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Morphological Variation of Liberica Coffee (*Coffea liberica* Hiern) in Kalipuro Sub-district, Banyuwangi Regency

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ABSTRACT

Coffea liberica has encountered challenges related to infraspecific taxa, leading to confusion and difficulty in taxonomic identification. This study aims to determine the Liberica coffee variant in the Kalipuro Sub-district based on morphological traits, to clarify whether it is more closely related to *Coffea liberica* var. *liberica* or *Coffea liberica* var. *dewevrei*. A field study was conducted to identify reference morphological traits used as the basis for grouping Liberica coffee variants. Quantitative and qualitative characteristics of the vegetative and reproductive phases were assessed and recorded. *Coffea liberica* exhibits four representative branch types: drooping with upward-curving tips, horizontal, declinate (drooping branch), and leaning upward. The study discovered that Liberica coffee in Kalipuro varies in leaf shape, colour, margins, apex, fruit colour, bean colour, and shape. However, some traits showed relatively low variability among accessions, and inconsistencies remained. Therefore, key characters i.e., leaf surface and shape index, number of flowers/inflorescences, fruit volume, bean shape, were used to determine the taxonomic position of Liberica coffee. The variety found in the Kalipuro more closely resembled *C. liberica* var. *dewevrei* than *C. liberica* var. *liberica,* based on a Jaccard similarity index of 0.6. Nevertheless, additional genetic research is required to clarify the taxonomic status of Liberica coffee in Kalipuro, as numerous shared characteristics lead to ambiguity among these varieties.

Keywords: Accession, coffee, characterisation, liberoid, morphological trait

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INTRODUCTION

Coffea is one of the most economically important genera among over 500 genera in

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the Rubiaceae family. *Coffea* comprises over 120 species, with *Coffea arabica* and *Coffea canephora* being the most commercially popular worldwide (Davis et al., 2011). Coffee is a major export commodity cultivated in approximately 80 countries, supporting the livelihoods of over 20 million people worldwide through production and related industries. It is produced either through a traditional system, wild harvesting, or managed agroforestry systems involving the removal of undergrowth and canopy. Commercial coffee species in Indonesia originate from Africa (Ayalew, 2018). Coffee is among Indonesia's leading commodities, alongside palm oil, rubber, cocoa, tea, and coconut. Indonesia supplies 7% of the global coffee demand (Direktorat Jendral Perkebunan of Indonesia, 2019). In 2021, it ranked as the fourth-largest coffee producer globally, after Brazil, Vietnam, and Colombia. In 2023, annual production reached 758,725 tons, with a productivity rate of 789 kg/ha (BPS Indonesia, 2024).

Since the Dutch colonial era, Banyuwangi Regency, especially the Slope of Mount Ijen, has been Indonesia's major coffee-producing region. In this region, the population of *C. liberica* remains significant alongside *C. arabica* and *C. canephora*, contributing to local coffee production. Coffee in Banyuwangi is produced through both large coffee plantations managed by state and private companies, and smallholder plantations owned and managed by local communities. In 2020, average coffee production—particularly Robusta—reached 876 kg/ha, the highest in East Java Province (Direktorat Jendral Perkebunan of Indonesia, 2021). With the expansion of coffee cultivation on Java Island, Banyuwangi Regency, specifically Kalipuro Sub-district, has become one of the areas with the high *Coffea* diversity. The primary crops planted by the local communities are *Coffea canephora* and *Coffea liberica* (Hakim et al., 2022).

For several years, *C. liberica* has faced infraspecific taxonomic issues. Although classified as a single species with two varieties— *Coffea liberica* var. *liberica* and *Coffea liberica* var. *dewevrei*—its taxonomy remains a source of confusion (Baltazar & Buot, 2019). The high diversity of Liberica coffee, combined with farmers' limited knowledge and ability to identify its variants, poses a challenge in accurately determining the taxa of *Coffea liberica* variants. Moreover, the difficulty in determining the taxa of Liberica coffee variants arises from a limited understanding of their morphological characteristics. As a result, beans from different varieties are often harvested and mixed, hindering proper selection. Resolving this taxonomic ambiguity is essential to improve classification accuracy and enhance the product's market value.

As one of the nation's coffee production centres, Kalipuro Sub-district holds unexplored potential for Liberica coffee diversity. Morphological variation observed in agricultural fields allows the examination of seed origin and environmental conditions as factors influencing this diversity. Such variants are determined by genetic variation and environmental factors (Wei et al., 2025). Morphologically, variants of *C. liberica* exhibit

differences that can be identified through detailed morphological analysis and subsequently confirmed through molecular analysis. In Kalipuro Sub-district, uncertainty exists regarding the classification of the local Liberica coffee variant, specifically whether it is more closely related to *C. liberica* var. *liberica* or *C. liberica* var. *dewevrei*. This study aims to determine the morphological variations of Liberica coffee variant in Kalipuro Sub-district, Banyuwangi Regency, to provide essential basic data for future genetic confirmation and to support conservation strategies.

MATERIALS AND METHODS

Study Area

This study was conducted from August to October 2022 in Kalipuro Sub-district, Banyuwangi Regency, East Java, Indonesia (7° 43' - 8° 46' South Latitude and 113° 53' - 114° 38' East Longitude) (Banyuwangikab, 2022a) (Figure 1). Banyuwangi Regency is located in the eastern part of Java Island and is primarily an agricultural region, dominated by extensive wet and dry land farming (Hakim et al., 2015). It is bordered by the Java Sea, the Bali Strait, and the Indian Ocean, with a tropical climate possess two seasons: rainy and dry seasons (Banyuwangikab, 2022b).

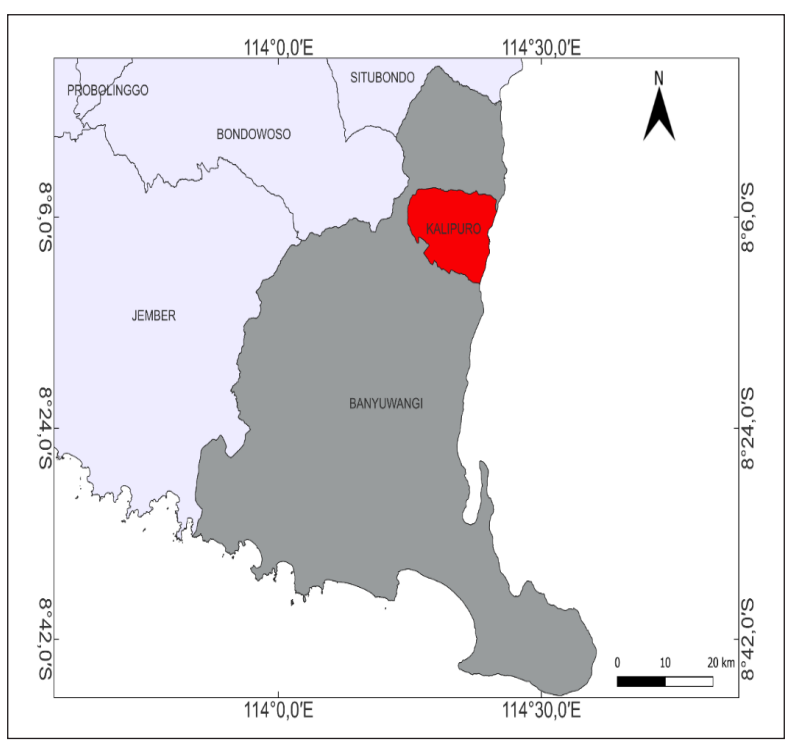

Figure 1. Location of the sampling site, Kalipuro Sub-district (Mukhoyyaroh et al., 2024)

Data Collection

Field studies were conducted to identify the reference morphological traits that would serve as the basis for classifying variants of Liberica coffee. The observed traits included qualitative and quantitative leaf characteristics (Ramadiana et al., 2018). Quantitative traits measured were trunk diameter; leaf length and width; petiole length; internode distance; fruit length and width, thickness, and weight; fruit flesh thickness; and the length, width, thickness, and weight of both hard-skinned beans and green beans. Leaf observations were conducted on mature leaves located more than three nodes from the terminal bud.

Leaf shape index (LL/LW) and leaf surface index (LLxLW) were calculated from leaf length (LL) and leaf width (LW) ratio. Measurement of length (L), width (W), and thickness (T) for fruit, green beans, and hard skin (HS) beans were used to calculate fruit volume (FLxFWxFT), fruit shape index (FL/FW), HS volume (HLxHWxHT), HS shape index (HL/HW), green bean volume (GBLxGBWxGBT), and green bean shape index (GBL/GBW). A hard skin bean (HS) refers to a coffee bean covered with a hard skin, while a green bean is a coffee bean with the hard skin removed. The morphometry illustration is shown in Figure 2. Quantitative measurements were conducted on five leaves and 100 fruits, beans, and HS beans per individual tree as replications.

The observed qualitative morphological traits included branching type, leaf shape; apex shape, leaf margin, stipule shape, leaf venation, ripe fruit colour, young leaf and fruit colour, and bean colour. The assessment method followed the Descriptors for Coffee (*Coffea* spp. and *Psilanthus* spp.) by the International Plant Genetic Resources Institute (IPGRI) (IPGRI, 1996; Ramadiana et al., 2018; Walyaro, 2006;). Qualitative trait observations for *C. liberica* were conducted on five mature leaves and 100 mature fruits and beans per individual tree as replications. Detailed trait descriptions and scoring guidelines are provided in Supplementary Table 1.

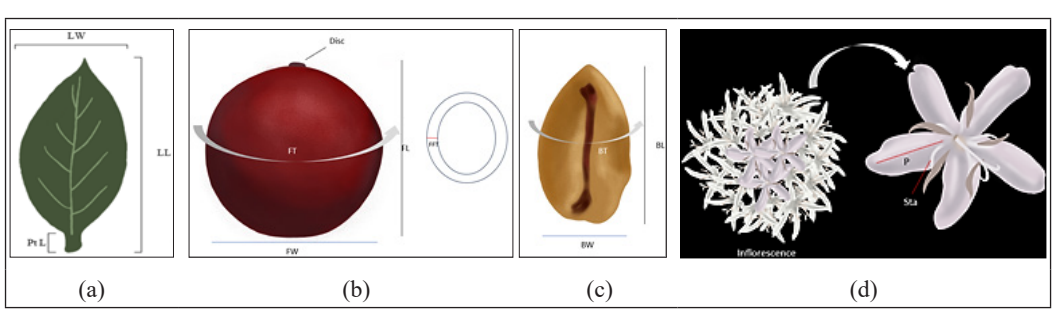

Figure 2. Morphological illustration of leaf measurement: a. leaf (LL: leaf length; LW: leaf width; Pt L; petiole length); b. fruit (FL: fruit length; FW: fruit width; FT: Fruit thickness; FFT: Fruit flesh thickness); c. bean (BL: bean length; BW: bean width; BT: bean thickness); d. Flower (P: petal; Sta: stamen)

Data Analysis

Measurement data for quantitative and qualitative morphological traits were tabulated, and statistical analysis was performed using standard deviation. Quantitative key characters were adapted from N'Diaye (2005) for *Coffea liberica* (Table 4), while the qualitative key character of bean shape was analysed separately (Table 2). Both qualitative and quantitative key characters were transformed into binary data for dendrogram construction using UPGMA algorithm based on Jaccard's similarity index, implemented in Paleontological Statistics (PAST) software.

Character states were subsequently analysed and interpreted manually to identify apomorphies (exclusive derived characters), following standard cladistic principles (Wiley & Liberman, 2011). Apomorphy can be divided into synapomorphies (shared by multiple accessions) and autapomorphies (unique to a single accession). Morphological traits were coded according to the observed variation, and character states were compared across all accessions. Autapomorphy was used to group individual accessions, while synapomorphies served only to describe cluster patterns. The identified apomorphic characters were then used to support the grouping patterns observed in the dendrogram and to provide diagnostic morphological traits for distinguishing among *Coffea liberica* accessions.

RESULTS

Morphological Leaf Variation of *Coffea liberica*

In plantations managed by local communities in Kalipuro Sub-district, coffee plants are predominantly *C. canephora* and *C. liberica*. *Coffea liberica* is locally known as "*kopi nangka"* or "jackfruit coffee" due to its distinctive jackfruit-like aroma and sour taste. Based on field exploration in coffee agroforestry plantations, four branching types of *C. liberica* were identified and labelled alphabetically as A, B, C, and D (Figure 3) to facilitate grouping. Type A is characterised by drooping branches with upward-curving tips. Type "A" is characterised by drooping branches with upward-curving tips. Type "B" is characterised by horizontal branches (90 degrees), type "C" by drooping (declinate) branches, and type "D" by upward-leaning branches at a 45° angle (Hickey & King, 2000; Tjitrosoepomo, 2011). Field exploration indicated that the branching type of *C. liberica* does not influence the morphological variation observed in the Kalipuro variant. Morphological trait variations were present across all branch types, with no specific traits associated exclusively with a particular branching type.

The leaf morphology of Liberica coffee, based on the qualitative traits, showed some variations, while other traits showed morphological similarity (Supplementary Table 2). Across the four branch types, the coffee plants are suspected to be a variant of *C. liberica* (*C. liberica* var. *liberica* and *C. liberica* var. *dewevrei*) that share certain leaf traits.

Distinguishing characteristics among accessions included variations in young leaf colour, mature leaf colour, leaf shape, apex leaf shape, and leaf margin (Supplementary Table 2). Young leaves from 17 accessions of *C. liberica* displayed a range of colours—reddish, brownish, and brownish green—with brownish being the most common (Figure 4). Meanwhile, mature leaf colours were predominantly dark green. Two accessions with the "D" branch type (D2, and D4) had green mature leaves, while all other “D” accessions, as well as all those from the "A", "B", and "C" types, had dark green mature leaves.

All the accessions of *C. liberica* had a similar elliptic leaf shape, although three accessions (A2, A5, and C3) had broader leaves, giving the elliptic shape a more rounded appearance (Figure 4). Leaf apex shape was either acuminate or acute. Only two accessions, A5 and C3, had an acute apex, both also showing rounded elliptic leaf shapes. Although A2 had a similar leaf shape, its apex was acuminate. All branch types exhibited leaves with either entire or undulate margins (Figure 4). Twelve of the 17 accessions had undulating margins, while the others had entire margins. All accessions had glossy leaf surfaces, triangular stipules, green petiole colour, and pinnate venation.

Quantitative leave traits indicated that all the *C. liberica* plants could be classified as *C. liberica* var. *dewevrei* based on key characteristics referenced in N'Diaye et al. (2005) (Table 4). The leaf surface index ranged from 313.79 to 721 cm^2, with an average of 541.93 cm^2 (Table 1), while the leaf shape index ranged from 1.69 to 2.45, with an average of 2.01. Petiole lengths ranged from 1.84 to 3.00 cm, affecting the shape and surface index. Another measured quantitative morphological trait was internode distance, which ranged from 5.30 cm to 10.58 cm. The smallest internode distance was found in the C3 accession, while the largest was found in the A5. Internode distance affects the productivity of Liberica coffee per individual tree, as it is related to the position of coffee fruit growth on the axillary internodes.

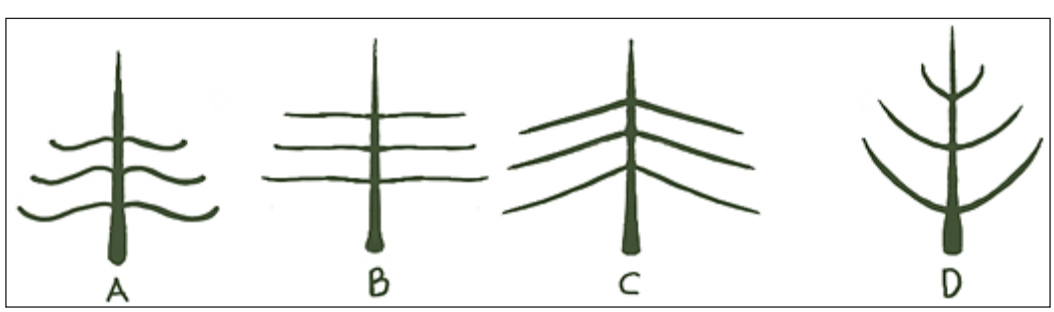

Figure 3. Illustration of branch types found in coffee plantations in Kalipuro Sub-district

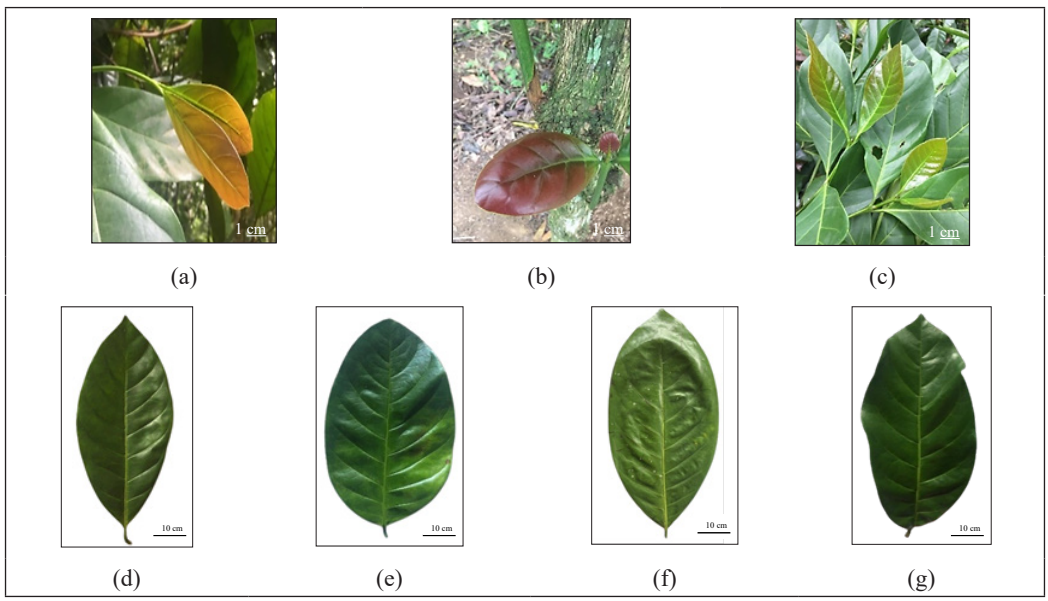

Figure 4. Coffea liberica vegetative traits: a. brownish young leaf colour; b. reddish young leaf colour; c. green-brownish young leaf colour; d. leaf shape elliptic with acuminate apex shape; e. elliptic tending to be rounded with an acute apex shape; f. mature leaf green colour with entire margin; g. mature leaf dark green colour with an undulate margin

Table 1
Quantitative morphology of leaves and internodes of C. liberica

Accession	Leaf Surface Index (cm^2)	Leaf Shape Index	Petiole Length (cm)	Internode Distance (cm)
A1	615.79±139.99	2.05±0.16	2.64±0.35	7.60±2.45
A2	625.65±134.75	1.79±0.06	2.54±0.15	9.95±3.72
A3	568.16±147.69	2.45±0.21	2.52±0.37	8.83±3.49
A4	467.84±123.59	1.87±0.24	1.84±0.21	10.24±3.40
A5	569.66±69.19	1.69±0.11	2.58±0.24	10.58±3.85
B1	612.8±66.73	1.95±0.09	2.16±0.27	8.00±3.50
B3	721±123.52	2.12±0.14	3.00±0.31	8.00±2.94
B5	485.69±112.11	2.07±0.10	1.66±0.42	6.04±1.86
C1	480.39±122.97	1.88±0.42	2.72±0.73	8.99±8.89
C2	432.13±99.22	2.01±0.23	2.08±0.29	6.69±2.70
C3	570.85±50	1.69±0.15	2.54±0.29	5.30±2.00
C4	313.79±34.23	2.15±0.20	1.88±0.39	6.13±2.56
C5	587.66±44.24	2.23±0.17	2.80 ± 0.27	6.59±3.69
D2	482.59±84.05	2.05±0.13	2.00±0.35	6.99±3.79
D3	606.47±174.86	2.28±0.24	2.80 ± 0.45	8.90±3.76
D4	592.62±23.16	2.07±0.18	1.92±0.19	8.04±2.84
D5	479.67±42.3	1.90±0.11	2.38±0.36	7.43±2.34
Average	**541.93±95.07**	**2.01±0.20**	**2.36±0.40**	7.90±1.53

Morphological Variations of *Coffea liberica* Fruit and Bean

Two variations in ripe fruit colour were observed among *C. liberica* accessions*:* red-orange (C2 and C4 Accessions) and red (the rest of accession) (Table 2; Figure 5). Two variations in bean colour were found in Liberica coffee, yellow and brown. Six of the 17 accessions (A3, B3, B5, C1, C2, and C3) had brown beans, while the others had yellow beans. However, this characteristic is not considered reliable for varietal differentiation, as it may change during moisture reduction and post-harvest processing. Liberica coffee variants also exhibited variations in fruit shape, including rounded and obovate forms. (Table 2; Figure 5). Notably, rounded fruits do not always produce a rounded bean shape, and an obovate fruit does not always yield an elliptic bean shape. For example, the B3 accession had an obovate fruit shape but a rounded bean. Similarly, some fruits with a rounded shape produced an elliptic bean shape. *Coffea liberica* var. *liberica* is typically associated with an elliptic bean shape, while *Coffea liberica* var. *dewevrei* is known for its rounded bean (Lagman, 2023; Sanchez et al., 2018). The *C. liberica* variety examined in this study display rounded and elliptical bean shapes, suggesting the possibility that these variants may be the hybrids of *liberica* and *dewevrei* types. However, previous research indicates that crossing *Coffea liberica* var. *liberica* with *Coffea liberica* var. *dewevrei* yields fertile offspring. Therefore, the variation in bean shape observed in *C. liberica* from Kalipuro is likely the result of hybridisation between the two varieties.

One of the notable traits in coffee plants is the fruit disc—the point of flower attachment, which varies among coffee plants. The disc shape found in the Liberica coffee variant in the Kalipuro Sub-district included: (1) small diameter with small protrusions, (2) large diameter with small protrusions, (3) large diameter with very prominent protrusions, (4) small diameter that was flat or not prominent, and (5) large diameter that was flat or not prominent (Table 2). The C4 and D5 accessions exhibited discs with large diameters and small protrusions, as well as large, very prominent discs. In contrast, most other accessions present fruit discs with small diameters and small protrusions. Accession A3 was found to have a distinctly large, very prominent disc. Notably, a large disc diameter does not always correspond with prominent protrusions, as seen in accession B3.

Table 2
Qualitative morphology of fruit and beans

Accession	Fruit Colour	Bean Colour	Fruit Shape	Bean Shape	Disc Shape
A1	Red	Yellow	rounded	elliptic	Small diameter, small protrusion
A2	Red	Yellow	obovate	elliptic	Small diameter, small protrusion
A3	Red	Brown	rounded	rounded	Large diameter very prominent
A4	Red	Yellow	rounded	elliptic	Small diameter, small protrusion
A5	Red	Yellow	obovate	elliptic	Small diameter, flat; small diameter, small protrusion

Table 2 (*continued*)

Accession	Fruit Colour	Bean Colour	Fruit Shape	Bean Shape	Disc Shape
B1	Red	Yellow	obovate	elliptic	Small diameter, flat; small diameter, small protrusion
B3	Red	Brown	obovate	rounded	Large diameter, small protrusion; large diameter, very prominent
B5	Red	Brown	rounded	rounded	Small diameter, small protrusion
C1	Red	Brown	rounded	elliptic	Small diameter, small protrusion
C2	Red-orange	Brown	rounded	rounded	Small diameter, small protrusion
C3	Red	Brown	rounded	elliptic	Small diameter, small protrusion
C4	Red-orange	Yellow	obovate	elliptic	Large diameter, very prominent; large diameter, small protrusion
C5	Red	Yellow	obovate	elliptic	Small diameter, very prominent; large diameter, very prominent
D2	Red	Yellow	rounded	rounded	Small diameter, small protrusion
D3	Red	Yellow	rounded	elliptic	Small diameter, small protrusion
D4	Red	Yellow	rounded	rounded	Small diameter, small protrusion
D5	Red	Yellow	rounded	rounded	Large diameter, small protrusion; large diameter, very prominent

The fruit volume of *C. liberica* ranged from 2.08 to 4.17 cm^3, with an average of 2.78 cm^3 (Table 3). Compared to a previous study (N'Diaye et al*.,* 2005) conducted in native populations in Africa, the Liberica coffee cherries from the Kalipuro Sub-district population can be grouped as suspected *Coffea liberica* var. *dewevrei*. The fruit shape index ranged from 0.16-1.52, with an average of 1.08. Quantitative measurements also showed variation in bean volume: hard skin (HS) bean volume ranged from 0.44 to 0.80 cm^3 (average 0.60 cm^3), while green bean volume ranged from 0.07 to 0.68 cm^3 (average 0.41 cm^3). The HS shape index ranged from 1.28 to 1.81 (average o1.44), and the green bean shape index ranged from 1.30 to 2.06 (average 1.51). The Liberica coffee variant is known to have thicker fruit flesh compared to other commercial coffee plants. This study revealed that fruit flesh thickness ranged from 0.71 to 1.42 mm. The thinnest was found in accession B5 (0.71 ± 0.30 mm), while the thickest was observed in accession A2 (1.42 ± 0.41 mm).

Morphological Variation of *Coffea liberica* Flower

Coffee flowers are arranged in the axils between internodes, with white petals and attached stamens. Generally, each flower has five petals and stamens, though some flowers have six, and rarely eight. However, Liberica coffee in this study showed 5 to 6 petals and stamens (Figure 5), with the number of petals equal to the number of stamens in all flowers observed.

Table 3
Quantitative morphology of fruit and beans

Accession	Fruit Weight (g)	HS Weight	Green Bean Weight	Fruit Flesh Thickness (mm)	Fruit Volume (cm^3)	Fruit Shape Index	HS Volume (cm^3)	HS Shape Index	Green Bean Volume (cm^3)	Green Bean Shape Index
A1	2.50±0.40	0.35±0.05	0.26±0.04	0.92±0.24	3.41±0.64	1.10±0.09	0.67±0.09	1.56±0.11	0.37±1.55	1.55±0.12
A2	1.53±0.24	0.35±0.05	3.01±0.04	1.42±0.41	2.22±0.33	1.12±0.07	0.51±0.08	1.44±0.10	0.07±1.39	1.39±0.08
A3	1.41±0.36	0.65±3.27	0.25±0.03	0.86±0.94	2.61±0.57	1.03±0.08	0.45±0.06	1.31±0.06	0.37±1.30	1.30±0.08
A4	1.35±0.28	0.31±0.03	0.24±0.03	0.73±0.21	2.24±0.50	1.15±0.09	0.44±0.07	1.41±0.14	0.38±1.42	1.42±0.07
A5	1.84±0.32	0.40±0.05	0.30±0.03	0.76±0.16	2.85±0.56	1.12±0.10	0.62±0.08	1.42±0.10	0.27±1.46	1.46±0.16
B1	1.59±0.34	0.37±0.06	0.27±0.05	0.90±0.29	2.20±0.56	1.08±0.11	0.56±0.09	1.34±0.08	0.43±1.35	1.35±0.15
B3	2.31±0.60	0.59±0.06	0.45±0.05	0.86±0.18	3.32±0.96	1.12±0.11	0.84±0.09	1.37±0.09	0.68±1.36	1.36±0.07
B5	2.02±0.23	0.44±0.04	0.30±0.03	0.71±0.30	2.56±0.43	1.11±0.09	0.59±0.06	1.52±0.09	0.46±1.51	1.51±0.16
C1	2.74±0.46	0.52±0.07	0.38±0.05	1.06±0.19	4.17±0.78	1.13±0.09	0.61±0.07	1.49±0.11	0.60±1.49	1.49±0.10
C2	2.64±0.46	0.53±0.08	0.39±0.05	0.85±0.23	3.51±0.72	0.99±0.10	0.80±0.11	1.51±0.10	0.61±1.36	1.36±0.08
C3	1.96±0.29	0.42±0.06	0.33±0.05	0.94±0.21	2.78±0.42	1.22±0.10	0.74±0.09	1.38±0.07	0.49±1.57	1.57±0.12
C4	1.27±0.27	0.33±0.04	0.26±0.03	0.92±0.26	2.08±0.60	1.52±0.16	0.49±0.99	1.31±0.21	0.38±1.88	1.88±0.21
C5	1.68±0.48	0.41±0.04	0.32±0.03	0.95±0.29	2.53±0.92	1.35±0.13	0.59±0.13	1.81±0.27	0.50±1.81	1.81±0.12
D2	1.72±0.47	0.41±0.07	0.33±0.06	0.94±0.16	2.67±0.77	0.16±0.01	0.48±0.06	1.35±0.11	0.07±1.46	1.46±0.09
D3	2.04±0.33	0.39±0.05	0.30±0.05	0.79±0.23	2.40±0.69	1.07±0.07	0.60±0.10	1.47±0.08	0.47±1.50	1.50±0.14
D4	2.12±0.34	0.41±0.07	0.33±0.06	0.87±0.19	2.87±0.47	0.97±0.05	0.57±0.10	1.54±0.11	0.51±1.25	1.25±0.07
D5	1.52±0.37	0.39±0.04	0.30±0.04	0.76±0.19	2.92±0.53	1.08±0.06	0.61±0.11	1.28±0.06	0.28±2.06	2.06±0.26
Average	**1.90 ±0.45**	**0.43±0.09**	**0.44±0.6**	**0.90 ±0.16**	**2.78±0.55**	**1.08±0.27**	**0.60±0.11**	**1.44±0.13**	**0.41±0.17**	1.51±0.22

Note. HS=hard skin

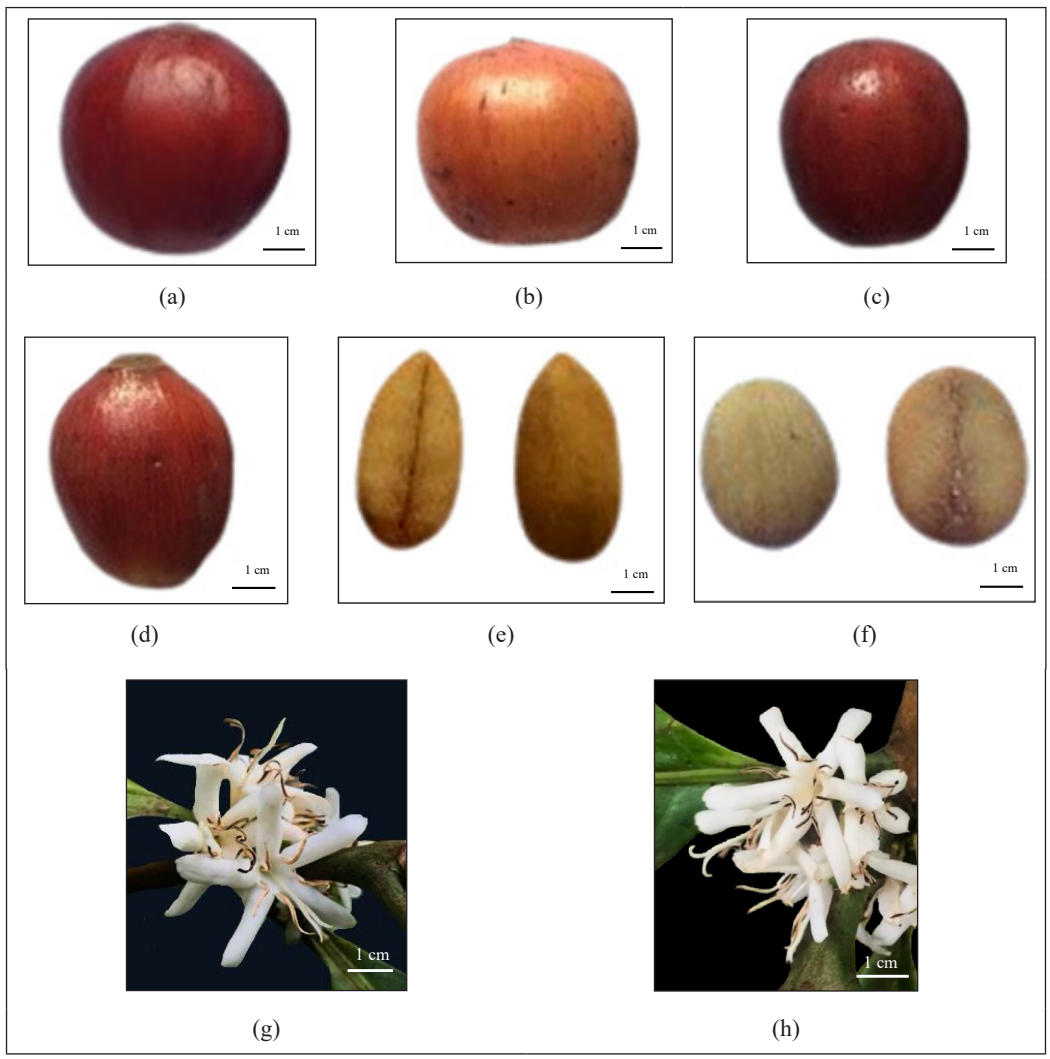

Figure 5. Coffea liberica generative traits: a. red fruit colour; b. red-orange fruit colour; c. rounded fruit shape; d. obovate fruit shape; e. yellow-elliptic bean; f. brown-rounded bean; g. flower with five petals; h. flower with six petals

The number of flowers per inflorescence ranged from 9 to 26 flowers, and inflorescent stalk lengths across the 17 *C. liberica* coffee accessions ranged from 0.30 cm to 0.60 cm, indicating variability. However, these traits could not serve as distinguishing characteristics among Liberica variants. Based on comparison with the findings of N'Diaye et al. (2005), the Liberica coffee variant from Kalipuro Sub-district is suspected to be var. *dewevrei,* based on the number of flowers/inflorescence. However, the number of flowers/inflorescence in the Liberica variants from Kalipuro Sub-district was higher than that reported in the previous study.

Based on the interpretation of all traits, the Liberica coffee variants can be grouped based on key characters that significantly distinguish them from those reported in the previous study (Table 4). Additionally, bean shapes (Table 2) serve as an important trait for distinguishing Liberica variants, as illustrated in the dendrogram (Figure 6). Using Jaccard's similarity coefficient of 0.7, the 17 *C. liberica* accessions from Kalipuro Sub-district were closely similar to *C. liberica* var. *dewevrei* and known to be distinct from *C. liberica* var. *liberica*.

Apomorphy is an evolutionary novelty that arises in a particular lineage, which can be either synapomorphies (shared among multiple accessions) or autapomorphies (unique to a single accession), providing valuable information for determining phylogenetic relationships (Choudhuri, 2014; Wiley & Lieberman, 2011). Autapomorphy refers to a unique trait found only in a single taxon that does not appear in another taxon, serving as a distinctive marker for taxonomic identification. Using this framework, accession C1 formed a separate subclade due to its larger fruit volume, representing an autapomorphy. This trait supports the distinct position of C1 in the dendrogram. Meanwhile, shared derived characters identified in the *C. liberica* var. *dewevrei* clusters include a leaf surface index > 200 cm², a leaf shape index ≤ 2.2, and more than three flowers per inflorescence. These traits help define the cluster but are not used for differentiating individual accessions.

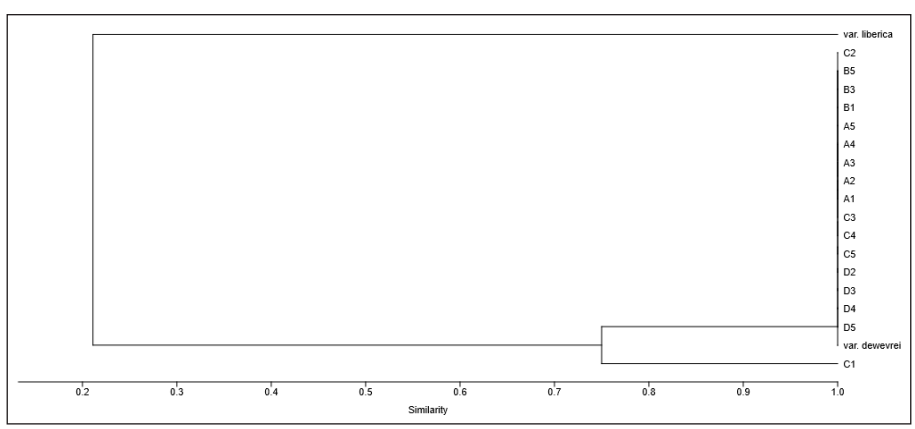

Figure 6. Coffea liberica dendrogram based on morphological traits using Jaccard's similarity

DISCUSSION

The variations in qualitative and quantitative traits are influenced by several factors, including the environment, genotypes, and possible interactions between the two factors (Martono, 2017). The relationships among coffee morphological traits are also influenced by several agronomic trait expressions, which produce heterogeneous effects when combined with inter- or intra-species occurrences (Kusolwa et al., 2019).

Table 4
Morphological comparison of C. liberica *found in Kalipuro Sub-district in comparison to a previous study*

	***C. liberica* variants**																	***C. liberica* Reference (N'Diaye et al., 2005)**	
Accession	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B3**	**B5**	**C1**	**C2**	**C3**	**C4**	**C5**	**D2**	**D3**	**D4**	**D5**	***var. liberica***	***var. dewevrei***
Leaf surface index (cm^2)	615.79 ± 139.99	625.65 ± 134.75	568.16 ± 147.69	467.84 ± 123.59	569.66 ± 69.19	612.8 ± 66.73	721 ± 123.52	485.69 ± 112.11	480.39 ± 122.97	432.13 ± 99.22	570.85 ± 50	313.79 ± 34.23	587.66 ± 44.24	482.59 ± 84.05	606.47 ± 174.86	592.62 ± 23.16	479.67 ± 42.3	131.20 (66.00-226.20)	218.20 (111.60-307.40)
Leaf shape index	2.05 ± 0.16	1.79 ± 0.06	2.45 ± 0.21	1.87 ± 0.24	1.69 ± 0.11	1.95 ± 0.09	2.12 ± 0.14	2.07 ± 0.1	1.88 ± 0.42	2.01 ± 0.23	1.69 ± 0.15	2.15 ± 0.2	2.23 ± 0.17	2.05 ± 0.13	2.28 ± 0.24	2.07 ± 0.18	1.9 ± 0.11	2.40 (1.90-2.80)	2.20 (1.70-2.70)
Number of Flowers/ inflorescences	16	13.60	13.80	8.60	10.60	17.60	16.20	20.80	22.60	15.20	16.60	9.20	9.80	13.60	26	19.60	20.40	2.90 (1.20-4.60)	3.30 (2.20-6.90)
Fruit volume (cm^3)	3.41 ± 0.64	2.22 ± 0.33	2.61 ± 0.57	2.24 ± 0.5	2.85 ± 0.56	2.2 ± 0.56	3.32 ± 0.96	2.56 ± 0.43	4.17 ± 0.78	3.51 ± 0.72	2.78 ± 0.42	2.08 ± 0.6	2.53 ± 0.92	2.67 ± 0.77	2.40 ± 0.69	2.87 ± 0.47	2.92 ± 0.53	4.00 (2.00-6.60)	2.90 (1.10-4.30)

Source: N'Diaye et al. (2005)

Adaptation of plants to environmental conditions influences the insertion angle between the trunk and the branch, leading to different branch growth directions. Coffee plantations with agroforestry systems generally apply multi-strata plants that serve as shade plants, affecting the light intensity captured by plants. Adaptation to shade or tree canopies is exemplified by the unique type "A" branch. Plants grown in shade-intolerant conditions will branch out towards light to increase light absorption by optimising the photosynthesis rate, as light is an important factor in photosynthesis (Ruberti et al., 2012). The direction of plant growth will generally lead to a source of sunlight (phototropism). Through phototropic responses, plants can reorient their growth direction toward or away from the light source to optimise photosynthetic light capture in the aerial portion (Liscum et al., 2014).

The leaf colour variations are also influenced by the canopy shade, affecting the light absorption efficiency by leaves (Yustiningsih, 2019). As shading increases, leaf brightness decreases. This change in leaf colour correlated with an increase in chlorophyll concentration (Brand, 1997; Kurniawan et al., 2021). Meanwhile, in the lower plants, the leaf colour of plants grown under intense light showed the darkest leaf colour compared to those under intense canopy (Rezai et al., 2018). Under low light intensity, chloroplasts concentrate on the sides of the cell walls, farthest from the light, causing leaves in shaded conditions to appear greener (Kisman et al., 2007). In such conditions, plants showed shade tolerance and avoidance strategies. Shade tolerance responses include increased chlorophyll content, specific leaf area, and photosystem II:I ratio, along with a decreased chlorophyll a:b ratio (Charrier, 2021; Wu et al., 2017).

The differences in the quantitative morphological traits in Kalipuro Sub-district differs from the previous study by N'Diaye et al. (2005) regarding the results of measurements on the original population of the Liberica coffee variants. Regarding the leaf size of *C. liberica*, the adaptive response of plants to specific conditions leads the plants to create smaller and narrower leaves to reduce evaporation (Morais et al., 2004). A previous study by Pompelli et al. (2012) also stated that Arabica coffee plants with full sun conditions have smaller leaves, enabling an increase in the effectiveness of cooling under conditions of high light intensity. Regarding leaf morphological variations, previous studies also mentioned that Liberica coffee variants have a round, elongated leaf shape (Santos & Cao, 2020; Udarno & Setiyono, 2015). Leaf margin in this research aligns with previous research (Baltazar & Buot, 2019), revealing that both variants have entire leaf margins and undulate features. Variations in leaf shape are caused by genetic control, while environmental factors are crucial for the final adjustment of the leaf shape (Dkhar & Pareek, 2014).

Shaded conditions also reduce temperature, which slows down the fruit ripening process. In addition, fertilisation factors affect bean size, weight, and organoleptic quality through the accumulation of fats and carbohydrates (Bote & Vos, 2017). Natural adaptive strategies influence fruit colour, shape, and size variation. Fruit shape is correlated with

the direction, period of cell division, and expansion, influencing fruit shape and ovary size (Wang et al., 2022). Genetic regulation also controls fruit shape and represents a quantitative trait involving complex interactions among multiple genes and environmental factors. The environmental factors influencing the fruit include temperature, light, and humidity (Liu et al., 2024). The coffee fruit and bean present various morphological shapes among coffee species and varieties. *Coffea liberica* var. *liberica* has an elliptic shape and is longer and wider than *C.liberica* var. *dewevrei* (Sanchez et al., 2018). *Coffea liberica* var. *dewevrei* in the Kalipuro Sub-District has a smaller bean size compared to *C. liberica* var. *liberica*, which aligns with the previous study by Lagman (2023), who stated that *C. liberica* var. *dewevrei* has a smaller and less elongated bean. The coffee yield is also influenced by the number of primary branches and internode distances in coffee plants, affecting coffee productivity (Martono, 2017).

The number of flowers per inflorescence determines the maximum number of fruits. However, a successful fruit set depends on effective pollination and environmental conditions (Centeno-Alvarado et al., 2024; Klein et al., 2003). The environmental factors affecting flowering are rainfall, water supply (Charrier & Berthaud, 1985), and photoperiod (Unigarro et al., 2023). High rainfall intensity caused coffee flowers to fall off, potentially decreasing the number of flowers per inflorescence. High rainfall intensity interferes with the pollen transfer process, thus hampering the reproductive process of flowering plants (Lawson & Rands, 2019). Genetic factors also influence plant flowering. The *MIKC1* gene is suspected to regulate the number of inflorescences by increasing inflorescences per branch and promoting flower production (Xu et al., 2024). Flower quantification in coffee plants is influenced by photoperiod in the equator region. Water supply and temperature also significantly influence flowering and fruit ripening. The coffee flowers develop from serial buds and are grouped in inflorescences located in the axils of plagiotropic branches. Floral structure can vary among genotypes within the same species (Silva et al., 2024).

The morphological variations in coffee, especially Liberica coffee, are strongly affected by environmental factors. The morphological variation of the Liberica coffee in the Kalipuro Sub-district can be clustered as *C. liberica* var. *dewevrei*, based on key characters, referred to the original African population of Liberica coffee described by N'Diaye et al. (2005), and bean shape as an important character. The clustered *C. liberica* var. *dewevrei* from Kalipuro Sub-district reveals a potential variation from its group (C1), based on fruit volume as an autapomorphy. However, this study cannot state that C1 is a new variant of *C. liberica* var. *dewevrei* from Kalipuro Sub-district due to the small sample population size. Further research with a larger sample population is required to confirm the findings. Inconsistencies in several qualitative morphological traits were considered insignificant for comparing variants, highlighting the need for an in-depth molecular study to confirm the taxonomic position of *C. liberica*. The high similarity of *C. liberica* morphological

traits can be influenced by the origin of the planted seeds. In addition, environmental factors are believed to strongly influence changes in plant morphology as adaptations to surrounding conditions; consequently, such morphological changes are often considered to be plastic in nature. Considering the introduction of Liberica coffee in Java Island, including on the east slope of Ijen, which occurred a hundred years ago, environmental influences may lead to variations and speciation, considering the evolution of *C. liberica*. Therefore, a comprehensive study of molecular variations must be conducted to confirm the morphological variations.

CONCLUSION

The study revealed that, morphologically, Liberica coffee in Kalipuro Sub-district is more closely related to *C. liberica* var. *dewevrei* compared to *C. liberica* var. *liberica*. Morphological analyses included measurement of quantitative traits (leaf surface and shape index, number of flowers per inflorescence, fruit volume) and qualitative traits (bean shape) followed by coding of character states into binary data, and dendrogram construction using Jaccard's similarity index and UPGMA clustering. Apomorphy, particularly autapomorphy, was applied to identify unique traits among individual accessions. Among all traits, fruit volume showed as the most distinctive characteristic for differentiating accessions, allowing C1 to be recognised as a potential new variant of *Coffea liberica* var. *dewevrei*; however, further in-depth study is required to conduct a valid and reliable identification. Due to the presence of numerous shared traits, differentiating these varieties remains complex, and additional genetic studies are necessary to confirm the taxonomic status of Liberica coffee.

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REFERENCES

Ayalew, B. (2018). Impact of shade on morpho-physiological characteristics of coffee plants, their pests and diseases: A review. *African Journal of Agricultural Research*, *13*(39), 2016-2024. https://doi.org/10.5897/AJAR2018.13408

Baltazar, A. M. P., & Buot, I. E. (2019). Short communication: Leaf architectural analysis of taxonomic confusing coffee species: *Coffea liberica* and *Coffea liberica* var. *dewevrei*. *Biodiversitas*, *20*(6), 1560-1567. https://doi.org/10.13057/biodiv/d200611

Banyuwangikab. (2022a). *Profil daerah Banyuwangi: Geografi* [Banyuwangi regional profile: Geography]. https://www.banyuwangikab.go.id/profil-daerah/geografi

Banyuwangikab. (2022b). *Profil daerah Banyuwangi: Geologi* [Banyuwangi regional profile: Geology]. https://www.banyuwangikab.go.id/profil-daerah/geologi

Bote, A. D., & Vos, J. (2017). Tree management and environmental conditions affect coffee (*Coffea arabica* L.) bean quality. *NJAS - Wageningen Journal of Life Sciences*, *83*, 39-46. https://doi.org/10.1016/j.njas.2017.09.002

BPS Indonesia. (2024). *Statistik kopi Indonesia 2023* [Indonesian coffee statistics 2023] (Vol. 8). Badan Pusat Statistik.

Brand, M. H. (1997). Shade influence plant growth, leaf colour and chlorophyll content of *Kalmia latifolia* L. cultivars. *HortScience*, *32*(2), 206-208. https://doi.org/10.21273/HORTSCI.32.2.206

Centeno-Alvarado, D., Lopes, A. V., & Arnan, X. (2024). Shaping pollinator diversity through coffee agroforestry management: A meta-analytical approach. *Insect Conservation and Diversity*, *17*(5), 729-742. https://doi.org/10.1111/icad.12755

Charrier, A., & Berthaud, J. (1985). Botanical classification of coffee. In R. J. Clarke & R. Macrae (Eds.), *Coffee: Botany, biochemistry, and production of beans and beverage* (pp. 13-47). Springer. https://doi.org/10.1007/978-1-4615-6657-1_2

Charrier, G. (2021). Perceiving neighbours to anticipate the struggle for light. *Plant Physiology*, *186*(4), 1760-1761. https://doi.org/10.1093/plphys/kiab260

Choudhuri, S. (2014). Fundamentals of molecular evolution. In S. Choudhuri (Ed.), *Bioinformatics for beginners* (pp. 27-53). Academic Press. https://doi.org/10.1016/B978-0-12-410471-6.00002-5

Davis, A. P., Tosh, J., Ruch, N., & Fay, M. F. (2011). Growing coffee: *Psilanthus* (Rubiaceae) subsumed on the basis of molecular and morphological data: Implications for the size, morphology, distribution, and evolutionary history of *Coffea*. *Botanical Journal of the Linnean Society*, *167*(4), 357-377. https://doi.org/10.1111/j.1095-8339.2011.01177.x

Direktorat Jendral Perkebunan of Indonesia. (2019). *Pembangunan perkebunan 2019: Laporan tahunan* [Plantation development 2019: Annual report]. http://ditjenbun.ppid.pertanian.go.id/doc/16/FA_Lap.Tahunan%20PERKEBUNAN%202019_fix_(03-04-2020)_LOW.pdf

Direktorat Jendral Perkebunan of Indonesia. (2021). *Statistik perkebunan non unggulan nasional 2020-2022* [National non-priority plantation statistics 2020-2022]. Sekretariat Direktorat Jendral Perkebunan.

Dkhar, J., & Pareek, A. (2014). What determines a leaf's shape? *EvoDevo*, *5*(1), Article 47. https://doi.org/10.1186/2041-9139-5-47

Hakim, L., Rahardi, B., Guntoro, D. A., & Mukhoyyaroh, N. I. (2022). Coffee landscape of Banyuwangi Geopark: Ecology, conservation, and sustainable tourism development. *Journal of Tropical Life Science*, *12*(1), 107-116. https://doi.org/10.11594/jtls.12.01.11

Hickey, M., & King, C. (2000). *The Cambridge illustrated glossary of botanical terms*. Cambridge University Press.

IPGRI. (1996). *Descriptors for coffee (Coffea spp. and Psilanthus spp.)*. International Plant Genetic Resources Institute. https://www.bioversityinternational.org/e-library/publications/detail/descriptors-for-coffee-coffea-spp-and-psilanthus-spp/

Kisman, Khumaida, N., Trikoesoemaningtyas, Sobir, & Sopandie, D. (2007). Karakter morfo-fisiologi daun, pendiri adaptasi kedelai terhadap intensitas cahaya rendah [Morpho-physiological characters of leaves, supporting soybean adaptation to low light intensity]. *Buletin Agronomi*, *35*(2), 96-102.

Klein, A. M., Steffan-Dewenter, I., & Tscharntke, T. (2003). Fruit set of highland coffee increases with the diversity of pollinating bees. *Proceedings of the Royal Society B: Biological Sciences*, *270*(1518), 955-961. https://doi.org/10.1098/rspb.2002.2306

Kurniawan, N. S. H., Kirana, I. A. P., Abidin, A. S., Jupri, A., Widyastuti, S., Hernawan, A., Nikmatullah, A., Sunarpi, H., & Prasedya, E. S. (2021). Analysis of leaf chlorophyll content of paddy plants during vegetative stage grown in soil media containing macroalgae organic fertiliser. *IOP Conference Series: Earth and Environmental Science*, *913*(1), Article 012025. https://doi.org/10.1088/1755-1315/913/1/012025

Kusolwa, P. M., Makwinja, F., Nashon, J., Marianna, M., & Kibola, A. (2019). Morphological diversity of wild coffee (*Coffea kihansiensis*) a potential coffee species for genetic improvement. *Tanzania Journal of Science*, *45*(4), 629-649. https://doi.org/10.65085/2507-7961.1677

Lagman, M. C. A. (2023). Variability in Philippine *Coffea liberica* provides insights into development amidst a changing climate. *Proceedings*, *89*(1), Article 27. https://doi.org/10.3390/ICC2023-14852

Lawson, D. A., & Rands, S. A. (2019). The effects of rainfall on plant-pollinator interactions. *Arthropod-Plant Interactions*, *13*(4), 561-569. https://doi.org/10.1007/s11829-019-09686-z

Liscum, E., Askinosie, S. K., Leuchtman, D. L., Morrow, J., Willenburg, K. T., & Coats, D. R. (2014). Phototropism: Growing towards an understanding of plant movement. *The Plant Cell*, *26*(1), 38-55. https://doi.org/10.1105/tpc.113.119727

Liu, J., Xu, Y., Fang, P., Guo, Q., Huang, W., Hou, J., Wan, H., & Zhang, S. (2024). Genetic regulation of fruit shape in horticultural crops: A review. *Horticulturae*, *10*(11), Article 1151. https://doi.org/10.3390/horticulturae10111151

Martono, B. (2017). Performance of the selected main tree of liberoid coffee in the peatland of Meranti Island, Riau. *Journal of Wetlands Environmental Management*, *5*(1), 32-38. https://doi.org/10.20527/jwem.v5i1.126

Morais, H., Medri, M. E., Marur, C. J., Caramori, P. H., De Arruda Ribeiro, A. M., & Gomes, J. C. (2004). Modifications on leaf anatomy of *Coffea arabica* caused by shade of pigeonpea (*Cajanus cajan*). *Brazilian Archives of Biology and Technology*, *47*(6), 863-871. https://doi.org/10.1590/S1516-89132004000600005

Mukhoyyaroh, N. I., Azrianingsih, R., & Hakim, L. (2024). Ecological factors and morphological traits of *Coffea liberica* Hiern in Kalipuro District, Banyuwangi Regency. *Plant Science Today*, *11*(2), 263-272. https://doi.org/10.14719/pst.2939

N'Diaye, A., Poncet, V., Louarn, J., Hamon, S., & Noirot, M. (2005). Genetic differentiation between *Coffea liberica* var. *liberica* and *C. liberica* var. *dewevrei* and comparison with *C. canephora*. *Plant Systematics and Evolution*, *253*(1-4), 95-104. https://doi.org/10.1007/s00606-005-0300-1

Pompelli, M. F., Pompelli, G. M., Cabrini, E. C., Arruda, E. C., Ventrella, M. C., & DaMatta, F. M. (2012). Leaf anatomy, ultrastructure and plasticity of *Coffea arabica* L. in response to light and nitrogen availability. *Biotemas*, *25*(4), 13-28. https://doi.org/10.5007/2175-7925.2012v25n4p13

Ramadiana, S., Hapsoro, D., & Yusnita, Y. (2018). Morphological variation among fifteen superior Robusta coffee clones in Lampung Province, Indonesia. *Biodiversitas*, *19*(4), 1475-1481. https://doi.org/10.13057/biodiv/d190438

Rezai, S., Etemadi, N., Nikbakht, A., Yousefi, M., & Majidi, M. M. (2018). Effect of light intensity on leaf morphology, photosynthetic capacity, and chlorophyll content in sage (*Salvia officinalis* L.). *Horticultural Science and Technology*, *36*(1), 46-57. https://doi.org/10.12972/kjhst.20180006

Ruberti, I., Sessa, G., Ciolfi, A., Possenti, M., Carabelli, M., & Morelli, G. (2012). Plant adaptation to dynamically changing environment: The shade avoidance response. *Biotechnology Advances*, *30*(5), 1047-1058. https://doi.org/10.1016/j.biotechadv.2011.08.014

Sanchez, J. C. S., Quilang, J. P., Mojica, R. M., & Cao, E. P. (2018). Interspecific and intraspecific variation in *Coffea* sp. using fruit metric and landmark-based geomorphometric analyses. *Philippine Journal of Science*, *147*(4), 659-665.

Santos, D. M. C., & Cao, E. P. (2020). SSR analysis of *Coffea liberica* var. *liberica* and *Coffea liberica* var. *dewevrei* in the Philippines. *Philippine Agricultural Scientist*, *103*(4), 357-361. https://doi.org/10.62550/CY7026019

Silva, L. O. E., Rodrigues, M. J. L., Almeida, R. N., Semedo, J. N., Rakocevic, M., & Partelli, F. L. (2024). Towards a minimum number of key flower traits in studies of *Coffea* spp. phenotype variability. *Scientia Horticulturae*, *337*, Article 113513. https://doi.org/10.1016/j.scienta.2024.113513

Tjitrosoepomo, G. (2011). *Morfologi tumbuhan* [Plant morphology]. Gadjah Mada University Press.

Udarno, M. L., & Setiyono, R. T. (2015). Penampilan kopi excelsa hasil eksplorasi di Kabupaten Kepulauan Meranti, Riau [Performance of excelsa coffee from exploration in Meranti Islands Regency, Riau]. *Jurnal Masyarakat Biodiv Indonesia*, *1*(3), 543-547. https://doi.org/10.13057/psnmbi/m010328

Unigarro, C. A., Imbachi, L. C., Darghan, A. E., & Flórez-Ramos, C. P. (2023). Quantification and qualification of floral patterns of *Coffea arabica* L. in Colombia. *Plants*, *12*(18), Article 3332. https://doi.org/10.3390/plants12183332

Walyaro, D. J. (2006). *Fourth consultancy report on crop improvement coffee research & technology support programme*. TaCRI, Lyamungu, Tanzania Funded by European Development Fund.

Wang, C., Cao, J., Hao, N., & Wu, T. (2022). Genetic and molecular regulation mechanisms in the formation and development of vegetable fruit shape. *Applied Sciences*, *12*(3), Article 1514. https://doi.org/10.3390/app12031514

Wei, J., Guo, T., Mu, Q., Alladassi, B. M. E., Mural, R. V., Boyles, R. E., ... & Yu, J. (2025). Genetic and environmental patterns underlying phenotypic plasticity in flowering time and plant height in sorghum. *Plant, Cell, & Environment*, *48*(4), 2727-2738. https://doi.org/10.1111/pce.15213

Wiley, E. O., & Lieberman, B. S. (2011). *Phylogenetics: Theory and practice of phylogenetic systematics* (2nd ed.). Wiley-Blackwell. https://doi.org/10.1002/9781118017883

Wu, Y., Gong, W., & Yang, W. (2017). Shade inhibits leaf size by controlling cell proliferation and enlargement in soybean. *Scientific Reports*, *7*(1), Article 9259. https://doi.org/10.1038/s41598-017-10026-5

Xu, G., Liu, Y., Yu, S., Kong, D., Tang, K., Dai, Z., Sun, J., Cheng, C., Deng, C., Yang, Z., Tang, Q., Li, C., Su, J., & Zhang, X. (2024). *CsMIKC1* regulates inflorescence development and grain production in *Cannabis sativa* plants. *Horticulture Research*, *11*(8), Article uhae161. https://doi.org/10.1093/hr/uhae161

Yustiningsih, M. (2019). Intensitas cahaya dan efisiensi fotosintesis pada tanaman naungan dan tanaman terpapar cahaya langsung [Light intensity and photosynthesis efficiency in shaded plants and plants exposed to direct light]. *BIO-EDU: Jurnal Pendidikan Biologi*, *4*(2), 44-49. https://doi.org/10.32938/jbe.v4i2.385

SUPPLEMENTARY DATA

Table S1
Assessment method for Coffea

Plant Organ	Descriptor	Reference	Assessment Method and Scale
Stem	Main branch direction	(IPGRI, 1996)	Observed on main stem; 1 = drooping, 2 = horizontal or spreading, 3 = semi-erect, 4 = other
	Stem diameter	(IPGRI, 1996)	Measured at 5 cm above the soil surface in seedlings and cuttings and 10 cm above the graft union in grafted trees by estimating the age of the tree
Leaf	Young leaf colour	(IPGRI, 1996)	1 = greenish, 2 = green, 3 = brownish, 4 = reddish, 5 = bronze (metallic brown), 6 = other
	Mature leaf colour	(IPGRI, 1996)	Observed on leaves located more than three nodes from the terminal bud; 1 = dark green, 2 = green, 3 = other
	Leaf shape	(IPGRI, 1996)	1 = obovate, 2 = ovate, 3 = elliptic, 4 = lanceolate, 5 = elliptic tending to round
	Leaf tip shape	(IPGRI, 1996)	1 = round, 2 = obtuse, 3 = acute, 4 = acuminate, 5 = apiculate, spatulate, 6 = other
	Stipule shape	(IPGRI, 1996)	1 = round, 2 = ovate, 3 = triangular, 4 = deltate, 5 = trapeziform, 6 = other
	Leaf length	(IPGRI, 1996)	Average of 5 mature leaves (observed on leaves located more than 3 nodes from the terminal bud), measured from petiole to leaf tip
	Leaf width	(IPGRI, 1996)	Average of 5 mature leaves (observed on leaves located more than 3 nodes from the terminal bud), measured at the widest part of the leaf
	Petiole length	(IPGRI, 1996)	Average 5 leaves, measured from the base to the insertion of the leaf blade
	Petal colour	(IPGRI, 1996)	1 = green, 2 = dark brown, 3 = other
Flower	Number of flowers per axil/ inflorescence	(IPGRI, 1996; Walyaro, 2006)	An average of 10 axils, randomly selected from different nodes
	Long inflorescent stalks	(IPGRI, 1996)	An average of 5 inflorescences, randomly selected from different nodes
	Number of petals per flower	(IPGRI, 1996)	An average of 5 flowers, randomly selected from different nodes
	Number of stamens per flower	(IPGRI, 1996)	An average of 5 flowers, randomly selected from different nodes

Table S1 (*continued*)

Plant Organ	Descriptor	Reference	Assessment Method and Scale
Fruit	Fruit colour	(IPGRI, 1996; Walyaro, 2006)	Observed on ripe fruit; 1 = yellow, 2 = yellow-orange, 3 = orange, 4 = reddish-orange, 5 = red, 6 = purplish-red, 7 = purple, 8 = purple-violet, 9 = violet, 10 = black, 11 = other
	Fruit shape	(IPGRI, 1996; Walyaro, 2006)	Average of 5 normally ripe fruit; 1 = round, 2 = obovate, 3 = ovate, 4 = elliptic, 5 = oblong, 6 = other
	Fruit disc shape	(IPGRI, 1996)	Observed at the tip of the cherry; 1 = absent, 2 = present but not prominent, 3 = prominent (cylindrical), 4 = beaked (resembling the shape of a bottleneck)
	Fruit length	(IPGRI, 1996; Walyaro, 2006)	Average of 100 mature fruit, measured at the longest part
	Fruit width	(IPGRI, 1996; Walyaro, 2006)	Average of 100 mature fruit, measured at the widest part
	Fruit thickness	(IPGRI, 1996)	Average of 100 mature fruit, measured at the thickest part
	Flesh thickness	(IPGRI, 1996)	Observation with a scale; 3 = thin, 5 = medium, 7 = thick
Bean	Bean length	(IPGRI, 1996)	Average of 100 mature normal beans, measured at the longest part
	Bean width	(IPGRI, 1996)	Average of 100 mature normal beans, measured at the widest part
	Bean thickness	(IPGRI, 1996)	Average of 100 mature normal beans, measured at the thickest part
	Bean colour	(IPGRI, 1996; Walyaro, 2006)	1 = yellow, 2 = purplish brown, 3 = brown
	Bean shape	(IPGRI, 1996; Walyaro, 2006)	1 = round, 2 = obovate, 3 = ovate, 4 = elliptic, 5 = oblong, 6 = other

Table S2
Qualitative leaf morphology of C. liberica

Accession	Young Leaf Colour	Mature Leaf Colour	Leaf Shape	Leaf Margin	Apex Shape	Stipule Shape	Petiole Colour	Leaf Surface	Venation
A1	reddish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
A2	brownish	dark green	elliptic (slightly rounded)	entire	acuminate	triangular	green	glossy	pinnate
A3	brownish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
A4	brownish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
A5	brownish	dark green	elliptic (slightly rounded)	undulate	acute	triangular	green	glossy	pinnate
B1	brownish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
B3	brownish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
B5	reddish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
C1	brownish green	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
C2	brownish green	dark green	elliptic	entire	acuminate	triangular	green	glossy	pinnate
C3	reddish	dark green	elliptic (slightly rounded)	entire	acute	triangular	green	glossy	pinnate
C4	brownish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
C5	reddish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
D2	brownish	green	elliptic	entire	acuminate	triangular	green	glossy	pinnate
D3	reddish	dark green	elliptic	entire	acuminate	triangular	green	glossy	pinnate
D4	reddish	green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate
D5	reddish	dark green	elliptic	undulate	acuminate	triangular	green	glossy	pinnate