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GROWTH AND MORPHOLOGICAL DIVERSITY OF 16 SINENSIS TEA CLONES (*Camellia sinensis* (L.) Kuntze var. sinensis) DURING SEEDLING PHASE

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ABSTRACT

This study investigated the morphological diversity and population structure of 16 *Sinensis* tea clones (*Camellia sinensis* (L.) Kuntze var. *sinensis*) during the nursery phase to support superior variety development. The research was conducted at the Gambung Tea and Kina Research Center, West Java, using morphological and growth trait analysis. Data were analyzed using Principal Component Analysis (PCA) and Cluster Analysis. The results revealed significant morphological variation among the clones, particularly in leaf number, shoot color, and leaf blade morphology. PCA indicated that 88% of the phenotypic variation was explained by five principal components, with the number of leaves and second leaf color at the p+2 position identified as the most influential traits for clonal differentiation. Cluster analysis classified the 16 clones into two distinct kinship groups, with the second group comprising 81.25% of the tested population. These findings provide essential insights into the genetic and morphological landscape of *Sinensis* tea clones, establishing a robust framework for parent selection and future breeding programs aimed at producing high-quality varieties for the international green tea market.

Key words: *Camellia sinensis*, Clonal diversity, Principal component analysis

INTRODUCTION

The tea plant (*Camellia sinensis* L.) is a crop that has been an important commodity for Indonesia since the 17th century . Tea plants generally grow in tropical and subtropical climates. like Indonesia, tea is well known for having the highest catechin content in the world (Putri *et al*., 2024). Most tea developed in Indonesia is the result of a cross between the sinensis and assamica varieties. In reality, both varieties have their own advantages. Assamica tea excels in harvest volume but has a less desirable brew flavor, while Sinensis tea has a high-quality brew but a small harvest volume.

Indonesia has been producing green tea to meet domestic demand, but its quality has not yet met international standards, and prices tend to be low because the primary raw material comes from the Assamica variety (Sriyadi, 2011; Trinovani *et al*., 2025). Therefore, to produce high-quality green tea, tea buds from the Sinensis variety are required. Sinensis tea in Indonesia exhibits high diversity, but its cultivation remains limited because the plants used are derived from seeds with low productivity (Sriyadi, 2011; Prayoga *et al*., 2022). Consequently, the Sinensis variety has not yet been utilized as a raw material to produce green tea that meets international quality standards.

Plant breeding plays a crucial role in increasing crop yields and enabling plants to adapt to the challenges of climate change by leveraging genetic diversity to develop varieties with improved stress tolerance, productivity, and quality (Geneti & Getaneh, 2021). One of the critical phases in plant breeding is the seedling phase. The seedling phase plays a vital role in supporting productivity from a plant breeding perspective. Seedling production provides a controlled environment to protect young plants from harmful impacts and optimize growth conditions (Wani *et al*., 2020). The success of field planting systems depends on factors such as successful seedling production, field adaptation, and crop management, highlighting the importance of the seedling phase in supporting overall productivity (Kacheyo *et al*., 2023).

These factors strengthen the need for studies on promising tea clones during the seedling phase, so that the results can be taken into account when planting these clones in the field. By selecting the right clones, researchers can ensure optimal and sustainable yields in accordance with local soil and climate conditions.

MATERIALS AND METHODS

This study was conducted from March to June 2025 at the Gambung Tea and Cinchona Research Center in Pasirjambu Subdistrict, Bandung Regency, West Java Province, at an elevation of approximately 1,300 meters above sea level. The planting materials used included the Yabukita clone, superior sinensis clones (GMBS 1–5), and exploration clones (I.1.93, I.1.100, I.2.85, II.1.32, II.1.38, II.2.43, II. 4.149, II.4.178, and SGMBA).

This study was designed using a non-block, non-replicated design, with each plant sample considered a separate entity. Observations were conducted descriptively based on the Tea Pre-Test Guidelines (PPU) published by the Ministry of Agriculture. Observations involved the analysis of tea plant morphological characteristics. The tea plant morphological traits observed included plant height, stem diameter, number of leaves , the presence of zigzag branches, the color of the second leaf from the p+2 young shoots, the presence of hairs on young shoots, leaf blade behavior, leaf blade shape, intensity of leaf green color, cross-sectional shape of the leaf blade, distance between leaf veins, shape of the leaf blade tip, waviness of the leaf blade margin, serration of the leaf blade margin, and shape of the leaf blade base.

Plant height was measured from the base of the stem to the growing point using a measuring tape. Stem diameter was measured with a vernier caliper at a height of 3 cm above the soil surface. The number of leaves was counted manually using a hand counter for all fully expanded leaves on each plant. The degree of relatedness among 16 clones of the sinensis variety was determined using Principal Component Analysis (PCA) and Cluster Analysis with the PAST3 software.

RESULTS AND DISCUSSION

Cluster analysis of clonal relationships

To determine the degree of relatedness among clones, cluster analysis can be performed.

Cluster analysis is used to confirm the grouping of closely related clones based on the distances between them. The cluster analysis identified 13 clone samples divided into two major groups. Clones within the same group indicate that they are closely related.

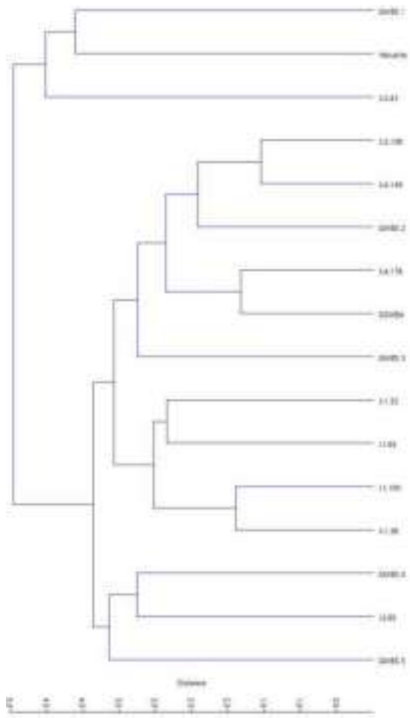

Figure 1. Cluster Analysis of 16 Tea Plant Clones (var. sinensis)

Analysis of genetic diversity is crucial for supporting the implementation of plant breeding programs, providing insights into population structure and the potential for improvement (He *et al*., 2021). Understanding the genetic distance between clones can guide the selection of parents for crossing, which has the potential to enhance heterosis and genetic diversity in their offspring (Nuryati *et al*., 2024). The data show the clones in each group, with Group 2 being the larger group, comprising 81.25% of the clones. Clones grouped together indicate that they are closely related (Sa'adah *et al*., 2025).

The PCA was conducted on 16 Sinensis tea plant clones evaluated based on four agronomic traits and twelve morphological traits. The analysis yielded five principal components (PCs) contributing 88% of the total variation, with eigenvalues ranging from 0.7416 to 2.5711. The cumulative percentage of total variation from the 16 traits in tea plants on PC5 remained below 90%. The first principal component (PC1) accounted for 30.547% of the variation, followed by PC2 at 20.034%, PC3 at 16.901%, PC4 at 11.714%, and PC5 at 8.812%. The clustering was based on traits, with the traits significantly influencing the grouping indicated by bold numbers. In the first principal component (PC1), the trait contributing significantly to the variation is the number of leaves. In PC2, the contributing trait is the color of the second leaf from position p+2 on young shoots. In PC3 and PC4, the relevant traits are leaf blade behavior, while in PC5, the contributing trait is the serration of the leaf blade margin.

Table 1. Members of the Dendrogram Clone

Cluster	1	2
Total	3	13
Percentage	18.75%	81.25%
Clone Member	GMBS 1, Yabukita, II.2.43	I.1.93, I.1.100, I.2.85, II.1.32, II.1.38, II.2.108, II.4.149, II.4.178, SGMBA, GMBS 2, GMBS 3, GMBS 4, GMBS 5

Principal component analysis

Principal Component Analysis (PCA) is a statistical technique used in plant breeding to reduce large datasets to a smaller set of uncorrelated variables while retaining most of the original data (Sarma, 2022). Biplot analysis shows the grouping of tea clones based on similarities in genetic and agronomic traits. Clones II.2.43, Yabukita, and GMBS 2 form a single quadrant characterized by similarities in the second leaf color of p+2 young shoots, leaf blade behavior, leaf margin waviness, leaf green color intensity, and cross-sectional shape of the leaf blade. Furthermore, clones II.2.108, II.4.149, II.4.178, and GMBS 1 showed significant similarity in plant height and number of leaves. The third quadrant included clones I.1.93, SGMBA, GMBS 3, and GMBS 5, where their relationship was assessed based on similarities in leaf base shape. Finally, clones I.1.100, I.2.85, II.1.32, II.1.38, and GMBS 4 form a cluster based on characteristics of leaf blade shape, interveinal spacing, and serration of the leaf margin.

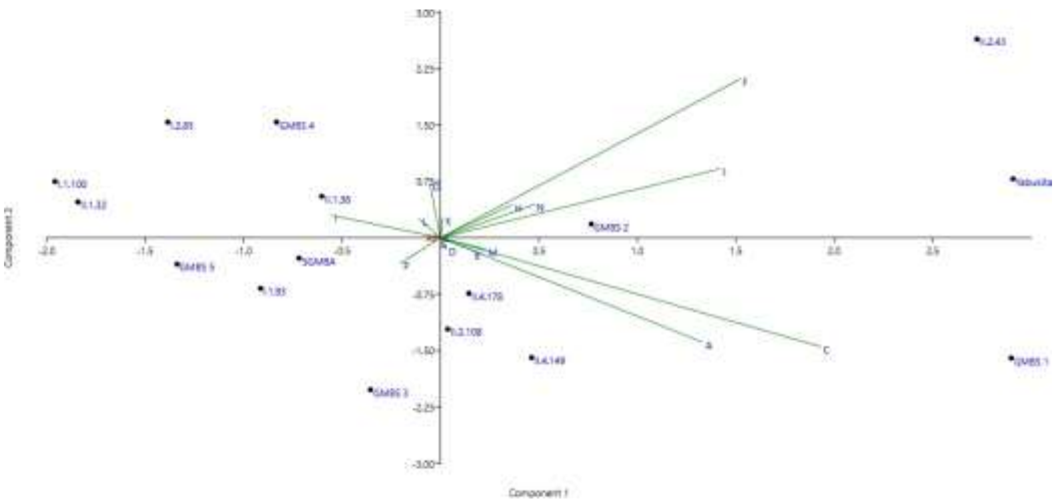

Figure 2. Biplot Diagram for Components 1 and 2

The ability of a characteristic to influence clustering can be assessed by the percentage of the eigenvalue. If the eigenvalue reaches 100%, this indicates that the characteristic has a full influence on the overall clustering. A characteristic is considered to influence clustering if its eigenvalue exceeds one. However, in this study, the selection of principal components (PCs) was based on a cumulative percentage reaching approximately 88%.

Table 2. Diversity Values of Tea Clones of the Sinensis Variety

PC	*Eigenvalue*	Variance (%)	Cumulative (%)
1	2.57113	30.5470	30.547
2	1.68625	20.0340	50.581
3	1.42253	16.9010	67.482
4	0.98593	11.7140	79.196
5	0.74170	8.81200	88.008
6	0.46731	5.55210	93.560
7	0.23887	2.83800	96.398
8	0.13919	1.65370	98.052
9	0.07523	0.89380	98.946
10	0.04540	0.53946	99.485
11	0.02516	0.29893	99.784
12	0.01109	0.13177	99.916
13	0.00479	0.05691	99.973
14	0.00228	0.02715	99.999
15	9.45E-34	1.12E-32	99.999

PCA results for 16 Sinensis tea plant clones evaluated based on four agronomic traits and twelve morphological traits. The analysis yielded five principal components (PCs) contributing 88% of the total variation, with eigenvalues ranging from 0.7416 to 2.5711. The cumulative percentage of total variation from the 16 traits in tea plants on PC5 remained below 90%. The first principal component (PC1) accounted for 30.547% of the variation, followed by PC2 at 20.034%, PC3 at 16.901%, PC4 at 11.714%, and PC5 at 8.812%. After the PCA analysis was conducted, the study proceeded to test the influence of each trait on the grouping of the sixteen tested clones.

Table 3. The Value of Character Traits on Grouping

Character	PC 1	PC 2	PC 3	PC 4	PC 5
Plant height	0.407	-0.425	0.134	-0.138	-0.284
Stem diameter	0.067	-0.068	-0.026	-0.051	-0.068
Number of leaves	**0.592**	-0.444	-0.060	0.021	0.412
Internode length	0.009	-0.044	-0.022	0.013	0.018
Presence of zig-zag branching	0.000	0.000	0.000	0.000	0.000
Leaf color of the second leaf from the p+2 young shoot	0.466	**0.647**	0.212	-0.244	-0.280
Presence of hairs on young shoots	0.000	0.000	0.000	0.000	0.000
Leaf blade morphology	0.111	0.134	**0.521**	**0.765**	0.165

Leaf blade shape	-0.169	0.092	-0.391	0.213	0.085
Intensity of leaf green color	0.435	0.281	-0.616	0.274	0.036
Cross-sectional shape of the leaf blade	0.003	0.079	0.266	-0.081	0.280
Distance between leaf veins	-0.033	0.078	-0.130	0.144	0.018
Shape of the leaf blade tip	0.071	-0.047	0.176	-0.004	-0.162
Waviness of the leaf blade margin	0.146	0.135	0.050	0.040	0.080
Serration of the leaf blade margin	-0.016	0.221	0.062	-0.365	**0.720**
Shape of the leaf blade base	-0.062	-0.104	-0.064	0.224	0.021

For the first principal component (PC1), the trait that contributed significantly to the variance was the number of leaves. For PC2, the contributing trait was the color of the second leaf from the p+2 position on young shoots. For PC3 and PC4, the relevant trait was leaf blade morphology, whereas for PC5, the contributing trait was leaf margin serration. Recent research confirms the use of a threshold of 0.5 to evaluate the contribution of variables. A PC value greater than 0.5 is used as a threshold in PCA for plant breeding because it ensures that only traits with a significant contribution to genetic or phenotypic variation are selected. This threshold helps identify biologically relevant traits. By focusing on highly contributing traits, breeders can improve selection efficiency and genetic progress in the development of superior varieties (Rakhmad *et al*., 2021). These results indicate that the first factor (PC-1) is predominantly influenced by plant morphological traits such as plant height and stem diameter, while the other factors (PC-2 to PC-5) reflect more specific variations in certain traits, which can be used for further plant classification or selection.

CONCLUSION

This study confirms significant morphological diversity among 16 *Sinensis* tea clones during the seedling phase, characterized by variations in leaf number, shoot color, and leaf blade morphology. Principal Component Analysis identified five components accounting for 88% of the total phenotypic variation, with the number of leaves and second leaf color at the p+2 position serving as the primary traits influencing clonal differentiation. Cluster analysis successfully categorized the 16 clones into two distinct kinship groups, with the second group dominating 81.25% of the tested population. These findings provide critical insights into the population structure of *Sinensis* tea clones, offering a reliable basis for parent selection and breeding strategies aimed at developing superior, high-productivity varieties that meet international quality standards for green tea production.

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