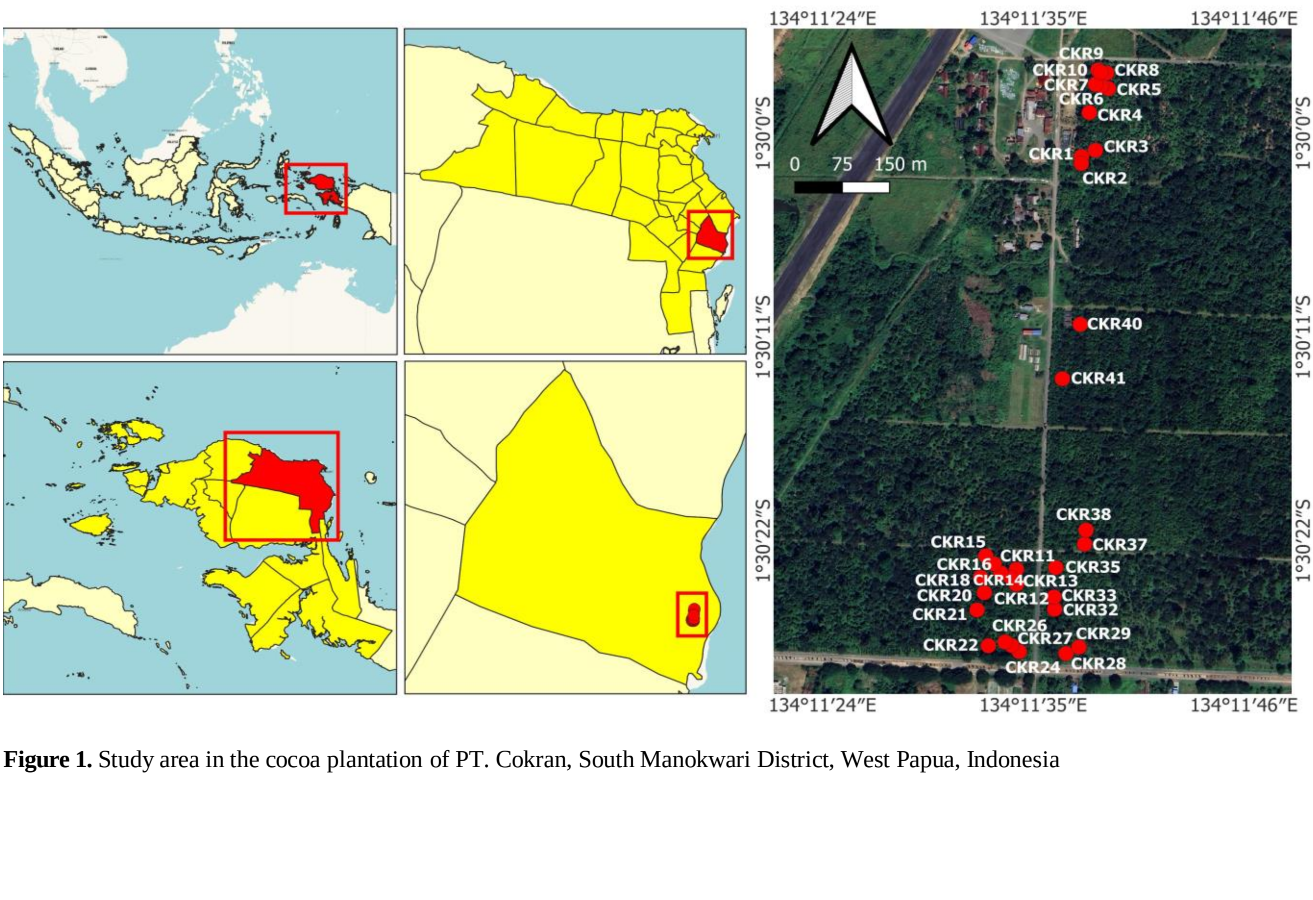

Figure 1. Study area in the cocoa plantation of PT. Cokran, South Manokwari District, West Papua, Indonesia

Table 1. Geographic locations of the 32 superior cocoa tree candidates in West Papua, Indonesia

Accession number	Garden block	S. ordinate	E. ordinate	Accession number	Garden block	S. ordinate	E. ordinate
CKR01	F	1°30'1.21"	134°11'37.28"	CKR18	B	1°30'23.51"	134°11'32.10"
CKR02	F	1°30'1.58"	134°11'37.27"	CKR20	B	1°30'24.32"	134°11'32.29"
CKR03	F	1°30'0.88"	134°11'37.99"	CKR21	B	1°30'25.24"	134°11'31.92"
CKR04	F	1°29'58.88"	134°11'37.68"	CKR22	B	1°30'27.13"	134°11'32.50"
CKR05	F	1°29'57.61"	134°11'38.65"	CKR24	B	1°30'27.45"	134°11'34.08"
CKR06	F	1°29'57.45"	134°11'38.30"	CKR26	B	1°30'27.12"	134°11'33.69"
CKR07	F	1°29'57.38"	134°11'37.99"	CKR27	B	1°30'26.94"	134°11'33.36"
CKR08	F	1°29'56.78"	134°11'38.57"	CKR28	C	1°30'27.54"	134°11'36.48"
CKR09	F	1°29'56.63"	134°11'38.12"	CKR29	C	1°30'27.21"	134°11'37.15"
CKR10	F	1°29'56.75"	134°11'38.26"	CKR32	C	1°30'25.20"	134°11'35.90"
CKR11	B	1°30'23.08"	134°11'33.94"	CKR33	C	1°30'24.55"	134°11'35.86"
CKR12	B	1°30'23.88"	134°11'33.94"	CKR35	C	1°30'23.00"	134°11'35.96"
CKR13	B	1°30'23.55"	134°11'33.70"	CKR37	D	1°30'21.75"	134°11'37.43"
CKR14	B	1°30'23.28"	134°11'33.14"	CKR38	D	1°30'21.01"	134°11'37.51"
CKR15	B	1°30'22.37"	134°11'32.37"	CKR40	D	1°30'10.11"	134°11'37.21"
CKR16	B	1°30'22.80"	134°11'32.80"	CKR41	D	1°30'12.99"	134°11'36.29"

Research materials

PT. Cokran has a cocoa plantation covering an area of 1,686 ha, planted from 25 to 60 m above sea level. The type of cocoa grown in this area is Trinitario F-1, which has been planted since 1985. Therefore, 32 selected accessions of Trinitario-type cocoa spread over four blocks. The determination of selected cocoa trees was based on the information from PT. Cokran farmer employees who regularly monitoring the cocoa plantation for 20 years. The selected cocoa tree accessions were labeled, and the ordinate point as the trees were located was determined using GPS (Table 1).

Research methods

The research was conducted by observation. The cocoa tree sampling was carried out using the purposive sampling technique (Taherdoost 2016), which covered four cocoa plantation blocks in 32 ordinate points where the accessions of superior cocoa parent-tree candidates grow (Table 1). The observation was based on the quantitative characteristics of the cocoa pod and beans on each superior cocoa parent-tree candidate accession. Three pod samples were collected from the main stem, primary, and secondary branches and repeated three times in two consecutive years; hence, there were 54 pod samples. Harvesting of all ripe cocoa pods was carried out throughout the year. The resistance of cocoa to pests and diseases was not observed in this research.

Cocoa yield

The cocoa pod yield was observed for two years on each selected tree accession. Ripe cocoa pods were taken from the main stem, primary, and secondary branches, three pieces each. Observed variables included the average pod length (cm), pod girth (cm), pod mass (g), and pod index. The index of cocoa pods is the number of pods to get 1 kg of dry cocoa beans, as follows:

$$Pod\ Index = \frac{1000\ g}{Seed\ dry\ mass/pod}$$

In addition, the young pod's color, the pod groove's depth, and the period/frequency of fertilization were monitored to help analyze kinship patterns.

Morphology of cocoa beans

Cocoa beans were taken from ripe cocoa pods on the main stem, primary, and secondary branches. The seeds were taken from each ripe pod, fermented, and dried using an electric oven (Seedburo Equipment-1022 W. Jackson BLVD, Chicago IL 60607) until the seed moisture content reached 7%. The observed variables included the average number of seeds/pods, seed fresh mass (g), seed dry mass (g), and seed dry mass/pod (g). Mass measurement was done by using an electric scale (ACS KC-5000P). Seed length (cm) and seed width (cm) were measured using calipers (Mitutoyo, Made in Japan). The quality of dry cocoa beans was determined based on the SNI 01-2323-2008 (BSN 2008; Pinem and Rambey 2019) criteria. The yield of cocoa seed was calculated using the formula:

$$Cocoa\ seed\ rendement\ = \frac{Seed\ dry\ mass}{Seed\ fresh\ mass} X\ 100\%$$

Seed dry yield potential

The yield potential of each candidate parent-tree cocoa accession was calculated based on the average seed dry mass/pod and the number of pod/tree/year without considering pest and disease infection factors. The average seed dry mass was obtained from all seeds in the pod samples collected from each accession and fermented separately.

The formula for calculating the potential production of dry cocoa beans for each accession per year is:

$$Dry\ seed\ yield\ (tree/year) = \sum pod\ x\ average\ of dry\ seed\ mass/pod$$

Grading of dry cocoa beans is needed to classify the physical quality classes of dry cocoa beans. According to SNI 01-2323-2008, the grouping is based on the number of dry seeds (moisture content 7%) weighing 100 grams (BSN

2008; Pinem and Rambey 2019). The five quality classes of dry cocoa beans are AA (≤85 seeds/100 g), A (86-100 seeds/100 g), B (101-110 seeds/100 g), C (111-120 seeds/100 g), and S (>120 seeds/100 g).

Data analysis

The quantitative data from the cocoa pod and bean variables measurements were analyzed using complete random variance analysis and continued with the LSD test at the 95% level using SAS 9.0 for Windows (Lawrence et al. 2016). Quantitative data together with qualitative data were analyzed to study the kinship patterns of superior cocoa tree candidate accessions using the Unweighted Pair-Group Method with Arithmetic mean (UPGMA method) with the Numerical Taxonomy and Multivariate System (NTSys program) verse 2.1. Genotype and phenotype variability were analyzed using the equations of Anderson and Bancroft (1952). The standard deviation of genetic variance $\left(\sigma_{\sigma_g^2}\right)$ and phenotype was calculated using the equation:

$$\sigma_{\sigma_g^2} = \sqrt{\frac{2}{r^2}\left[\frac{(MS_{Genotipe})^2}{df_{Genotipe}{}^{+2}} + \frac{(MS_{Error})^2}{df_{Error}{}^{+2}}\right]}$$

$$\sigma_{\sigma_p^2} = \sqrt{\frac{2}{r^2}\left[\frac{(MS_{Genotipe})^2}{df_{Genotipe}{}^{+2}}\right]}$$

Where:
MS : Mean of Square
df : Degree of freedom
r : Replication

If the value $\sigma_p^2 \leq 2\,\sigma_{\sigma_p^2}$, then phenotypic variance falls into a narrow category; $\sigma_p^2 > 2\,\sigma_{\sigma_p^2}$ shows wide phenotypic diversity (Syukur et al. 2011).

The genotypic and phenotypic coefficients of variation were computed as follows:

$$GVC = \frac{\sqrt{\delta_g^2}}{\bar{x}}\ X\ 100\%$$

$$PVC = \frac{\sqrt{\delta_p^2}}{\bar{x}}\ X\ 100\%$$

The Coefficient Of Genotypic (GVC) and Phenotypic Variance (PVC) is divided into three categories: Wide: ≥14.5%, Medium: 5%≤14.5%, and Narrow: <5% (Knight 1979; Milligan et al. 1990).

Heritability in a broad sense (Hbs) was computed as follows (Johnson et al. 1955):

$$Hbs = \frac{\delta_g^2}{\delta_p^2}\ x\ 100\%$$

Heritability is classified as High ≥50%, Medium 20%≥H>50%, and Small <20% (Elrod and Stanfield 2002). The 24 agronomic characters analyzed using the software NTSys are used to group (cluster) cocoa accessions.

RESULTS AND DISCUSSION

Cocoa is a cauliform plant; the pods grow on the stem and branches of the plant (Goya et al. 2022). Generally, a young cocoa pod is green and red; it turns yellow when it is ripe, and when a young cocoa pod is red, it turns orange when it is ripe. Cocoa pods are generally oval to oblong and have 5 internal grooves and 5 alternating groove ridges. The depth of the pod groove is almost flat, shallow, deep, and the surface of the cocoa pod skin is smooth and slightly rough. The results of analysis of variance for 4 pod characters in 32 cocoa tree accessions (Table 2) show that pod length ranges from the shortest 14.00 cm (CKR-38; significantly different from other accessions) to the longest 35.00 cm (CKR-12; significantly different from other accessions).

The smallest pod girth of the cocoa was 16.00 cm (CKR-18 accession; significantly different from other accessions), while the largest pod girth was 35.33 cm (CKR-40 accession; significantly different from other accessions). The lowest fresh mass of the ripe pod was 196.67 g (CKR-38 accession; significantly different from other accessions), while the highest was 1165.00 g (CKR-40 accession; significantly different from other accessions). The cocoa pod index states how many cocoa pods are needed to obtain 1000 g of dry cocoa beans. The smaller the amount of cocoa pod required to obtain 1000 g of dry cocoa beans, the higher the index of the pod (Figure 2).

Farmers faced challenges in choosing the right cocoa pod size to produce a higher yield. In the CKR-12 accession, 9.66 pods were needed to obtain 1 kg of dry cocoa beans, significantly different from other accessions. This shows that the number of seeds in the pod was large (r = -0.6), the dry mass of each seed was high (r = -0.79), and the dry mass of seeds per pod (r = -0.80), indicating the fewer the number of pods needed to get 1 kg of dry cocoa beans. The maximum quantity of up to 20 pods required to obtain 1,000 g of dry cocoa beans is shown by the accessions of CKR-03, CKR-04, CKR-07, CKR-09, CKT-15, CKR-22, CKR-26, CKR-40 and CKR-41 (Figure 2). The age for cocoa pods to reach maturity was around 50-180 days after pollination (Orwa et al. 2009), and inside the pod, the seeds were arranged in 5 grooves with a placenta in the middle. Ripe cocoa pods that are ripe must be immediately harvested because if it is late, the seeds in the pod will germinate and cannot be used. This is because cocoa beans are recalcitrant as their seeds are not dormant (Wibowo et al. 2021). For consumption or trade purposes, fresh cocoa beans must be fermented for 5-7 days to remove the pulp and develop the chemical qualities of the beans, and the fermented cocoa beans should then be dried to a moisture content of 7% (Dzelagha et al. 2020). Generally, the number of seeds in a cocoa pod is 30-40 (Tetteh and Obeng 2021; Goya et al. 2022). The pod and bean characters are important for distinguishing and classifying cocoa genotypes (Adenuga et al. 2015). Moreover, a study on morphological characterization of elite cocoa trees found that leaf, pod, and bean traits were useful in differentiating cocoa genotypes (Ballesteros et al. 2015).

The number of seeds per pod is an important trait for tracing variations in the morphological features of cocoa and also a determinant factor in measuring crop yield (Tetteh and Obeng 2021). The number of seeds per pod, seed fresh mass, seed dry mass, and seeds dry mass per pod produced by the CKR-12 accession was greater and significantly different from other accessions (Table 3.A). The more seeds in a pod, the higher the dry mass of the seeds per pod (r = 0.76).

Table 2. Analysis of morphological characters of cocoa pods in 32 accessions

Accession number	Pod length (cm)				Pod girth (cm)				Pod fresh mass (g)			
	Stdev		*Main data*		*Stdev*		*Main data*		*Stdev*		*Main data*	
CKR-01	0.58	±	17.33	hijkl	0.58	±	27.67	cdefghi	60.83	±	480.00	fghij
CKR-02	1.73	±	19.00	fghijk	1.00	±	26.00	ghi	92.92	±	493.33	fghij
CKR-03	1.80	±	29.00	bc	2.50	±	20.50	klm	152.75	±	593.33	cdef
CKR-04	1.89	±	30.67	b	1.53	±	19.17	m	90.18	±	606.67	cdef
CKR-05	2.52	±	16.33	klm	1.53	±	25.33	ij	15.28	±	556.67	cdefgh
CKR-06	1.53	±	17.33	hijkl	0.58	±	28.33	cdefgh	41.63	±	533.33	defghi
CKR-07	1.73	±	20.00	fghi	1.15	±	30.33	bc	56.86	±	593.33	cdef
CKR-08	1.00	±	20.00	fghi	3.21	±	29.33	bcde	15.28	±	653.33	cd
CKR-09	1.00	±	20.00	fghi	0.00	±	30.00	bcd	5.00	±	625.00	cde
CKR-10	0.50	±	26.50	cd	0.50	±	20.00	lm	26.46	±	420.00	ijk
CKR-11	0.58	±	20.33	fgh	1.53	±	27.67	cdefghi	5.77	±	546.67	defghi
CKR-12	2.00	±	35.00	a	0.50	±	22.00	kl	182.30	±	996.67	b
CKR-13	0.76	±	27.17	c	0.58	±	18.83	m	32.15	±	433.33	hijk
CKR-14	0.58	±	15.67	lm	1.00	±	30.00	bcd	5.00	±	565.00	cdefg
CKR-15	0.76	±	26.83	cd	1.76	±	21.33	klm	66.58	±	506.67	efghij
CKR-16	2.89	±	16.67	jklm	2.65	±	26.00	ghi	26.46	±	390.00	jk
CKR-18	1.26	±	28.17	bc	1.50	±	16.00	n	64.29	±	426.67	hijk
CKR-20	0.58	±	19.67	fghij	1.15	±	29.33	bcde	25.17	±	423.33	ijk
CKR-21	1.15	±	19.67	fghij	0.58	±	30.33	bc	10.00	±	600.00	cdef
CKR-22	1.73	±	19.00	fghijk	0.58	±	26.33	fghi	55.08	±	433.33	hijk
CKR-24	3.79	±	17.67	ghijkl	2.08	±	26.67	efghi	11.55	±	436.67	ghijk
CKR-26	1.00	±	22.00	klm	1.00	±	27.00	efghi	30.55	±	386.67	jk
CKR-27	2.52	±	18.67	ghijkl	4.04	±	27.67	cdefghi	225.02	±	496.67	efghij
CKR-28	0.58	±	18.67	ghijkl	0.58	±	28.67	cdefg	35.12	±	526.67	defghi
CKR-29	6.08	±	22.00	ef	1.53	±	27.33	defghi	15.28	±	546.67	defghi
CKR-32	0.58	±	15.67	lm	0.58	±	27.67	cdefghi	10.00	±	390.00	jk
CKR-33	1.00	±	17.00	ijklm	1.15	±	25.67	hij	5.00	±	345.00	k
CKR-35	4.04	±	18.67	ghijkl	3.51	±	28.33	cdefgh	20.00	±	680.00	c
CKR-37	1.53	±	20.67	efg	0.00	±	29.00	cdef	75.06	±	536.67	defghi
CKR-38	1.00	±	14.00	m	1.00	±	23.00	jk	15.28	±	196.67	l
CKR-40	0.58	±	23.67	de	0.58	±	35.33	a	223.34	±	1165.00	a
CKR-41	1.00	±	22.00	ef	3.46	±	32.00	b	10.00	±	1080.00	ab
LSD 95%			3.23				2.80				131.14	

Note: Numbers in the same column and followed by the same letter are not significantly different at the 95% level

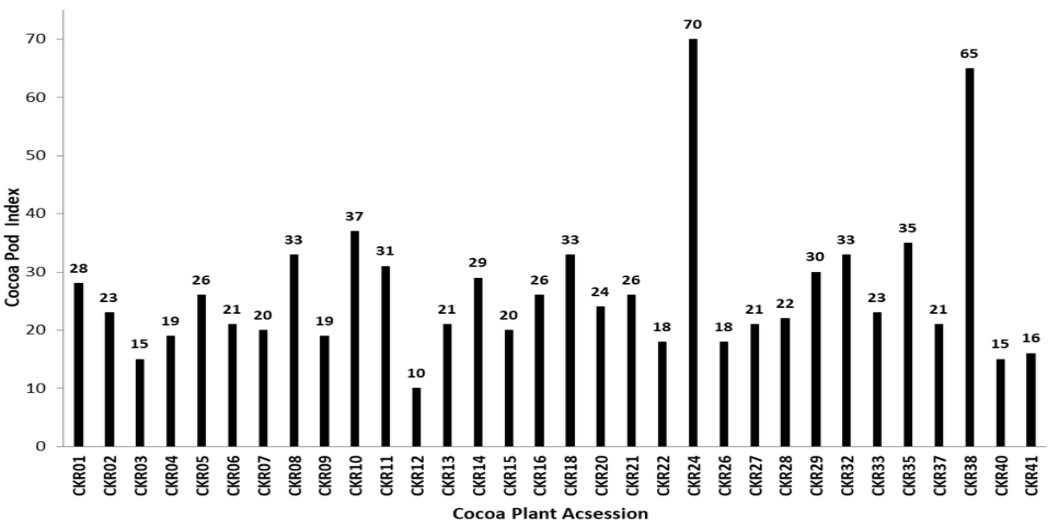

Figure 2. Pod index of 32 cocoa accessions

Table 3.A. The analysis of cocoa seed characters in 32 accessions

Accession number	Seed number/pod			Seed fresh mass			Seed dry mass			Seeds dry mass/pod		
	Stdev	*Main data*		*Stdev*	*Main data*		*Stdev*	*Main data*		*Stedev*	*Main data*	
CKR-01	1.0	± 35	n	0.37	± 2.54	hijkl	0.01	± 1.01	fghij	1.36	± 35.36	kl
CKR-02	2.0	± 42	ijk	0.37	± 2.80	fghijk	0.01	± 1.04	efghi	1.66	± 43.67	hij
CKR-03	3.0	± 44	ghi	0.41	± 4.54	b	0.03	± 1.47	b	4.88	± 64.54	bc
CKR-04	1.0	± 41	jk	0.27	± 3.58	cde	0.08	± 1.29	c	3.72	± 53.03	efg
CKR-05	1.0	± 40	kl	0.22	± 2.69	fghijk	0.19	± 0.96	ghijk	7.80	± 38.45	jk
CKR-06	1.0	± 50	cd	0.44	± 2.92	fghij	0.04	± 0.92	ijkl	2.06	± 45.83	hi
CKR-07	3.0	± 43	hij	0.08	± 2.93	fghij	0.09	± 1.14	de	7.29	± 49.20	fgh
CKR-08	1.0	± 29	o	0.36	± 2.89	fghij	0.11	± 1.03	efghij	2.53	± 29.81	lm
CKR-09	1.0	± 54	b	0.20	± 2.63	ghijkl	0.02	± 1.00	fghijk	0.08	± 53.99	ef
CKR-10	2.0	± 25	p	0.13	± 3.15	efg	0.08	± 1.08	defg	2.66	± 27.06	m
CKR-11	1.0	± 30	o	0.60	± 2.72	fghijk	0.08	± 1.08	defg	3.32	± 32.44	lm
CKR-12	1.0	± 61	a	0.27	± 5.81	a	0.10	± 1.70	a	5.21	± 103.66	a
CKR-13	2.0	± 45	fgh	0.42	± 3.74	cd	0.04	± 1.05	efgh	3.75	± 47.15	h
CKR-14	1.0	± 46	efg	0.13	± 2.29	kl	0.01	± 0.76	mn	1.22	± 34.97	kl
CKR-15	1.0	± 45	fgh	0.23	± 2.65	ghijkl	0.11	± 1.09	def	4.68	± 49.17	fgh
CKR-16	1.0	± 40	kl	0.50	± 2.47	ijkl	0.03	± 0.96	ghijk	1.77	± 38.54	jk
CKR-18	1.0	± 37	mn	0.19	± 2.41	jkl	0.03	± 0.8	klm	1.52	± 29.73	lm
CKR-20	1.0	± 40	kl	0.40	± 2.73	fghijk	0.06	± 1.03	efghij	2.55	± 41.20	ij
CKR-21	1.0	± 44	ghi	0.15	± 2.70	fghijk	0.02	± 0.88	klm	1.51	± 38.73	jk
CKR-22	1.0	± 51	c	0.21	± 2.48	ijkl	0.12	± 1.11	def	6.38	± 56.64	de
CKR-24	0.6	± 30	o	0.10	± 1.50	m	0.01	± 0.48	o	2.77	± 14.49	n
CKR-26	1.0	± 45	fgh	0.11	± 2.45	ijkl	0.03	± 1.20	cd	1.94	± 54.16	ef
CKR-27	1.0	± 43	hij	0.36	± 2.66	ghijk	0.05	± 1.11	def	3.15	± 47.62	gh
CKR-28	2.0	± 48	de	0.21	± 2.96	fghi	0.01	± 0.94	hijk	1.68	± 45.11	hi
CKR-29	1.0	± 35	n	0.01	± 2.32	kl	0.01	± 0.91	jkl	0.93	± 31.73	lm
CKR-32	1.0	± 45	fgh	0.01	± 2.12	l	0.01	± 0.68	n	0.73	± 30.45	lm
CKR-33	1.0	± 38	lm	0.28	± 2.58	hijkl	0.11	± 1.15	de	3.97	± 43.68	hij
CKR-35	0.6	± 27	p	0.73	± 3.21	def	0.13	± 1.08	defg	2.87	± 28.85	m
CKR-37	0.6	± 45	gh	0.43	± 2.90	fghij	0.06	± 1.05	efgh	2.15	± 47.03	h
CKR-38	1.0	± 36	mn	0.05	± 1.25	m	0.04	± 0.44	o	1.79	± 15.74	n
CKR-40	1.0	± 47	ef	0.52	± 4.02	bc	0.05	± 1.45	b	1.66	± 68.12	b
CKR-41	1.0	± 42	ijk	0.22	± 3.06	efgh	0.14	± 1.48	b	6.23	± 62.17	cd
LSD 95%		2.2			0.53			0.0.12			5.79	

Note: Numbers in the same column and followed by the same letter are not significantly different at the 95% level

The seed number and size are essential for determining cocoa yield (Tetteh and Obeng 2021). The seed dry mass of the CKR-12 accession (1.70 g) shows a superiority compared to the national superior cocoa clones such as KW-617/ICCRI-09, with a seed dry mass ranging from 1.07-1.55 g (ICCRI 2019). The shape of cocoa beans varied from oval to oblong. The seed dry mass per pod was determined by pod length (r = 0.53) and was only slightly influenced by pod girth (r = 0.03). The longest cocoa seed was 2.62 cm (CKR-40), the widest cocoa seed was 1.52 cm (CKR-07), and the thickest was 0.97 cm (CKR-24), which was significantly different from the other accessions. At the same time, the CKR-18 accession showed the lowest character (Table 3.B).

The dryness level of the beans largely determined the yield of cocoa beans. The higher the seed dry mass, the higher the yield level of cocoa seeds. The higher the yield (r = 0.25), the higher the seed fresh mass per pod. Accessions CKR-26 and CKR-41 had high yields of 49.08% and 48.66%, respectively, significantly different from the others. This shows that accessions CKR-26 and CKR-41 had denser seeds.

Grading of dry cocoa beans is needed to classify the physical quality classes. According to SNI 01-2323-2008, the group is categorized based on the number of dry seeds (moisture content 7%) weighing 100 g (BSN 2008; Pinem and Rambey 2019). Six accessions (CKR-03, CKR-04, CKR-12, CKR-26, CKR-40, and CKR-41) had a dry cocoa beans quality AA (≤85 seed/100 g). In comparison, 14 accessions produced quality A (86-100 seeds/100 g), five accessions produced quality B (101-110 seeds/100 g), and one accession performed quality C (111-120 seeds/100 g). Five accessions produced quality S (>120 seeds/100 g) (Table 3.B). The number of pod components per tree over 1 year is essential to determine the production potential per tree and unit area. However, farm management factors, climate, pests, diseases, soil fertility, and fruiting intensity are also influenced by tree productivity, whether fruiting throughout the year or at specific periods. The result shows that the number of pods ranged from 45-180 pods per tree per year (Figure 3).

The potential for dry seed production per tree per year depended on the number of pods per tree (r = 0.79), seed dry mass per pod (r = 0.59), seed yield (r = 0.13), and other external factors. Eight accessions, CKR-02, CKR-03, CKR-04, CKR-09, CKR-12, CKR-26, CKR-28, and CKR-41, had a high production potential of more than 6000 g per tree (Figure 4).

Table 3.B. Analysis of seed characteristics of 32 accessions

Accession number	Seed length		Seed width		Seed thick		Seed rendement		Seed quality
	Stdev	*Main data*	*Stdev*	*Main data*	*Stdev*	*Main data*	*Stdev*	*Main data*	
CKR-01	0.14	± 2.36 abcde	0.05	± 1.40 abc	0.14	± 0.86 abcd	5.68	± 40.26 bcdef	A
CKR-02	0.14	± 2.02 ghijkl	0.15	± 1.35 abcd	0.07	± 0.95 ab	5.08	± 37.59 cdefghij	A
CKR-03	0.09	± 2.18 defghij	0.03	± 1.22 bcde	0.07	± 0.79 bcdef	2.93	± 32.47 hijkl	AA
CKR-04	0.14	± 2.27 cdefgh	0.10	± 1.44 ab	0.10	± 0.78 bcdef	2.34	± 36.17 cdefghij	AA
CKR-05	0.07	± 1.92 jkl	0.09	± 1.21 bcde	0.15	± 0.81 abcdef	5.69	± 35.61 cdefghijk	B
CKR-06	0.10	± 2.30 bcdef	0.05	± 1.25 bcde	0.01	± 0.69 defg	4.52	± 31.82 ijkl	B
CKR-07	0.05	± 2.05 fghijk	0.51	± 1.52 a	0.09	± 0.91 abc	3.24	± 38.88 bcdefgh	A
CKR-08	0.13	± 2.02 fghijkl	0.26	± 1.25 bcde	0.08	± 0.85 abcd	2.01	± 35.71 cdefghijk	A
CKR-09	0.30	± 2.22 defghi	0.10	± 1.30 abcde	0.10	± 0.80 abcdef	2.21	± 38.13 cdefghi	A
CKR-10	0.03	± 2.03 fghijkl	0.07	± 1.24 bcde	0.19	± 0.78 bcdef	3.65	± 34.48 efghijkl	A
CKR-11	0.13	± 2.05 fghijk	0.05	± 1.25 bcde	0.05	± 0.80 abcdef	8.45	± 40.92 bcde	A
CKR-12	0.19	± 2.38 abcd	0.12	± 1.43 ab	0.05	± 0.65 fgh	3.09	± 29.34 kl	AA
CKR-13	0.10	± 2.20 defghi	0.07	± 1.33 abcde	0.10	± 0.67 efgh	3.19	± 28.19 l	A
CKR-14	0.09	± 2.21 defghi	0.21	± 1.17 cdef	0.13	± 0.84 abcd	1.56	± 33.25 ghijkl	S
CKR-15	0.11	± 1.99 ijkl	0.08	± 1.12 def	0.10	± 0.74 cdefg	1.16	± 41.19 bcd	A
CKR-16	0.18	± 2.22 defghi	0.09	± 1.21 bcde	0.11	± 0.73 defg	9.09	± 40.28 bcdef	B
CKR-18	0.34	± 1.77 l	0.13	± 0.95 f	0.10	± 0.40 i	1.34	± 33.35 ghijkl	S
CKR-20	0.13	± 2.08 efghij	0.04	± 1.28 abcde	0.08	± 0.71 defg	3.22	± 38.04 cdefghij	A
CKR-21	0.05	± 1.90 jkl	0.04	± 1.13 def	0.03	± 0.60 gh	1.77	± 32.61 hijkl	C
CKR-22	0.15	± 2.17 defghij	0.06	± 1.27 bcde	0.23	± 0.69 defgh	1.16	± 44.78 ab	A
CKR-24	0.06	± 2.53 abc	0.03	± 1.32 abcde	0.08	± 0.97 a	3.46	± 31.65 jkl	S
CKR-26	0.10	± 2.00 ghijkl	0.02	± 1.21 bcde	0.02	± 0.85 abcd	1.09	± 49.08 a	AA
CKR-27	0.15	± 2.28 cdefg	0.03	± 1.23 bcde	0.06	± 0.83 abcde	4.61	± 42.07 bc	A
CKR-28	0.22	± 2.25 defghi	0.12	± 1.23 bcde	0.11	± 0.84 abcd	1.88	± 31.84 ijkl	B
CKR-29	0.07	± 2.10 efghij	0.13	± 1.12 def	0.11	± 0.84 abcd	0.13	± 39.08 bcdefg	B
CKR-32	0.13	± 2.00 hijkl	0.05	± 1.17 cdef	0.09	± 0.65 fgh	0.16	± 31.92 ijkl	S
CKR-33	0.20	± 2.43 abcd	0.08	± 1.30 abcde	0.13	± 0.85 abcd	1.61	± 44.64 ab	A
CKR-35	0.34	± 1.79 kl	0.12	± 1.16 cdef	0.05	± 0.85 abcd	3.75	± 34.28 fghijkl	A
CKR-37	0.31	± 2.27 cdefghi	0.26	± 1.11 ef	0.10	± 0.52 hi	3.48	± 36.66 cdefghij	A
CKR-38	0.31	± 2.27 cdefghi	0.26	± 1.11 ef	0.10	± 0.70 defg	3.12	± 34.96 defghijk	S
CKR-40	0.08	± 2.62 a	0.05	± 1.34 abcde	0.05	± 0.75 cdefg	4.50	± 36.48 cdefghij	AA
CKR-41	0.11	± 2.57 ab	0.16	± 1.32 abcde	0.19	± 0.93 ab	7.33	± 48.66 a	AA
LSD 95%		0.28		0.24		0.16		6.46	

Note: Numbers in the same column and followed by the same letter are not significantly different at the 95% level. AA: ≤85 seed/100 g; A: 86-100 seeds/100 g; B: 101-110 seeds/100 g; C: 111-120 seeds/100 g; S: >120 seeds/100 g

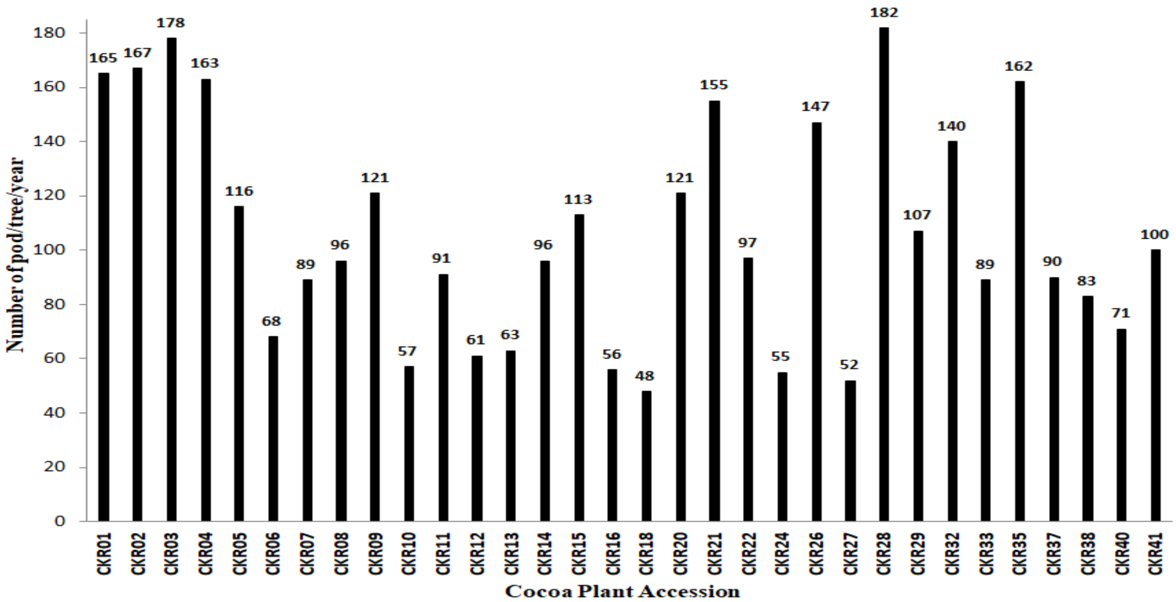

Figure 3. Pod number/tree/year of 32 cocoa plant accessions

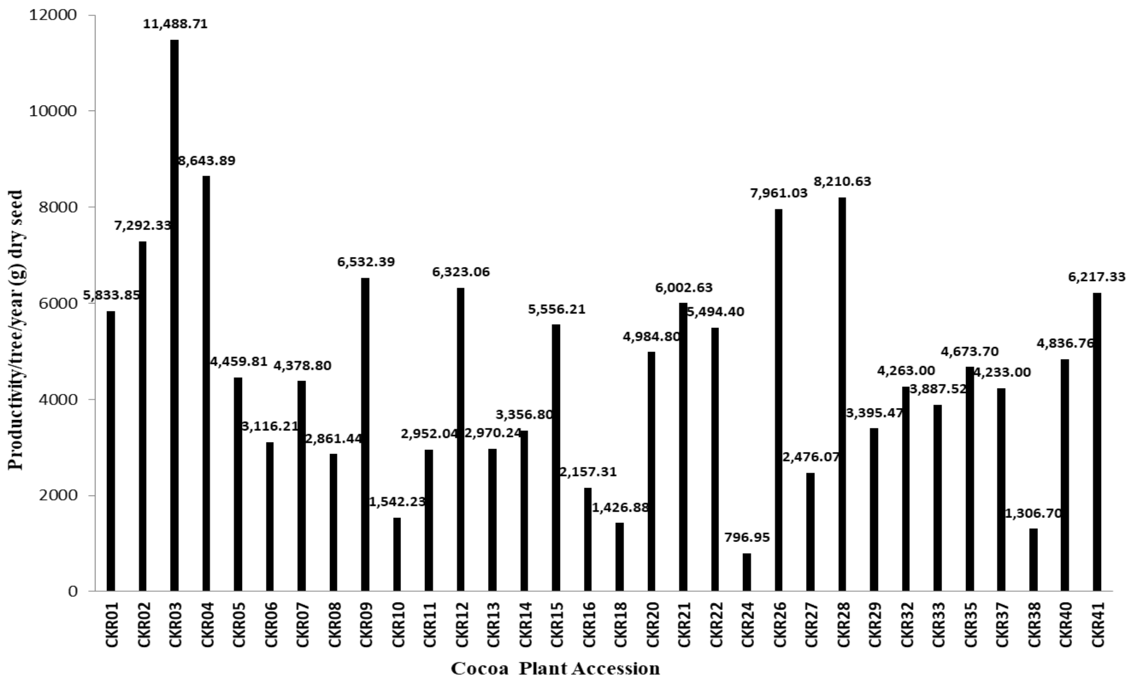

Figure 4. Productivity/tree/year (g dry seed)

Table 4. Coefficient of variance. Phenotypic and genotypic coefficient of variation and heritability of cocoa accession characters in 32 accessions

Source of variance	Means	CV (%)	GVC (%)	PVC (%)	H^2 (%)
Pod length	20.91	8.27	23.24	25.10	92.59
Pod girth	26.34	5.95	15.75	17.05	92.49
Pod fresh mass	551.98	14.80	35.37	38.25	92.47
Seed number/pod	41.33	3.32	18.98	19.26	98.56
Seed fresh mass	2.87	11.31	46.48	30.24	92.62
Seed dry mass	1.04	7.11	28.00	25.98	95.80

Note: CV: Coefficient Variance; GVC: Genotypic Variance Coefficient; PVC: Phenotypic Variance Coefficient; H^2: Heritability in broad sense

Dry seed productivity between 4,000 g to less than 6,000 g per tree per year is produced by 11 accessions, while 13 accessions had less than 4,000 g per tree per year, assuming no attack from plant pests. The observed production potential of the 32 accessions shows that if the plant population was 1,100 trees per hectare, the potential yield of the 32 accessions was between 0.88 tonnes/ha (CKR-24 accession) and 12.64 tonnes/ha (CKR-03 accession). All accessions except CKR-10, CKR16, CKR-18, CKR-24, CKR-27, and CKR-38 had higher production potential when compared to the national superior cocoa clones such as KW-617/ICCRI-09 with a yield potential of 1.837-2.745 tons/ha/year (ICCRI 2019).

All parameters show a Coefficient of Variance (CV) value below 15% (Table 4), indicating good data precision. Based on the analysis (Table 4), all characters had a large Genotypic Coefficient of Variance (GVC) and a large Phenotypic Coefficient of Variance (PVC), which has broad criteria, while H^2 has high criteria. GVC shows the magnitude of the genetic variance of the desired parameters and was used to determine the magnitude of genetic and environmental influences on the differences in a variable. GVC values of less than 5% are said to have a narrow distribution of characters, so the activity of genetic manipulation has little potential for success. Ahsan et al. (2015) added that if the genotypic and phenotypic variance traits are low, the improvement of PVC and GVC values is needed. However, all the characters shown by all cocoa accessions produced a high variance of both genotype and phenotype traits. Deepa et al. (2019) said that these characters can be major descriptors when selecting high-yielding cocoa clones. Some of the cocoa accessions tested had high productivity of more than 8 t/ha when the yield per plant is converted to hectares (with a plant population of 800 per hectare), except CKR-6, CKR-8, CKR-10, CKR-11, CKR-13, CKR-16, CKR-18, CKR-24, CKR-27, CKR-38 accessions which had lower productivity than the national cocoa clone. The national cocoa clone productivity is 3.67 t/ha in MCC-01 clone, 3.13 t/ha in MCC-02 clone, 2.50 t/ha in Sulawesi-1 clone, and 2.75 t/ha in Sulawesi-2 clone (ICCRI 2024).

The coefficient of genotypic variance ranged from 15.75% for pod girth to 46.48% for seed fresh mass character. The highest coefficient of genotypic variation was 46.48% produced by fresh seed mass. The coefficient of phenotypic variation has the same trend as the coefficient of genotypic variation for all observed characters (Figure 5). This follows Ahsan et al. (2015) and Kartahadimaja et al. (2021) that state there is a close relationship between the coefficients of genotypic and phenotypic variation. This shows that the environment less influences these characters, and the selection can be applied to traits of more promising genotypes.

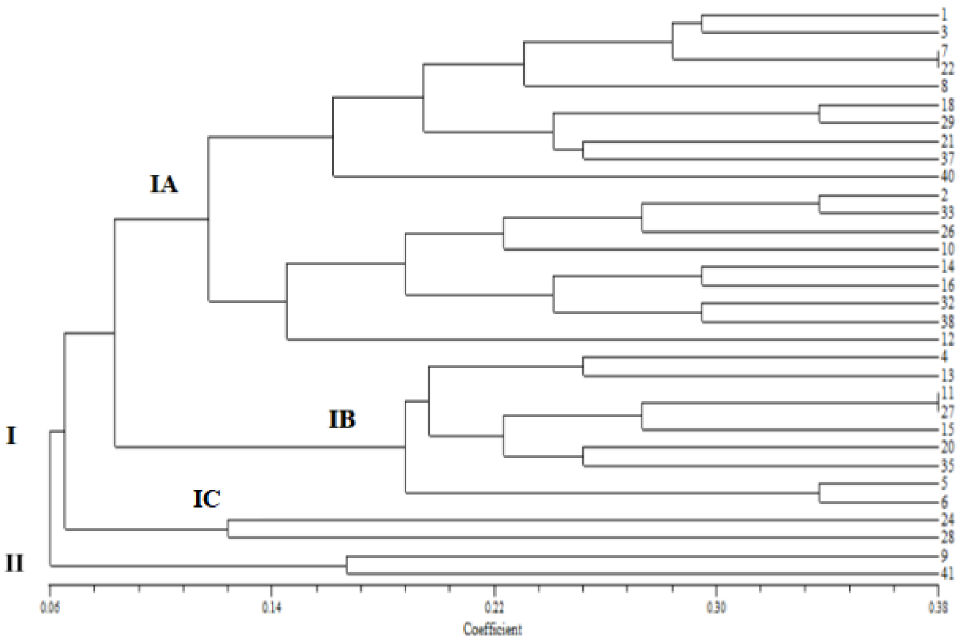

Figure 5. Dendrogram of character similarity of the 32 cocoa accessions

Heritability is the proportion of genetic variance to phenotypic variance. Heritability is a genetic parameter that indicates traits inherited by the elder to the next offspring. The heritability values describe that genetic factors or environmental factors influence characters. The heritability value ranges from 0% to 100%; the closer to 100%, the higher the heritability, which is influenced by genetic factors. Conversely, the closer to 0%, the lower the heritability, which means that environmental factors influence the character's appearance. A plant character with wide genetic diversity and high heritability values shows the character variation in a population, and genetic factors heavily influence the character's appearance. High GVC and heritability values of the characters indicate that the plant characters have a significant genetic influence, so the phenotype appearance of characters will be more expressed as influenced by the genetics and little influenced by the environment (Islam et al. 2013).

Generally, a plant character with a high GVC value does not necessarily have a high heritability value and vice versa. However, this study found that the morphological characters with wide PVC and high GVC values had high heritability. Thus, the GVC value and heritability are linearly the same, indicating that the traits are least influenced by external environmental variation (Binse et al. 2009). The heritability value of cocoa parameters in this study ranges from 92.47% to 98.56%, and this value is included in the high heritability criteria, which means that genetic rather than environmental factors influence the characters. According to Ogunniyan and Olakojo (2014) and Rahajeng et al. (2020), the greater value of broad sense heritability coupled with the wider genetic advance in characters indicate the plant parameters under the control of additive genetic effects. Cocoa clones with high yield potential were CKR-01, CKR-02, CKR-03, CKR-04, CKR-05, CKR-07, CKR-09, CKR-012, CKR-14, CKR-15, CKR-20, CKR-21, CKR-22, CKR-26, CKR-27, CKR-29, CKR-30, CKR-31, CKR-32, CKR-33, CKR-34, CKR-35, CKR-36, CKR-37, CKR-40, and CKR-41. The wide genotypic variance coefficient and broad sense of heritability for each observed character support these results. This indicates that the genetic factors of superior clones influence the potential for high yields.

Cluster analysis

The data of 24 morpho-agronomy characters were analyzed to obtain the kinship relation among 32 cocoa accessions (Figure 5). The results of the phenetic relationship of 32 cocoa clones had a similarity coefficient value between 0.06-0.38. Furthermore, the grouping patterns based on the dendrogram of character similarity of the 32 cocoa accessions revealing the two large groups are separated by a similarity coefficient value of 0.06. The lowest similarity at 0.06 contained two groups, namely group I, consisting of 30 accessions, and group II, consisting of only two accessions, namely accession CKR-9 and CKR-41. The difference between accession CKR-9 and CKR-41 is that the other accessions lay in pod length, pod girth, pod fresh mass, pod index, seed fresh mass, seed dry mass, and seed quality. Group I formed sub-group IA, which consisted of 19 accessions (CKR-12, CKR-38, CKR-32, CKR-16, CKR-14, CKR-10, CKR-26, CKR-33, CKR-2, CKR-40, CKR-37, CKR-21, CKR-29, CKR-18, CKR-8, CKR-22, CKR-7, CKR-3, and CKR1). In contrast, sub-group IB consisted of 9 accessions (CKR-6, CKR-5, CKR-35, CKR-20, CKR-15, CKR-15, CKR-27, CKR-11, CKR-13, CKR-4), and sub-group IC consisted of 2 accessions (CKR-28 and CKR-24). The accession of CKR-7 and CKR-22 in group IA and CKR-11 and CKR-27 in group IB have a similarity coefficient of 0.38. The characters of CKR-7 and CKR-22 are dissimilar in Marquette height, flower anthocyanin, leaf tip color, pod skin color, and pod groove. At the same time, CKR-11 and CKR-27 had dissimilar characteristics in terms of Marquette height, upper leaf surface, young pod skin color, pod groove, pod tip end, and mature pod skin color. The result of cluster analysis indicated a diverse character variation of the morpho-agronomy among the 32 cocoa accessions.

In conclusion, the research results show that eight accessions had a high production potential of more than 6,000 g per tree. Therefore, the recommended accessions for a high yield potential are CKR-02, CKR-03, CKR-04, CKR-09, CKR-12, CKR-26, CKR-28, and CKR-41. Based on the pod index calculation, the highest pod index value to get 1,000 g of dry cocoa beans was produced by the CKR-12 accession with ten pods, while CKR-03 and CKR-40 accessions produced 15 pods, and CKR-41 accession produced 16 pods. Based on the physical quality of dry cocoa beans, which are classified as grade AA, they were produced by six accessions, namely CKR-03, CKR-04, CKR-12, CKR-26, CKR-40, and CKR-41. The genetic parameters showed a wide phenotypic and genotypic coefficient of variations and high heritability among the 32 accessions. Based on the cluster analysis, a wide variation of agro-morphological characters was observed among the 32 cocoa accessions. However, some cocoa accessions (CKR-07 and CKR-22, CKR-11, and CKR-27) had a higher similarity level of 38%.

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