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# Morphological Characterization and Kinship Analysis of the Kepel Plant *(Stelechocarpus Burahol)*

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**Abstract**

*Kepel (Stelechocarpus burahol) is an endemic Javanese plant whose natural populations are declining, requiring conservation based on scientific evidence. This study aimed to characterize the morphological variation and analyze the phenotypic relationships of kepel populations across five ecological zones in Kebumen Regency: West, South, Central, East, and North. A total of 25 individuals were examined using a quantitative descriptive survey. Vegetative traits (leaf length, leaf width, stem diameter) and generative traits (flower diameter) were measured, while environmental parameters were recorded to support data interpretation. Numerical taxonomy analysis was conducted using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based on standardized Euclidean distances. The results showed substantial morphological variation among zones, with stem diameters ranging from 27.7 to 30.5 cm and leaf lengths from 17.5 to 19.8 cm. Significant correlations were observed between soil pH, humidity, and temperature with key morphological traits ($r = 0.70–0.90$). The UPGMA dendrogram revealed three major clusters corresponding to distinct microhabitats. These findings indicate local adaptation of kepel populations in Kebumen and provide a scientific basis for both in situ and ex situ conservation of local germplasm.*

## Introduction

The kepel plant (*Stelechocarpus burahol*) is one of Indonesia's endemic species originating from Java and is widely recognized for its ecological, cultural, and economic importance (Saputra et al., 2024; Restiani et al., 2024). Historically, the plant has been closely associated with Javanese cultural traditions and is often cultivated in palace environments, symbolizing prestige and heritage (Mulyanto et al., 2024; Santosa & Noorwatha, 2025; Hellman, 2017). Ecologically, kepel contributes to biodiversity conservation in tropical landscapes, while economically it offers opportunities for utilization in food, cosmetics, and herbal industries.

However, despite its importance, the sustainability of kepel populations is increasingly under threat. Rapid land conversion, urban expansion, and limited natural regeneration have led to a gradual decline in its distribution, making conservation efforts urgently needed and requiring a solid scientific foundation (Ige et al., 2024; Huang et al., 2018; Zhang et al., 2025). Beyond its cultural symbolism, kepel has attracted scientific attention due to its bioactive compounds. Studies indicate that the fruit and other plant parts contain aromatic substances and metabolites with potential pharmaceutical and nutraceutical applications (Babbar et al., 2023; Abbas et al., 2023; Karim & Azlan, 2012; Mohammed et al., 2025; Dincheva et al., 2023).



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Such potential elevates the value of kepel not only as a heritage species but also as a strategic biological resource. Nevertheless, sustainable utilization depends heavily on the availability of accurate information regarding its diversity, adaptability, and population structure. Without adequate knowledge of variation within the species, conservation and breeding strategies may be ineffective or even counterproductive.

Morphological diversity represents one of the most accessible indicators for understanding variation within plant populations. Differences in vegetative and generative traits often reflect adaptive responses to environmental pressures and may signal underlying genetic differentiation (Linhart & Grant, 1996; Napier et al., 2023; Lachowiec et al., 2016). For conservation biology, recognizing such variation is fundamental because it helps determine priorities for protection, propagation, and germplasm management. In the context of kepel, several studies have reported variability in leaf morphology, stem characteristics, and floral structures across different regions.

However, much of this work remains largely descriptive and has not systematically connected morphological expression with ecological gradients or spatial heterogeneity (Ricklefs & Miles, 1994; Dent & Grimm, 1999). Kebumen Regency provides an especially relevant setting for addressing this limitation. The region is characterized by diverse ecological conditions, including variation in altitude, temperature, soil acidity, humidity, light exposure, and landscape types. Such heterogeneity creates multiple environmental niches that may influence phenotypic plasticity and morphological differentiation.

Consequently, kepel populations growing in different parts of Kebumen may exhibit distinctive characteristics shaped by local environmental dynamics. Understanding these patterns is essential for designing conservation strategies that are sensitive to ecological context rather than relying on generalized assumptions. To analyze morphological relationships more objectively, numerical taxonomy offers a robust methodological pathway. Among available techniques, the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) has been widely used to classify individuals based on similarity matrices derived from observable characters (Darkwa et al., 2020; Odong et al., 2011; Akin-Idowu et al., 2016; Madeira et al., 1997).

This approach enables researchers to construct phenetic relationships and visualize clustering patterns that may correspond with ecological or geographical factors. Previous applications in various plant taxa demonstrate that UPGMA can reveal meaningful group structures relevant to conservation planning (Liu et al.,2023; Escudero et al., 2003). Despite its recognized utility, this method has not yet been applied to kepel populations in Kebumen, leaving an important analytical gap.

Considering the ecological importance, economic potential, and conservation urgency of kepel, research integrating morphological characterization with numerical analysis becomes highly significant. Such integration can generate baseline data for identifying distinct groups, recognizing unique populations, and formulating strategies for in situ and ex situ preservation. Furthermore, it supports local government initiatives in protecting regional biodiversity and managing genetic resources sustainably.

Therefore, this study aims to identify morphological variation of kepel across five ecological zones in Kebumen Regency and to analyze phenotypic kinship relationships using the UPGMA clustering method. The results are expected to provide a scientific reference for conservation


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policy, germplasm management, and future breeding or domestication programs. By linking morphology, environment, and classification, the study seeks to contribute to a more comprehensive understanding of how endemic species survive and adapt within rapidly changing landscapes.

## Methods

### Research Location and Timeline

The research was conducted in Kebumen Regency, Central Java, which has varied topography ranging from coastal lowlands to hills. The observation sites were divided into five ecological zones: West, South, Central, East, and North. Data collection was conducted from September to November 2025, coinciding with the peak flowering and fruiting phase of kepel plants (Kacjan et al., 2021).

### Materials and Equipment

The research materials consisted of kepel plants (Stelechocarpus burahol) that had fruited at least once, in accordance with sample selection standards for local fruit plant morphology research. The equipment used included a ruler, digital calipers, a digital scale, a digital camera, a pH meter, a thermometer, a hygrometer, a GPS, and a light intensity meter. All equipment was calibrated before use.

### Research Design and Sampling Techniques

The research used a quantitative descriptive survey method. Five individual plants were purposively selected in each zone, resulting in a total sample size of 25. Sample selection was based on: (1) healthy plants; (2) accessible for morphological measurements, and complete vegetative and generative organs. This design follows a similar approach to research on the morphological characterization of tropical endemic plants.

### Observation Variables

Plant characteristics observed included leaf size and shape, leaf color, stem diameter, and texture as basic growth characteristics and plant identification. Flower diameter, flower color, perianth texture, and floral aroma were used to assess phenotypic variation, which is an important part of plant morphological classification (Parachnowitsch et al., 2012; Santos et al., 2012). Environmental parameters, including air temperature and humidity, light intensity, pH, soil temperature and humidity, altitude, soil texture, and rainfall, were observed to determine the influence of ecological conditions on changes in plant morphology. Measurement of these factors helps explain how tropical plants adapt through phenotypic variations that occur in both vegetative and generative traits (Reich et al., 2003).

### Observation Procedure

Each variable was measured three times per individual to reduce observation bias. Data were recorded on a standardized observation sheet and supported by photographic documentation for validation.


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## Data Analysis

### *Data Standardization*

All quantitative morphological data were standardized using the Z-score method to ensure comparable ranges and units before cluster analysis (Ishmawati, 2024).

### *Kinship Analysis (UPGMA)*

Phenotypic relationships were analyzed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based on Euclidean distance. The analysis was performed using the latest version of PAST software. This method was chosen because it is able to stably group individuals based on the level of similarity in morphological traits.

### *Morphology–Environment Correlation Analysis*

Pearson correlation was used to assess the relationship between morphological characteristics and environmental parameters. Correlation values were interpreted based on the strength of the relationship according to the general coefficient category ($r = 0.70–0.90$ is considered strong).

## Results and Discussion

### Vegetative Morphological Variation of Kepel Plants

Observations of vegetative morphology included leaf length, leaf width, leaf shape index, and stem diameter. The average summary results for each zone are presented in Table 1. Differences in average values between zones indicate variation in vegetative morphology in kepel plants. The North Zone showed the highest values for most vegetative parameters.

Table 1. Average Vegetative Characteristics of Kepel Plants Across Five Ecological Zones

| Zone | Leaf length (cm) | Leaf width (cm) | Leaf shape index | Stem diameter (cm) |
|---|---|---|---|---|
| West | 18.86 ± 0.11 | 7.48 ± 0.08 | 2.52 ± 0.03 | 29.08 ± 0.33 |
| South | 17.64 ± 0.11 | 7.08 ± 0.08 | 2.49 ± 0.03 | 27.82 ± 0.08 |
| Central | 18.74 ± 0.11 | 7.42 ± 0.13 | 2.53 ± 0.03 | 28.88 ± 0.26 |
| East | 18.78 ± 0.13 | 7.46 ± 0.11 | 2.52 ± 0.02 | 28.94 ± 0.21 |
| North | 19.60 ± 0.16 | 7.92 ± 0.08 | 2.48 ± 0.03 | 29.80 ± 0.59 |

### Generative Morphological Variation

Generative character observations focused on flower diameter. A summary of the average values is presented in Table 2.

Table 2. Average Flower Diameter of Kepel Plants in Five Ecological Zones

| Zone | Flower diameter (cm) |
|---|---|
| West | 2.66 ± 0.05 |
| South | 2.40 ± 0.07 |
| Central | 2.72 ± 0.08 |
| East | 2.72 ± 0.08 |
| North | 2.86 ± 0.05 |

There is variation in flower diameter between zones, with the highest value occurring in the North zone.



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### Qualitative Morphological Characteristics of Kepel Plants

Observations of qualitative morphological characteristics were conducted to supplement information regarding phenotypic variation between zones. Observed characteristics included leaf shape, leaf color, stem texture, flower color, flower aroma, perianth texture, and fruit position. The results of observations per zone are presented in Table 3. These qualitative characteristics show clear variation between zones, particularly in leaf color, stem texture, and flower aroma.

Table 3. Qualitative Morphological Characteristics of Kepel Plants in Five Ecological Zones

| Qualitative Character | West | South | Middle | East | North |
|---|---|---|---|---|---|
| Leaf shape | Elliptic–lanceolate | Elliptical | elliptic-oval | Elliptic–lanceolate | lanceolate |
| Leaf color | dark green | greenish green | dark green | Light green | very dark green |
| Stem texture | smooth | a bit rough | slightly rough | Smooth | rough |
| Flower color | pale yellow | greenish yellow | pale yellow | Bright yellow | greenish yellow |
| Floral aroma | medium | Weak | medium | Medium–strong | strong |
| Perianth texture | soft | a bit thick | soft | Thick | thick-rough |

### Converting Qualitative Characters to Numerical Data

Representative values for each zone are shown in Table 4. This section complements the quantitative data and serves as a basis for integration in the analysis of morphological diversity.

Table 4. Numerical Scores for Qualitative Characters Per Zone

| Characteristics | West | South | Middle | East | North |
|---|---|---|---|---|---|
| Leaf shape | 2.5 | 2.0 | 1.5 | 2.5 | 3.0 |
| Leaf color | 3.0 | 2.0 | 3.0 | 1.0 | 4.0 |
| Stem texture | 1.0 | 2.0 | 2.0 | 1.0 | 3.0 |
| Flower color | 1.0 | 2.0 | 1.0 | 3.0 | 2.0 |
| Floral aroma | 2.0 | 1.0 | 2.0 | 2.5 | 3.0 |
| Perianth texture | 1.0 | 2.0 | 1.0 | 3.0 | 3.5 |

### Environmental Parameters at Observation Locations

Environmental parameters in each zone include air temperature, air humidity, soil pH, and elevation. A summary is presented in Table 6. Environmental parameters across zones have a fairly wide range of values, particularly temperature and humidity.



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Table 5. Average Environmental Parameters Across Five Ecological Zones

| Zone | Temperature (°C) | Humidity (%) | pH land | Height (mdpl) |
|---|---|---|---|---|
| West | 26.88 | 78.74 | 6.26 | 138.60 |
| South | 31.00 | 68.48 | 7.02 | 14.80 |
| Central | 28.58 | 74.12 | 6.54 | 48.60 |
| East | 28.70 | 79.16 | 6.48 | 64.20 |
| North | 25.92 | 81.98 | 5.92 | 228.60 |

**Correlation between Morphology and Environmental Parameters**

Pearson correlation analysis was used to assess the relationship between morphological characters and environmental parameters. The main results are shown in Table 6. The correlation values indicate a strong relationship between the variables.

Table 6. Correlation Coefficients Between Morphological Characters and Environmental

| Variable Pairs | r |
|---|---|
| Leaf Length – Air Humidity | +0.80 |
| Stem Diameter – Soil pH | +0.70 |
| Leaf Length – Air Temperature | –0.90 |
| Leaf Width – Humidity | +0.78 |
| Leaf Shape Index – Height | +0.81 |

**Phenotypic Distance Matrix (Squared Euclidean Distance)**

Relationship analysis was conducted using a squared Euclidean distance matrix between 25 kepel plant samples. This matrix was used as the basis for constructing a dendrogram. The average matrix is shown in Table 7.

Table 7. Average Phenotypic Distance Between Zones (Squared Euclidean Distance)

| Zone → | West | South | Middle | East | North |
|---|---|---|---|---|---|
| West | **0** | 682 | 451 | 713 | 989 |
| South | 682 | **0** | 1174 | 1390 | 1722 |
| Central | 451 | 1174 | **0** | 298 | 474 |
| East | 713 | 1390 | 298 | **0** | 367 |
| North | 989 | 1722 | 474 | 367 | **0** |

**Morphological Relationship Dendrogram (UPGMA)**

UPGMA analysis of the distance matrix yielded three main clusters from 25 kepel plant samples. The dendrogram visualization can be seen in Figure 1.

The clustering analysis classifies the samples into three major groups based on their morphological similarity. Cluster 1 consists of individuals from BA-01 to SE-05, indicating a relatively small inter-sample distance and suggesting that specimens from the western and southern zones tend to share close phenotypic characteristics. Cluster 2 includes TE-01 to TE-05 together with TI-01 and TI-02, reflecting a moderate level of variation and implying partial differentiation while still maintaining observable similarities. Cluster 3 groups TI-03 to TI-05 with UT-01 to UT-05 and represents the widest internal divergence, pointing to stronger morphological heterogeneity among samples originating from the eastern and northern areas.



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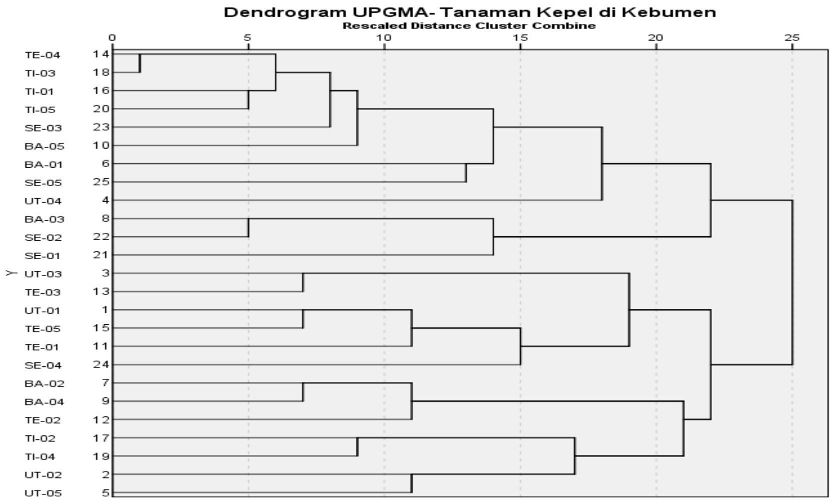


*Figure 1. Dendrogram of UPGMA Analysis Results*

A closer look at pairwise distances reveals several notable relationships. The smallest distance is observed between BA-03 and BA-04, marking them as the most phenotypically similar pair within the dataset. Another relatively close association appears between BA-02 and SE-01, which is particularly interesting because the samples come from different ecological zones yet still demonstrate strong resemblance. In contrast, the greatest distances occur in comparisons involving UT-02 with TI-03, TE-04 with UT-02, and TI-04 with UT-05. These pairs represent the most extreme morphological divergence, emphasizing the presence of substantial variation across certain geographic locations.

**Principal Component Analysis (PCA)**

Principal Component Analysis (PCA) was conducted to evaluate the patterns of morphological and environmental diversity across five ecological zones of the kepel plant. The PCA used 16 variables consisting of quantitative morphological characters (leaf length, leaf width, leaf index, stem diameter, flower diameter), environmental factors (temperature, humidity, soil pH, altitude), and qualitative morphological characters that were converted to numerical scores. The PCA results showed that three principal components had the largest eigenvalues and together explained 81.8% of the total diversity, with respective contributions: PC1 at 61.6%, PC2 at 20.2%, and PC3 at 12.9%.

The first two components (PC1 and PC2) sufficiently described the diversity patterns between zones and were used for further interpretation. The two-dimensional PCA plot (PC1–PC2) showed a clear separation between the zones. The Southern Zone was in the positive quadrant of PC1, while the Northern Zone was in the negative quadrant of PC1. The East Zone is in the positive quadrant of PC2, while the Central and West Zones are in the negative quadrant. This pattern indicates that there are environmental and morphological gradients that differentiate the five zones.

Table 8. Variable Loadings on PC1 and PC2

| Variable | PC1 | PC2 |
|---|---|---|
| Leaf length | -1.092 | -0.086 |
| Leaf width | -1.108 | 0.068 |



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| | | |
|---|---|---|
| Leaf index | 0.253 | -0.655 |
| Stem diameter | -1.099 | -0.090 |
| Flower diameter | -1.019 | -0.051 |
| Temperature | 1.076 | 0.268 |
| Humidity | -1.039 | 0.062 |
| Soil pH | 1.109 | 0.116 |
| Altitude | -1.063 | -0.001 |
| Leaf shape (score) | -0.815 | 0.502 |
| Leaf color (score) | -0.713 | -0.484 |
| Stem texture (score) | -0.415 | 0.245 |
| Flower color (score) | 0.016 | **1.054** |
| Floral aroma (score) | -1.034 | 0.196 |
| Perianth texture (score) | -0.515 | 0.990 |

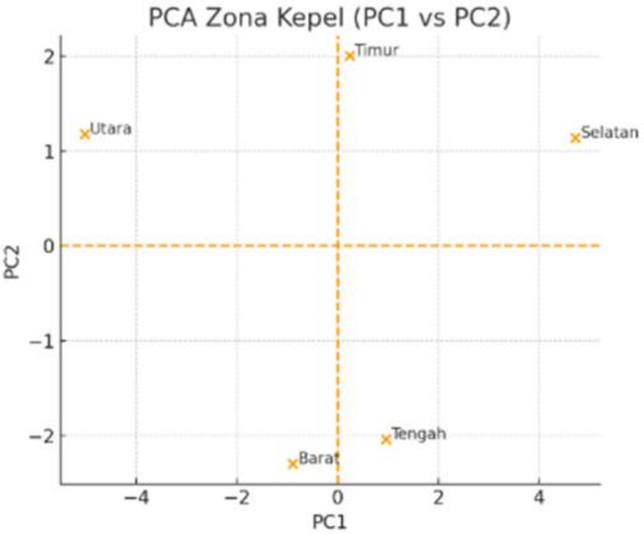


*Figure 2. PCA plot of the Kepel zone (PC1 vs PC2)*

Description:

PC1 explains 61.6% of the variance; PC2 explains 20.2% of the variance. The Southern Zone lies far on the positive side of PC1, while the Northern Zone lies on the negative side of PC1. The Eastern Zone has a high positive value on PC2.

**Vegetative Morphological Variation and Environmental Influence**

Differences in leaf length, leaf width, and stem diameter between zones indicate phenotypic adaptation to environmental variations. The Northern Zone, with its low temperatures and high humidity, produces longer and wider leaves (Avianto & Saputra, 2024), in line with the theory that humid conditions increase leaf size by reducing evaporation and increasing photosynthetic efficiency. This pattern is supported by findings showing that kepel plants in temperate regions have more developed vegetative characteristics, including larger stem diameters.

The positive correlation between air humidity and leaf characteristics confirms a functional relationship between humid environments and phenotypic growth (Sellin et al., 2013). The


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Southern Zone, with its highest temperature (31°C), exhibits smaller leaf size compared to other zones. This pattern is consistent with the theory of tropical plant adaptation, which states that leaves shrink at high temperatures to reduce water loss through transpiration.

**Variation in Generative Morphology**

The larger flower diameter in the Northern zone compared to other zones indicates that humid environmental conditions with lower temperatures support the formation of more optimal reproductive structures. According to Silberbauer-Gottsberger et al. (2003) and Saunders (2020) flowering in the Annonaceae family is strongly influenced by temperature and humidity, so zones with cooler microclimates allow for better development of generative organs.

**Discussion of Qualitative Morphological Characters**

Variation in qualitative characters indicates phenotypic adaptation patterns appropriate to the environmental conditions in each zone. The Northern zone scored high on leaf color, stem texture, perianth texture, and floral aroma, reflecting strong adaptation to humid environments with lower light intensity. This finding aligns with findings that visual traits such as leaf color and perianth texture correlate with microhabitat in the Annonaceae family.

The Southern Zone displayed the lowest scores for several traits, such as leaf color, floral aroma, and fruit position, indicating environmental stress due to high temperatures and low humidity. These environmental factors are known to influence the formation of leaf pigments and floral volatile compounds (Farré-Armengol et al., 2020; Paul et al., 2022). Variation between zones supports the UPGMA cluster pattern, which indicates a grouping of high-humidity zones and a separation of zones with extreme conditions, consistent with previous research.

**Effect of Environmental Parameters on Plant Morphology**

Correlation values indicate a strong relationship between morphological traits and environmental conditions, such as temperature, humidity, and soil pH. The very strong negative correlation between air temperature and leaf length ($r = -0.90$) indicates that increasing temperature is inversely related to the development of certain vegetative traits. This aligns with the temperature-influenced model of tropical plant growth.

Meanwhile, a positive relationship between soil pH and stem diameter ($r = +0.70$) indicates that a pH close to neutral increases nutrient availability, thus supporting stem growth. A similar relationship was reported by Rodrigues et al. (2018) who found that soil pH influences the variability of morphological traits in a study of tropical plant diversity.

**Interpretation of UPGMA Clusters and Implications for Phenotypic Relationships**

The dendrogram resulting from the UPGMA analysis formed three main clusters indicating variation in phenotypic relationships among kepel samples. This grouping based on morphological character similarities reflects differences in environmental pressures and possible differences in genetic sources.

***Cluster 1: Homogeneous Population***

Cluster 1, consisting of BA-01 to SE-05, shows very little morphological variation. This uniformity indicates that the samples likely grew in environments with similar and relatively stable conditions. This finding aligns with research by Fakhry et al. (2019) and Niewiarowski



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& Roosenburg (1993), which states that phenotypic homogeneity is often found in kepel plants grown in environments with similar microhabitat conditions.

***Cluster 2: Population Adaptive to High Humidity***

Cluster 2, which includes TE-01 to TE-05, as well as TI-01 and TI-02, exhibits morphological characteristics with larger leaves and thicker stem diameters. This cluster is consistent with zones with high humidity, such as the Northern Zone. Such conditions have been reported by Wulandari E. and Firdiana N. as factors that enhance the vegetative performance of kepel plants.

***Cluster 3: Populations with High Environmental Stress***

Cluster 3, consisting of TI-03 to TI-05 and UT-01 to UT-05, had the largest morphological distance between samples. This variation indicates environmental heterogeneity, likely originating from the Southern zone, which has high temperatures and more alkaline soil pH. According to Chevin & Hoffmann (2017) extreme conditions such as high temperatures can cause greater phenotypic variation in tropical plants.

***PCA Analysis Discussion***

PCA results indicate that PC1 represents an environmental gradient separating zones based on differences in temperature, humidity, and soil pH. High positive loadings on temperature and pH, and negative loadings on leaf length, leaf width, stem diameter, flower diameter, and humidity, indicate a transition from cool-humid to hot-dry conditions. The Southern Zone has the highest positive PC1 values, with high temperature stress and a more alkaline pH, which can reduce the size of vegetative organs, while the Northern Zone has negative PC1 values, with larger leaves and stems, consistent with humid microhabitat conditions.

PC2 is primarily influenced by generative traits such as flower color and perianth texture, thus better representing reproductive variation than environmental factors. The Eastern and Northern Zones have high PC2 values because they exhibit greater floral trait diversity than the other zones. The relationship between PCA and UPGMA is also consistent, demonstrated by the strong separation of the Southern Zone in both PCA and UPGMA cluster space and the close proximity of the Eastern and Northern Zones in both analyses, in line with findings that PCA and clustering generally produce similar patterns in studies of tropical plant diversity.

**Implications for Conservation and Breeding**

The findings of morphological diversity and phenotypic relationship patterns provide a strong basis for developing in situ and ex situ conservation strategies. Populations in cluster 2 have the potential to be developed as a genetic resource for high-growth varieties, while populations in cluster 3 are important to maintain due to their tolerance to extreme environmental stress. In the context of breeding, these clusters can serve as sources of germplasm representing diverse traits and ecological adaptations (Lestari, 2013). This is crucial for developing superior kepel varieties that meet conservation and economic needs

## Conclusion

This study demonstrates the morphological diversity of kepel plants in Kebumen, influenced by differences in environmental conditions between zones, as seen through variations in vegetative, generative, and qualitative characteristics. UPGMA analysis grouped 25 samples


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into three clusters reflecting variations in temperature, soil pH, humidity, and altitude. PCA confirmed this pattern, contributing 81.8% to the diversity. The Southern Zone was the most distinct population due to the environmental stress of heat and high pH, while the Northern and Eastern Zones showed close associations due to humid conditions and more stable morphology. These findings confirm that the interaction of morphological and environmental factors plays a significant role in shaping kepel variation patterns, thus providing a basis for future conservation and breeding strategies.

## Suggestion

Further research is recommended using genetic analysis to validate morphological relationships and expanding sampling locations to better represent the kepel population in Kebumen. In situ conservation efforts should focus on populations with high diversity, while ex situ conservation can be conducted by selecting representative individuals from each UPGMA cluster. Regular monitoring of environmental conditions such as temperature, humidity, and soil pH is important because changes in these factors can affect the growth and sustainability of kepel populations in their natural habitat.

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