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Morphological characterization and clustering analysis of three local jackfruit cultivars (*Artocarpus heterophyllus*) in Lamongan District, East Java, Indonesia

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Abstract. *Ullah LR, Purnama PR, Wisanti. 2025. Morphological characterization and clustering analysis of three local jackfruit cultivars* (Artocarpus heterophyllus) *in Lamongan District, East Java, Indonesia. Biodiversitas 26: 1920-1928.* Lamongan District is among jackfruit (*Artocarpus heterophyllus*) producers in East Java, Indonesia, where three local cultivars including `*Nangka Bubur*`, `*Nangka Kandel*`, and `*Nangka Salak*` have been identified. This study aimed to characterize and cluster the morphology of these 3 cultivars from Lamongan. Six trees per cultivar were assessed for 41 morphological characters (32 qualitative and 9 quantitative). Data were analyzed using Principal Component Analysis (PCA), k-means clustering, hierarchical clustering, correlation, and heatmap plots. Clustering methods successfully separated the tree cultivars. From the 41 characters, 4 uniform and least variance characters were excluded. Correlation analysis identified positively correlated characters such as spine density, fruit shape, spine diameter, falke texture, flake shape, and spine color. Based on variable importance plot, biplot PCA, and heatmap analysis, 11 diagnostic characters were identified: mesocarp thickness, spine length, pulp color at ripe stage, fruit shape, shape of spine, seed coat color, seed shape, flake texture, spine density, flake shape, and stalk attachment to fruit. The stated discoveries would provide helpful insight into the process of agricultural improvement, particularly concerning jackfruit.

Keywords: *Artocarpus heterophyllus*, clustering analysis, multivariate analysis, PCA, sustainable agriculture

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* Lam.) is a species of the family Moraceae that produces exotic and edible fruit. This species is native to the Western Ghats of India and is commonly cultivated throughout tropical countries, including Indonesia, Bangladesh, Thailand, Malaysia, the Philippines, and Sri Lanka (Ragone 2007; Rahaman et al. 2018). The tree has been widely distributed across tropical regions due to its adaptability to various soil types and climatic conditions, making it an important crop for both subsistence and commercial farming (Baliga et al. 2011; Swami et al. 2012). Jackfruit is considered one of the largest tree-borne fruits in the world, with individual fruits weighing up to 35 kg (Jagdale et al. 2021). At the national level, jackfruit production in Indonesia reached 906,514 tons in 2021; 813,756 tons in 2022; and 789,200 tons in 2023 (BPS 2023a) with East Java contributing 182,741.4 tons in 2021 and 175,867.1 tons in 2022 to the national production (BPS 2023b). Furthermore, the flesh can be consumed as fresh or processed food in various maturity stages, ranging from unripe to fully ripened (Ranasinghe et al. 2019). Jackfruit is recognized as a "superfood" because of its nutritional benefits (Mondal et al. 2024). Each 100 g of ripe jackfruit pulp contains carbohydrates 16-25.4 g, protein 1.2-1.9 g, fat 0.1-0.4 g, energy 88-410 kJ, fiber 1.0-1.5 g, and water 72-94 g. Moreover, the protein content in seeds ranges from 5.3 to 6.8%, and the carbohydrate content varies between 37.4 and 42.5% (Jagdale et al. 2021).

Many countries consume jackfruit, commonly called 'poor man's food' in Bangladesh, because it provides significant sustenance during shortages of staple foods (Rajkumar et al. 2018; Chikkanna 2021). The affordability, high yield, and nutritional value make jackfruit an important food security crop in several developing countries (Khan et al. 2021). Various parts such as young jackfruit and flower heads have been used for several ethnic dishes in Indonesia, including *gudeg* (sweet jackfruit stew), young jackfruit soup, and jackfruit chips (Yudhistira 2022). However, jackfruit is largely considered a crop that is not exploited to its full potential globally (Ranasinghe et al. 2019; Khan et al. 2021).

The identification of jackfruit is commonly based on the morphological characteristics, including the habits of a medium-sized evergreen tree, inflorescences on the trunk or branches, unisexual, monoecious, and green to brownish-yellow compound fruit (Khan et al. 2021). Additionally, the fruit is structurally circular to ellipsoid, and the leaves have morphologies that range from inverted oval to oval (Mondal et al. 2024). There are morphological differences in seed length and weight, pulp sweetness, aroma, taste, and exocarp scale density, size, and shape (Dhakar et al. 2020; Mondal et al. 2024). These observed variations are significantly relevant for the conservation and use of germplasm, particularly in addressing climatic change and market needs (Dhakar et al. 2020). Moreover, a clustering analysis of 11 jackfruit accessions in West Kalimantan, Indonesia, found that 3 groups were clustered based on morphology (Safitri et

al. 2017). The morphology characterization and clustering analysis are important for plant breeding programs and germplasm collection (Daley et al. 2020).

Lamongan District is a significant producer of `*Nangka Bubur*`, `*Nangka Kandel*`, and `*Nangka Salak*` culitivars in East Java, Indonesia. At the district level, Lamongan's jackfruit production has shown a steady increase from 22,487 tons in 2021 to 22,972 tons in 2022, and 26,641 tons in 2023, demonstrating the region's growing importance in jackfruit cultivation (BPS 2023c). Despite this growth, proper identification and characterization of these cultivars remain challenging due to their significant morphological diversity. The morphological variations lead to difficulties for farmers and breeders in identifying existing cultivars. Therefore, this study aimed to address the morphological variance among three jackfruit cultivars in Lamongan District and define the important diagnostic characters to use for discrimination. The information obtained could be helpful for cultivation and breeding programs to improve jackfruit quality and productivity.

MATERIALS AND METHODS

Study area

This research was conducted in 3 sites in Solokuro Sub-district, Lamongan District, East Java, Indonesia (Table 1; Figure 1). Samples were collected from 3 cultivars of jackfruit trees, including vegetative and generative organs, in August-November 2023. Six trees with a minimum age of 2 production years were selected as samples for each cultivar.

Procedures

Three mature fruits for each tree were selected randomly as replicates. Herbarium specimens were made from leafy branches of 30 cm in size, while flake and seed specimens were collected in 70% ethanol solution. A total of 41 morphological characters were examined and weighted as shown in Tables 2 and 3 (for qualitative and quantitative characters, respectively) based on the Descriptors for jackfruit (*A. heterophyllus*) (IPGRI 2000) with some modifications.

Table 1. Study area in Lamongan District, East Java, Indonesia

	'NB'	'NK'	'NS'
Geographical description (Latitude: S, Longitude: E)	6°54'35.30" S 112°24'30.29" E	6°55'27.88" S 112°24'51.46" E	6°56'15.92" S 112°23'57.64" E
Village, sub-district	Dagan, Solokuro	Banyubang, Solokuro	Takerharjo, Solokuro
Altitude (m asl.)	+70 mdpl	+70 mdpl	+70 mdpl
Number of Accessions (trees)	6	6	6
Soil texture	Sandy	Sandy	Laterite soil

Note: NB: *Nangka Bubur*; NK: *Nangka Kandel*; NS: *Nangka Salak*

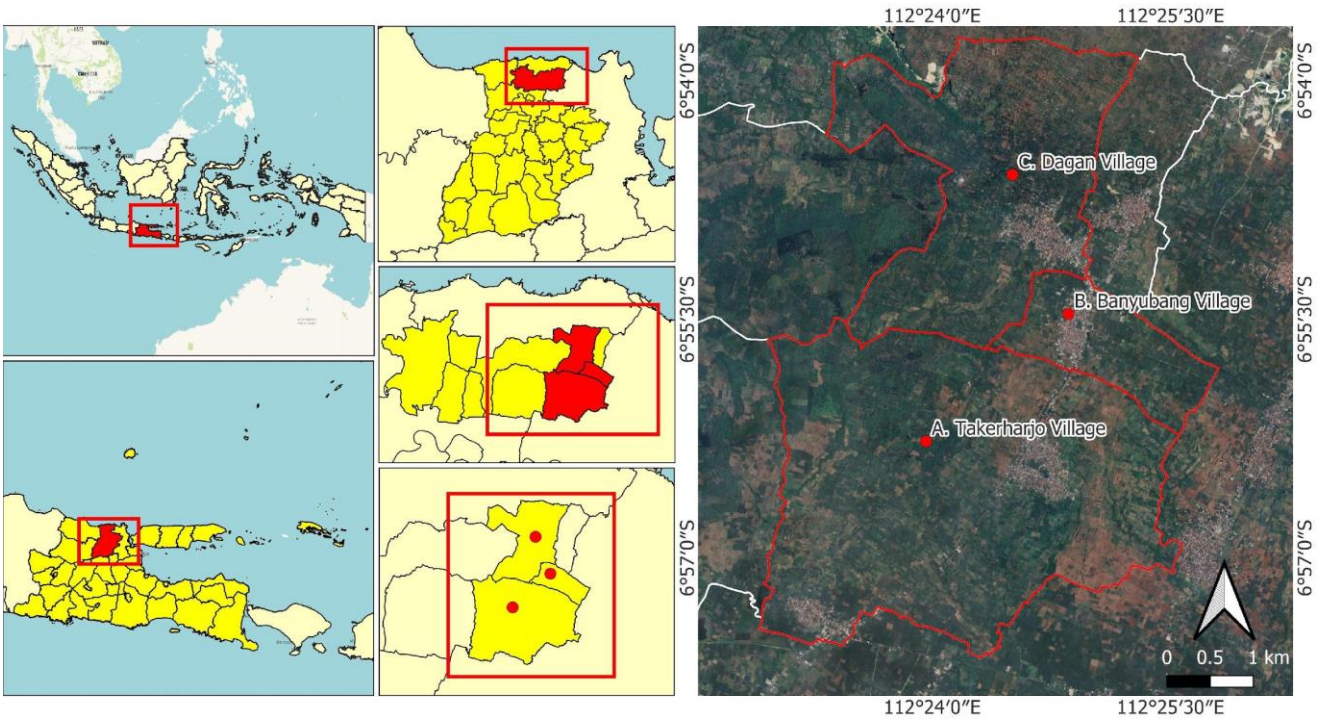

Figure 1. The sites of jackfruit samples collection in Lamongan District, East Java, Indonesia: A. Takerharjo Village; B. Banyubang Village; and C. Dagan Village

Table 2. Categorical morphological descriptors of jackfruit

Characters	Character states weight
Vegetative characters	
Growth habits	erect (1); others (0)
Crown shape	broadly pyramidal (1); spherical (0)
Trunk surface	rough (1); smooth (0)
Trunk color	brown (1); others (0)
Branching density	dense (1); sparse (0)
Apical dominance	strong (1); weak(0)
Leaf color	dark green (1); light green (0)
Leaf blade shape	elliptic (1); broadly elliptic (0)
Leaf apex shape	acute (1); obtuse (0)
Leaf base shape	oblique (2); cuneate(1); rounded (0)
Leaf blade margin	entire (1); undulate (0)
Leaf upper surface pubescence	glabrous (1); dense (0)
Leaf lower surface pubescence	glabrous (1); dense (0)
Petiole shape	rounded (1); flattened (0)
Crotch angle of petiole	acute (<90°) (1); obtuse (≥90°) (0)
Generative characters	
Fruit-bearing position	main trunk (2); primary branch (1); secondary branch (0)
Fruit shape	clavate (2); oblong (1); ellipsoid (0)
Stalk attachment to fruit	inflated (2); flattened (1); depressed (0)
Spine color	green (1); yellowish green (0)
Shape of spine	hexagon (1); pentagon (0)
Spine density	spearse (2); intermediate (1); dense (0)
Flake shape	rectangular (2); irregular (1); spheroid (0)
Pulp color at the ripe stage	deep yellow (2); light yellow (1); coppery red (0)
Pulp taste	sweet (2); insipid (1); sour (0)
Pulp flavour	strong (2); intermediate (1); weak (0)
Pulp consistency	firm (2); soft(1); slimy(0)
Flake texture	soft (2); fibrous (1); melting (0)
Seed shape	reniform (2); ellipsoid (1); oblong (0)
Seed surface pattern	uniform (1); regular striations (0)
Seed coat thickness	thin (1); thick (0)
Seed coat color	creamish (2); dull brown (1); brown (0)
Adherence of seed coat to kernel	difficult to separate (1); easily separable (0)

Table 3. Measured morphological parameters of jackfruit

Characters	Character states weight
Leaf blade length cm)	Measured from the base to the tip of the leaf blade
Leaf blade width (cm)	Measured at the widest point (cm)
Fruit length (cm)	Measured at the longest point (cm)
Fruit diameter (cm)	Measured at the widest point (cm)
Stalk length (cm)	Measured from the base of the peduncle to the base of fruit at maturity.
Spine length (cm)	Measured from the base to the spine tip (cm)
Spine diameter (mm)	Measured at the widest point (mm)
Weight of fresh flake with seed (g)	Average of 20 flakes (g)
Mesocarp thickness (cm)	Measured after removing seed (cm)

Data analysis

All these 9 quantitative characters were analyzed with One-Way ANOVA and Tukey HSD to identify any significant differences among the samples using the R program version 4.3.2 embedded in RStudio 2024.12.0. The quantitative data were analyzed using one-way ANOVA followed by Tukey HSD post-hoc test ($p<0.05$) to determine significant differences among cultivars.

Clustering analysis was conducted through multiple methods, including Principal Component Analysis (PCA) plot, k-means clustering plot (k = 3), and hierarchical clustering (dendrogram). The heatmap and correlation plot were developed to cluster jackfruit samples according to character states. The variable importance plot and PCA biplot were used to show the character states that contributed most significantly to this clustering study. PCA plot, PCA biplot, k-means clustering, and dendrogram were analyzed using the R package 'factoextra' (Kassambara and Mundt 2016) and shown with 'ggplot2' (Wilkinson 2011). Meanwhile, the heatmap plot was generated with the 'pheatmap' program (Kolde and Kolde 2015) and the variable importance plot used the 'randomForest' software (Breiman et al. 2018). Character states presenting uniform values across all samples were omitted from the clustering study.

RESULTS AND DISCUSSION

Morphological-variation

The morphology of local jackfruit cultivars shows variation in 38 characters, among which 3 characters were uniform, such as trunk surface, leaf apex shape, and seed coat thickness. The growth habits were excluded due to the least variation, while the remaining 37 characters were analyzed using subsequent clustering. The morphological variation of jackfruit organs, including leaves, seeds, flakes, fruits, and spines, are shown in Table 4 and Figure 2.

The 9 quantitative characters are measured in this study, while the remaining are qualitative and presented as descriptive observations in Tables 2 and 3. The leaf shape of NB was specifically found to be elliptic, while cultivars NK and NS appeared broadly elliptic. NB had the narrowest leaf blade width (5.63 ± 0.15^{a} cm) and the most extended leaf blade length (12.67 ± 0.52^{c} cm). Regarding fruit morphology, NB presented the most significant length (48.05 ± 1.23^{c} cm) and the least diameter (15.12 ± 0.20^{a} cm), leading to an ellipsoid shape. Meanwhile, NS had an oblong shape, and NK had a clavate shape. NB possessed the most extended stalk size, followed by NK and NS measured at 4.00 ± 0.00^{c}, 3.33 ± 0.52^{b}, 3.00 ± 0.00^{a} cm, respectively. The differences between these 3 cultivars were identified by the distinctive flakes showing spheroid, irregular, and rectangular shapes for NB, NK, and NS, respectively. NK had the heaviest fresh flake weight (20.00 ± 1.00^{c} g) and the thickest mesocarp (1.90 ± 0.14^{c} cm) compared to other cultivars. The seed morphology of these 3 cultivars was distinct, with NB, NK, and NS presenting reniform, ellipsoid, and oblong shapes, respectively. The shapes of NB and NS spines were hexagons, NK had pentagon spines, while NB was denser and the least in diameter (6.45 ± 0.10^{a} mm).

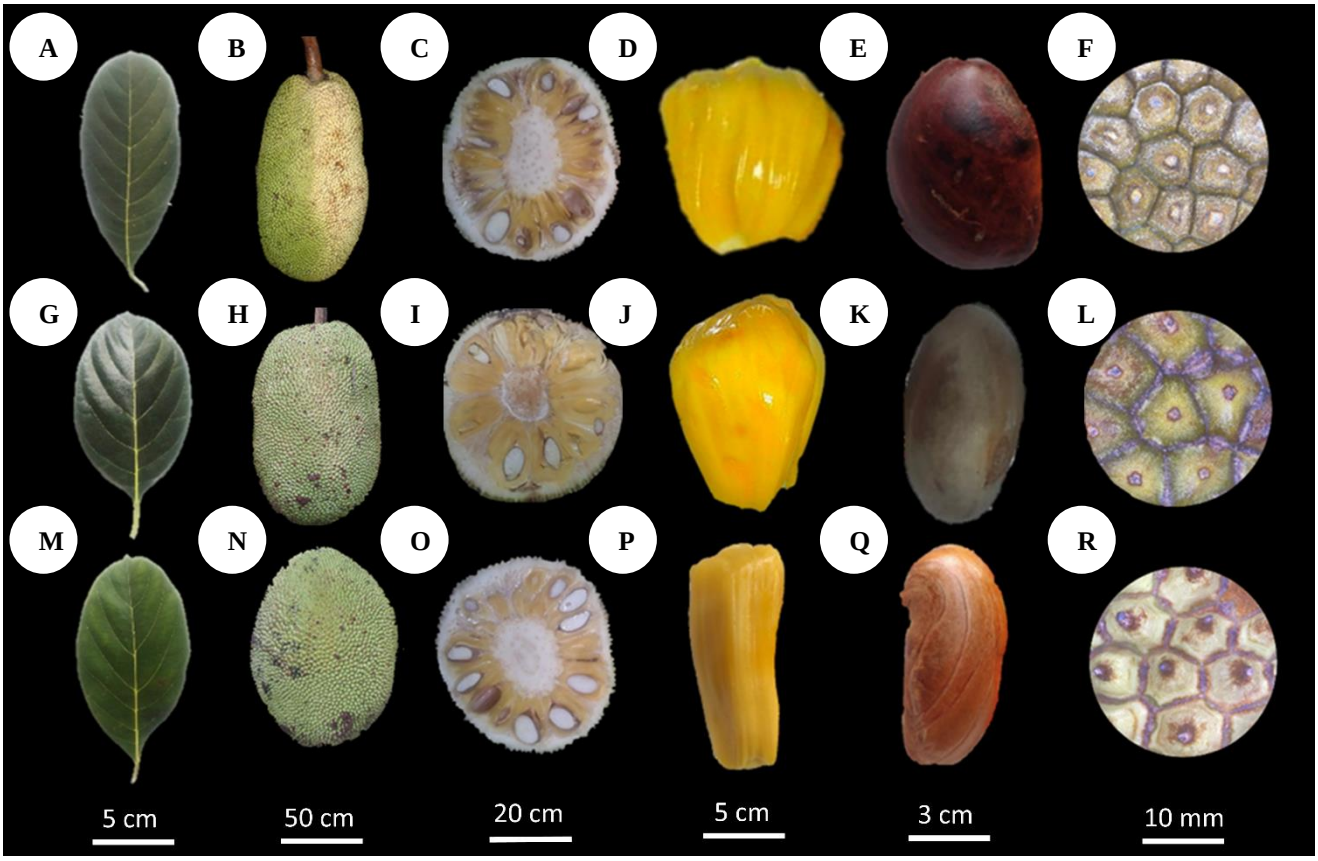

Figure 2. The morphological observations of 3 local jackfruits in Lamongan District, East Java, Indonesia. From left to right: leaves, compound fruits shape, compound fruits in cross-sectioning, flakes, seeds, and spines. A-F: cv. *Nangka Bubur*; G-L: cv. *Nangka Kandel*; and M-R: cv. *Nangka Salak*

Table 4. The mean and standard deviation value of quantitative characters

Characters	`NB`	`NK`	`NS`
Leaf blade length (cm)	12.67±0.52^{c}	11.83±0.41^{b}	10.33±0.52^{a}
Leaf blade width (cm)	5.63±0.15^{a}	7.53±0.12^{c}	6.50±0.00^{b}
Fruit length (cm)	48.05±1.23^{c}	41.67±3.83^{b}	32.83±2.04^{a}
Fruit diameter (cm)	15.12±0.20^{a}	19.00±0.00^{c}	17.22±0.27^{b}
Stalk length (cm)	4.00±0.00^{c}	3.33±0.52^{b}	3.00±0.00^{a}
Weight of fresh flake with seed (g)	12.90±0.15^{b}	20.00±1.00^{c}	10.80±0.20^{a}
Mesocarp thickness (cm)	1.50±0.16^{b}	1.90±0.14^{c}	0.63±0.15^{a}
Spine diameter (mm)	6.45±0.10^{a}	9.43±0.15^{c}	8.38±0.25^{b}
Spine length (cm)	2.00±0.00^{c}	1.17±0.17^{a}	1.83±0.17^{b}

Note: Value with difference superscript letter shows a significant difference at $\alpha = 0.05$

Cluster analysis dimensional reduction (PCA), k-means clustering, and dendrogram

Based on cluster analysis, the morphology of three jackfruit cultivars was separated into 3 distinct clusters (Figure 3). The same cluster was used to assemble all of the sample members of the same genotype, and approximately 53.1% of variance components clustered the entire jackfruit genotypes. A pattern observed in both PCA and k-means plots was clustering all samples inside the same cluster. Samples of NB were separated from the other two cultivars along a distinct principal component, by 36.7% of variance, while clusters of NK and NS were positioned closely and separated by 16.4% of variance (Figures 3.A and 3.B). These results were consistent with the dendrogram showing that NK was closely related to NS (Figure 3.C), and NB was separated from both clusters.

The correlation plot shows characters with a positive or negative correlation (Figure 4.A). Morphological characters such as spine density, fruit shape, spine diameter, flake texture, flake shape, and spine color possessed a strong positive correlation. Fruit with clavate shape and sparse density and wide green spines tended to have rectangular and soft flakes. The heatmap plot shows characters in which jackfruit cultivars have similar morphological patterns and presents variance among samples in the same cultivars (Figure 4.B). For instance, seed surface pattern, leaf upper surface pubescence, leaf lower surface pubescence, fruit-bearing position, leaf color, crown shape, and adherence of seed coat to the kernel were characterized by high variability in the same cultivar.

Defining diagnostic morphological characters

Several methods were used to identify significant morphological characters contributing to the cluster analysis of three jackfruit cultivars, including a variable importance

plot, biplot PCA, heatmap plot, and Venn diagram (Figure 5). Each method comprised the selected top 15 among 37 examined characters for clustering analysis. From the original 41 morphological characters studied, 4 characters were excluded (trunk surface, leaf apex shape, seed coat thickness, and growth habits) due to uniformity or minimal variation across samples. For each analytical method (Variable Importance Plot, Biplot PCA, and Heatmap plot), we independently identified and ranked characters based on their discriminatory power, with the Variable Importance Plot using mean decrease accuracy values, the Biplot PCA using contribution to principal components, and the Heatmap Plot using normalization values of character weights. This approach allowed us to identify the most significant characters through statistical verification across multiple analytical techniques. The Variable Importance Plot visualized the relative importance of the predictor of jackfruit characters in a random forest model (Figure 5.A). The weight of fresh flake with seed, pulp color at the ripe stage, and seed shape were the top 3 with the highest Mean Decrease Accuracy (MDA) values. This plot suggests these three characters are key to discriminating `NB`, `NK`, and `NS` cultivars. The Biplot PCA shows the contribution of each jackfruit character to the principal component (Figure 5.B). Moreover, several characters, such as spine density, fruit shape, spine color, flake shape, and flake texture were influenced by discriminating between `NK` and `NS` apart from `NB`. In contrast, leaf blade shape, stalk attachment to fruit, and others were separated `NB` away from other cultivars. Meanwhile, the Heatmap Plot shows the grouping pattern between the top 15 important characters and three jackfruit cultivars (Figure 5.C). The color intensity represents the similarity based on the normalization value of character weight. The `NB` cultivar can be distinguished from `NK` and `NS` based on stalk length, stalk attachment to the fruit, flake texture, flake shape, spine color, spine density, and fruit shape. The `NK` had unique characteristics such as spine length, shape of spine, pulp color at ripe stage, and fruit diameter. While, `NS` differed in mesocarp thickness, seed coat color, seed shape, and fresh flake weight with seed compared to `NB` and`NK`.

All the individual approaches mentioned above consisted of 15 top important characters, among which 11 were concluded to overlap (Figure 5.D). The 11 characters included mesocarp thickness, spine length, pulp color at the ripe stage, fruit shape, spine shape, seed coat color, seed shape, flake texture, spine density, flake shape, and stalk attachment to fruit. These were considered important diagnostic characters for distinguishing NB, NK, and NS cultivars.

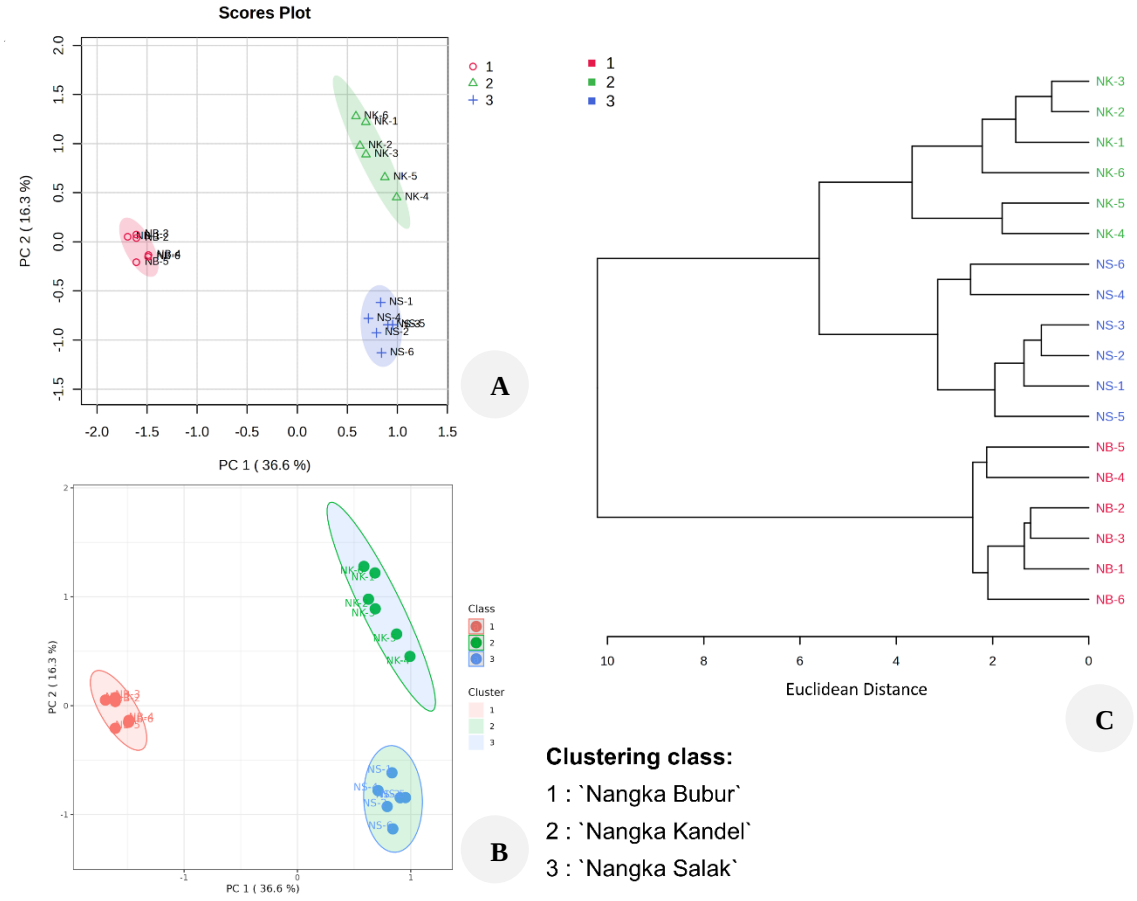

Figure 3. The examination of three jackfruit cultivars, utilizing 37 morphological characteristics, indicates that all clustering classes were categorized within the same genotype: A. PCA plot; B. K-means clustering plot (k = 3); and C. Dendrogram of hierarchical clustering plot.

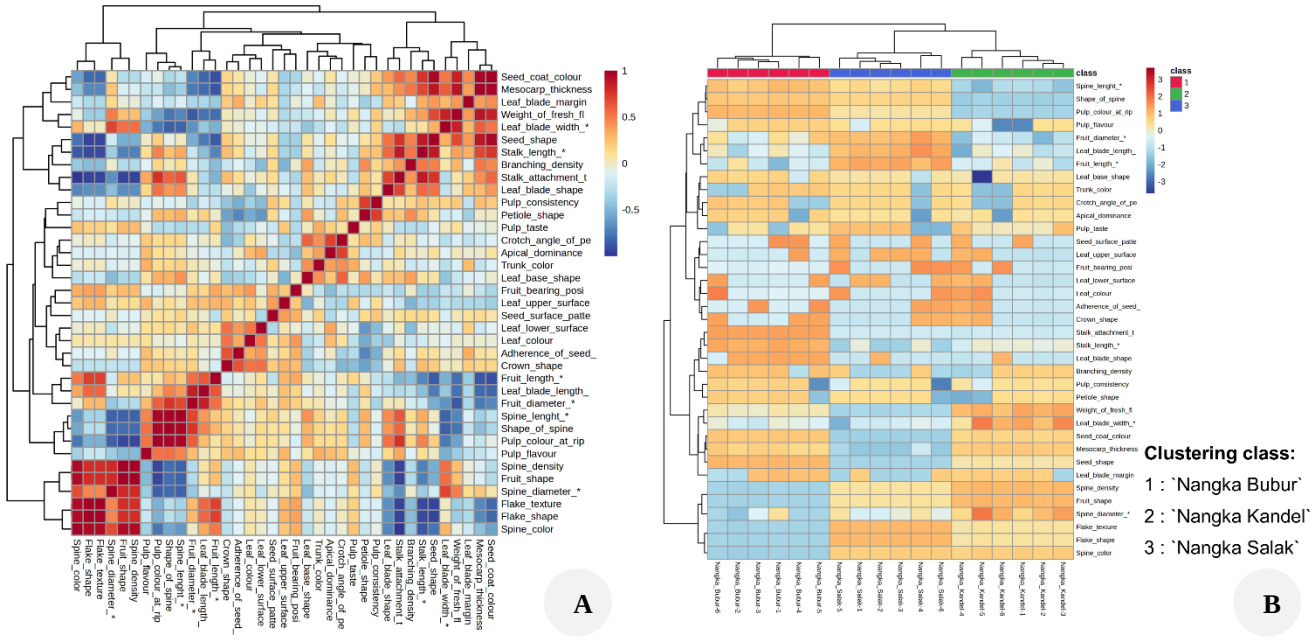

Figure 4. Clustering analysis of 37 examined morphological characters of jackfruit shown in: A. Correlation plot; and B. Heatmap plot. A higher score (red) in the plot signifies a positive correlation and vice versa, while a higher heatmap value represents the normalization value of character weight

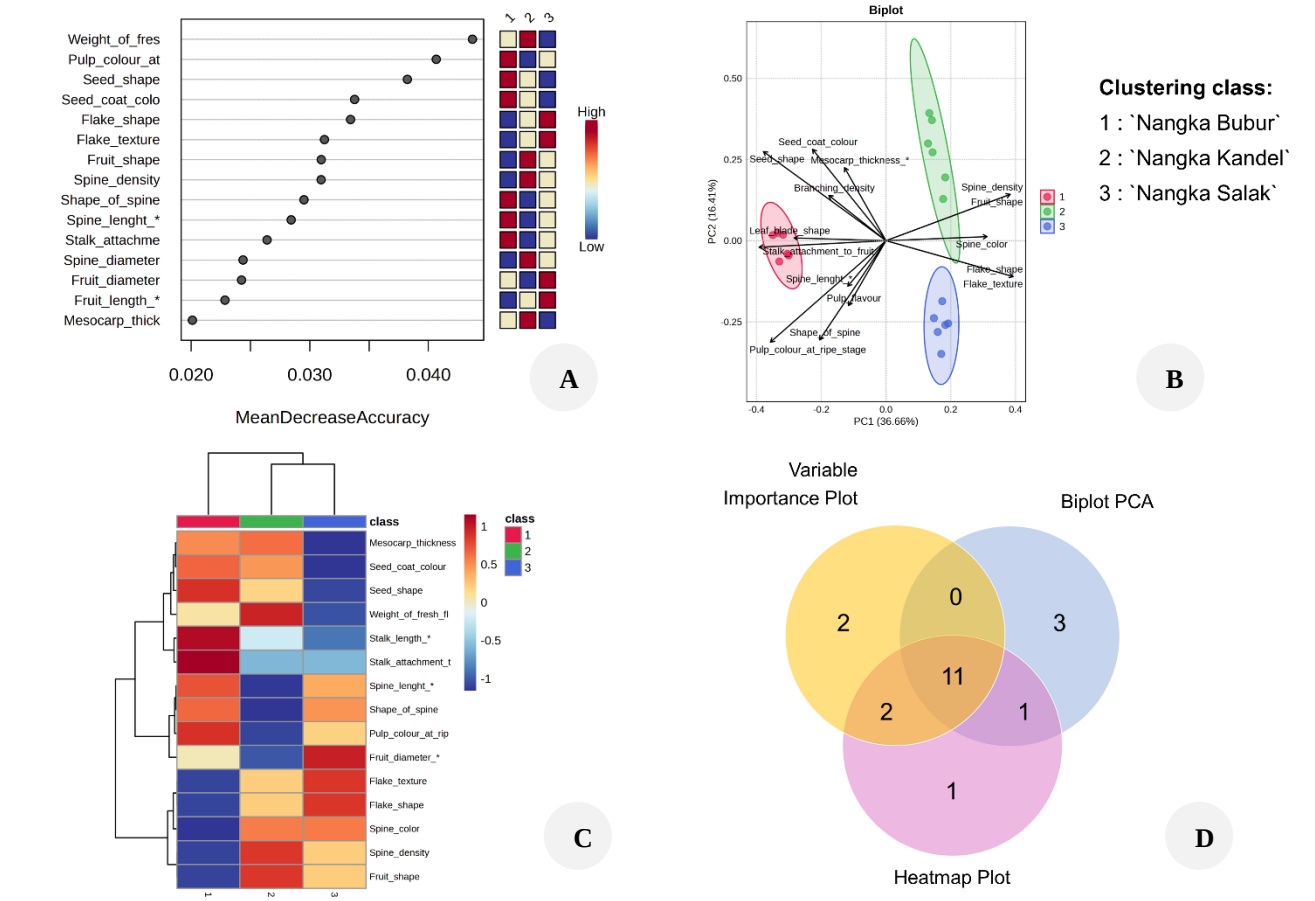

Figure 5. Defining important morphological characters that contributed to the clustering analysis of three jackfruit cultivars based on: A. Variable Importance Plot; B. Biplot PCA; and C. Heatmap plot. Eleven characters overlapped from these 3 methods, as shown in: D. Venn diagram. The higher value of mean decrease accuracy in the variable importance plot represents the greater contribution of character to clustering. The direction and length of an arrow in the PCA biplot show the contribution and importance of the variable to PCA. The heatmap plot's color intensity represents the character weight's normalization value

Discussion

Morphological characters are commonly used to determine the market preference and quality of fruits. This study's varying flake texture, color, and pulp consistency categories are crucial for jackfruit marketability. `NK`, which has a fibrous texture, coppery red color, and pulp consistency, is preferred for a ready-to-eat snack. Meanwhile, `NB` is preferred for industrial applications due to the melting texture as well as the requirement of less processing time and energy. Dewi et al. (2021) reported 'Nangka Bubur' and `Nangka Bilulang` cultivars in South Kalimantan could be discriminated using pulp texture, flavor, taste, consistency, and juiciness.

Quantitative characteristics such as lamina length and width, fruit length and diameter, spine length and diameter, flake weight, and mesocarp thickness exhibit notable variation among the three jackfruit cultivars evaluated (Table 4). Sulassih et al. (2015) showed that seed length, fruit length, and diameter varied similarly. Additionally, variations in fruit weight amongst jackfruit cultivars were noted by Dey and Baruah (2019). Additionally, in Bogor, West Java, Sulassih et al. (2015) reported morphological variance in 30 jackfruit accessions. Certain traits—like fruit surface, skin thickness, and flake shape—are crucial to categorizing these accessions. For classifying and differentiating various plant species, quantitative evaluation of morphological characteristics using conventional morphometric techniques is still useful (Patil and Baghat 2016).

Jagadeesh et al. (2007) reported a similar result, showing variability in the shape and density of spines on the rind, as well as differences in bearing, size, shape, latex, flake size, flake color, quality, and maturity period of jackfruit from the Western Ghats of India. A combination of genetic variability due to cross-pollination and environmental factors such as different agroclimatic conditions is responsible for potential morphological changes observed in the size of the leaves and fruits of various genotypes (Ningot et al. 2018; Mahla et al. 2022). Jackfruit is well known to be monoecious, implying that distinct male and female inflorescences are present on the same plant. In this case, the tree blossoms are pollinated by a variety of vectors, such as the wind, birds, and insects, leading to a high rate of cross-pollination (Luna-Esquivel et al. 2013; Mijin et al. 2021). According to Moreles-Flores et al. (2024), every genotype contains unique genetic information influencing growth and development when combined with environmental factors such as temperature changes, sunlight exposure, nutrient concentrations, and water availability.

Morphological variation can inform the selection of superior varieties suitable for specific agroecological zones, facilitate commercial varieties' development, and enhance jackfruit's economic and nutritional value in the global market. Varieties are crucial for germplasm improvement as breeders use genetic collections to develop plants with desired qualities. According to Chandrashekar et al. (2018), height is an important consideration when selecting superior tree cultivars due to the greater difficulty of spraying and collecting fruit from tall trees. Character selection is essential for jackfruit farmers in determining suitable cultivars for various agroecological zones due to morphological heterogeneity. The number of plant varieties, history, and trait polymorphism can be determined through morphological examination (Nakintu et al. 2023).

Clustering analysis showed that the 3 jackfruit genotypes tested did not cluster with each other, suggesting the classification into separate groups (Figure 3). Despite the proximity of 3 villages with no physical boundaries, a genetic exchange might have led to the visually similar species found in all sites. This result was inconsistent withh another study conducted by Shyamalamma et al. (2008), which reported morphological similarity among jackfruit samples from sites with identical environmental conditions. Therefore, the genetic background of the tree cultivars was believed to contribute more to morphological variation than environmental conditions.

Clustering on the heatmap shows a significant grouping of the three jackfruit cultivars studied 'NB', 'NK', and 'NS'. This finding indicates consistent characteristics among cultivars based on Figure 3.A, with the most discriminative morphological characters including fruit shape, flake shape, flake texture, spine density, spine shape, seed shape, seed coat color, pulp color, and fresh fruit weight. Viscosi and Cardini (2011) demonstrated that morphometric approaches combined with clustering analysis through heatmaps effectively differentiated four *Orofea* species based on ten leaf characters. Jin et al. (2015), Jiménez-Mejías et al. (2017), and Chuanromanee et al. (2019) stated that multivariate statistical analysis through heatmaps can provide a deep understanding of morphological character contributions to taxonomic groping. These results are supported by the Venn diagram, which shows 11 morphological characters that effectively differentiate the three jackfruit cultivars (Figure 3.D).

The intraspecific variation in jackfruit occurs among 3 cultivars in Lamongan District. Several characters were found to vary among different or in the same cultivars, as shown in Figure 4.B**.** A total of 11 among 41 morphological characters were found to be effectively discriminative in identifying NB, NK, and NS cultivars (Figure 5). The study result showed variation in fruit shapes, namely ellipsoid and clavate. This result aligns with jackfruit in India (Chandrashekar et al. 2018) and Uganda (Gwokyalya et al. 2024). Among these variations, there are similarities in `NK` and `NS` characters with jackfruit in Uganda and India. `NK shows similarities in irregularly shaped flake characters similar to those found in jackfruit in Uganda (Gwokyalya et al. 2024). NS has similarities with jackfruit in India regarding soft flake texture (Chandrashekar et al. 2018). `NB` has a melting flake texture consistent with Devi et al. (2022), which found a soft flake consistency.

Morphological characteristics such as fruit shape, flake shape, flake texture, seed shape, seed coat color, mesocarp thickness, spine density, and spine shape on PC1 contribute significantly to differentiating cultivars, while PC2 emphasizes spine length and color (Figure 5.B). NB shows a strong correlation with negative PC1, indicating its unique morphology, especially in flake shape and texture characteristics, whereas `NK` shows affinity to positive PC1, but shares similarities with `NS` on PC2 in spine color

and density characteristics, which is reinforced by the heatmap and dendrogram showing the closeness of these two cultivars. The Venn diagram identifies 11 discriminative morphological characters that overlap among the three analysis methods, similar to Moreles-Flores et al. (2024) findings that showed variety clustering based on firmness. Fruit weight, antioxidants, and carotenoid content confirm that PCA is capable of showing genetic variability among cultivars and provides insights into complex relationships of morphological characters for plant breeding and superior variety selection (Chandrashekar et al. 2018).

In conclusion, this study successfully identified distinguishing morphological characteristics among three jackfruit cultivars (*Nangka Bubur*, *Nangka Kandel*, and *Nangka Salak*) in Lamongan District, East Java, Indonesia, based on 11 key diagnostic morphological characters, including mesocarp thickness, spine length, pulp color at ripe stage, fruit shape, shape of spine, seed coat color, seed shape, flake texture, spine density, flake shape, and stalk attachment to fruit. These findings demonstrate that morphological markers can serve as practical tools for cultivar identification and classification. Furthermore, the result provide valuable insight for plant breeders and farmers highlighting traits associated with desirable such as fruit size, texture and disease resistance. Finally, this research contributes to both the development of superior jackfruit cultivars and the conservation of local genetic diversity by preventing genetic erosion through unregulated hybridization.

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REFERENCES

Badan Pusat Statistik (BPS). 2023a. Production of Fruit Plants, 2021-2023. Central Bureau of Statistic, Jakarta. [Indonesian]

Badan Pusat Statistik (BPS). 2023b. Production of Mangosteen, Melinjo, Jackfruit by Regency/City and Type of Plant in East Java Province (quintal), 2021 and 2022. Statistics of East Java Province, Surabaya. [Indonesian]

Badan Pusat Statistik (BPS). 2023c. Annual Production of Fruits and Vegetables by Crop Type in Lamongan Regency. Central Bureau of Statistics, Lamongan. [Indonesian]

Baliga MS, Shivashankara AR, Haniadka R, D'Souza J. 2011. Phytochemistry, nutritional and pharmacological properties of *Artocarpus heterophyllus* Lam (jackfruit): A review. Food Res Intl 44 (7): 1800-1811. DOI: 10.1016/j.foodres.2011.02.035.

Breiman L, Cutler A, Liaw A, Wiener M. 2018. Package' Randomforest'. University of California Berkeley, Berkeley.

Chandrashekar KG, Vijayakumar RM, Subramanian S, Kavino M, Joel AJ. 2018. Morphological characterization of Jackfruit (*Artocarpus heterophyllus* Lam.) local genotypes under coffee ecosystem of lower Pulney hills. Intl J Curr Microbiol Appl Sci 7 (3): 2210-2224. DOI: 10.20546/ijcmas.2018.703.261.

Chikkanna GS. 2021. Technical facts on the current scenario and future potential of jackfruit processing. Res Biotica 3 (2): 94-106. DOI: 10.54083/ResBio/3.2.2021.94-106.

Chuanromanee TS, Cohen JI, Ryan GL. 2019. Morphological Analysis of Size and Shape (MASS): An integrative software program for morphometric analyses of leaves. Appl Plant Sci 7 (9): e11288. DOI: 10.1002/aps3.11288.

Daley OO, Roberts-Nkrumah LB, Alleyne A. 2020. Morphological diversity of breadfruit [*Artocarpus altilis* (Parkinson) Fosberg] in the Caribbean. Sci Hortic 266: 109278. DOI: 10.1016/j.scientia.2020.109278.

Devi HL, Das B, Singh S, Jamatia D, Debbarma N, Debbarma LL, Majumder P. 2022. Studies on in situ characterization and evaluation of non-descript jackfruit genotypes of Tripura, India. J Andaman Sci Assoc 27: 45-53.

Dewi RS, Hardiansyah H, Mahrudin M. 2021. Species diversity of *Artocarpus* in the riverbank at Beringin Kecana Village, Tabunganen Sub-district, South Kalimantan. Wahana Bio J Biologi dan Pembelajarannya 13 (2): 124-136. DOI: 10.20527/wb.v13i2.12058. [Indonesian]

Dey B, Baruah K. 2019. Morphological of Jackfruit (*Artocarpus heterophyllus* Lam.) of Assam, India. Intl J Curr Microbiol Appl Sci 8 (11): 1005-1016. DOI: 10.20546/ijcmas.2019.811.118.

Dhakar MK, Das B, Sarkar PK, Nath V, Singh AK, Bhatt BP. 2020. Diversity in jackfruit (*Artocarpus heterophyllus* Lam.): Insights into fruit characterization for the identification of superior genotypes. Plant Genet Resour 18: 307-315. DOI: 10.1017/S1479262120000325.

Gwokyalya R, Nanteza A, Wagaba H, Kayondo SI, Kazigaba D, Nakabonge G. 2024. Morphological and genetic characterization of jackfruit (*Artocarpus heterophyllus*) in the Kayunga and Luwero districs of Uganda. BMC Plant Biol 24 (1): 355. DOI: 10.1186/s12870-024-05064-x.

International Plant Genetic Resources Institute (IPGRI). 2000. Descriptor for Jackfruit (*Artocarpus heterophyllus*). International Plant Genetic Resources Institute, Rome.

Jagadeesh SL, Reddy BS, Basavaraj N, Swamy GSK, Gorbal K, Hedge L, Raghavan GSV, Kajjidoni ST. 2007. Inter tree variability for fruit quality in jackfruit selections of Western Ghats of India. Sci Hortic 112 (4): 382-387. DOI: 10.1016/j/scienta.2007.01.016.

Jagdale YD, Mahale SV, Zohra B, Nayik GA, Dar AH, Khan KA, Abdi G, Karabagias IK. 2021. Nutritional profile and potential health benefits of superfoods: A review. Sustainability 13 (16): 9240. DOI: 10.3390/su13169240.

Jiménez-Mejías P, Cohen JI, Naczi RFC. 2017. The study of online digitized specimens revalidates *Andersonlossum boreale* as a species different from *A. virginianum* (Boraginaceae). Phytotaxa 295 (1): 22-34. DOI: 10.11646/phytotaxa.295.1.2.

Jin T, Hou X, Li P, Zhou F. 2015. A novel method of automatic plant species identification using sparse representation of leaf tooth fetaures. PLoS One 10 (10): e0139482. DOI: 10.1371/journal.pone.0139482.

Kassambara A, Mundt F. 2016. Factoextra: Extract and Visualize the Result of Multivariate Data Analyses. https://CRAN.R-project.org/package=factoextra, R Package Version 1.0.3. DOI: 10.32614/CRAN.package.factoextra.

Khan AU, Ema IJ, Faruk MR, Tarapder SA, Khan AU, Noreen S, Adnan M. 2021. A review on importance of *Artocarpus Hetrophyllus* L. (Jackfruit). J Multidiscip Appl Nat Sci 1 (2): 106-116. DOI: 10.47352/jmans.v1i2.88.

Kolde R, Kolde MR. 2015. Package 'Pheatmap'. R Package. https://cran.ms.unimelb.edu.au/web/packages/pheatmap/pheatmap.pdf

Luna-Esquivel G, Alejo-Santiago G, Ramírez-Guerrero L, de Lourdes A-GM. 2013. La Yaca (*Artocarpus heterophyllus* Lam.) un Fruto de Exportación. Agro Product 6: 65-70. [Spanyol]

Mahla JS, Soni NV, Patel PC, Patel AV, Dasalania JP, Roul S. 2022. Variability, character association and path analysis for *Annona* yield and quality attributes. Emerg Life Sci Res 8 (2): 229-239. DOI: 10.31783/elsr.2022.82229239.

Mijin S, Ding P, Saari N, Ramlee SI. 2021. Effects of pollination techniques and harvesting stage on the physico-chemical characteristics of jackfruit. Sci Hortic 285: 110199. DOI: 10.1016/j.scienta.2021.110199.

Mondal T, Bauri FK, Datta S, Mandi G, Mahato S, Misra DK, Patil P. 2024. Genetic resources management of jackfruit (*Artocarpus heterophyllus* (Lam.)). Intl J Minor Fruits Med Aromat Plants 10 (1): 1-12. DOI: 10.53552/ijmfmap.10.1.2024.1-12.

Moreles-Flores DA, Montalvo-González E, Chacon-López MA, Santacruz-Varela A, Zamora-Gasga VM, Berumen-Varela G, de Lourdes García-

Magaña M. 2024. Jackfruit genotypes in Southern Nayarit: A comparative study of morphological, physiological, physicochemical, phytochemical, and molecular assessment. Horticulturae 10 (9): 918. DOI: 10.3390/horticulturae10090918.

Nakintu J, Andama M, Alberecht C, Wangalwa R, Lejju JB, Olet EA. 2023. Morphological traits of jackfruit (*Artocarpus heterophyllus* Lam.): Indicators of diversity, selection and germplasm dispersion in Uganda. Sci Afr 22: e01900. DOI: 10.1016/j.sciaf.2023.e01900.

Ningot EP, Dahale MH, Uikey AC, Naitam PC. 2018. Variability studies on physico-chemical characteristics of jackfruit genotypes from Eastern Maharashtra, India. Intl J Curr Microbiol Appl Sci 6: 2294-2298.

Patil AA, Bhagat KS. 2016. Plant identification by leaf shape recognition: A review. Intl J Eng Trends Technol 35 (8): 359-361. DOI: 10.14445/22315381/ijett-v35p273.

Ragone D. 2007. Breadfruit: Diversity, conservation and potential. Acta Hortic 757: 19-30. DOI: 10.17660/ActaHortic.2007.757.1.

Rahaman MA, Rahman A, Miah MG, Hoque MA, Rahman MM. 2018. Productivity and profitability of Jackfruit-eggplant agroforestry system in the terrace ecosystem of Bangladesh. Turk J Agric Food Sci Technol 6 (2): 124-129. DOI: 10.24925/turjaf.v6i2.124-129.1330.

Rajkumar MB, Gundappa B, Tripathi MM, Rajan S. 2018. Pests of jackfruit. In: Omkar (eds). Pests and Their Management. Springer, Singapore. DOI: 10.1007/978-981-10-8687-8_18.

Ranasinghe RASN, Maduwanthi SDT, Marapana RAUJ. 2019. Nutritional and health benefits of jackfruit (*Artocarpus heterophyllus* Lam.): A review. Intl J Food Sci 2019: 4327183. DOI: 10.1155/2019/4327183.

Safitri NB, Wasian, Palupi T. 2017. Identification of genetic diversity with morphological character *Artocarpus heterophyllus* Lamk West Borneo, Indonesia. Agrovigor: J Agroekoteknologi 10 (1): 49-55. DOI: 10.21107/agrovigor.v10i1.2828. [Indonesian]

Shyamalamma S, Chandra SBC, Hegde M, Naryanswamy P. 2008. Evaluation of genetic diversity in jackfruit (*Artocarpus heterophyllus* Lam.) based on amplified fragment length polymorphism markers. Genet Mol Res 7 (3): 645-656. DOI: 10.4238/vol7-3gmr457.

Sulassih, Sobir E, Santosa M, Tirtawinata R. 2015. Variability genetic analysis for jackfruit (*Artocarpus heterophyllus* Lam.) based on morphological marker. Proc 2nd Nat Sem Trop Fruit Archipel. Tropical Fruit Plants Research Institute, Solok. [Indonesian]

Swami SB, Thakor NJ, Haldankar PM, Kalse SB. 2012. Jackfruit and its many functional components as related to human health: A review. Comprehensive Rev Food Sci Food Safety 11 (6): 565-576. DOI: 10.1111/j.1541-4337.2012.00210.x.

Viscosi V, Cardini A. 2011. Leaf morphology, taxonomy and geometry morphometrics: A simplified protocol for beginners. PLoS One 6 (10): e25630. DOI: 10.1371/journal.pone.0025630.

Wilkinson L. 2011. ggplot2: Elegant graphics for data analysis by WICKHAM, H. Biometrics 67 (2): 678-679. DOI: 10.1111/j.1541-0420.2011.01616.x.

Yudhistira B. 2022. The development and quality of jackfruit-based ethnic food, *gudeg*, from Indonesia. J Ethnic Foods 9: 19. DOI: 10.1186/s42779-022-00134-7.