








# Morphological diversity of arabica coffee (*Coffea arabica*) by in-situ exploration in three agroecosystems West Java, Indonesia

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## ABSTRACT

Arabica coffee, a type of coffee in high demand, is cultivated in various regions. West Java is a significant contributor to Arabica coffee production in Indonesia. This region has various coffee agroecosystems. The research aims to identify the diversity of West Java Arabica coffee cultivated in different agroecosystems. The research involved observing plantation locations of Arabica coffee in Cimaung, Cilengkrang, and Pangalengan, West Java, in three agroecosystems (agroforestry, intercropping area, and residential area). Fifty-two accessions were found and analyzed using the Shannon diversity index for qualitative characters, Principal Component Analysis (PCA), and Cluster analysis. The Shannon diversity index revealed the range between 0.221 and 1.55; the PCA results show a variability of 43.208% on two main components (PC1-PC2), indicating a wide variation for Arabica coffee accessions. The characteristics of fruit, seed, and leaf qualitative traits were influential in determining diversity. The cluster analysis explained the distribution patterns of agroecosystems and the relationship of each accession. It showed a close relationship between agroforestry and residential areas. The cluster analysis also revealed distinct variations of accessions in the agroforestry and residential area at Cilengkrang compared to others. Based on the results, these findings could potentially be used as basic knowledge to develop a new Arabica coffee clone, especially in West Java.

**Key words:** Accession; agroecosystem; cluster analysis; diversity index; principal component analysis.

## 1 INTRODUCTION

Coffee is a beverage commodity obtained from plantations and is beneficial for health development due to its phytochemical compounds, such as caffeine, flavonoids, and antioxidants (Surma; Sahebkar; Banach, 2024; Maxiselly et al., 2023a). Other benefits include effective prevention of the risks associated with Parkinson's and chronic liver diseases (Wang et al., 2023; Di Pietrantonio et al., 2024). As a tropical country, Indonesia was ranked as the fourth largest coffee producer worldwide in 2022 (Tampubolon et al., 2023), with 96.06% of the plantations owned by the community (Badan Pusat Statistik - BPS, 2023).

The history of coffee cultivation in Indonesia started during the Dutch East Indies era in the late 17th century (Andini et al., 2021) with the introduction of Arabica coffee (*coffea arabica*). Arabica coffee then gradually developed as a plantation commodity and a cultivated. However, in 1876, the production of Arabica coffee planted in the lowlands experienced a setback due to leaf rust diseases (*Hemileia vastatrix*) (Rico et al., 2021). Consequently, Robusta coffee (*Coffea canephora*) was introduced to Indonesia as a replacement for Arabica coffee. In those times, Robusta was more resistant than the Arabica type to damaging diseases (Wibowo; Atmajawati; Ali, 2024), which could be the main reason why the Arabica coffee development in Indonesia is less

than that of Robusta for bean production. In contrast, Arabica coffee has benefits compared to Robusta, which still needs to encourage production. For instance, Arabica coffee contains less caffeine and has a pleasant flavor and scent compared to Robusta (Maxiselly et al., 2023b). Additionally, it has a higher market demand than Robusta. Thus, to ensure the sustainable development of the Indonesian coffee industry, it is important to encourage the production of Arabica coffee varieties suitable to agroecosystems of Indonesia.

Coffee is planted in almost all provinces in Indonesia. Different areas in Indonesia have distinct coffee types with unique features, such as Gayo and Manglayang coffee originating from Aceh and West Java, respectively (Andini et al., 2021; Iskandar et al., 2018). West Java Province is one of the provinces contributing to the largest coffee production in Indonesia, with a production value of 23.7 thousand tons in 2022 (BPS, 2023). The coffee grown in West Java, particularly in Bandung, is mostly Arabica (Fithriyyah; Wulandari; Sendjaja, 2020). Several coffee plantation centers in Bandung include Cilengkrang, Cimaung, and Pangalengan. These three regions have popular coffees, namely Manglayang coffee, Puntang coffee, and Malabar coffee, respectively. Community farmers acquired the coffee plantations at this location, which have existed since ancient times. According to the information obtained, there are still several old coffee plants, but the types

and varieties of coffee are not yet known. These conditions can be used to find the best coffee germplasm, which could be utilized to develop the coffee plant itself.

Plant breeding programs require basic information such as genetic diversity and plant variability within a population. Genetic diversity can provide important information for plant breeding and germplasm conservation (Melese; Kolech, 2021). The observation of potential germplasm can be identified by exploring and utilizing identified characteristics. Exploration activities are carried out to search for and collect genetic resources in several areas by observing for data and information about the plants (Pathirana; Carimi, 2022). Exploration is a method of collecting germplasm through in-situ observation of an area such as forests, agricultural land, agroforestry, and residential areas.

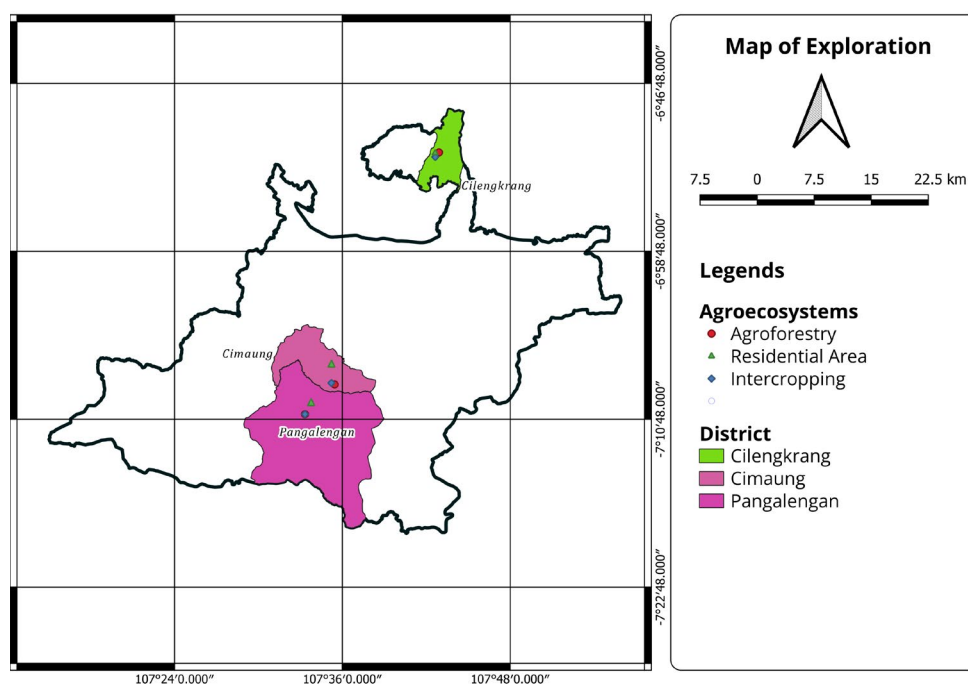
The germplasm identification at a location should be conducted using characterization. Characterization is an activity that evaluates a plant's characters to predict the potential germplasm. Morphological characters can be used as a plant classifying reference which can visually identify plant traits practically. (Gebreselassie; Tesfaye; Gedebo, 2024). Various analysis methods, such as the Shannon diversity index, Principal Component Analysis, and cluster analysis, are applied to interpret morphological characterization data. The approach for classified variation of qualitative characters can be examined using Shannon's diversity index (Yirga, 2021). PCA and cluster analysis can be selected to find variations in the distribution of coffee plant accessions from exploration at central producer coffee (Prastowo; Arimarsetiowati, 2019; Zasari; Kartika; Altin, 2023).

Based on that outlined, the research related to the exploration and characterization of coffee in three agroecosystems in the West Java area was carried out to observe the phenotypic diversity between accessions and their distribution patterns based on morphological characteristics, agroecosystem, and location. This research was conducted to analyze coffee germplasm with superior and potential morphological characteristics, and it would be used for plant breeding programs in coffee.

## 2 MATERIAL AND METHODS

### 2.1 Study area

The research used the experimental method of the exploratory field with purposive sampling (Prastowo; Arimarsetiowati, 2019; Zasari; Kartika; Altin, 2023). The Research was conducted from September 2023 to December 2023 at several locations in West Java, Indonesia. An observation was conducted in situ along sites distributed over different agroecosystems of cultivated coffee in three locations in Bandung Regency: Cilengkrang, Pangalengan, and Cimaung. The regions have various elevations from 1,138 to 1,485 meters above sea level (masl). In detail, the Cilengkrang region has an elevation of 1,252.3–1,279.8 masl, the Pangalengan region has an altitude of 1,311.6–1,432.2 masl, and the Cimaung region is 1,138.1–1,485.3 masl. The agroecosystem categories consisted of agroforestry, intercropping, and residential areas. The precise coordinates of agroecosystems are presented in Figure 1.



**Figure 1:** Map of exploration field of *Coffea arabica* at several locations in Bandung.

## 2.2 Materials

Fifty-two (52) accessions were explored and characterized from different locations in Bandung. Meanwhile, the tools used include the Global Positioning System (GPS) to determine the coordinates and elevation of places, meters, and callipers with an accuracy of 0.1 mm, and questionnaires used during interviews with farmers of coffee plants for verification of coffee plants at the observation location.

## 2.3 Procedures

The initial data regarding specific accession fields of Arabica coffee in each region were selected based on the consideration of farmers as key informants. This selected supported by direct field observation and a coffee production center in Bandung Regency to select a representative agroecosystem in each region. A purposive sampling assesses the individual accession's good physical condition. Fifty-two selected accessions were labeled with a specific code. Code alphabetically described a location, such as Cilengkrang, Pangalengan, and Cimaung, were shortened to CL, P, and C, respectively. Then, the First code number described different agroecosystems such as Agroforestry (1), Intercropping (2), and Residential Area (3), and the second code number described the number of accessions at each agroecosystem.

A total of 22 morphological characters of coffee were examined based on the International Plants Genetic Resources Institute (IPGRI) for characterization purposes (International Plant Genetic Resources Institute - IPGRI, 1996). The morphological characteristics observed in this study were vegetative and fruit-related, defined for qualitative and quantitative categories. The code [99] was used if no representative characters exist in the accession. The observation procedures of each morphological trait are presented in Table 1.

## 2.4 Data analysis

Data analysis was conducted using Shannon's diversity index for qualitative characters, Principal Component Analysis (PCA), and Cluster analysis—the data of qualitative characters to obtain the frequency of criteria of characters and Shannon's diversity index. Shannon's diversity Index formula was used  $H' = -\sum P_i \ln P_i$ . Where  $H'$  means Shannon's diversity index,  $P_i$  is the relative abundance of each character, and  $\ln p_i$  is the natural logarithm of relative abundance (Weldemichael, 2020). PCA was used to observe which variables influence the diversity of coffee accessions in Bandung. The relationship between accessions and agroecosystem patterns based on their morphological characters was analyzed using a cluster analysis approach. The cluster analysis used a dissimilarity matrix of Euclidean distances and transformed to agglomerative of Ward's.

Processing data using XLSTAT 4.1 software, integrated directly with Microsoft Excel, and analysis results were displayed in tables, biplot graphs of PCA, and dendrograms.

## 3 RESULTS

### 3.1 Phenotypic diversity of qualitative characters

The Arabica coffee accessions were investigated by diversity index using 14 qualitative characters. The analysis results obtained varying frequency and diversity index values for each character (Table 2). The diversity index on qualitative characters can indicate the existence of sufficient variation among the accessions observed (Weldemichael, 2020). In this research, the level of Shannon diversity index ( $H'$ ) was classified into three categories namely  $H'$  less than 0.5 means low diversity,  $H'$  between 0.5-0.75 means medium diversity, and  $H'$  more than 0.75 means high diversity (Azam et al., 2023).

The range of the Shannon diversity index was identified from 0.221 to 1.55, with an average value of 0.789. In this finding,  $H'$  less than 0.5 or low diversity was found in 4 characters there are plant height ( $H'=0.461$ ), habit of the plant ( $H'=0.365$ ), leaf apex shape ( $H'=0.317$ ), and leaf petiole color ( $H'=0.221$ ). Medium diversity ( $H'=0.5-0.75$ ) was exhibited in only one character, namely fruit shape ( $H'=0.534$ ). The other characters have high diversity ( $H' \geq 0.5$ ), such as young shoot color ( $H'=0.752$ ), leaf shape ( $H'=0.828$ ), seed shape ( $H'=0.883$ ), angle of insertion on primary branch ( $H'=0.946$ ), overall appearance ( $H'=0.972$ ), branching habit ( $H'=0.972$ ), young leaf color ( $H'=1.08$ ), stipule shape ( $H'=1.17$ ), and fruit color ( $H'=1.55$ ).

### 3.2 Genetic Diversity by Principal Component Analysis (PCA)

The results of the variability of *Coffea arabica* are shown in Table 3. Five PCs can be found that can explain the characters influencing the grouping of accessions with eigenvalues more than 1. The contribution of characters at each PC was determined from eigenvalues  $>1$ , while components with eigenvalues  $<1$  were avoided. That indicated the contribution of each character to diversity based on the eigenvalues of each principal component (PC) (Maulana et al., 2023). Then, the components of each character have a significant meaning that shows the contribution of each PC (Jarwar et al., 2019). PC 1 contributed to the diversity of 29.330%, provided by the characteristics of branching habit, fruit color, fruit shape, seed shape, leaf length, leaf width, fruit length, seed length, seed width, and seed thickness. PC 2 contributed 13.879% from growth habit characters, primary branch insertion angle, stipule shape, leaf tip shape, and stem diameter. PC 3 contributed 8.638% of the characteristics

**Table 1:** List of morphological character description of coffee plant.

Characters	Criteria
Qualitative characters	
Habit of plant (HoP)	[1] Bush (<5m - without distinct trunk); [2] Shrub or small tree (<5m - one or more trunks); [3] Tree (>5m - single trunk)
Overall appearance (OA)	[1] Elongated conical; [2] Pyramidal; [3] Bushy
Branching habit (BH)	[1] Very few branches (primary); [2] Many branches (primary) with few secondary branches; [3] Many branches (primary) with many secondary branches; [4] Many branches (primary) with many secondary and tertiary branches.
Angle of insertion of primary branches (AB)	[1] Drooping; [2] Horizontal or spreading; [3] Semi-erect
Stipule shape (SS)	[1] Round; [2] Ovate; [3] Triangular; [4] Deltate (equilateral triangular); [5] Trapeziform; [6] Other
Young leaf colour (YLC)	[1] Greenish; [2] Green; [3] Brownish; [4] Reddish brown; [5] Bronze; [6] Other
Leaf shape (LS)	[1] Obovate; [2] Ovate; [3] Elliptic; [4] Lanceolate; [5] Other
Shape of leaf apex (SLA)	[1] Round; [2] Obtuse; [3] Acute; [4] Acuminate; [5] Apiculate; [6] Spatulate; [7] Other
Leaf petiole colour (LPC)	[1] Green; [2] Dark brown; [3] Other
Young shoot colour (YSC)	[1] Green; [2] Dark brown; [3] Other
Colour of fruit (CF)	[1] Yellow; [2] Yellow-orange; [3] Orange; [4] Orange-red; [5] Red; [6] Red-purple; [7] Purple; [8] Purple-violet; [9] Violet; [10] Black; [11] Other
Fruit shape (FS)	[1] Roundish; [2] Obovate; [3] Ovate; [4] Elliptic; [5] Oblong; [6] Other
Shape of seed (SoS)	[1] Round; [2] Obovate; [3] Ovate; [4] Elliptic; [5] Oblong; [6] Other
Plant height (PH)	[1] Very short (<50 cm); [3] Short (50 cm- 100 cm); [7] Tall (100 cm- 150 cm); [9] Very Tall (>150 cm)
Quantitative characters	
Leaf length (LL)	Average of five mature leaves measured from petiole end to apex (SI unit: mm)
Leaf width (LW)	Average of five mature leaves measured at widest part (SI unit: mm)
Fruit length (FL)	Average of five normal mature green fruits, measured at the largest part (SI unit: mm)
Fruit width (FW)	Average of five normal mature green fruits, measured at the widest part
Seed length (SL)	Maximum length average of five normal mature seeds (SI unit: cm)
Seed width (SW)	Maximum width average of five normal mature seeds (SI unit: cm)
Seed thickness (ST)	Maximum thickness average of five normal mature seeds
Stem diameter (SD)	Measured at 5 cm above ground level in seedling and cutting trees or 10 cm above graft union in grafted trees. Specify the approximate tree age (SI unit: cm)

**Table 2:** Frequency distribution and Shannon diversity index of 14 qualitative characters of Arabica Coffee accessions.

Character	Code	Description	Number of Accessions	Percent (%)	Diversity Index (H')
HoP	1	Bush	4	7.69%	0.365
	2	Shrub	47	90.38%	
	3	Tree	1	1.92%	
OA	1	Elongated conical	15	28.85%	0.972
	2	Pyramidal	8	15.38%	
	3	Bushy	29	55.77%	
BH	1	Very few branches	29	55.77%	0.972
	2	Many primary branches with few secondary branches	15	28.85%	
	3	Many primary branches with many secondary branches	8	15.38%	
AB	1	Drooping	30	57.69%	0.946
	2	Horizontal	7	13.46%	

Continue.

Table 2: Continuation...

Character	Code	Description	Number of Accessions	Percent (%)	Diversity Index (H')
SS	3	Semi erect	15	28.85%	1.17
	1	Round	2	3.85%	
	2	Ovate	15	28.85%	
	3	Triangular	11	21.15%	
YLC	4	Deltate	24	46.15%	1.08
	1	Greenish	20	38.46%	
	2	Green	19	36.54%	
	3	Brownish	13	25.00%	
LS	2	Ovate	4	7.69%	0.828
	3	Elliptic	34	65.38%	
	4	Lanceolate	14	26.92%	
SLA	4	Acuminate	5	9.62%	0.317
	5	Apiculate	47	90.38%	
LPC	1	Green	49	94.23%	0.221
	2	Dark brown	3	5.77%	
YSC	1	Green	31	59.62%	0.752
	2	Dark brown	20	38.46%	
	3	Other	1	1.92%	
CF	1	Yellow	2	3.85%	1.55
	4	Orange-red	15	28.85%	
	5	Red	13	25.00%	
	6	Red-purple	11	21.15%	
	7	Purple	1	1.92%	
	99	No representative	10	19.23%	
	FS	1	Roundish	36	
2		Obovate	1	1.92%	
4		Elliptic	4	7.69%	
5		Oblong	1	1.92%	
99		No representative	10	19.23%	
SoS	1	Round	34	65.38%	0.883
	4	Elliptic	8	15.38%	
	99	No representative	10	19.23%	
PH	7	Tall (100 cm- 150 cm)	9	17.31%	0.461
	9	Very Tall (>150 cm)	43	82.69%	

Note: The habit of the plant (HoP), Overall appearance (OA), Branching habit (BH), Angle of insertion on primary branches (AB), Stipule shape (SS), Young leaf color (YLC), Leaf shape (LS), Shape of leaf apex (SLA), Leaf petiole color (LPC), Young shoot color (YSC), Color of fruit (CF), Fruit shape (FS), Shape of seed (SoS), Plant height (PH).

of plant height, vegetative development, and plant growth habits. PC 4 contributed 7.316%, with the highest character contribution being the color of young leaves and the color of young shoots. PC 5 contributed 6.786%, with the largest character contribution being leaf petiole color. The main contribution of diversity shown by the first two PCs, with

a total variation of 43.208%, visualized in the biplot graph, is shown in Figure 2. This contribution is more significant than Maulana et al. (2023), which has 38.09% for PC1 and PC2. Figure 2 illustrates the distribution of coffee accession based on Quadrant I to Quadrant IV. Quadrants I and IV have fewer accessions than quadrants II and III.

**Table 3:** Eigenvalue, variability, cumulative of PCs, and character values influencing the diversity of *Coffea arabica* at Bandung.

	PC 1	PC 2	PC 3	PC 4	PC 5
Eigenvalue	6.453	3.053	1.900	1.609	1.493
Variability (%)	29.330	13.879	8.638	7.316	6.786
Cumulative %	29.330	43.208	51.846	59.162	65.948
<b>Characters</b>					
HoP	0.011	0.458	0.079	0.005	0.057
PH	0.047	0.184	0.247	0.055	0.013
OA	0.137	0.044	0.446	0.008	0.052
BH	0.228	0.159	0.237	0.029	0.001
AB	0.198	0.262	0.114	0.000	0.093
SS	0.106	0.320	0.004	0.195	0.007
YLC	0.101	0.063	0.116	0.406	0.011
LS	0.015	0.000	0.092	0.004	0.279
SLA	0.009	0.387	0.004	0.263	0.030
YSC	0.045	0.178	0.108	0.061	0.234
LPC	0.000	0.180	0.073	0.330	0.001
CF	0.475	0.085	0.010	0.045	0.030
FS	0.761	0.003	0.011	0.044	0.002
SoS	0.653	0.003	0.020	0.035	0.002
ST	0.011	0.401	0.040	0.045	0.046
LL	0.434	0.023	0.094	0.004	0.009
LW	0.228	0.047	0.100	0.005	0.073
FL	0.578	0.002	0.049	0.001	0.251
FW	0.680	0.122	0.010	0.036	0.034
SL	0.579	0.001	0.029	0.010	0.266
SW	0.649	0.089	0.011	0.014	0.002
ST	0.508	0.042	0.008	0.016	0.000

Notes: Numbers in bold are characters that have significant values than others. The habit of the plant (HoP), Overall appearance (OA), Branching habit (BH), Angle of insertion of primary branches (AB), Stipule shape (SS), Young leaf color (YLC), Leaf shape (LS), Shape of leaf apex (SLA), Leaf petiole color (LPC), Young shoot color (YSC), Color of fruit (CF), Fruit shape (FS), Shape of seed (SoS), Plant height (PH), Leaf length (LL), Leaf width (LW), Fruit length (FL), Fruit width (FW), Seed length (SL), Seed width (SW), Seed thickness (ST), and Stem diameter (SD).

### 3.3 Distribution patterns based on agroecosystem variations and observed locations

The distribution pattern of accessions based on agroecosystems in Bandung was explained in the dendrogram, as shown in Figure 3 and Figure 4. Figure 3 shows the distribution pattern of agroecosystems, which consist of three clusters, each describing different agroecosystems. The results showed that the cluster of agroforestry agroecosystems contained the close

dissimilarity value with residential area agroecosystems, while intercropping agroecosystems have separate relationships.

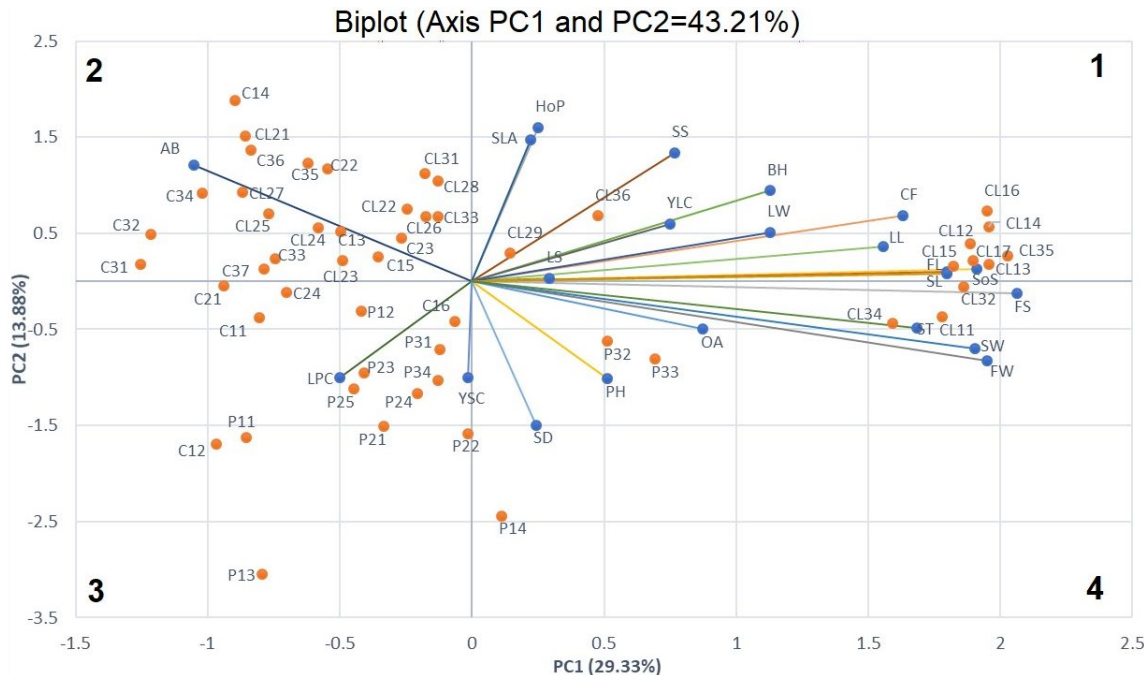
We also investigated the agroecosystems of each observed location (Figure 4). The results were categorized into three main clusters based on cut points. One of the important aspects is establishing the optimal number of clusters, which involves deciding where to separate a dendrogram to find the proper or natural cluster using a cut point (Roba; Mohammed, 2024). Cluster 1 consists of accessions originating from the agroforestry and residential area agroecosystems of Cilengkrang, CL1, and CL3, respectively. In cluster 2, only accessions originate from the residential area of the agroecosystem of Cimaung (C3). Cluster 3 has six members, namely accessions originating from the agroecosystem of agroforestry, intercropping, and residential area of Pangalengan (code consists of P1, P2, and P3 respectively), intercropping agroecosystem of Cilengkrang (CL2) and agroecosystem of agroforestry and intercropping of Cimaung (C1 and C2).

### 3.4 Cluster analysis of accessions

The relationship patterns between the accessions were explained in cluster analysis. Accessions closely related are grouped in the same cluster, while accessions of distant relatives are in different groups (Prastowo; Arimarsetiowati, 2019). The accessions were divided into five main classes, as shown in Figure 5. The cluster division was based on the cut point with a dissimilarity value of 56.5 and a total dissimilarity value of 450. The cut point indicated the optimal division that can divide the accession groups. Cluster 1 has 10 accessions originating from Cilengkrang, namely CL11, CL12, CL13, CL14, CL15, CL16, CL17, CL32, CL34, and CL35. Hence, the coffee plants investigated in this region showed the vegetative phase, with no fruit or other flower organs. Cluster 2 and cluster 4 each comprised only three accessions, cluster 3 contains 25 accessions, and cluster 5 comprises 11 accessions. The accessions from cluster 2 were grouped because they had similarities in young leaf color, fruit shape, and fruit color.

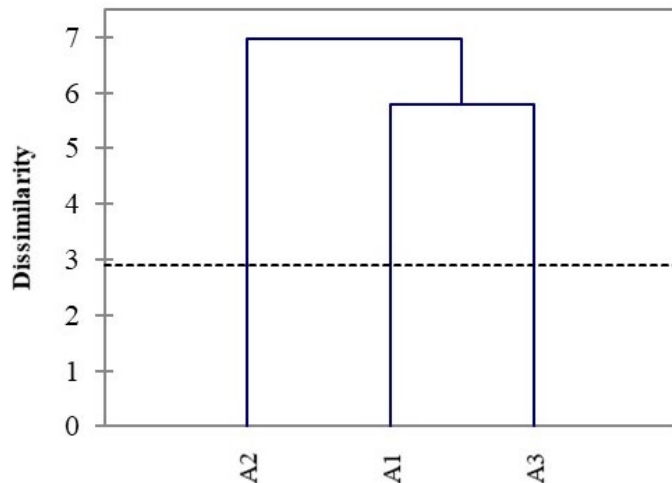
## 4 DISCUSSION

Morphological characteristics are essential in determining the genetic diversity of the coffee plant. Based on our findings, phenotypics with qualitative character have an average score of Shannon diversity index of 0.789 or medium diversity. This method was computed using phenotypic frequencies to estimate the overall diversity for each qualitative character. Low diversity has been identified in several characteristics, such as plant height, plant habit, leaf apex shape, and leaf petiole color. A low diversity index indicates a possible close relationship between accessions having the same characteristics (Yirga, 2021). The appearance of qualitative characters will not change or will be slightly



**Figure 2:** Biplot graph of Arabica coffee accessions on the PCA. Notes: Habit of the plant (HoP), Overall appearance (OA), Branching habit (BH), Angle of insertion of primary branches (AB), Stipule shape (SS), Young leaf color (YLC), Leaf shape (LS), Shape of leaf apex (SLA), Leaf petiole color (LPC), Young shoot color (YSC), Color of fruit (CF), Fruit shape (FS), Shape of seed (SoS), Plant height (PH), Leaf length (LL), Leaf width (LW), Fruit length (FL), Fruit width (FW), Seed length (SL), Seed width (SW), Seed thickness (ST), and Stem diameter (SD). Code alphabetically describes locations such as CL= Cilengkrang; P= Pangalengan; C= Cimaung. The first code number described different agroecosystems: 1 = Agroforestry, 2 = Intercropping, and 3 = Residential area, and the second code number described the number of accessions on each agroecosystem.

### Dendrogram



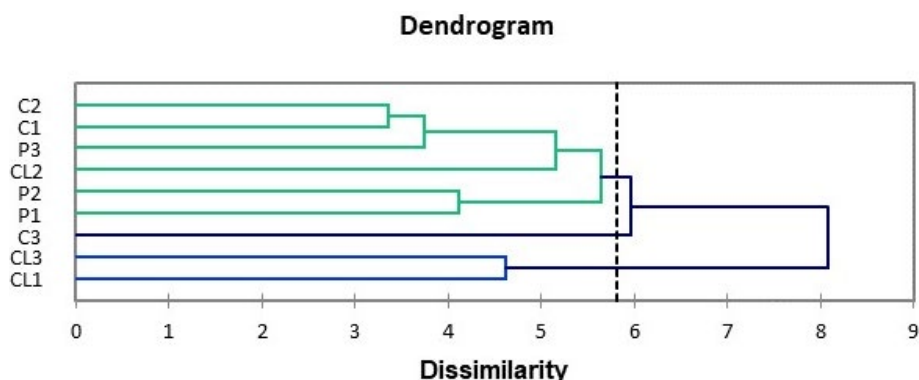
**Figure 3:** Distribution pattern of *Coffea Arabica* based on group of agroecosystems. The alphabet 'A' is agroecosystem, and the code number describes different agroecosystems such as 1 = Agroforestry; 2 = Intercropping; and 3 = Residential area.

influenced by environmental factors, and they are controlled only by simple genes (Wahyudi et al., 2023). In this study, ten accessions did not represent fruit and seed characters because these accessions were not in the generative phase. The difference in the growth phase is thought to be due to the different sources of accessions. Environmental factors such as climate and topography also allow for differences in the timing of the generative phase of the coffee plant. This statement is supported by the argument of Oguz et al. (2022), which states that abiotic stress can affect the vegetative and generative phases of the plant differently. The low intensity of sunlight can cause delayed fruit ripening (Maxiselly et al., 2023b).

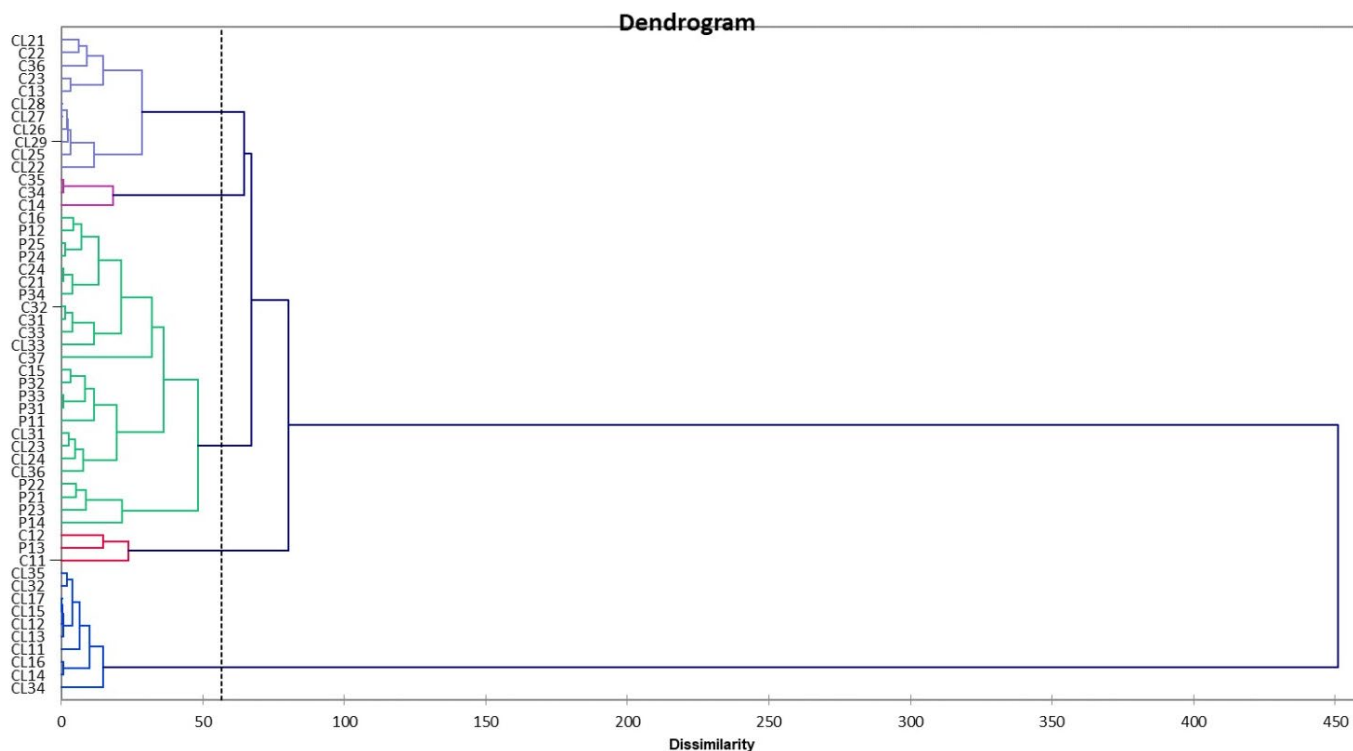
PCA is a multivariate analysis that can interpret a variable by explaining the dataset using a correlation matrix. The PCA approach can simplify the data dimensions. The PCA can interpret the relationship between accessions and estimate the correlation of characters as variables (Maxiselly et al., 2024). The biplot graph of PCA explains the diversity and interrelationships between variables (Figure 2). The biplot graph expressed the distribution of accessions with observed characters divided into four quadrants. The position of the vectors and genotype points

shows the magnitude of characters (Jarwar et al., 2019), as closer characters vector and accession show greater value. Quadrants I and IV have fewer accessions than quadrants II and III. Quadrant 1 has eight accessions, all of which have the exact origin; there are Cilengkrang origins. Quadrant 2 has 20 accessions with the defining character angle of insertion of primary branches (AB). Quadrant 3 has 16 accessions with similar characters of leaf petiole color (LPC) and young shoot color (YSC). Quadrant IV has six accessions, differentiated by stem diameter, plant height, fruit shape, fruit length, fruit width, and seed thickness.

The biplot graphs can also identify correlation by examining the angle between two vectors. The acute angle (Closer to 0°) indicates that characters are strong and correlate positively. In contrast, the obtuse angle (Closer to 180°) indicates that characters are strongly negatively correlated (Solihin et al., 2023). Figure 2 shows a strong and positive correlation between leaf shape, width, and length. Meanwhile, the strongly negative correlation, almost reaching 180°, is between vectors of leaf petiole color and stipule shape.



**Figure 4:** Distribution pattern of *Coffea Arabica* based on agroecosystem variations of each observed location. Code alphabetically described observed locations such as CL= Cilengkrang; P= Pangalengan; C= Cimaung. The alphabet code is agroecosystem, and the code number describes different agroecosystems, such as 1 = Agroforestry, 2 = Intercropping, and 3 = Residential area.



**Figure 5:** Cluster analysis of accessions. Code alphabetically describes locations such as CL= Cilengkrang; P= Pangalengan; C= Cimaung. The first code number described different agroecosystems, such as 1 = Agroforestry, 2 = Intercropping, and 3 = Residential Area, and the second code number described the number of accessions on each agroecosystem.

Cluster analysis determines how close and related one accession is to another accession based on its morphological characters (Gebreselassie; Tesfaye; Gedebo, 2024). One method of cluster analysis is Agglomerative Hierarchical Clustering (AHC). This method works by grouping data from each member into large clusters (Mahmood et al., 2022). The results of AHC are shown in the form of a dendrogram based on the dissimilarity value. The data is more similar to other data if the dissimilarity value of the two has a small difference.

Distribution patterns of agroecosystem population were analysed using cluster analysis (Figure 3 and Figure 4). The mean performance of the agroecosystem population was conducted to form an agroecosystem cluster. The agroecosystems of agroforestry and intercropping in Cimaung have a narrow relationship. Likewise, the agroforestry and intercropping agroecosystems in Pangalengan have a close morphological relationship. This result is possible because the population areas are quite close. The agroecosystems' closely identical environment and geographical closeness explain the morphological similarity (Bonny et al., 2019). The accessions originating from agroforestry and residential agroecosystems in Cilengkrang tend to be more diverse than other agroecosystems at different locations. There is considerable research on how characteristics vary across environmental gradients. For example, an agroforestry system with shade plants pointed to higher growth and productivity of Robusta-type coffee and the physiology of leaf characteristics of Arabica-type coffee (Piato et al., 2020; Isaac et al., 2024). That leads to a range of characteristic values that might be observed in a particular plant genotype (Buchanan et al., 2019).

The geographical location was one of the isolation factors contributing to accession variability (Roba; Mohammed, 2024). However, cluster analysis showed that some accessions from the same agroecosystems were grouped in different clusters (Figure 5). This result shows genetic diversity within the coffee population in each location (Khemira et al., 2024). Differentiate relationship accessions because differences influence genotypes, environmental factors, or both (Yirga; Gebreselassie; Tesfaye, 2021). The accessions with distant clusters can be used in the hybridization to obtain a more significant heterotic response (Asegid; Garedew; Tefera, 2023). Cluster analysis benefits breeders in improving the genotype base by selecting a representative accession from a specific cluster. There is an opportunity to develop hybrid vigor through cross-pollination of different parents in different clusters.

## 5 CONCLUSION

The results describe the morphological diversity of *Coffea arabica* in Bandung Regency. The qualitative morphologies that contribute most to the variation of Arabica

coffee based on the diversity index of Shannon. The cluster analysis explained the distribution patterns of agroecosystems and the relationship of each accession. It showed a close relationship between agroforestry and residential areas. Based on the results, these findings could potentially be used as basic knowledge to develop a new Arabica coffee clone, especially in West Java.

## 6 AUTHOR CONTRIBUTION

Conceptual idea: Maxiselly, Y.; Maharani, Y.; Methodology design: Maxiselly, Y; Bakti, C.; Atiningsih, F.G.; Data collection: Atiningsih, F.G.; Rasiska, S.; Hutapea, D.; Data analysis and interpretation: Wahyudin, A.A.; Maxiselly, Y.; Atiningsih, F.G.; Writing and editing: Maxiselly, Y.; Wahyudin, A.A.; Atiningsih, F.G.; Rasiska, S.; Hutapea, D.; Bakti, C.; Maharani, Y.

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