BIODIVERSITAS
Volume 24, Number 5, May 2023
Pages: 3073-3080

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240563

Coffea liberica leaf and tree architecture model of confusing accession in Poncokusumo, Malang District, East Java, Indonesia

ERONA WAFARETTA[1,♥], YOGA DWI JATMIKO[2], WENNY BEKTI SUNARHARUM[3], LUCHMAN HAKIM[2]

[1]Doctoral Program of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia. Tel.: +62-341-575841, ♥email: ewafaretta@gmail.com

[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia

[3]Department of Food Science and Technology, Faculty of Agricultural Technology, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia

Manuscript received: 17 January 2023. Revision accepted: 30 May 2023.

Abstract. *Wafaretta E, Jatmiko YD, Sunarharum WB, Hakim L. 2023.* Coffea liberica *leaf and tree architecture model of confusing accession in Poncokusumo, Malang District, East Java, Indonesia. Biodiversitas 24: 3073-3080.* Some *Coffea liberica* W.Bull varieties appear in the same garden with the same planting pattern in the Poncokusumo. This could be due to differences in tree architecture from one accession to another. This research aims to identify the architectural and morphological characteristics of *C. liberica* stems and leaves and determine differences in coffee variety accession through morphological differences in *C. liberica* plants and leaf architecture. The research was conducted from July 2021 to August 2022 in the *C. liberica* plantation in Poncokusumo Sub-district, Malang District, East Java, Indonesia. The research sample consisted of four *C. liberica* trees from each accession and was carried out in four stages: observation, data/image recording, measurement, and data analysis. This research found: each accession has a different plant architecture model and a different branching model; three accessions appear to have different leaf morphological characters, namely margin type, apex angle, and base angle; dendrogram and PCoA results show that each accession has significant differences. Further research at the genetic level and the effect of abiotic or biotic elements on the growth and development of this coffee tree is necessary to enlighten the *C. liberica* variety's high potential for the growth of this coffee production in the local community.

Keywords: *Coffea liberica*, leaf morphology, morphology characteristic, trees accession, tree architecture model

INTRODUCTION

Coffea liberica W.Bull is grown in low volumes worldwide and has limited influence on international trade, although being capable of being produced in huge quantities in the Philippines, Malaysia, and Indonesia (Davis et al. 2020). *C. liberica* is a species of local coffee that has not been studied much in Indonesia, even though *C. liberica* has uniqueness and advantages compared to other coffee species (Khasanah and Noordwijk 2019). One of the uniqueness and advantages of the *C. liberica* plant is the characteristics of varied growing locations and high survival. *C. liberica* is more adaptable and can grow in the lowlands (Budiman 2012). Although, according to Davis et al. (2022), *C. liberica* grows in an environment with evenly distributed rainfall and relatively high humidity, its resistance tolerance is so high that it can survive even in dry conditions. It grows well at 600-1,000 meters above sea level (Nurdin et al. 2022), which is suitable for the growth and production of *C. liberica* plants (Supriadi et al. 2018). *C. liberica* can grow well in the lowlands and has been developed on peatlands in Jambi (Supriadi et al. 2018; Khasanah and Noordwijk 2019) to mountainous lands (Farohii et al. 2020) even *C. liberica* can also be used as an opportunity for peatland agroforestry conservation in Indonesia (Mawardhi and Setiadi 2018).

The differences in environmental cultivation conditions can affect the characteristics of *C. liberica* plants and leaves. According to Baltazar and Buot (2019), environmental conditions and ecosystems around cultivation greatly influence the shape of this coffee variety. The differences in environmental conditions and land characteristics on the cultivation resulted in the different emergence of the accession of the *C. liberica* plant. Even though the explanation for this *C. liberica* varieties differences is still confusing due to morphological properties, molecular markers, and plant treatment. In addition, accession is defined as an individual or plant population exhibiting certain morphological characteristics and genetic variations that precede the emergence of varieties and are caused by external and internal factors (Bianchi et al. 2020). Coffee is a plant whose growth and development are highly sensitive to environmental conditions, planting/cultivation patterns, climate, shade plants, and the surrounding ecosystem. Coffee's complex growth necessitates more attention to every detail of the surrounding factors to obtain good variants and production (Gomes et al. 2020).

The emergence of plant accessions in *C. liberica* plantations shows the influence of different environmental conditions where *C. liberica* plants are cultivated. The emergence of liberica accession is evidenced by Haniefan and Basunanda's (2022) research in Kalibagor Village, Sukorejo District, Kendal District, Central Java, which found five groups of accession of *C. liberica* plants. Likewise, Sianipar's research (2017) in North Sumatra also showed the emergence of accessions of the 13

morphological characters analyzed which 12 characters had diversity. Meanwhile, the results of field observations at the location of *C. liberica* cultivation in the coffee garden of Jajang Village, Poncokusumo District, also found three dominant accessions of the *C. liberica* plant; the emergence of *C. liberica* plant accessions resulted in plant morphological heterogeneity. According to Farohii et al. (2020), the environmental conditions of a certain place can produce a different morphology of the *C. liberica* plant. The observation from the field shows that *C. liberica* in the gardens of the Kalibagor Village community has various characteristics, so Haniefan and Basunanda (2022) observed 40 existing plant accessions in their research. Physically, the development of the *C. liberica* plant is marked by the appearance of plant morphological accessions. The morphological accession of the *C. liberica* plant is characterized by differences in morphology and tree architecture. According to Hollender and Dardick (2014), the architecture of a tree consists of several components, including the structure of the arrangement of leaves, buds, and fruit, the angle and orientation of the branches, then the diameter of the stem, and the size of the branches.

Plant architecture is currently an exciting area of research because plant architecture is constantly adapting based on the plant genome and the environmental conditions in which plants grow. Environmental factors such as shade, temperature, soil, and so on significantly impact a plant's architectural form (Motisi et al. 2019). The conservation and characterization of conserved accessions are critical for confirming genetic diversity, which is important for bioeconomics and genetic improvement (Bianchi et al. 2020). This research is a case study in which many accessions were discovered in the same plantation, namely the Liberika Coffee Plantation in the Poncokusumo District of Malang District; it could be due to differences in abiotic and biotic factors from one accession to another. Small farmers in Poncokusumo, East Java, rely heavily on coffee as a cash crop. Coffee consumption and appreciation are increasing, making more sustainable coffee growing, and ethnobotanical studies are crucial to assist tourism and conservation development (Hakim 2021). The uniqueness of the *C. liberica* plant and fruit must be explored. Accessions in each plant's cultivation must be studied more deeply to facilitate sorting variants in future coffee cultivation development. Therefore, this research aims to: (i) identify the architectural and morphological characteristics of *C. liberica* stems and leaves and (ii) determine differences in accessions of coffee varieties found in coffee plantations through differences in the morphological characteristics of *C. liberica* plant and leaf architecture.

MATERIALS AND METHODS

Research area

The location of this research is the *C. liberica* plantation located in Poncokusumo District, Malang District, East Java (Figure 1). The research location was based on the opinion of Farohii et al. (2020), who stated that the Poncokusumo area has good characteristics for plantation and agricultural development. Poncokusumo Sub-district has relatively good land character: slightly fine soil texture, moderate slope, 888 meters above sea level altitude, and relatively shallow adequate soil depth. Poncokusumo Sub-district has the potential to integrate coffee-based agroforestry and tourism development due to its ecosystem's physical characteristics (weather, air, water, climate, soil, and topography) and abiotic ecosystems that are suitable for developing coffee-based agroforestry agriculture and agrotourism (Hakim et al. 2019). Furthermore, the land condition is very suitable for coffee plantations, so the Poncokusumo District area has the potential for developing *C. liberica* plantations.

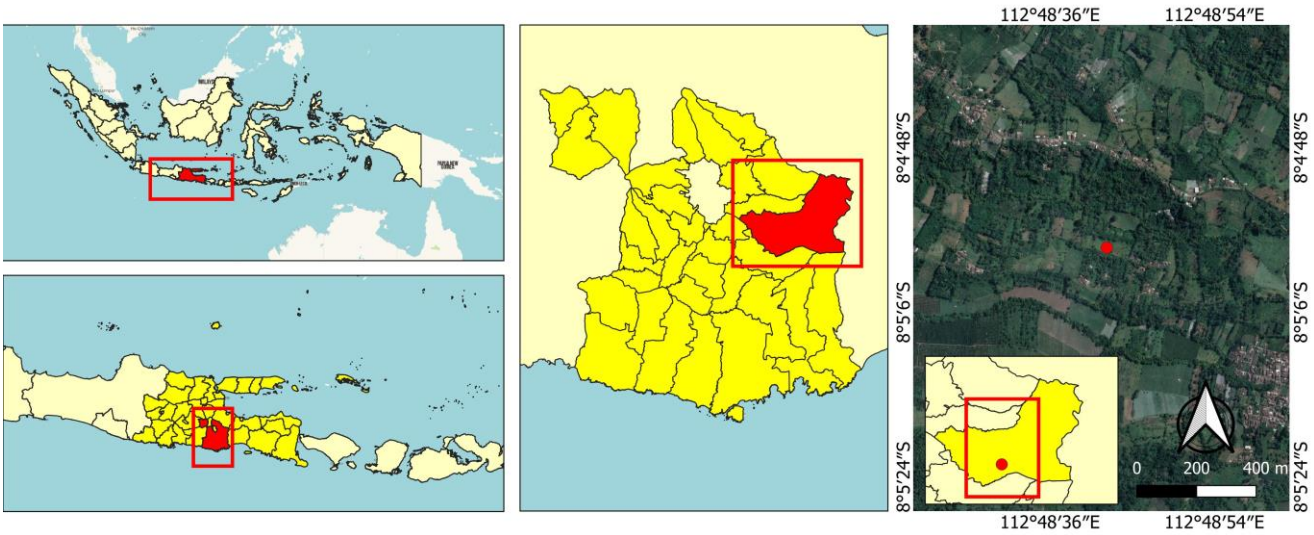

Figure 1. Map of research locations of *Coffea liberica* plantation in Poncokusumo Sub-districts, Malang District, East Java, Indonesia

Data collection

This research was conducted from July 2021-August 2022 and is located at the *C. liberica* plantation in Poncokusumo Sub-district, Malang District, East Java. The research subjects were *C. liberica* plants, and the research sample consisted of several accessions of *C. liberica* plants and leaves that developed in Coffee Gardens, Poncokusumo Sub-district, Malang District. This research was conducted through 3 stages: the first stage of determining accession, the second is the tree and leaves architecture characterization stage, and the third is the measurement stage.

The stage of determining accession was carried out by observing all the *C. liberica* plants in the garden to find coffee plant accessions that were formed based on their morphological observations. Furthermore, determining accession focused on the architectural appearance of trees, branches, and leaves based on Halle et al. (1978) as a plant architecture reference book. Therefore, the observation stage aims to find accession to the dominant *C. liberica* plants in gardens/plantations. Based on the findings of this accession, then the coffee plant samples were determined deliberately using purposive sampling. The number of selected coffee plant samples was four trees for each accession. Finally, samples of the *C. liberica* plant accession were used to identify the architecture of the *C. liberica* plant and leaves.

At the tree and leaves architecture characterization stage, photo documentation/pictures of the garden, plants, branches, and leaves of *C. liberica* were carried out. Image recording is done using a digital camera according to the observed morphology. Images of plants, branches, and leaves were taken, with three images for each accession. Data analysis of branch structure and plant branching was done by analyzing images recorded with a digital camera; the sketching technique was applied to this analysis. Leaf shape analysis was also conducted through images/photos recorded with a digital camera and analyzed through a literature review. At the measurement stage, plant and leaf morphological parameters were measured, which included: (i) characteristic tree parameters, including tree height, tree root circumference, the distance between trees, and branch diameter, and (ii) stem and leaf parameters, including stem structure, branching, leaf shape, leaf length, and leaf width. The tree height, tree stem circumference, the distance between trees, and branch diameter were measured in the garden/plantation using a tape measure, while the leaf length and width were measured using a ruler. Tree and leaf morphology measurements were carried out for each accession with a total sample of 4 trees.

Data analysis

Qualitative and quantitative information was gathered from the leaf and the tree, and each qualitative characteristic was assigned a number value. These values were entered into statistical software to perform cluster and ordination analysis. Therefore, cluster analysis was used to highlight the links between the species and group them into clusters with comparable leaf architectural characteristics. The unweighted paired group average (UPGMA) and the Euclidean similarity index were used in this investigation. The bootstrap value for each calculation was 1000. Additionally, an ordination analysis using Principal Coordinates Analysis (PCoA) was carried out to show how different each Coffee species is from the others. The statistical analysis used Hammer et al. (2001) PAST (Paleontological Statistical Software) software.

RESULTS AND DISCUSSION

Coffea liberica plants in Jajang Village, Poncokusumo Sub-district, are all the same age, seven years. This research's field observations discovered several morphologically distinct *C. liberica* plants. The classification of *C. liberica* in Poncokusumo discovered three types of dominant accessions. The following description includes morphological comparisons of tree architecture and leaf.

***Coffea liberica* tree architecture stem and leaf**

Coffea liberica is a ligneous (tree-shaped) plant. The measurements of three *C. liberica* plant accessions in the Poncokosumo Sub-district revealed differences in tree height and stem circumference (Table 1). The average height of *C. liberica* plants in Jajang Village coffee plantations is 5.20 meters, and the average stem circumference is 30 centimeters. The observations of the *C. liberica* plants revealed differences in tree height and tree stem circumference, with accession 1 reaching a height of 5.63 m, accession 2 reaching a height of 5.23 m, and accession 3 reaching a height of 4.78 m. The *C. liberica* tree is seven years old and grows older and larger than its current height. According to Davis et al. (2022), the *C. liberica* tree can grow 5-11m tall with an average stem of 42cm. The difference in average tree height between accession circumferences is that accession 1 is 5.63 m, accession 2 is 5.23 m, and accession 3 is 4.78 m. Meanwhile, for tree stem circumference, the average length of accession 1 is 34.25 cm, while the average length of accession 2 is 29 cm, and accession 3 is 28.5 cm. Based on these data, it can be observed that the taller the tree, the longer the circumference of the tree stem.

In this research, identifying the stems of the *C. liberica* plant was focused on the architectural model of the plant as seen from the branching model; the main stem, the branching pattern, and the canopy type. *C. liberica* plants from all accessions have the same type of branching: monopodial with virga singularis branches. Virga singularis is a branch's growth direction, grows swiftly with long internodes, and may be created from dormant or wild buds. Because the angle between the stem and the branch is so minimal, the direction of branch growth is only at the base (Tjitrosoepomo 2009). Figure 2 shows three distinct architectural differences in the stems and main branches of the *C. liberica* plant.

Table 1. Morphology and architecture model of *Coffea liberica* tree

Morphology	Accession-1	Accession -2	Accession -3
Tree Height (m)	6,63	5,23	4,78
Stem circumference (cm)	34,25	29,00	28,50
Tree architecture model	Rauh	Massart	Roux
Branching model	Monopodial, Orthotropic	Monopodial, Plagiotropic	Monopodial, Plagiotropic
Branching pattern	Opposite	Opposite	Opposite
Canopy type	Single	Single	Single
Branching properties	Virga singularis	Virga singularis	Virga singularis

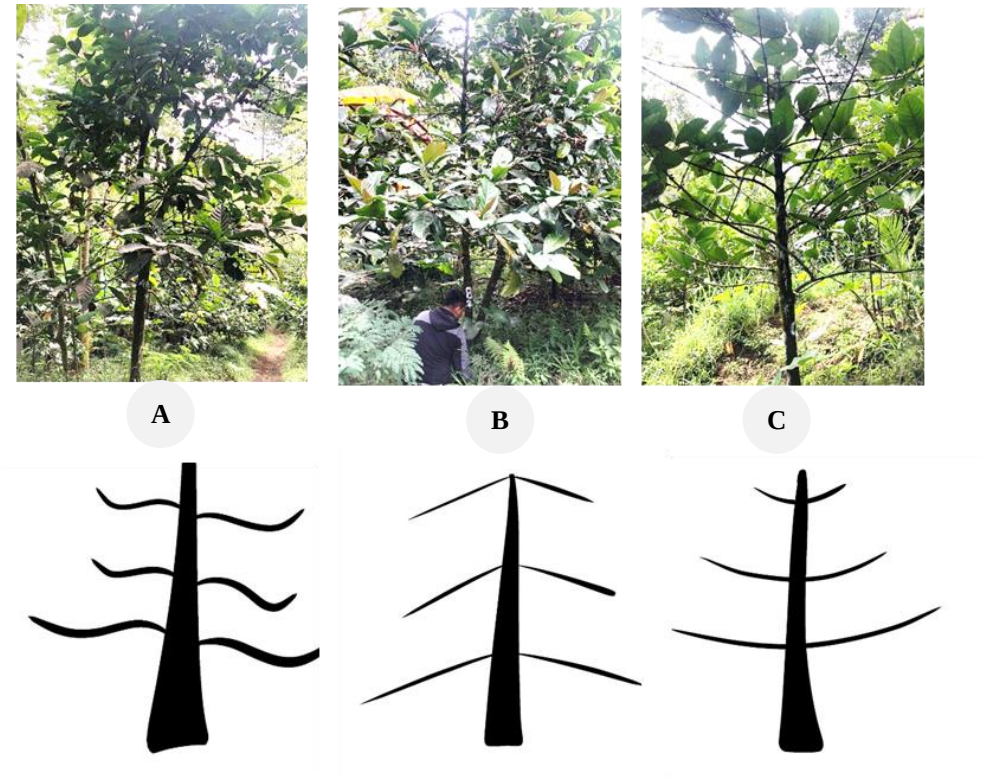

Figure 2. Representative of *Coffea liberica* tree architecture and branches tree (A. Accession-1; B. Accession-2; and C. Accession -3)

The architectural model of Accession 1 is the Rauh plant with orthotropic monopodial branching. The primary branches of the orthotropic structure of the Rauh model are morphogenetically comparable to the stem, and they all exhibit rhythmic growth (Lin et al. 2018). In the Rauh model, monopodium orthotropic branching and rhythmic growth result in low stemflow and interception (Darmayanti and Fiqa 2017). Accession 2 architecture is the Massart branching model with monopodial plagiotropic branching, while Accession 3 architecture is the Roux branching model with monopodial plagiotropic branching. The Massart and Roux models have a plagiotropic structure, monopodial, non-phyllomorphic structure, and continuous growths, with the major branches in the Massart model arranged in whorls (Lin et al. 2018). The Massart model had an orthotropic monopodium main stem, plagiotropic main branch, and branches arranged in a bouquet due to rhythmic growth (Darmayanti and Fiqa 2017). Observations on the main stem found three accessions that showed a real difference in the architectural model of the branching tree, as shown in Figure 2. Even though these three plants have similar branching patterns and canopy types: opposite and single, while opposite or alternate branching patterns were reported, most tree branches were vertical (including inclined) or horizontal. Therefore, when multiple canopy levels exist in a single tree, the canopy type is either single or multiple (Stewart 2011).

Following the architectural model of the *C. liberica* tree, the branching forms of this plant also have significant differences (Figure 3). The shape of the branches on the *C. liberica* plant's branches demonstrates the differences in each branch as well as the architecture of the tree. Many models show the branching of accession 1, with the main branch growing wavy and the tip pointing upwards. In contrast, in the Massart architectural model's branching of plants in accession 2, the branches appear to be in the direction of branches curved downwards. Accession 2's

branching morphology contrasts sharply with Accession 3, which has a roux architectural model with an upward branching direction.

Three accessions of *C. liberica*'s leaves were identified, and the results revealed considerable variations in leaf size and structure/shape. For leaf size, Davis et al. (2022) also stated that *C. liberica* leaves have larger leaf sizes than other coffee species. *C. liberica* leaves measured in Poncokusumo coffee plantations revealed differences between accessions, with accession 2 having the most extended leaves (34,5 ± 4,50 cm), followed by accession 1 (31,8 ± 2,9 cm) and accession 3 (29,4 ± 3,17 cm). Meanwhile, accession 2 had the widest leaf width (16,01 ± 2,28 cm), followed by accession 3 (15,93 ± 1,81 cm), and accession 1 had the smallest leaf width (14,65 ± 1,59 cm). According to these data, the shape of the coffee leaves in accession 1 appears slimmer than in accessions 3 and 2, which are more elliptical. The leaf length and width are standard to larger than liberica leaves in the Philippines, which are 7.1-12 cm wide and 16.4-26.7 cm long (Baltazar and Buot 2019).

The observations in Figure 4 show the *C. liberica* leaf surface color is dark green in all three accessions, with a chartreuse color of the young leaf. There are some apparent parallels among the morphological traits of the leaves in Table 2, including leaf attachment, leaf arrangement, laminar form, medial symmetry, leaf venation, and leaf surface. However, there are various variances in the morphological characters of *C. liberica* leaves in some aspects, mainly the margin type, apex angle, and base angle. Petioles, oval shapes with symmetrical right and left sides, pinate vein shapes, and lustrous surfaces are all characteristics of *C. liberica* leaves. Differences in leaf morphology appear in the margin type, apex angle, and base angle. The leaf margins of Accession 1 are straight/entire type, but they are gently undulating on the upper side/undulate type, and it has a sharp base angle. It also has an acute-undulate tip that is tapered with a blunt tip. Accession 2 shows an acute apex angle, undulate type, and rounded base angle. As a result, this investigation showed differences in accession 1 with an acute-obtuse apex angle and accession 2 with a rounded base angle. In addition, the leaf edges appear to be a complete type, with a pointed base angle, in contrast to accession 3, which has a pointed tip.

According to Baltazar and Buot (2019), the shape of *C. liberica* leaves in Poncokusumo has a petiolate shape on the leaf attachment with an opposite arrangement, elliptic shape, and acute shape on the apex angle. The findings of this research revealed differences in the morphology of *C. liberica* in Poncokusumo, specifically in the margin type, apex and base angle. Previous research stated that the margin type of *C. liberica* was the entire shape and the same as *C. liberica* var. dewevrei. However, this research discovered differences in accessions 1 and 2, which found an undulate margin type. Furthermore, the apex and base angle from *C. liberica* and *C. liberica* var. dewevrei have an acute shape. Still, this research discovered obtusion at the apex angle of accession 1 and a rounded shape at the base angle of accession 2. Based on the result could imply that accession 3 is most similar to the type of *C. liberica* and that accessions 1 and 2 are *C. liberica* that has experienced morphological changes or the emergence of new variants.

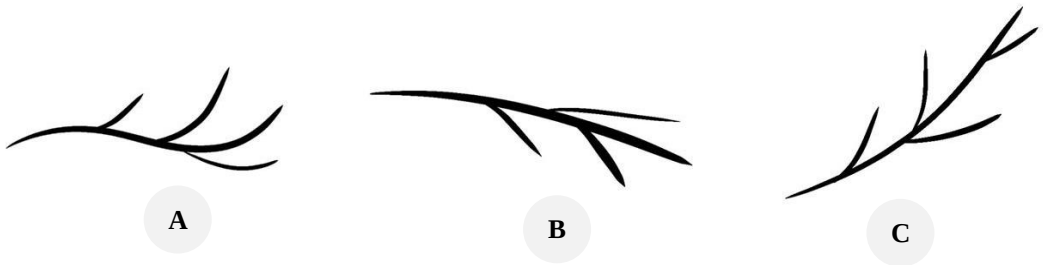

Figure 3. The architecture of the branches of the *Coffea liberica* tree (A. Accession-1; B. Accession-2, and; C. Accession-3)

Figure 4. *Coffea liberica* leaf samples. (A. Accession-1; B. Accession-2; and C. Accession-3)

Table 2. General morphological leaves character of *Coffea liberica* accessions

Morphology	Accession-1	Accession-2	Accession-3
Laminar length (cm)	31,8 ± 2,9	34,5 ± 4,50	29,4 ± 3,17
Laminar morphology width (cm)	14,65 ± 1,59	16,01 ± 2,28	15,93 ± 1,81
Leaf color	Dark Green	Dark Green	Dark Green
Young leaf color	Chartreuse	Chartreuse	Chartreuse
Leaf attachment	Petiolate	Petiolate	Petiolate
Leaf arrangement	Opposite	Opposite	Opposite
Laminar shape	Elliptic	Elliptic	Elliptic
Medial symmetry	Symmetrical	Symmetrical	Symmetrical
Margin type	Entire-Undulate	Undulate	Entire
Apex angle	Acute-Obtuse	Acute	Acute
Leaf venation	Pinnate	Pinnate	Pinnate
Base angle	Acute	Rounded	Acute
Leaf surface	Glossy	Glossy	Glossy

Accession determination

The dendrogram (Figure 5) and scatter plot (Figure 6) of the *C. liberica* data demonstrate notable variations in each accession. The dendrogram revealed that each plant in one accession group had a great deal of variation, which the dendrogram determined based on the morphological characteristics of the leaves and trees. That might be because each tree in a single accession has somewhat different plant and leaf sizes, making it impossible for the stem and leaf sizes in a single accession with the same architectural features to be uniform. The dendrogram also reveals that accession 2 and 3 share 80% of the same physical characteristics. The findings of the PCoA analysis in this research demonstrate that each accession's coordinates are in a distinct quadrant, and the scatter plot indicates that these coordinates do not overlap. The graph shows these three accessions' architectural models differ significantly. Still, since Accessions 2 and 3 are on the same side of the quadrant, there are some parallels between the two accessions. Determining the type of variety through this accession will maximize these results if tracing accession differences is further continued to the genetic level. The geographical conditions of the coffee plantations also influence these results. Overall, Poncokusumo's *C. liberica* morphology matches those of other *C. liberica* features as found in Baltazar and Buot's (2019) research.

This research result revealed that determining the species of Coffea liberica accessions shows significant differences in morphology. According to the research of Motisi et al. (2019), microclimate significantly influences the formation of plant architecture. Shade plants, the temperature, physical and soil chemical properties, and each location's slope can all be part of the desired microclimate. As a result, *C. liberica* planted in a coffee garden in Poncokusumo and receiving the same cultivation pattern may produce different accessions. According to the findings of this research, a new variant of *C. liberica* was discovered in terms of morphology and architecture. This can be traced further with more thorough genetic research to confirm the *C. liberica* Poncokusumo variant; that could be a suggestion for further research. Moreover, *C. liberica* has three genetic variants: *C. liberica* var. *liberica* / *C. liberica* W. Bull ex Hiern, *C. liberica* var. *dewevrei* (De Wild. and T. Durand) *Le Brun*, and *C. liberica f. bridson bwambensis*. This variant has few morphological differences, but genetic analysis is needed to shows that there are significant differences (Diaye et al. 2005; Crisafulli et al. 2022). Therefore, genetic testing is needed on three liberica accessions in Poncokusumo, to determine whether the environment or the variant is a significant factor that causes differences in accessions in one cultivation location.

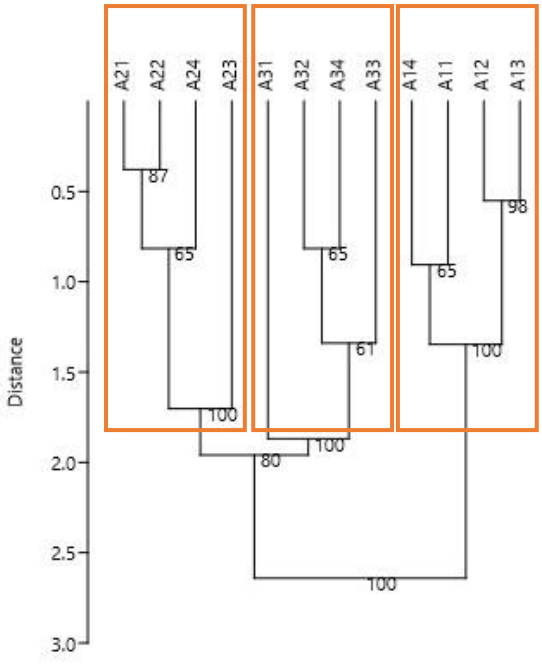

Figure 5. Dendrogram using UPGMA clustering approach using Eucledian as the distance measure. Bootstrap value: 1000

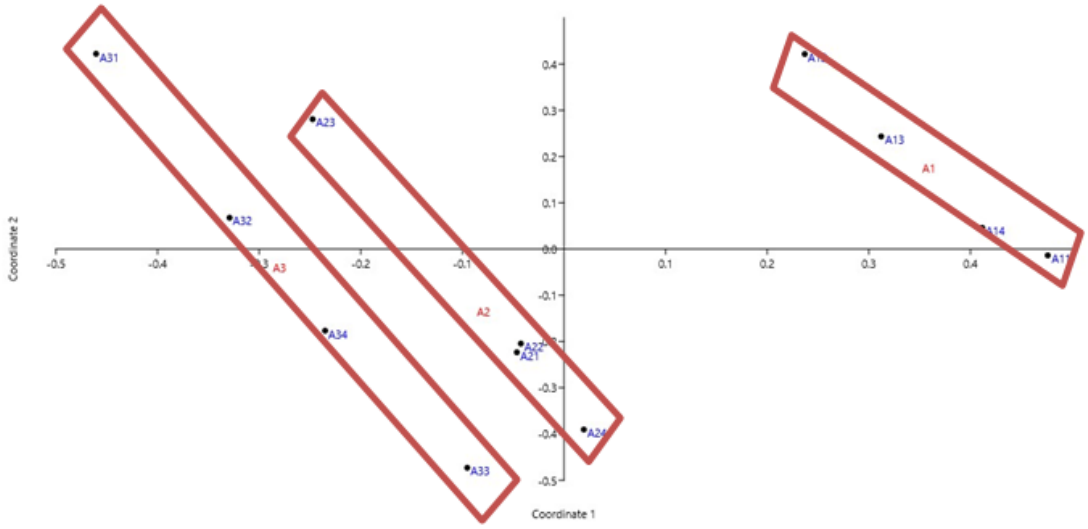

Figure 6. Principal Coordinate Analysis (PcoA) on 3 *Coffea liberica* accessions

This research on the morphological characteristics of *C. liberica* plants and leaves concludes: (i) The morphological characteristics of the *C. liberica* plant in Poncokusumo District show that: (a) the average tree height is 5.23-6.63 m, (b) the average stem circumference is 28.5-34 cm, (c) each accession has a different plant architectural model and a different branching model, (d) the leaves of each accession have quite varied sizes but the same at the leaf color and young leaf color, (e) the morphological characteristics of the three accessions show several morphological differences, namely margin type, apex-angle, and base-angle, (ii) the dendrogram results show a similarity in accessions 2 and 3 of 80%, the PCoA graph shows that each accession has significant differences but accessions 2 and 3 show sufficiently close coordinates. Furthermore, *C. liberica* plants in Poncokusumo Sub-district are grouped into three accessions, as observed from the plant's architecture model and leaf morphological characteristics. The *C. liberica* accession types identified in this research require further molecular analysis to determine the liberica coffee variant by their accessions. In addition, *C. liberica* cultivation in that area must be maintained because it has become a source of income for the local community.

ACKNOWLEDGEMENTS

We would like to give our gratitude to Biology Department, Universitas Brawijaya, Indonesia, for supporting this research and Kemenristek-Dikti Doctoral Dissertation Research Grant Program 2022 for financial support. Furthermore, all authors declare no conflicts of interest in this paper.

REFERENCES

Baltazar AMP, Buot IE. 2019. Short Communication: Leaf architectural analysis of taxonomically confusing coffee species: *Coffea liberica* and *Coffea liberica* var. *dewevrei*. Biodiversitas 20 (6): 1560-1567. DOI: 10.13057/biodiv/d200611.

Bianchi PA, Silva LRA, Alencar AAS, Santos PHAD, Pimenta S, Sudré CP, Corte LED, Gonçalves LSA, Rodrigues R. 2020. Biomorphological characterization of Brazilian *Capsicum chinense* Jacq. germplasm. Agronomy 10 (3): 447. DOI: 10.3390/agronomy10030447.

Budiman H. 2012. Prospek Tinggi Bertanam Kopi. Pustaka Baru Press, Yogyakarta. [Indonesian]

Crisafulli P, Guercia E, Navarini L. 2022. Discrimination of *Coffea liberica* and *Coffea liberica* var. *dewevrei*: Silverskin morphological traits and seed diterpenes content. Trop Plant Biol 15: 247-259. DOI: 10.1007/s12042-022-09319-5.

Darmayanti AS, Fiqa AP. 2017. The canopy structure and its impact on hydrological performance of five local trees species grown in the Purwodadi Botanic Garden. J Trop Life Sci 7 (1): 40-47. DOI: 10.11594/jtls.07.01.07.

Davis AP, Gargiulo R, Fay MF, Sarmu D, Haggar J. 2020. Lost and found: *Coffea stenophylla* and *C. affinis*, the forgotten coffee crop species of West Africa. Front Plant Sci 11: 616. DOI: 10.3389/fpls.2020.00616.

Davis AP, Kiwuka C, Faruk A, Walubiri MJ, Kalema J. 2022. The re-emergence of C. liberica as a major crop plant. Nat Plants 8: 1322-1328. DOI: 10.1038/s41477-022-01309-5.

Diaye AN, 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 Syst Evol 253: 95-104. DOI: 10.1007/s00606-005-0300-1.

Farohii SMKB, Laili S, Zayadi H. 2020. The classification of plantation land capability class and mapping in the Sumberejo Village, Poncokusumo Malang. E-Jurnal Ilmiah Biosaintropis (Bioscience-Tropic) 6 (1): 66-71. DOI: 10.33474/e-jbst.v6i1.310. [Indonesian]

Gomes L, Bianchi F, Cardoso I, Fernandes R, Filho EF, Schulte R. 2020. Agroforestry systems can mitigate the impacts of climate change on coffee production: A spatially explicit assessment in Brazil. Agric Ecosyst Environ 294: 106858. DOI: 10.1016/j.agee.2020.106858.

Hakim L, Siswanto D, Rahardi B, Zayadi H. 2019. Fostering coffee agroforestry for agrotourism development in degraded land in a buffer zone of a national park: A case study from Poncokusumo, Malang, Indonesia. Eurasia J Biosci 13: 1613-1620.

Hakim L. 2021. Coffee: ethnobotany, tourism and biodiversity conservation in East Java. IOP Conf Ser: Earth Environ Sci 743 (2021): 012063. DOI:10.1088/1755-1315/743/1/012063.

Halle F, Oldeman RAA, Tomlinson PB. 1978. Tropical trees and Forests: An Architectural Analysis. Springer-Velag, Berlin Heidelberg, New York. DOI: 10.1007/978-3-642-81190-6.

Hammer, Harper DAT, Ryan PD. 2001. Past: Paleontological statistics software package for education and data analysis. Palaeontol Electron 4 (1): 9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Haniefan N, Basunanda P. 2022. Eksploration and indentification of *C. liberica* (Coffee Liberica) in Sukorejo, Kendal District. Jurnal Vegetalika 11 (1): 11-18. DOI: 10.22146/veg.44325. [Indonesian]

Hollender CA, Dardick C. 2014. Molecular basis of angiosperm tree architecture. New Phytol 206: 541-556. DOI: 10.1111/nph.13204.

Khasanah N, Noordwijk MV. 2019. Subsidence and carbon dioxide emissions in a smallholder peatland mosaic in Sumatra, Indonesia. Springer: Mitig Adapt Strateg Glob Chang 24: 147-163. DOI: 10.1007/s11027-018-9803-2.

Lin Y, Jiang M, Pellikka P, Heiskanen J. 2018. Recruiting conventional tree architecture models into state-of-the-Art LiDAR mapping for investigating tree growth habits in structure. Front Plant Sci 9: 220. DOI: 10.3389/fpls.2018.00220.

Mawardhi AD, Setiadi D. 2018. Strategi pemanfaatan lahan gambut melalui pengembangan agroforestri kopi liberica (*Coffea liberica*). In: Herlinda S et al. (eds). Seminar Nasional Lahan Suboptimal Proceeding. Universitas Sriwijaya, Palembang 18-19 Oktober 2018. [Indonesian]

Motisi N, Ribeyre F, Poggi S. 2019. Coffee tree architecture and its interactions with microclimates drive the dynamics of coffee berry disease in coffee trees. Nat Sci Rep 9: 2544. DOI: 10.1038/s41598-019-38775-5.

Nurdin, Zakaria F, Azis MA, Rahim Y, Rahman R, Kasim M. 2022. Comparison of land suitability class for endemic *Coffea liberica* Pinogu HP. Acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia. Sains Tanah J Soil Sci Agroclimatol 19 (1): 42-51. DOI: 10.20961/stjssa.v19i1.56441. [Indonesian]

Sianipar H. 2017. Keragaman Genetik Populasi Kopi Liberica (*Coffea liberica* W. Bull Ex. Hiern) di Kecamatan Betara berdasarkan Karakter Buah dan Biji. [Thesis]. Universitas Jambi, Jambi. [Indonesian]

Stewart FA. 2011. The Evolution of Shelter: Ecology and Ethology of Chimpanzee Nest Building. [Ph.D. Dissertation]. University of Cambridge, Cambridge, UK.

Supriadi H, Ferry Y, Ibrahim MSD. 2018. Teknologi Budidaya Tanaman Kopi. IAARD Press, Badan Penelitian dan Pengembangan Pertanian, Jakarta. [Indonesian]

Tjitrosoepomo G. 2009. Morfologi Tumbuhan. Gadjah Mada University Press, Yogyakarta. [Indonesian]