

Phenotypic diversity and characterization of several avocado (*Persea americana*) germplasm grown in Subang, West Java, Indonesia

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Abstract. Fitri DR, Susanto S, Lukman L, Sukmana D. 2026. Phenotypic diversity and characterization of several avocado (*Persea americana*) germplasm grown in Subang, West Java, Indonesia. *Biodiversitas* 27 (4): d270430. <https://doi.org/10.13057/biodiv/d270430>. Avocado (*Persea americana*) exhibits broad morphological and phenological variation that supports germplasm characterization and the evaluation of phenotypic diversity for cultivar development. This study compared the morphological, phenological, yield, and fruit-quality characteristics of three Lampung avocado accessions (Lampung 1, Lampung 2, and Lampung 3) with the commercial cultivar Miki (Cipedak) under relatively uniform environmental conditions in Subang, West Java. Observations included vegetative growth, flowering and harvesting periods, leaf morphology, reproductive traits, fruit physical characteristics, productivity, edible portion, and biochemical traits (fat and sugar contents). Data were analyzed using analysis of variance followed by Tukey's HSD test to determine significant differences among accessions. The results showed significant variations among accessions, particularly in leaf size and area, fruit set, fruit size and weight, edible portion, fat and sugar contents. The fruit of Lampung 1 was 56% heavier than Miki, Lampung 2 showed comparable fruit weight, and Lampung 3 produced smaller fruits. Lampung 1 and Lampung 2 exhibited a 14% higher edible portion compared to Miki. Differences were also observed in fruit productivity, with Lampung 1 producing the highest yield at 7.13 kg per plant, while Lampung 3 had the lowest. Variations in sugar and fat contents were observed among accessions. Lampung 2 showed higher fat content, Lampung 1 had comparable fat content to Miki, while Lampung 3 exhibited higher fat and sugar contents. The relatively higher fat content observed in certain accessions indicates their potential for further evaluation for value-added utilization. Overall, Lampung 1 and Lampung 2 demonstrate better yield and fruit quality traits. However, as this study was conducted at a single location and during one growing season, multi-location and multi-season evaluations are required to confirm yield stability, adaptability, and further potential utilization.

Keywords: Edible portion, fat content, flowering period, fruit set, shoot growth

INTRODUCTION

Avocado (*Persea americana*) is a valuable horticultural crop recognized for its numerous benefits and market potential, and widely adapted in tropical and subtropical regions (Poudel et al. 2018; Yangaza et al. 2024). Avocados are rich in nutrients, including monounsaturated fatty acids, vitamins, phenolic compounds, and various bioactive compounds (Marra et al. 2024; Muhammad et al. 2024). These health benefits are present in all fruit parts, including the flesh, skin, and seed, contributing to its recognition as a "superfood" (Nguyen et al. 2021; Lyu et al. 2023).

In Indonesia, avocado is widely cultivated primarily due to its high economic value and adaptability to diverse agroclimatic conditions. Furthermore, one of the strengths of avocado is its genetic diversity, which is reflected in fruit shape, weight, seed size, flesh thickness, and nutritional content (Afzal et al. 2022; Ishaq et al. 2022; Sari et al. 2024). This genetic variability represents an important resource for cultivar improvement, conservation, and utilization of avocado germplasm. This variability is

essential for selecting potential traits to develop better cultivars. Lampung region is one of the sources of avocado germplasm, where several accessions may have unique traits that enhance genetic diversity and potential utilization. Therefore, the exploration and characterization of Lampung avocado accessions are valuable for supporting germplasm utilization and conservation.

National avocado production in Indonesia increased from 669,260 tons in 2021 to 874,046 tons in 2023, with East Java, Central Java, and West Java as major producers, while Lampung ranks eighth (BPS 2024). This trend highlights the role of avocado as a commercial crop and strongly supports its further development. However, most local accessions remain unregistered, with only 40 cultivars formally released as national cultivars as of 2024, including well-known cultivars such as Miki (Cipedak) (Direktorat Perbenihan Hortikultura 2024). Miki, a cultivar originating from South Jakarta and officially registered in 2015, is widely cultivated and recognized as one of the most popular cultivars, particularly in West Java.

The limited characterization of local germplasm highlights the need for underutilized accessions. In this context, this

study examines variations in plant traits among selected Lampung accessions relative to a commercial cultivar to support germplasm utilization. Understanding plant trait responses to environmental conditions provides critical insights into avocado growth and development (Ramírez-Gil et al. 2023). Lampung 1, Lampung 2, and Lampung 3 accessions were cultivated at PT Perkebunan Buah Subang alongside commercial cultivars, including Miki and other introduced varieties. Preliminary findings suggest that these accessions may complement commercial cultivars while showing good adaptability to the Subang environment. The site was selected for its diverse avocado cultivars, intensive management practices, and strategic role in supplying markets in Jakarta and West Java.

Phenophysiological studies examining the relationship between plant growth and environmental conditions are essential for cultivar development (Adelina et al. 2021). This can be achieved by analyzing phenological and morphological traits, fruit quality, and yield to guide accession selection (Nkosi et al. 2024; Sedlák et al. 2025). Such analyses are also fundamental for characterizing phenotypic variation and supporting conservation and sustainable utilization of plant genetic resources. However, information on the germplasm and phenotypic characteristics of Lampung avocado accessions remains limited, as these accessions have not yet been widely utilized or developed. In addition, previous studies in Indonesia and other tropical regions have generally focused on describing individual accessions without comparison to established cultivars.

Accordingly, this study examines Lampung avocado accessions in comparison with Miki cultivar under relatively uniform environmental conditions in Subang Regency. This study provides a comparative evaluation of Lampung accessions grown outside their origin, enabling clearer identification of trait differences and promising accessions for further evaluation and utilization. This study

also provides a foundation for multi-location trials to assess adaptability and performance across diverse agroecological conditions.

This study hypothesized that Lampung avocado accessions exhibit distinct phenological, morphological, yield, and fruit-quality traits compared with the Miki cultivar under uniform environmental conditions. Specifically, it further tested whether any accession shows higher productivity, edible portion, and biochemical quality (fat and sugar contents). Accordingly, the study addressed two questions: (i) how Lampung accessions differ from Miki in vegetative growth, phenology, and reproductive performance; and (ii) which Lampung accessions exhibit yield and fruit-quality traits supporting their potential development for further utilization?

MATERIALS AND METHODS

Study area and period

This study was conducted at PT Perkebunan Buah Subang, located in Kasomalang Sub-district, Subang District, West Java, Indonesia, from April 2024 to January 2025 (Figure 1). The research site is located at 6°42'28.76" South Latitude (S) and 107°44'27.44" East Longitude (E). Avocado plants at the study site area were approximately 50 ha in area and predominantly cultivated with various domestic and introduced avocado accessions. The area's altitude ranged from 443 to 713 meters above sea level (masl), with an average annual rainfall of 2.215 mm. Furthermore, the dry season typically occurs from May to August (BPS Subang District 2025). The average daily temperature and relative humidity recorded on site ranged from 23.3-27.3°C and 56-88%, respectively.

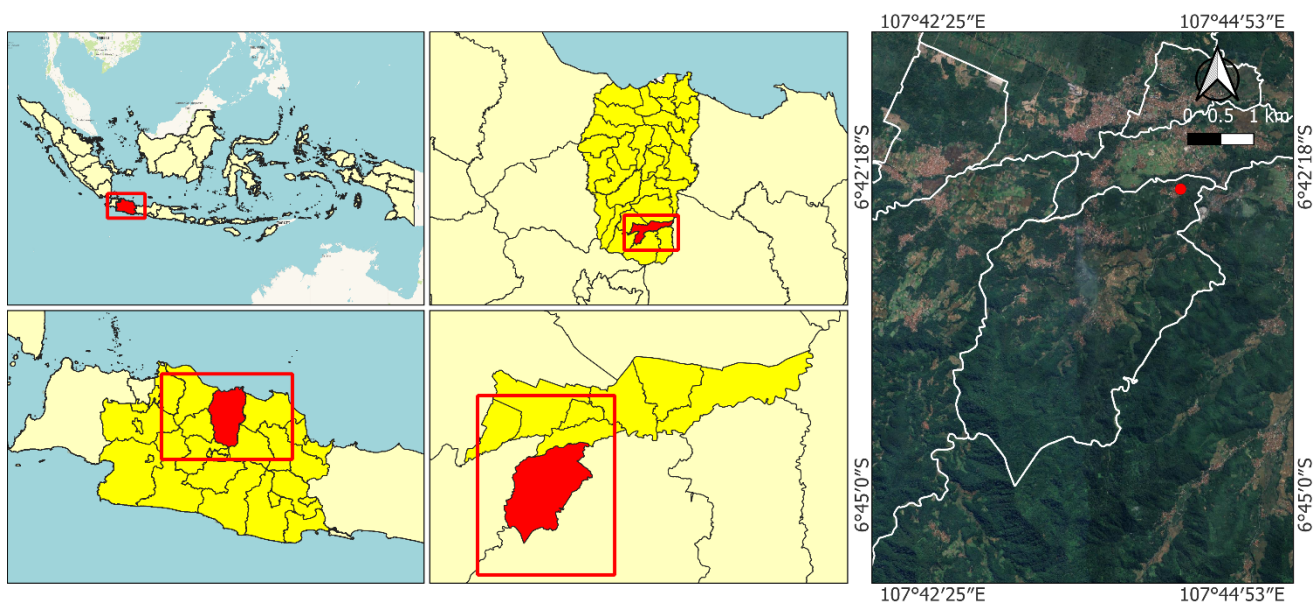


Figure 1. Research site at PT Perkebunan Buah Subang, Pasanggrahan Village, Kasomalang Sub-district, Subang District, West Java, Indonesia

Plant materials

The research materials consisted of four avocado accessions and one cultivar, namely three Lampung accessions (Lampung 1, Lampung 2, and Lampung 3) and the commercial Miki cultivar used for comparison. Miki is a popular cultivar that has been officially registered by the Indonesian Ministry of Agriculture since 2015. All plants were 3–4 years old, planted at a spacing of 5 m x 5 m, and were in the generative phase. Research samples were taken from four trees per accession, for a total of 16 trees. The number of plant samples was limited mainly due to the availability of Lampung 3 plants that had entered the generative phase, so the number of plants in other accessions was adjusted.

Plant maintenance

All avocado plants received consistent cultivation practices, including irrigation, fertilization, pest and disease management, and canopy pruning. Irrigation was performed using a drip system connected to a rainwater reservoir to ensure an adequate water supply during the dry season. Fertilization was applied four times a year in the vegetative phase and monthly during the reproductive phase, using a mix of organic, inorganic, and liquid fertilizers. Pest and disease management is conducted preventively through routine pesticide applications every two weeks. Pruning was performed to shape the canopy and remove unproductive or diseased branches. Additionally, weed control was managed manually around the plants and mechanically in the inter-row areas.

Procedures

Plant morphology

Morphological observations focused on plant organs, including stems, leaves, and flowers. Plant height parameters, stem circumference, and crown diameter were measured using a measuring tape, while stem circumference was measured 20 cm above ground level. The number of leaves per plant was estimated by dividing the plant into two parts, and the leaves were manually counted using a counter. Furthermore, the calculated results were multiplied by two to obtain the number of leaves per plant. A total of ten representative adult and healthy leaf samples from each plant were selected to measure leaf length, width, and area, with leaf area measured using the Petiole Pro application. The application provided a calibrated scale template for accurate image-based leaf area estimation. Leaves were positioned flat on the template with the lamina and petiole fully visible and unfolded. Images were taken under adequate lighting and without shadows to ensure precise detection of leaf edges and scale markers. Subsequently, the application automatically calculated leaf area based on the calibrated scale.

Plant phenology

Avocado phenological observations were carried out weekly for one flowering cycle, recording the generative development phases from the initial flower emergence to the transition to fruit set. These data were used to identify the flowering and fruit development periods. Observed

parameters included the number of inflorescences, the number of flowers, the number of fruits formed, and the percentage of fruit set. Ten quaternary branches were selected from each plant based on the criteria of having a representative number of inflorescences and flowers compared to other branches.

The number of inflorescences on the ten selected branches was counted, while the flowers and fruits formed on each inflorescence were manually recorded to obtain the total number of flowers and fruits formed. The data were then used to calculate the percentage of fruit set using the following formula:

$$\text{Fruit set (\%)} = \frac{\text{Number of fruit formed}}{\text{Total number of flowers}} \times 100$$

Length, width, edible portion of fruit, and productivity

Ten representative fruits were observed from each accession at physiological ripeness without washing or any additional treatment. Fruit length and width were measured using a millimeter-scale ruler, while total fruit weight was determined using a digital scale with an accuracy of 0.01 g. Subsequently, the fruit was cut vertically to divide it into skin, seed, and flesh, which were weighed separately. The calculation of the edible portion required data obtained from measuring the edible parts of the fruit, using the following formula:

$$\text{Edible portion (\%)} = \frac{\text{Fruit flesh weight (g)}}{\text{Total fruit weight (g)}} \times 100$$

In addition to physical characteristics, productivity data for each accession were obtained from the PT Perkebunan Buah Subang 2024 database, which records total yields per plant through an online web-based system. The yield data were measured based on the cumulative weight of harvested fruits per plant during the production period and were recorded following standardized plantation management and data collection procedures. The productivity data were collected from the same plants used in this study, ensuring consistency with the observed morphological and fruit-quality traits. Lampung accessions entered their fruiting season in 2024. Therefore, productivity records were only available in 2024. These data were used to link the morphological traits and fruit quality, providing an overview of the accession's advantages.

Fat and sugar contents

Fat content analysis was conducted following the Soxhlet method (AOAC 2012). The sample was initially dried, ground into small particles, and placed in a porous thimble. 2 g sample was placed in the thimble; petroleum ether solvent was evaporated with Soxhlet for 4 hours and transferred to the condenser (to cool to room temperature). Then, the thimble was removed from the Soxhlet extraction flask, its contents were stirred, the thimble was returned to the Soxhlet extraction flask, and extraction was performed for 2 hours using the same solvent. The petroleum ether-containing fat was transferred into a clean, dry weighing bottle with a known weight, then evaporated over a water bath until slightly concentrated and further dried in an oven at 100°C until a constant weight was reached. The weighing bottle was cooled in a desiccator until it reached room

temperature and was weighed. The weight of the residue in the weighing bottle was expressed as the fat weight.

$$\text{Fat content \%} = \frac{\text{Fat weight (g)}}{\text{Sample weight (g)}} \times 100\%$$

The total soluble solids content represents the sugar content because its main component is a sugar complex. Ten fruit samples from each accession at a ripeness level suitable for consumption were used. The fruit flesh was homogenized using a mortar, and then the total soluble solids were measured using an SW-593 Digital Refractometer. Prior to measurement, the instrument was calibrated using distilled water to ensure accuracy. Calibration was performed by placing a drop of distilled water on the sensor surface, closing the prism cover, and pressing the calibration button until the reading displayed 0.0 °Brix. The sensor surface was cleaned and dried with tissue before measurement. Subsequently, the extract sample was dropped onto the refractometer sensor, and the instrument displayed the total soluble solids (°Brix) value.

Data analysis

The observed data were statistically analyzed using a completely randomized design (CRD), which was considered appropriate due to the relatively uniform environmental conditions across the study site, with elevation ranging from 500 to 600 meters above sea level (masl), minimizing environmental heterogeneity. All sampled trees were of the same age (3-4 years) and were in the generative phase. Prior to analysis, the data were tested for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test and Bartlett's test. Analysis of variance (ANOVA) was performed to evaluate differences among accessions, and significant effects were further tested using Tukey's HSD test. Statistical significance was determined

at $p < 0.05$ and $p < 0.01$. All analyses were conducted using R software (RStudio).

RESULTS AND DISCUSSION

Flowering and harvest periods

Based on observations, there was significant variation in the flowering period among avocado accessions, as seen from differences in flower initiation time and flowering period. This difference is then divided into two stages, as shown in Figure 2. Lampung 1 exhibits the earliest flowering, occurring in late April until early November, indicating its genetic potential for earlier flowering than other accessions, with a total duration of approximately six months. Lampung 2 had the longest flowering period, from early May to late December, with a total flowering duration of up to seven months. In contrast, Lampung 3 and Miki showed the shortest flowering duration, approximately five months. Miki also exhibited relatively later flowering, with initiation occurring in late May. Based on the data, flowering was relatively low in August and September and increased again in the subsequent months. A similar pattern of two stages of flowering in avocados was also reported in Kenya by Mulwa et al. (2019).

The avocado harvest time in this study occurred at around 150-160 days after anthesis (DAS) for Lampung Accessions and 170-180 days for Miki. Among Lampung avocado accessions, different harvest times were observed (Figure 3). Lampung 1 started harvesting in the middle of September, Lampung 2 and Lampung 3 in late September, while Miki started harvesting in late October, around a month later compared to the three Lampung accessions.

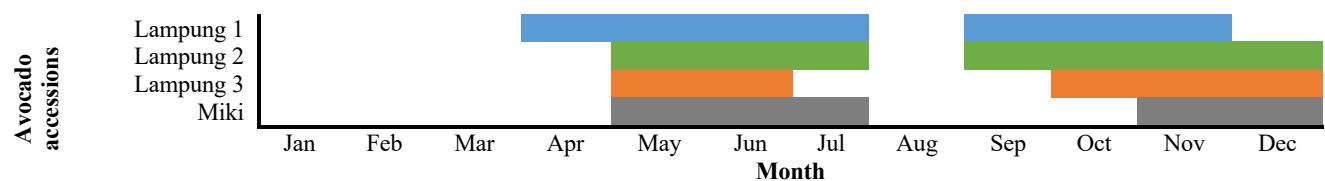


Figure 2. Flowering time of various avocado accessions. Blue: Lampung 1 at April-July and September-November, Green: Lampung 2 at May-July and September-December, Orange: Lampung 3 at May-June and October-December, Grey: Miki at May-July and November-December

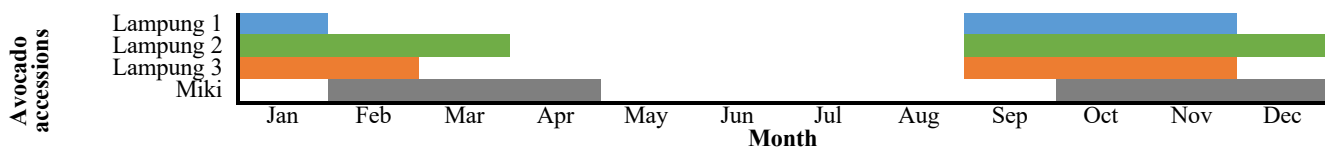


Figure 3. Harvest period of avocado accessions. Blue: Lampung 1 at January and September-November, Green: Lampung 2 at January-March and September-December, Orange: Lampung 3 at January-February and September-November, Grey: Miki at February-April and October-December

There were two stages of the harvest period. The first harvest period of Lampung accessions occurred from September to November, and the second period occurred from January to February in the following year, while the first and second harvesting periods of Miki were around a month later than those of Lampung accessions. Moreover, the peak harvest for Lampung 1 and Lampung 3 is in January and October, Lampung 2 in February and November, and Miki in April and November. Harvest period varies among commercial cultivars, such as Cengkho (February-April), Apenina (July-August and January-February), Roro (February-March and August-September), and Mega (April and September) (Direktorat Perbenihan Hortikultura 2024). A difference in harvest time has an advantage in prolonging fruit availability to meet market demand. However, it is important to note that determining the optimal harvest time is critical because it directly affects the overall quality of the fruit. Consumers tend to prefer fruits that are harvested at a more mature age rather than harvested early (Canete et al. 2018).

Based on the observed flowering to harvesting periods, Lampung 1, Lampung 3, and Miki exhibited similar flowering to harvest durations of approximately six months. Lampung 1 initiated flowering in April and was harvested in September. Lampung 3 initiated flowering in early May and was harvested in September, while Miki initiated flowering in late May and was harvested in October. In contrast, Lampung 2 showed a shorter duration of approximately five months, with flowering initiation in May and harvest in September. The highest flowering intensity, approximately 80%, was recorded in June for Lampung 1, July for Lampung 2 and Miki, and October for Lampung 3.

Avocado plant growth

Table 1 shows that the four avocado accessions generally did not differ significantly in terms of plant height, crown diameter, and stem circumference. On the other hand, the number of primary branches differed significantly ($p < 0.05$). Miki had the highest number (4.00), whereas all Lampung accessions showed no significant differences among them, ranging from 2.25 to 2.75. The difference among accessions also occurred in leaf number ($p < 0.05$). Miki produced a significantly higher number of leaves (8,477) compared to the Lampung accession (3,432 to 4,337 leaves) (Table 1). Morphological variation was observed among accessions despite being grown in a similar field environment. This suggests that genetic factors may

contribute to the observed differences in growth-related traits. Differences in leaf number may also reflect the complex and multifactorial interaction between genotype and environmental conditions (Teressa et al. 2021).

Avocado leaf morphology

Leaf morphological characteristics across avocado accessions showed significant variation in all parameters, with significant differences observed in leaf width ($p < 0.05$), leaf length ($p < 0.01$), and leaf area ($p < 0.05$) (Table 2). Lampung 1 showed the highest value among other accessions in leaf width, with the largest leaf width, length, and area, measuring 9.72 cm, 17.66 cm, and 92.82 cm², respectively. Miki, on the other hand, showed the smallest values, with a width of 7.77 cm, a length of 15.09 cm, and an area of 71.27 cm². These differences can be seen in Figure 4, which shows that leaf length and leaf width significantly contribute to differences in leaf area. Leaves are a major vegetative organ, generally serving as the primary site of photosynthesis and carbon assimilation, while also contributing to transpiration and physiological regulation related to plant growth and development (Lawson and Milliken 2022). Furthermore, aside from the differences in leaf size, the leaf morphology of Lampung 1, Lampung 3, and Miki avocados exhibited an ovate shape, characterized by a wider leaf base and a tapered or narrower leaf tip. Lampung 2 exhibited a lanceolate shape characterized by a tapered leaf base and tip (Figure 4).

Color of avocado plant shoots

This study revealed striking differences in leaf buds and clear variation among accessions. Lampung 2 had prominent red-pigmented buds, while Lampung 1 had yellowish buds, and Lampung 3 and Miki showed predominantly light green buds (Figure 5). The red color in Lampung 2 buds appeared throughout the plant, and according to Tellez et al. (2016), this is attributed to the presence of anthocyanin pigments, secondary metabolites typically expressed in young leaves. These compounds not only provide color but also offer adaptive advantages, such as reducing photoinhibition by filtering excess light and acting as a defense mechanism against herbivores. Chen et al. (2021) emphasized that red pigmentation in the buds can serve as a visual warning signal, effectively reducing pest attacks, especially insects. This bud color trait can also be used for the initial identification of accessions or cultivars.

Table 1. Plant height, crown diameter, stem circumference, number of primary branches, and number of leaves per plant

Accession/ cultivar	Plant height (m)	Crown diameter (m)	Stem circumference (cm)	Number of primary branches	Number of leaves per plant
Lampung 1	4.30	4.73	54.45	2.25 b	3,926 b
Lampung 2	3.83	3.88	49.40	2.75 ab	3,432 b
Lampung 3	3.93	3.77	51.08	2.75 ab	4,337 ab
Miki	4.03	4.26	57.33	4.00 a	8,477 a
Significance	ns	ns	ns	*	*

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

Avocado phenology in flowering and fruiting phases

There were significant variations in reproductive traits among avocado accessions, particularly in the number of flowers per inflorescence ($p < 0.01$), the average number of fruits formed per inflorescence ($p < 0.05$), and fruit set ($p < 0.05$). Lampung 2 exhibited the highest number of flowers per inflorescence (255.50 flowers), while Lampung 3 had the lowest (166.00 flowers). Lampung 1 and Miki did not differ significantly among them, with values of 207.25 flowers and 199.75 flowers, respectively (Table 3). Avocado inflorescences are panicles (branched compound clusters), consisting of clusters of flowers that can develop into fruit (Alcaraz and Hormaza 2021). This variation in inflorescence number reflects the accession's genetic potential for reproductive capacity, which is an important trait in superior avocado selection.

The number of fruits formed showed variation, with Lampung 2 and Miki having the same value of 5.00 fruits per inflorescence, Lampung 1 produced 4.75 fruits, while Lampung 3 showed the lowest value at 3.25 fruits. Fruit set also differed among accessions, with Miki having the highest fruit set percentage at 2.59%, while Lampung 1 was 2.29%, then Lampung 2 and Lampung 3 showed the lowest values at 1.97% and 1.99%, respectively. Although Lampung 2 had the highest number of flowers per inflorescence, its fruit set percentage was lower than Miki's, indicating that a high flower number does not always equate to successful fruit set. In comparison, Chen et al. (2007) reported fruit set percentages for three global avocado cultivars, Bacon, Fuerte, and Zutano, at 1.50%, 1.36%, and 1.67%, respectively. This comparison indicates that local Indonesian avocado accessions tend to have higher fruit set and potentially could be more widely developed. Therefore, assessing fruit set percentage is an important indicator of reproductive success, particularly during the transition from flowering to fruit development.

Morphology of avocado fruit

Significant variation was observed in all parameters, including fruit length, fruit width, seed length, and seed width, which showed significant variation at $p < 0.01$ among the avocado accessions. Lampung 1 produced the longest fruit, with a length and width of 16.20 cm and 9.23 cm,

respectively, while Lampung 3 produced the shortest fruit, with a length of 11.83 cm and a width of 8.83 cm. Lampung 2 and Miki had fruit length of 13.50 cm and 13.05 cm and fruit width of 8.85 cm and 9.10 cm, respectively, showing in the range between of Lampung 1 and Lampung 3 (Table 4). There was a tendency that the longer fruit shape also produced long-shaped seeds, whereas the shortest fruit tended to produce round seeds (Figure 6). These results indicate that fruit shape plays a role in determining seed morphology, with longer fruit tending to produce oval-shaped seeds, while rounder fruits tend to produce round seeds.

Table 2. Width, length, and area of leaves

Accession/ cultivar	Leaf width (cm)	Leaf length (cm)	Leaf area (cm ²)
Lampung 1	9.72 a	17.66 a	92.82 a
Lampung 2	8.44 ab	17.24 a	83.00 ab
Lampung 3	8.25 b	16.02 ab	80.48 ab
Miki	7.77 b	15.09 b	71.27 b
Significance	*	**	*

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

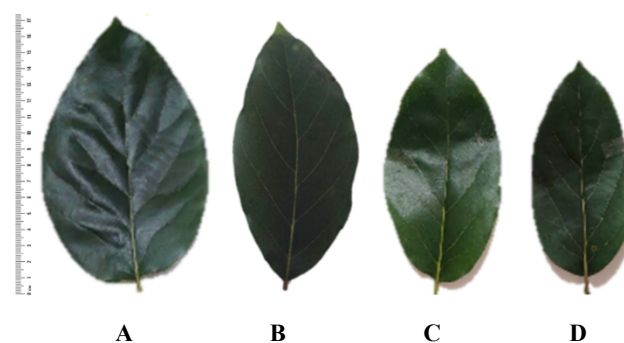


Figure 4. Leaf morphological characteristics of: A. Lampung 1, B. Lampung 2, C. Lampung 3, D. Miki



Figure 5. Plant shoot color of: A. Lampung 1, B. Lampung 2, C. Lampung 3, D. Miki

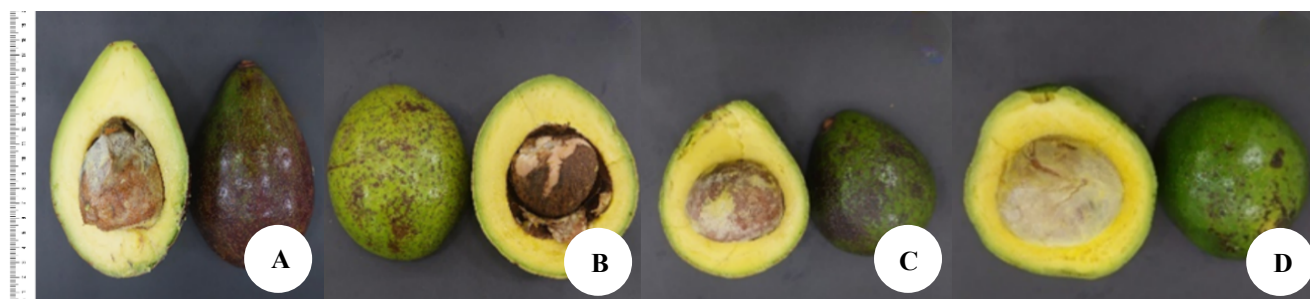


Figure 6. Performance of fruit of: A. Lampung 1, B. Lampung 2, C. Lampung 3, D. Miki

Table 3. Number of inflorescences, flowers, and fruit set

Accession/ cultivar	Average number of flowers per 10 quarter branches		Average number of fruits formed per inflorescence	Fruit set (%)
	Inflorescence	Flowers per inflorescence		
Lampung 1	35.50	207.25 ab	4.75 ab	2.29 ab
Lampung 2	37.50	255.50 a	5.00 a	1.97 b
Lampung 3	28.50	166.00 b	3.25 b	1.99 b
Miki	37.00	199.75 ab	5.00 a	2.59 a
Significance	ns	**	*	*

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

Table 4. Fruit and seed size

Accession/ cultivar	Fruit length (cm)	Fruit width (cm)	Seed length (cm)	Seed width (cm)
Lampung 1	16.20 a	9.23 a	6.23 a	5.18 b
Lampung 2	13.50 b	8.85 bc	5.80 b	4.55 c
Lampung 3	11.83 c	8.83 c	4.85 c	4.80 bc
Miki	13.05 bc	9.10 ab	5.10 c	5.85 a
Significance	**	**	**	**

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

Productivity, fruit weight, and its proportion

In terms of productivity, as shown in Table 5, Lampung 1 was able to surpass Miki's productivity at 7.13 kg per plant. Lampung 2 showed a similar value, while Lampung 3 was the lowest productivity only 3.42 kg per plant, which was lower than Miki (4.06 kg per plant). The lower productivity of Lampung 3 may be due to the lower flower number and fruit set compared to other accessions. However, it should be noted that these productivity data were obtained from a single production season. Therefore, the comparison should be interpreted as a preliminary indication rather than evidence of accession superiority. Further multi-season observations in the following year are needed, particularly for Lampung 3, to evaluate the stability of its productivity performance. The fruit weight

among accessions differed significantly. The fruit weight of Lampung 1 was 56% higher, Lampung 2 was similar, while Lampung 3 was lower compared to Miki, with a significance level at $p < 0.01$ (Table 5). The edible portion of Lampung 1 and Lampung 2 reached 79%, significantly higher than Lampung 3 and Miki, which reached 69% with a significance level at 1%. The edible portion of Lampung 1, Lampung 2, and Lampung 3 is not far compared with other commercial, domestic and global cultivars. Domestic cultivars such as Ijo Panjang and Ijo Bundar have edible portion percentages of 73.11% and 71.24%, respectively (Marsigit et al. 2016). Global commercial cultivars such as Fuerte and Hass have edible portions of 75.85% and 68.75%, respectively (Rodríguez-Carpena et al. 2011). The edible portion is one of the important parameters in the process of selecting potential accessions (Karapetsi et al. 2021).

Based on Figure 7, several correlations were observed between leaf morphology and fruit formation. The number of fruits formed showed a positive correlation with fruit set was positively correlated with fruit set ($r = 0.72$), and fruit set was further positively correlated with productivity ($r = 0.54$). Furthermore, leaf area also showed positive correlations with key fruit traits, including fruit length ($r = 0.57$), fruit weight ($r = 0.59$), seed length ($r = 0.60$), and edible portion ($r = 0.61$), suggesting that larger leaf area may enhance assimilate production for fruit development. These relationships indicate that greater leaf area contributes not only to fruit growth but also to improved fruit quality.

Table 5. Productivity, weight and proportion of fruit

Accession/cultivar	Productivity (kg/plant)	Fruit weight (g)	Skin weight (g)	Seed weight (g)	Fruit flesh weight (g)	Edible portion (%)
Lampung 1	7.13 a	725.45 a	63.18 a	87.40 b	574.73 a	79.22 a
Lampung 2	4.71 ab	505.10 b	38.30 b	66.58 c	399.73 b	79.12 a
Lampung 3	3.42 b	391.25 c	29.13 c	86.98 b	272.93 d	69.76 b
Miki	4.06 ab	464.25 b	37.98 b	102.45 a	323.13 c	69.63 b
Significance	*	**	**	**	**	**

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

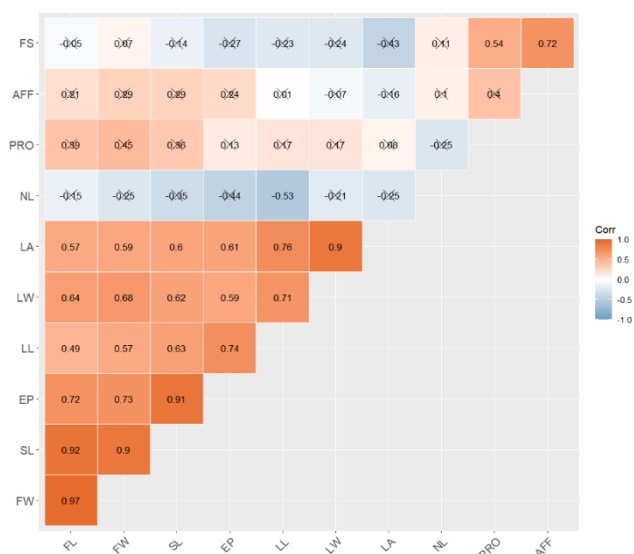


Figure 7. The correlation between leaf morphology and fruit performance. FL: Fruit Length, FW: Fruit Weight, SL: Seed Length, EP: Edible Portion, LL: Leaf Length, LW: Leaf Width, LA: Leaf Area, NL: Number of Leaves, PRO: Productivity, AFF: Average Number of Fruits Formed

Table 6. Fat and sugar contents in fruit

Accession/cultivar	Fruit quality	
	Fat content (%)	Sugar content (°Brix)
Lampung 1	51.07 b	5.60 c
Lampung 2	55.57 a	10.10 a
Lampung 3	53.57 ab	11.00 a
Miki	51.00 b	8.30 b
Significance	*	**

Note: Means followed by the same letter in the same column do not differ statistically among themselves by the Tukey HSD test. Significance: ns: not significant, *: $p < 0.05$, **: $p < 0.01$

Fat and sugar contents

The fat and sugar contents of the avocado accessions showed significant variation. Lampung 2 had the highest fat content at 55.57%, while Miki had the lowest at 51.00% ($p < 0.05$). Meanwhile, sugar content also varied notably, with Lampung 2 and Lampung 3 showing the highest sugar content at 10.10°Brix and 11.0°Brix, respectively, while Miki recorded at 8.3°Brix ($p < 0.01$) (Table 6). These results indicate clear differences in biochemical composition among

the evaluated accessions. Variation in fat and sugar content may reflect differences in fruit quality attributes related to nutritional composition. Lampung 2 showed higher fat levels compared to the other accessions, while Lampung 1 had fat content similar to Miki, and Lampung 3 exhibited relatively high levels of both fat and sugar contents. The combination of higher productivity, greater edible portion, and high fat content suggests that Lampung 1 and Lampung 2 have potential for further development as candidate cultivars for fresh consumption. Lampung 2 also shows potential for further exploration for value-added utilization, particularly in relation to its relatively higher fat content.

Discussion

The result of this study showed that Lampung 1, Lampung 2, and Lampung 3 demonstrated competitiveness in some aspects and had better performance compared to Miki. Lampung 1 consistently excelled in terms of large fruit size, high fruit flesh weight, and the highest percentage of edible portion, producing fruits that were 56% heavier and had a 14% higher edible portion than Miki. Lampung 2 also excelled, particularly with its higher fat content, approximately 9% greater than Miki, along with a 14% higher edible portion. Both accessions also maintained productivity comparable to Miki. Lampung 2 and Lampung 3 accessions exhibited higher fat content, while Lampung 1 was similar compared to Miki. Based on these advantages, Lampung 1 and Lampung 2 avocados show promising potential for development as candidates for new cultivars, while Lampung 3 still requires further observation due to its lower flowering and fruit formation during the study.

In relation to reproductive performance, avocado flowers have a unique reproductive type known as dichogamy, specifically the protogynous type, where male and female flower phases appear at different times. This system is divided into two flowering types: type A and type B. In type A, flowers bloom as female in the morning and as male in the afternoon of the following day, while in type B, flowers bloom as female in the afternoon and as male the following morning (Sagwe et al. 2022). This phase separation encourages cross-pollination, thus supporting reproductive success and enhancing potential fruit set (Hapuarachchi et al. 2024).

Understanding flowering time is essential for effective crop management, particularly for climate adaptation (Jung

and Müller 2009; Deva et al. 2023). Knowledge of flowering time enables producers to optimize irrigation, fertilization, and other agronomic practices to ensure optimal flowering, thereby improving harvest efficiency and fruit quality. Variations in flowering time among accessions arise from the interaction between genetic and environmental factors. The genetics of each accession largely influence variation in flowering time, however, environmental conditions such as water availability, temperature, and nutrient status also play significant roles. In tropical regions, water stress is considered one of the most influential environmental regulators of flowering processes (Taiz et al. 2015). The presence of an irrigation system facilitates the controlled application of water stress in specific blocks, allowing flowering induction to be managed more effectively. In this context, variation in flowering time observed among the Lampung accessions and the Miki cultivar may reflect differential phenotypic responses to local microclimatic conditions.

Beyond flowering behavior, vegetative characteristics also play a critical role in supporting reproductive development. Larger leaf size is potentially associated with higher photosynthetic rates because it can capture more light, thereby enhancing the availability of assimilates for both vegetative and generative growth, including flower and fruit formation (Okajima et al. 2012). Differences in leaf area, therefore, represent not only morphological variation but may also be related to differences in the plant's ability to support reproductive development. In this study, leaf characteristics were positively correlated with fruit size, as indicated by Lampung 1, which had the largest leaf area and consequently produced the heaviest fruits among all accessions evaluated. Larger leaf area may reflect enhanced photosynthetic capacity, supporting assimilate accumulation and improving fruit development. A similar case has been reported in pummelo, where the leaf-to-fruit ratio plays a critical role in regulating assimilate allocation and significantly influences fruit quality traits (Pratama and Susanto 2019). This finding is further supported by studies in avocado, which have shown that leaf photosynthetic efficiency is closely associated with dry matter accumulation and fruit development (Shezi et al. 2019). However, fruit formation results from complex interactions between genetic and environmental factors, as well as crop management practices (Gaurha et al. 2024). These findings indicate that further evaluation is required to clarify the relative contributions of genetic and environmental factors to the observed traits.

The Lampung accessions demonstrated promising adaptability under Subang growing conditions. Their earlier flowering also provided additional advantages such as earlier harvesting and reduced risk of late-season environmental stress. Based on harvest-time data, Miki required approximately 1 month longer to produce fruit than the Lampung accessions. Such evaluations are essential for understanding the phenotypic responses of Lampung 1 and Lampung 2 and supporting their potential as candidate cultivars. At the same time, further assessment of Lampung 3 is required to clarify its production stability. The morphological, physical, and chemical characterization

of fruits was conducted using commonly applied approaches in fruit research to explain phenotypic differences among cultivars or accessions within the environment, as reported by Susanto et al. (2024).

From a biodiversity perspective, this study highlighted the importance of local avocado accessions as valuable germplasm resources that contribute to avocado diversity. Such characterization is essential for enriching genetic diversity and supporting the conservation and utilization of avocado germplasm. However, the differences in characteristics among the Lampung accessions and the Miki cultivar observed in this study should be interpreted as preliminary results, as the phenotypic responses were observed only under a single environmental condition and during a single growing season. Therefore, the findings of this study provide a scientific basis for further research with a broader experimental scope. Further studies related to multi-location and multi-season evaluations, combined with molecular characterization, postharvest quality and consumer acceptance, should be conducted to support the development of Lampung 1 and Lampung 2 as new cultivar candidates.

In conclusion, this study demonstrated clear phenotypic, phenological, and fruit-quality differences among three Lampung avocado accessions and the commercial cultivar Miki grown under uniform conditions in Subang, West Java. Lampung 1 showed the highest productivity, with fruits that were 56% heavier and had an edible portion approximately 14% higher than Miki. Lampung 2 exhibited productivity comparable to Miki but achieved a similarly high edible portion and the highest fat content (55.57%), supporting its potential for further evaluation in fruit quality. In contrast, Lampung 3 had the lowest productivity, although it showed relatively high levels of fat and sugar. Phenologically, all Lampung accessions flowered and reached harvest approximately one month earlier than Miki. However, as this research was limited to a single location and single growing season, the observed differences should be interpreted as preliminary characterization results and may not reflect environmental variability or year-to-year stability. Therefore, multi-location and multi-season evaluations combined with molecular characterization are recommended to confirm genetic distinctness and adaptability. Further studies should also assess postharvest quality and consumer acceptance to support cultivar development and commercialization of the Lampung 1 and Lampung 2 accessions, while further exploration is needed to clarify the low productivity of Lampung 3.

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