Journal of Oil Palm Research
DOI: https://doi.org/10.21894/jopr.2025.0039

THE GENETIC INFLUENCE ON OIL PALM PHENOLOGY-RELATED TRAIT INHERITANCE IN CAMEROON ACCESSION

TRININGSIH[1]*; SUJADI[1]; HERI ADRIWAN SIREGAR[1] and YURNA YENNI[1]

ABSTRACT

The characterisation of oil palms based on inflorescence phenology is vital for developing oil palm varieties with precocious traits. However, the study on genetic control for these traits still needs to be improved. This study evaluated the genetic variability at the inflorescence phase of 20 Cameroon accessions grown at Adolina Estate, North Sumatra, Indonesia. The analysis of variance for female and male inflorescence phenological traits showed significant differences between Cameroon accessions. This study revealed that genetic control for phenology phases is lower than the environmental control. Also, the heritability of the period from spear leaf to 70% open to ripening is about 23%, with a 5% genotypic coefficient of variance. Cluster analysis successfully grouped the accession into two major groups with no relationship between geographical origin and clustering pattern. This study gives insights into the genetic parameters and breeding potential of Cameroon accession in a way that allows accession selection based on inflorescence traits. A high environmental effect influences the observed phenotypes, so selection based on related traits will not be effective.

Keywords: BBCH, cluster analysis, coefficient variability, genetic variance.

Received: 10 May 2024; **Accepted:** 8 May 2025; **Published online:** 29 July 2025.

INTRODUCTION

The narrow genetic base of current commercial oil palm cultivars has encouraged oil palm breeders to pay more attention to improving genetic resources for sustainable oil palm breeding (Arias *et al.*, 2013). According to Sayekti *et al.* (2015), the introduced germplasm is a promising genetic resource as breeding material to increase genetic diversity. One of the oil palm germplasm collections maintained by the Indonesian Oil Palm Research Institute (IOPRI) was introduced from Cameroon in 2008. Cameroon is one of the central origins of oil palm (*Elaeis guineensis* Jacq.) in Africa (Sarimana *et al.*, 2017), and introducing these accessions can enrich the existing genetic diversity.

Germplasm collections are essential resources in plant breeding, mainly when accessions are described based on critical traits (Sujadi *et al.*, 2019a). Therefore, selecting the best accession for future breeding programmes can be conducted through characterisation and evaluation based on these traits (Li-Hammed *et al.*, 2015). Classical methods, which focus on agronomic performance or phenotype, are still efficient for understanding differences between accessions (Santosa *et al.*, 2015). One of the morphological characterisations of oil palm is the inflorescence phase, known as phenology (Hernawati *et al.*, 2022), which can help determine the precocious genotypes (Sujadi *et al.*, 2019b). Trimanto *et al.* (2020) stated that phenology-related traits are particularly important as they relate to the initial stages of plant breeding. Therefore, studies on these traits, such as precocity, are valuable in germplasm collection breeding programmes.

Both genetic and environmental factors influence the phases of development and sex determination in oil palm inflorescence (Suresh *et al.*, 2021). However, Corley and Tinker (2015) reported that determining the flowering pattern on oil palms may require more work due to the

[1] Indonesian Oil Palm Research Institute,
Jl. Brigjend Katamso No. 51,
20158, Medan, North Sumatra, Indonesia.

* *Corresponding author e-mail: Triningsih271@gmail.com*

different phases and periods of male and female flowering. Previous studies described the influence of the environment on oil palm inflorescence development, such as temperature (Pradiko *et al.*, 2019), rainfall, soil water depth (Mubarok *et al.*, 2022) and length of irradiation (Legros *et al.*, 2009). The influence of genetics contributing to oil palm inflorescence has yet to be widely reported. Identifying oil palm genotypes with precocious traits in plant breeding supports yield improvement programmes (Maskromo *et al.*, 2017). So, studying the genetic role in inheriting precocity traits should be a high concern.

Genetic parameters, such as genotype, phenotype, environment, genotype by environment (G×E) interaction, genetic diversity coefficient and heritability must be estimated before improving the trait (Lubis *et al.*, 2014). Also, the population's genetic variability and trait inheritance pattern are responsible for the success of plant improvement (Adhikari *et al.*, 2018). Nevertheless, the information on genetic parameters based on phenology-related traits is still limited. Therefore, this study aims to evaluate the genetic variability and population structure of oil palm based on the inflorescence phases of Cameroon accession.

MATERIALS AND METHODS

Planting Materials

The open-pollinated palms collected from seven sites (Nkong Biyen, Maloundou, Ballong I, Fapdolop, Bamese, Efok and Kola) in Cameroon. These palms were from IOPRI collection labelled as CMR and was planted in the AD13S trial in 2010. The experiment was conducted at Adolina Estate, PT. Perkebunan Nusantara IV, Serdang Bedagai, North Sumatra, Indonesia. The climatic conditions at the study site included (1) temperature was around 25°C-28°C with an average of 27°C; (2) annual rainfall ranging from 1,718-2,130 mm/yr; (3) average daily humidity ranged at 75.0%-89.0%; and (4) average solar radiation at 15.6 MJ/m^2/day.

Data Collection

The phenology of inflorescence phases was recorded from January 2017 to June 2023. The duration of the phenological phase, starting from the opening of leaves to fruit development, was recorded for each leaf frond every 10 days based on the scale of *Biologische Bundesantalt Bundessortenamt und Chemische Industrie* (BBCH) (Moreno & Romero, 2015). The number of leaf fronds recorded as replication in this study. The number of inflorescences was calculated as the sex ratio (ISR) defined as the ratio of female flower (FF) to total inflorescences (Adam *et al.*, 2011). The description of the observed traits in this study is presented in *Table 1*.

TABLE 1. INFLORESCENCE AND RELATED TRAITS DESCRIPTION IN THIS STUDY

BBCH code	Description
Female flowering	
159	Spear leaf 70.0% open
501	Emergence of 10.0% of the floral structure
601	Female pre-anthesis 1: The rachillae are tight toward the centre
607	Female anthesis: Opening of the stigma lobes
807	Fruit ripens
Male flowering	
159	Spear leaf 70.0% open
501	Emergence of 10.0% of the floral structure
601	Pre-anthesis
607	Anthesis
609	End of flowering
Flower production	
	Female flower
	Male flower
	Hermaphrodite
	Sex ratio

Statistical Methods

The mixed linear model used in this study based on Henderson (1985) is as Equation (1):

$$y = X\beta + Z_a + e \quad (1)$$

where y is the vector of observed traits, X is the design matrix of observed fixed effects, β is the vector of experimental effects (fixed effects), Z is the design matrix of observed random effects, a is the vector of accession palm effects (random effects), and e is the vector of residual effects.

Analysis of variance was conducted to part the source of variation following the model by Swaray *et al.* (2021). The analysis of variance is presented in *Table 2* and for the differences between treatments, the Duncan test (P<0.01 and P<0.05) was conducted using RStudio version 1.3-6.0 with the agricolae package (De Mendiburu, 2019).

The components of variances were estimated to determine the genetic variation, heritability and genotypic coefficients of variation among accession on phenology-related traits. Broad-sense heritability (h^2b) [Equation (4)] is described as the proportion of the genotypic (σ^2g) to the phenotypic variance (σ^2p) estimated using the formula given by Hanson *et al.* (1956). Johnson *et al.* (1955) categorised the broad-sense heritability (%) as low (<30%), moderate (30%-60%) and high (>60%). The genotypic

coefficients of variation (GCV) were estimated from the following Equation (5) by Burton (1952), where a trait has a wide genotypic variability if the genotypic coefficient of variation (GCV) value is >20%, moderate 10%-20%, and low 0%-10% (Sivasubramaniam & Madhava Menon, 1973). The genetic variation is analysed by Restricted Maximum Likelihood (REML) using program RStudio version 4.3.1 lme4 package [Equation (2)]. PBSTAT-CL (https://apps.pbstat.com) is used for cluster analysis.

$$\text{Genetic variance } (\sigma^2 g) = \frac{(MSG\text{-}MSE)}{ng} \quad (2)$$

$$\text{Error variance } (\sigma^2 g) = MSE \quad (3)$$

$$\text{Broad sense heritability } (h^2 b) = \frac{(\sigma^2 g)}{(\sigma^2 p)} \times 100 \quad (4)$$

$$GCV = \frac{\sqrt{\sigma^2 g}}{X} \times 100 \quad (5)$$

where, X is general mean for the characters.

RESULTS AND DISCUSSION

Performance of Inflorescence Phases

Analysis of variance shows highly significant differences among Cameroon accessions at each phase of female and male inflorescence (*Table 3*). The differences among the accessions also indicated a high genetic diversity in these populations (Maskromo *et al.*, 2017). Also, genetic diversity positively contributed to increasing the genetic base in oil palm populations for future oil palm breeding programmes (Swaray *et al.*, 2021).

The female inflorescence period of 20 Cameroon accessions is presented in *Table 4*. The results show significant differences at 1.0% and 5.0% levels based on Duncan's multiple range test (DMRT). The period from the first leaf to visible inflorescence in the axil (BBCH 159-501) ranges from 266-362 days, with an average of about 315 days. Accession CMR075/24-14 has the shortest duration and significantly differed from the others, while CMR001/35-14 has the longest time. This result indicates a longer duration when compared to previous studies on other cultivars, such as Golden Hope (238 days), Dami (250 days), United

TABLE 2. ANALYSIS OF VARIANCE AND EXPECTED MEAN SQUARES OF OIL PALM PHENOLOGY TRAITS

Source of variation	Degree of freedom	Mean square	Expected mean square
Accession (g)	(g-1)	MSG	$\sigma^2_e + n\sigma^2_r + nr\sigma^2_g$
Replication (r)	(r-1)	MSR	$\sigma^2_e + n\sigma^2_g + nr\sigma^2_r$
Error (e)	(r-1) (g-1)	MSE	σ^2_e

Note: n - harmonic mean destined for accession palms/ replicate; MSG - mean square of genotype; MSR - mean square of replicate; MSE - mean square of error; σ^2_g - genotypic variance; σ^2_e - environmental variance; σ^2_r - replication variance.

TABLE 3. ANALYSIS OF VARIANCE OF CAMEROON ACCESSION FOR FEMALE AND INFLORESCENCE DURATION (DAY)

Characters	MSG	MSR	MSE	CV (%)
Female inflorescence stage				
159-501	38,922.8**	150,911.9**	3,257.9	18.1
501-601	1.1**	1.5**	412.2	48.7
601-607	45.2*	73.4**	26.0	40.4
607-807	34.6**	135.1**	5.8	31.5
159-807	61.3**	118.1**	3.5	9.6
Male inflorescence stage				
159-501	57,465.0**	40,295.7**	6,572.5	28.2
501-601	1,296.9**	458.3^{ns}	443.0	53.1
601-607	68.0**	27.9^{ns}	24.5	38.8
607-609	15.2**	3.2^{ns}	5.9	22.2
159-609	46,714.1**	33,659.0**	6,794.2	24.2

Note: **- significant at α = 1%; *- significant at α = 5%; MSE - mean squares of environment; MSG - mean squares of genotype; MSR - mean squares of replicate; (159-501) - duration from spear leaf 70% open to inflorescence visible in axil; (501-601) - duration from inflorescence visible in axil to pre-anthesis; (601-607) - duration from pre-anthesis to anthesis; (607-807) - duration from anthesis to ripening of fruit; (159-807) - duration from Spear leaf 70.0% open to ripening of fruit; (607-609) - duration from anthesis to end of flowering; (159-607) - duration from Spear leaf 70.0% open to anthesis; CV - coefficient of variation.

Plantations (218 days) and Guthrie (242 days) (Forero *et al.*, 2012), as well as on the commercial plant DxP Simalungun (227 days) (Pradiko *et al.*, 2019). Cameroon accessions in this study are categorised as non-precocious genotypes.

In the inflorescence phase, from visible in axil to pre-anthesis (BBCH 501-601), the development of FF requires 42 days. Accession CMR102/33-16 has the shortest duration and was not significantly different from the other 14 accessions. The average duration range from pre-anthesis to anthesis (BBCH 601-607) is about 13 days. CMR075/24-14, which shows the shortest duration in the first leaf appearance, also shows the shortest duration in the anthesis phase at 11 days. These results show a shorter duration compared to the flowering of 8 varieties belonging to the IOPRI reported by Pradiko *et al.* (2019) on the duration from visible in axil to pre-anthesis (55-100 days) and from pre-anthesis to anthesis (12-20 days).

The required time from anthesis to ripening of fruit (BBCH 607-807) is 200-288 days, with an average of 243 days. Accession CMR075/24-14 has the shortest duration, followed by CMR023/25-16, CMR047/32-22, CMR073/30-11, CMR028/36-4, CMR103/34-23 and CMR102/36-21. Meanwhile, CMR075/28-19 and CMR074/32-14 has the longest time. In this phase, Cameroon accession palm shows longer duration compared to *Deli* x *Nigeria* (153-155 days) (Suresh *et al.*, 2021) and Angola accessions (144-174 days) (Sujadi *et al.*, 2017). The difference in duration from anthesis to fruit ripening is due to genetic and environmental factors. This phase involves complex biological processes from fruit formation and enlargement to oil synthesis in the kernel and mesocarp (Razali *et al.*, 2012). Arifin *et al.* (2014) added that the oil synthesis phase in oil palm fruit at 17 weeks after anthesis was influenced mainly by climate such as temperature and rainfall.

The total time of female inflorescence, from spear leaf 70% open to ripening of fruit (BBCH 159-807), takes about 613 days on average, with a range of duration between 522 and 668 days. Accession CMR075/24-14 has the shortest female inflorescence emergence period while CMR001/35-14 has the longest time. Female inflorescence has a longer period compared to previous studies, such as in the DxP Marihat took 444 days (Mubarok *et al.*, 2022), Angola accession (385-495 days) (Sujadi *et al.*, 2019a) and 8 IOPRI varieties (452-484 days) (Pradiko *et al.*, 2019). Comprehensive analyses with

TABLE 4. MEAN COMPARISON AND STANDARD ERROR (±) OF CAMEROON ACCESSION FOR FEMALE INFLORESCENCE DURATION

Accession	Female inflorescence stage				
	(159-501)	(501-601)	(601-607)	(607-807)	(159-807)
CMR001/29-16	$297.4^{f} \pm 7.5$	$42.4^{bcd} \pm 2.6$	$11.6^{bc} \pm 0.6$	$273.8^{abc} \pm 10.1$	$625.4^{cde} \pm 7.8$
CMR001/35-14	$362.3^{a} \pm 7.5$	$37.0^{cd} \pm 2.6$	$13.4^{abc} \pm 0.6$	$254.9^{b-e} \pm 10.1$	$667.8^{a} \pm 7.8$
CMR023/25-16	$313.1^{c-f} \pm 7.5$	$44.5^{abc} \pm 2.6$	$11.7^{bc} \pm 0.6$	$212.8^{fg} \pm 10.1$	$582.2^{fgh} \pm 7.8$
CMR023/26-14	$337.4^{bc} \pm 7.4$	$40.2^{bcd} \pm 2.6$	$13.3^{abc} \pm 0.6$	$238.3^{def} \pm 10.0$	$629.4^{bcd} \pm 7.7$
CMR028/31-18	$332.0^{bcd} \pm 7.6$	$40.1^{bcd} \pm 2.7$	$12.0^{bc} \pm 0.6$	$237.0^{def} \pm 10.3$	$621.2^{cde} \pm 7.9$
CMR028/36-04	$324.9^{b-e} \pm 8.1$	$37.8^{bcd} \pm 2.9$	$14.4^{a} \pm 0.7$	$226.8^{d-g} \pm 10.9$	$604.1^{d-g} \pm 8.4$
CMR032/30-24	$292.2^{f} \pm 8.2$	$38.0^{bcd} \pm 2.9$	$12.2^{abc} \pm 0.7$	$244.6^{c-f} \pm 11.0$	$587.1^{fgh} \pm 8.5$
CMR032/33-27	$296.6^{f} \pm 7.9$	$40.4^{bcd} \pm 2.8$	$12.2^{abc} \pm 0.7$	$246.4^{c-f} \pm 10.7$	$595.7^{fgh} \pm 8.2$
CMR047/27-26	$316.9^{b-f} \pm 7.1$	$52.5^{a} \pm 2.5$	$11.8^{bc} \pm 0.6$	$255.5^{b-e} \pm 9.7$	$636.8^{bc} \pm 7.4$
CMR047/32-22	$330.5^{bcd} \pm 8.3$	$42.2^{bcd} \pm 2.9$	$11.7^{bc} \pm 0.7$	$217.1^{fg} \pm 11.2$	$601.7^{e-h} \pm 8.6$
CMR073/30-11	$301.9^{ef} \pm 7.0$	$42.1^{bcd} \pm 2.4$	$12.3^{abc} \pm 0.6$	$221.0^{efg} \pm 9.4$	$577.5^{h} \pm 7.2$
CMR073/35-09	$325.0^{b-e} \pm 7.9$	$38.6^{bcd} \pm 2.8$	$12.3^{abc} \pm 0.7$	$257.7^{a-d} \pm 10.7$	$633.8^{bc} \pm 8.2$
CMR074/28-14	$339.4^{b} \pm 7.9$	$46.5^{ab} \pm 2.8$	$13.8^{ab} \pm 0.7$	$253.4^{b-e} \pm 10.6$	$653.2^{ab} \pm 8.2$
CMR074/32-14	$303.1^{ef} \pm 7.3$	$37.9^{bcd} \pm 2.6$	$13.4^{abc} \pm 0.6$	$288.2^{a} \pm 9.9$	$642.6^{bc} \pm 7.6$
CMR075/24-14	$266.9^{g} \pm 7.9$	$43.9^{abc} \pm 2.8$	$11.1^{c} \pm 0.7$	$200.4^{g} \pm 10.6$	$522.5^{i} \pm 8.2$
CMR075/28-19	$301.2^{ef} \pm 7.8$	$45.0^{abc} \pm 2.7$	$14.0^{ab} \pm 0.7$	$281.5^{ab} \pm 10.5$	$641.8^{bc} \pm 8.1$
CMR102/33-16	$323.5^{b-e} \pm 7.8$	$34.0^{d} \pm 2.7$	$13.3^{abc} \pm 0.7$	$253.6^{b-e} \pm 10.5$	$624.6^{cde} \pm 8.1$
CMR102/36-21	$340.2^{b} \pm 8.0$	$40.9^{bcd} \pm 2.8$	$12.0^{bc} \pm 0.7$	$232.1^{d-g} \pm 10.8$	$625.3^{cde} \pm 8.3$
CMR103/34-23	$293.5^{f} \pm 7.3$	$44.8^{abc} \pm 2.5$	$12.2^{abc} \pm 0.6$	$229.5^{d-g} \pm 9.8$	$580.2^{gh} \pm 7.5$
CMR103/36-14	$311.2^{def} \pm 7.8$	$41.6^{bcd} \pm 2.7$	$13.1^{abc} \pm 0.7$	$240.8^{c-f} \pm 10.5$	$606.8^{def} \pm 8.1$
Mean ± SE	315.5 ± 7.7	41.6 ± 2.8	12.6 ± 0.7	243.3 ± 10.4	613.0 ± 8.0

Note: (159-501) - duration from spear leaf 70% open to inflorescence visible in axil; (501-601) - duration from inflorescence visible in axil to pre-anthesis; 601-607 - duration from pre-anthesis to anthesis; (607-807) - duration from anthesis to ripening of fruit; (159-807) - duration from spear leaf 70% open to ripening of fruit; Means with the same letters of the alphabet within the same column are not significantly dissimilar at $p<0.05$ with Duncan's new multiple range test (DNMRT); SE - standard error.

weather data need to be conducted to determine how weather factors influence the length of the inflorescence phase. However, for selection options on phenology characters, CMR075/24-14 can be selected as a precocious accession when compared to the other accessions and can prioritised in selection programmes aimed at enhancing early maturity.

Table 5 displays the male inflorescence period of 20 accessions. The duration ranges from 239-370 days for BBCH 159 to BBCH 501, with an average duration of about 290 days. Accession CMR023/25-16 has the shortest duration at 239 days. During the inflorescence phase, from visible in axil to pre-anthesis (BBCH 501-601), the development of male flowers (MF) requires 39 days and CMR001/29-16 has the shortest time. As seen in the previous female inflorescence results, the timing of MF and FF is different. Because of their different morphologies, the male and female inflorescences have different phase times (Yaakub *et al.*, 2023). Corley and Tinker (2015) found that the male inflorescence rachis bears 100 and 300 spikelets, with each spikelet containing 400-1,500 flowers. Conversely, the female inflorescence comprises around 150 rachillas, each containing between five and 30 flowers.

The average time from pre-anthesis to anthesis (BBCH 601-607) was approximately 13 days, with accession CMR074/28-14 having the shortest duration. The phase from anthesis to the end of flowering (BBCH 607-609) had an average duration of 11 days across all Cameroon accessions. Accession CMR023/25-16 shows the shortest time, around 9 days, which is not significantly different from the other 12 accessions. The Cameroon accessions needed slightly longer time as Mubarok *et al.* (2022) found that the timeframe from anthesis to the conclusion of flowering was about eight days.

The phase duration from spear leaf 70.0% open to fruit ripening varied between and within individual accessions, as presented in *Figure 1*. There is high variability between 20 accessions, although some are from the exact origin, *i.e.* Accession CMR075/24-14 with CMR073/30-11, CMR075/28-19 and CMR074/32-14. The variability is also found within individual accession palms, as indicated by the extensive range of short and longer inflorescence phases. This variation is due to the Cameroon accessions derived from open-pollinated crosses, which account for the high genetic variability among individual palms. The result of this study is in line with those of

TABLE 5. MEAN COMPARISON AND STANDARD ERROR (±) OF CAMEROON ACCESSION FOR MALE INFLORESCENCE STAGE

Accession	Male inflorescence stage				
	(159-501)	(501-601)	(601-607)	(607-609)	(159-609)
CMR001/29-16	$370.3^{a} \pm 19.6$	$31.0^{c} \pm 5.1$	$11.2^{cd} \pm 1.2$	$13.4^{a} \pm 0.5$	$412.6^{a} \pm 19.9$
CMR001/35-14	$264.1^{cde} \pm 13.9$	$53.4^{a} \pm 3.6$	$15.2^{ab} \pm 0.8$	$10.6^{cde} \pm 0.4$	$332.7^{b-e} \pm 14.1$
CMR023/25-16	$239.2^{e} \pm 27.0$	$41.4^{abc} \pm 7.0$	$11.7^{bcd} \pm 1.6$	$9.2^{e} \pm 0.8$	$292.4^{e} \pm 27.4$
CMR023/26-14	$276.3^{b-e} \pm 15.3$	$41.1^{abc} \pm 3.9$	$12.7^{bcd} \pm 0.9$	$11.4^{bcd} \pm 0.4$	$330.2^{b-e} \pm 15.5$
CMR028/31-18	$330.7^{ab} \pm 21.6$	$33.1^{c} \pm 5.6$	$13.5^{a-d} \pm 1.3$	$10.2^{cde} \pm 0.6$	$377.4^{ab} \pm 22.0$
CMR028/36-04	$248.0^{e} \pm 13.3$	$42.3^{abc} \pm 3.4$	$14.0^{a-d} \pm 0.8$	$10.6^{cde} \pm 0.4$	$304.4^{de} \pm 13.5$
CMR032/30-24	$254.7^{e} \pm 17.2$	$40.1^{abc} \pm 4.4$	$13.1^{a-d} \pm 1.0$	$11.1^{bcd} \pm 0.5$	$308.0^{cde} \pm 17.5$
CMR032/33-27	$291.2^{b-e} \pm 18.1$	$38.6^{abc} \pm 4.7$	$13.3^{a-d} \pm 1.1$	$11.1^{bcd} \pm 0.5$	$343.1^{b-e} \pm 18.4$
CMR047/27-26	$299.8^{b-e} \pm 20.2$	$52.5^{ab} \pm 5.2$	$11.5^{bcd} \pm 1.2$	$10.7^{cde} \pm 0.6$	$363.8^{a-d} \pm 20.6$
CMR047/32-22	$290.3^{b-e} \pm 21.6$	$37.5^{bc} \pm 5.6$	$16.7^{a} \pm 1.3$	$11.5^{bcd} \pm 0.6$	$344.5^{b-e} \pm 22.0$
CMR073/30-11	$322.8^{abc} \pm 19.1$	$33.9^{c} \pm 4.9$	$12.5^{bcd} \pm 1.1$	$10.8^{cde} \pm 0.5$	$369.3^{abc} \pm 19.4$
CMR073/35-09	$272.5^{b-e} \pm 17.2$	$32.2^{c} \pm 4.4$	$13.0^{bcd} \pm 1.0$	$12.7^{ab} \pm 0.5$	$317.8^{b-e} \pm 17.5$
CMR074/28-14	$316.8^{a-d} \pm 17.6$	$39.7^{abc} \pm 4.5$	$10.4^{d} \pm 1.0$	$10.9^{cde} \pm 0.5$	$367.0^{abc} \pm 17.9$
CMR074/32-14	$324.4^{abc} \pm 17.6$	$33.3^{c} \pm 4.5$	$11.1^{cd} \pm 1.0$	$12.0^{abc} \pm 0.5$	$369.0^{abc} \pm 17.9$
CMR075/24-14	$297.9^{b-e} \pm 10.0$	$36.5^{c} \pm 2.5$	$10.6^{d} \pm 0.6$	$10.5^{cde} \pm 0.3$	$345.0^{b-e} \pm 10.1$
CMR075/28-19	$291.2^{b-e} \pm 15.6$	$53.1^{ab} \pm 4.0$	$12.5^{bcd} \pm 0.9$	$11.0^{b-e} \pm 0.4$	$356.8^{a-d} \pm 15.8$
CMR102/33-16	$256.5^{de} \pm 15.3$	$37.6^{bc} \pm 3.9$	$14.6^{abc} \pm 0.9$	$10.6^{cde} \pm 0.4$	$308.7^{cde} \pm 15.5$
CMR102/36-21	$268.9^{cde} \pm 17.6$	$35.3^{c} \pm 4.5$	$13.9^{a-d} \pm 1.0$	$10.1^{de} \pm 0.5$	$318.1^{b-e} \pm 17.9$
CMR103/34-23	$257.0^{de} \pm 19.1$	$38.0^{abc} \pm 4.9$	$12.9^{bcd} \pm 1.1$	$10.6^{cde} \pm 0.5$	$308.0^{cde} \pm 19.4$
CMR103/36-14	$325.1^{abc} \pm 18.1$	$32.2^{c} \pm 4.7$	$12.0^{bcd} \pm 1.1$	$11.3^{bcd} \pm 0.5$	$369.4^{abc} \pm 18.4$
Mean ± SE	289.9 ± 17.8	39.2 ± 4.6	12.9 ± 1.1	11.1 ± 0.5	342.0 ± 18.1

Note: (159-501) - duration from spear leaf 70.0% open to inflorescence visible in axil; (501-601) - duration from inflorescence visible in axil to pre-anthesis; 601-607 - duration from pre-anthesis to anthesis; (607-609) - duration from anthesis to end of flowering; (159-607) - duration from spear leaf 70.0% open to anthesis; Means with the same letters of the alphabet within the same column are not significantly dissimilar at $p<0.05$ with Duncan's new multiple range test (DNMRT); SE - standard error.

Sarimana *et al.* (2017), which shows that about 26.0% of genetic variability between individuals and 74.0% within individuals derived from open pollination.

Genetic Performances of Inflorescence Phase

Variance components can be partitioned into phenotype, environment and genotype variances to obtain information on genetic variability (Lubis *et al.*, 2014). Based on the variance components shown in *Table 6*, the environmental factors dominate all phases of oil palm inflorescence as indicated by the low broad-sense heritability values (<30.0%). The lowest heritability is found in BBCH 501-601 (3.1%) and BBCH 601-607 (1.3%). Meanwhile, the highest heritability is achieved in MF of BBCH 159-501 (29.3%). Considering the high influence of environmental effects, selection based on related traits will not be effective (Devesh *et al.*, 2018). These results also in line with Paterson *et al.* (2015), who stated that oil palm phenology was related to climatic factors affecting each inflorescence phase. Climate factors that affect oil palm phenology have been reported, such as rainfall (Mubarok *et al.*, 2022), growth degree days (Pradiko *et al.*, 2019), length of irradiation and drought (Legros *et al.*, 2009). A previous Pradiko *et al.* (2019) study reported that in the temperature range of 23ºC-34ºC, three varieties (DxP AVROS, DxP Dumpy and DxP PPKS 540) had shorter inflorescence.

Based on these criteria, the GCV value of Cameroon accessions in all female flowering phases was low (5.0%-9.5%), while the male flowering generally exhibited a moderate GCV. The results indicated that inflorescence in the 20 Cameroon accessions tested was more strongly influenced by the environment, especially in female flowering. A high genetic variability is required to improve or enhance the performance of these traits. Agronomic field improvements, such as selecting oil palm varieties based on suitable climatic conditions or implementing water management systems, were recommended to reduce the duration of inflorescence development. According to Sujadi *et al.* (2020), the Lame, Langkat, PPKS 540, and Simalungun varieties, which have longer fruit development phases, were predicted to be better suited for regions with low rainfall. Conversely, varieties with shorter fruit development phases, such as Dumpy, AVROS and PPKS 540, were expected to adapt more readily to rising air temperatures. Suharyanti *et al.* (2020) reported that water shortage affects inflorescence period, especially in the sex determination phase, so drought mitigation could have been pursued through proper water management. Therefore, it is imperative to conduct further research on the other genotypes/varieties to compare with this research and reassess at the phenology of these accessions under varying climatic conditions to gain deeper insight into environmental effects.

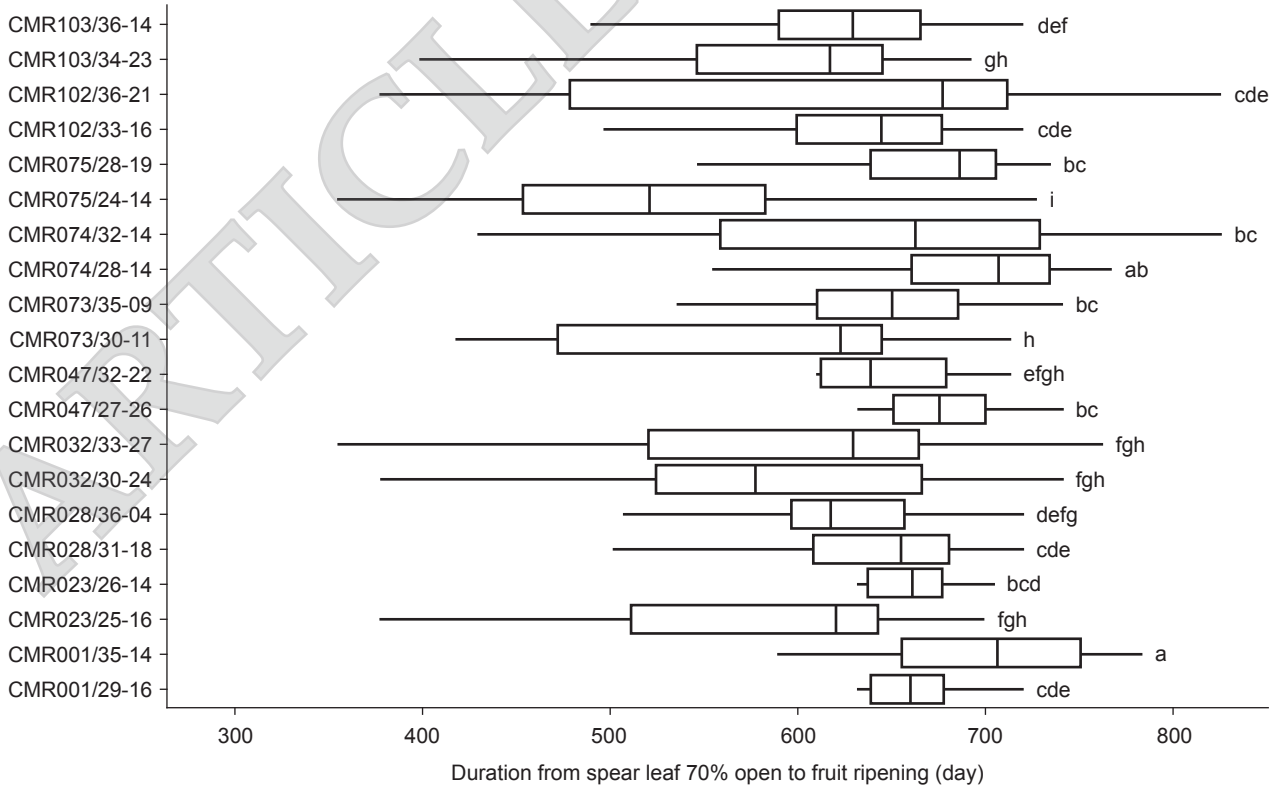

Figure 1. Box plot duration from spear leaf 70% open to the ripening of the fruit of 20 Cameroon accession palms. The same letters of the alphabet on the graph are not significantly dissimilar at $p<0.05$ *with Duncan's multiple range test (DMRT).*

Performances of Female, Male Production and Sex Ratio

Analysis of variance among the 20 Cameroon accessions showed highly significant differences in MF, FF, hermaphrodite (HF) and ISR (*Table 7*). The results also showed significant differences among replication on all traits, indicating that accession performance was inconsistent. Corley and Tinker (2015) reported that the sexual phase pattern of oil palm is complex and cannot be determined due to the different phases and timing of male and female inflorescence, depending on environmental factors.

This study found that environmental effects highly influence FF, MF, HF and ISR traits. It was known from the low heritability value of the four traits (<30.0%), indicating that environmental effects play a more significant role in controlling these traits. This result was also in line with Swaray *et al.* (2020), who reported that the production of MF, FF and aborted flowers was more influenced by the environment, with a percentage of the environmental variance of more than 60% in 24 progeny-test experiments. Abdullah *et al.* (2017) reported that climatic factors, such as water availability and length of irradiation for MF and FF production, respectively, influence the sex differentiation of oil palms. This finding is also supported by Harahap and Lubis (2018), who stated that water dynamics affect the phases of oil palm flowering development in the formation of flower parts, sex differentiation, flower emergence and fruit ripening.

The performance of 20 Cameroon accessions on FF, MF, HF and ISR traits is shown in *Figure 2*. The results show MF production ranges from 2 and 13 (12.0%-59.0%) flowers/palm/yr. Accession CMR075/24-14 has the highest MF production. Meanwhile, ISR ranges from 41.0%-88.0%, with an average of 64.0%. Over half (55.0%) of the 20 accessions palm shows an ISR of over 60.0%. Accessions CMR023/25-16 and CMR073/30-11 has the highest ISR, 88.0% and 80.0% respectively. It indicates that the ISR of the observed Cameroon accessions is still within a reasonable range. The optimal ISR was considered to be between 70.0% and 80.0%, as reported by Swaray *et al.* (2021). In line with a study by Sitepu *et al.* (2021), ISR in six PPKS varieties of eight years old palms ranged from 53.2% and 73.0%, indicating a sufficient availability of pollen for pollination.

TABLE 6. VARIANCE COMPONENT, HERITABILITY AND GENOTYPIC COEFFICIENT OF VARIATIONS FOR FEMALE AND MALE INFLORESCENE

Description	σ^2g	σ^2e	σ^2p	h^2b (%)	GCV (%)
Female flowering phases					
159-501 Spear leaf 70.0% open to inflorescence visible in axil	665.4	3,258.0	3,923.4	17.0	8.2
501-601 Inflorescence visible in axil to pre-anthesis	12.9	412.1	425.1	3.1	8.6
601-607 Pre-anthesis to anthesis	0.4	25.9	26.3	1.3	5.0
607-807 Anthesis to ripening of fruit	539.3	5,885.4	6,424.7	8.4	9.5
159-807 Spear leaf 70.0% open to ripening of fruit	1,053.0	3,498.0	4,551.0	23.1	5.3
Male flowering phases					
159-501 Spear leaf 70% open to inflorescence visible in axil	2,723.0	6,576.0	9,299.0	29.3	18.0
501-601 Inflorescence visible in axil to pre-anthesis	40.4	442.8	483.2	8.4	16.2
601-607 Pre-anthesis to anthesis	1.9	24.5	26.5	7.4	10.9
607-609 Anthesis to end of flowering	0.5	6.0	6.5	7.1	6.1
159-607 Spear leaf 70.0% open to anthesis	2,129.0	6,799.0	8,928.0	23.8	13.5

Note: σ^2g - genotypic variance; σ^2e - error variance; σ^2p - phenotypic variance; h^2b - broad-sense heritability; GCV - genotypic coefficient of variation.

TABLE 7. ANALYSIS OF VARIANCE AND GENETIC COMPONENTS FOR INFLORESCENE PRODUCTION TRAIT AND SEX RATIO

Trait	Mean ± SE	MSG	MSR	MSE	σ^2g	σ^2e	σ^2p	h^2b (%)
FF	13.0 ± 0.3	714.1**	183.2**	14.5	3.2	14.5	17.7	18.4
MF	7.4 ± 0.3	1,975.8**	89.8**	21.5	9.3	21.5	30.8	30.3
HF	0.2 ± 0.1	8.7**	2.5**	0.5	0.1	0.5	0.6	6.5
ISR	64.2 ± 2.8	289.5	61.3	3.3	1.3	3.5	4.6	29.2

Note: MF - male flower; FF - female flower; HF - hermaphrodite; ISR - sex ratio; MSG - mean square genotype; MSR - mean square replicate; MSE - mean square error; σ^2_g - genotypic variance; σ^2_e - error variance; σ^2_p - phenotypic variance; h^2b - broad sense heritability.

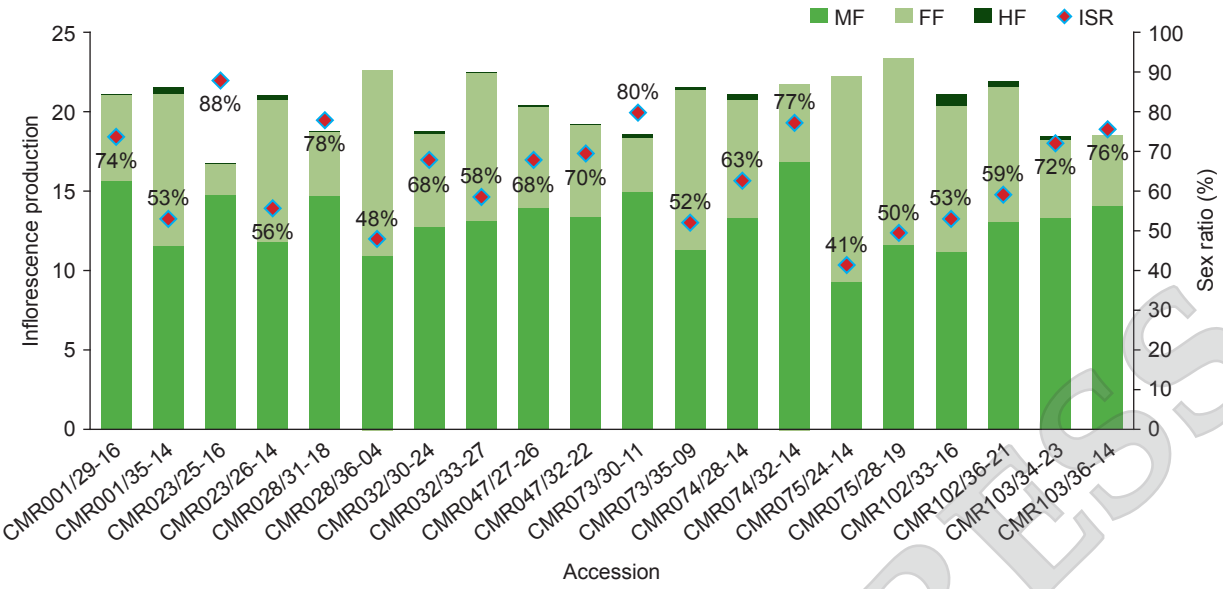

Figure 2. Performance of 20 Cameroon accession palms for female flower (FF), male flower (MF), hermaphrodite (HF) and sex ratio (ISR).

Genetic Distance Analysis on Flowering Phases and Flower Production Traits

Genetic distance and genetic variability analysis are the methods to understand the genetic characteristics of oil palm (Faizah *et al.*, 2016). In this study, the evaluation of genotypic variability based on phenological traits was carried out through cluster analysis using Ward's coefficient and Gower's method. The results divided the twenty accessions from Cameroon into two main groups (*Figure 3*). Group 1 (green colour) comprises nine accessions that has a longer period of inflorescence except for CMR028/36-4 with a similarity of 13.0%-47.0%. The accessions in Group 2 (red colour) displays a relatively shorter period of inflorescence with a genetic similarity level of 10.0%-53.0%. The results of this study differ from a study conducted by (Sujadi *et al.*, 2019b) on the same accessions using morphological traits, where the genetic distance was divided into three main groups with a degree of dissimilarity of 19.0%. Cluster analysis using molecular markers on Cameroon accessions (with different numbers of accessions) was also reported in several studies, with the results of genetic similarity ranging from 52.0%-87.0% (Tasma & Arumsari, 2013) and 42.5%-67.5% (Santosa *et al.*, 2015). Information related to group analysis based on the inflorescence phase characteristics of oil palm is still limited. Therefore, the findings of this study provide a significant contribution to further understanding the genetic variability of oil palm, particularly in the context of the inflorescence phase.

Based on cluster analysis, it is known that accessions from different origins show neighbourhoods to other accessions (*Figure 3*). In both Group 1 and Group 2, accessions from different origins are represented, indicating that the same accession is not consistently assigned to a single group. In line with a study by Salim *et al.* (2023), Cameroon accessions palm clustering pattern differed based on geographical location, as populations from different locations are randomly distributed. Although the accessions have the same origin palm number, the accession palm are derived from different seeds, so they are assumed to be non-identical. It can be caused by the high level of genetic exchange through seed dispersal (Arias *et al.*, 2013). Santosa *et al.* (2015) added the possibility that pollen carried by wind or insects comes from different palm, so they have different genomic structures. Therefore, the consideration of genotype selection with precocious characters should be based on individual palm among Cameroon accessions.

CONCLUSION

This study on genetic variability and distance analysis provides valuable insights into the genetic characteristics of oil palm accessions from Cameroon, particularly concerning phenological traits. The study indicated that Cameroon accessions are not precocious genotypes. Early developmental stages and fruit ripening suggest strong environmental influences, while genetic effects at specific stages indicate substantial diversity among accessions. However, there are traits with high h^2b and GCV in the early stage of inflorescence that show strong genetic control and variability, making them ideal for selection. Agronomic field improvement is recommended to

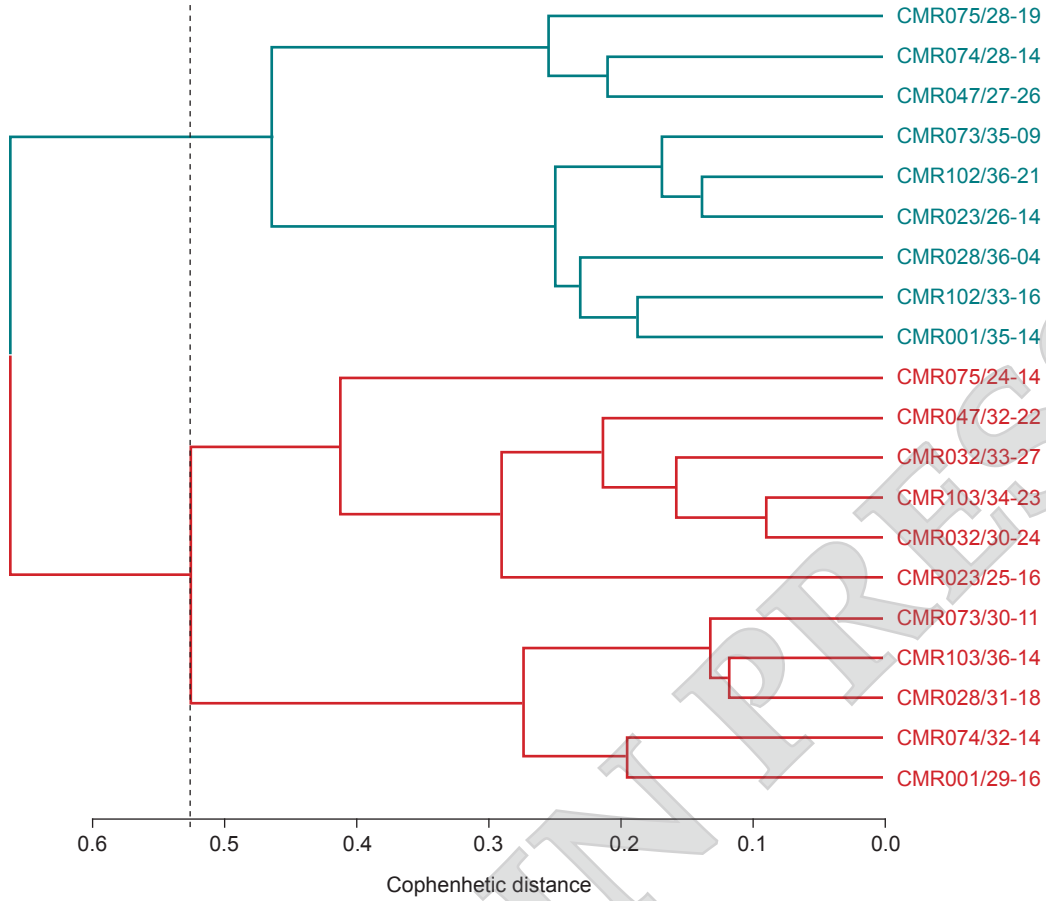

Figure 3. Genetic distance between 20 Cameroon accession palms according to Ward's coefficient.

improve the performance of these traits. Therefore, it is necessary to carry out further research on the other genotypes to compare with this research and investigate the phenology of these accessions on different climates conditions is essential to assess environmental impacts.

ACKNOWLEDGEMENT

The author wishes thank to the Indonesian Oil Palm Research Institute (IOPRI) for funding this research. We also thank all parties in helping to prepare the article.

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