



## **GENETIC DIVERSITY OF JACKFRUIT (*Artocarpus heterophyllus* Lam.) PROVENANCES BASED ON MORPHOLOGICAL PARAMETERS**

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### **SUMMARY**

Jackfruit (*Artocarpus heterophyllus* L.) is one of the most widely cultivated fruits in Indonesia. This study was carried out during 2011–12 on the jackfruit germplasm planted at the forestry and plantation area of Gunungkidul Regency, Yogyakarta Province, Indonesia. The germplasm comprised a large collection of jackfruit accessions with 11 different origins, i.e., East Java, Central Java, West Java, Bali, Medan, Pekanbaru, Lampung, East Kalimantan, South Kalimantan, Kendari, and Lombok. This study aimed to assess the variation in jackfruit provenances on the basis of morphological characters. Overall, 71 morphological characters were used to score and standardize the jackfruit land races. The Indonesian jackfruit provenances with different origins showed morphological variations in terms of fruit shape, fruit skin color, spike sharpness, spike density, and fruit flesh. UPGMA revealed that jackfruit provenances divided into two clusters with similarity coefficients ranging from 49.25% to 76.12%. The jackfruit genotypes collected from South Kalimantan Selatan and Lombok had the highest similarity index (76.12%). Thus, this finding might be useful for future jackfruit breeding programs and germplasm conservation for future generations.

**Keywords:** Jackfruit, morphological characters, provenances

**Key findings:** The observed morphological variations among jackfruit genotypes with different origins can be used for sustainable jackfruit utilization, germplasm development, and conservation for future generations.

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### **INTRODUCTION**

Jackfruit (*Artocarpus heterophyllus* L.) belongs to the family Moraceae and is widely distributed in tropical countries, such as Indonesia, Brazil, Thailand, India, Philippines, and Malaysia (Chowdhury et

al., 1997). Past studies assumed that jackfruit plants originated from Western Ghats, India, and later spread to several countries in South and Southeast Asia and even to Southern China. The jackfruit was also spread from Asia to tropical African regions, particularly to countries in

Eastern Africa, such as Zanzibar, Kenya, Uganda, and Madagascar. In the middle of the 17th century to the end of the 19th century, jackfruit accessions were further spread to several tropical and subtropical countries in the American continent, including Brazil, Suriname, Caribbean, and the United States. Jackfruit plants are also found in Australia, where they are mainly grown in tropical regions, such as Northern Queensland (Haq, 2006). Jackfruit, a fast-growing species, can be easily raised in nurseries under different light intensities and low moisture stress (Bolanle, 2018).

Jackfruit is an annual fruit tree that may reach ages of dozens of years. It grows as an evergreen tree that has a short trunk with a dense treetop. It easily reaches heights of 10 m to 20 m and has trunk diameters of 30 cm to 80 cm (Elevitch and Manner, 2006). The bark of the jackfruit tree is reddish-brown and smooth. A milky juice is released in the event of injury to the bark. The leaves are alternate, spirally arranged, gummy, thick, and divided into a petiole and a leaf blade (Moncur, 1985). The petiole is 2.5 cm to 7.5 cm long. The leathery leaf blade is 20 cm to 40 cm long, 7.5 cm to 18 cm wide, and oblong to ovate in shape. The jackfruit tree is a monoecious tree, and the male and female flowers are found separately (Rahman *et al.*, 1999).

Jackfruit has a compound fruit that consists of a collection of many fruits. Each fleshy jackfruit petal contains one seed known as *nyamplung*. In jackfruit and *cempedak*, undeveloped or unpollinated fleshy petals, which are known as *dami*, are found among fleshy petals and may be thick, large, sweet, and edible (Widyastuti, 1993). Young and ripe jackfruit parts, including seeds, are most commonly consumed. Young jackfruit has good mineral contents, especially calcium and phosphorus. Jackfruit seeds are considered as a source of carbohydrates, protein, and energy. Ripe jackfruits, including seeds, have the highest level of vitamin A (330 SI per 100 g) when compared with young jackfruits (Suprapti, 2004). Jackfruit seeds are abundant and

contain high amounts of starch. Soft and hard jackfruit seeds have starch contents of 92.8% and 94.5%, respectively (Madruga *et al.*, 2014)

Jackfruit may be utilized for various purposes and as a fresh vegetable and fruit. Young jackfruit, which is known as *gori* by the Javanese, may be processed into various forms of foods and cuisines (Widyastuti, 1993). In addition to fresh consumption, ripe jackfruits are commonly used in a mixture of various foods. Ripe jackfruit may be processed into various types of food and beverage products, such as chips, dried candies, and syrups. Jackfruit seeds may be boiled and used as snacks or processed into flour (Suprapti, 2004). Jackfruit, an important dryland horticultural tree, grows well with minimal care and maintenance. Jackfruit genotypes for commercial cultivation are selected on the basis of fruit and flake quality characters, fruit weight, fruit rind weight per kg fruit, number of flakes per kg fruit, weight of flakes per kg fruit, and individual fresh flake weight (Kavya *et al.*, 2019)

Morphological characters are still used as introductory bases to classify the genetic diversity of different genotypes. Classification based on morphological traits may be used as an appropriate and ready reference for plant biodiversity maps, especially maps for Angiospermae. Morphological characters may be more easily and practically observed than other characters (Jones and Luchsinger, 1986). They are influenced by environmental and physiological factors and are also supported by biochemical and molecular characters that determine intra- and interspecific diversity (Zhao *et al.*, 2007). Mursyidin and Khairullah (2020) stated that although morphological markers have certain limitations, they are still commonly used in analyzing genetic diversity.

However, research based on morphological characters is still rarely conducted in Indonesia. In Indonesia, research on jackfruit is limited to the flavonoid compounds produced by jackfruit bark (Musa, 2004). The identification of jackfruit genetic diversity

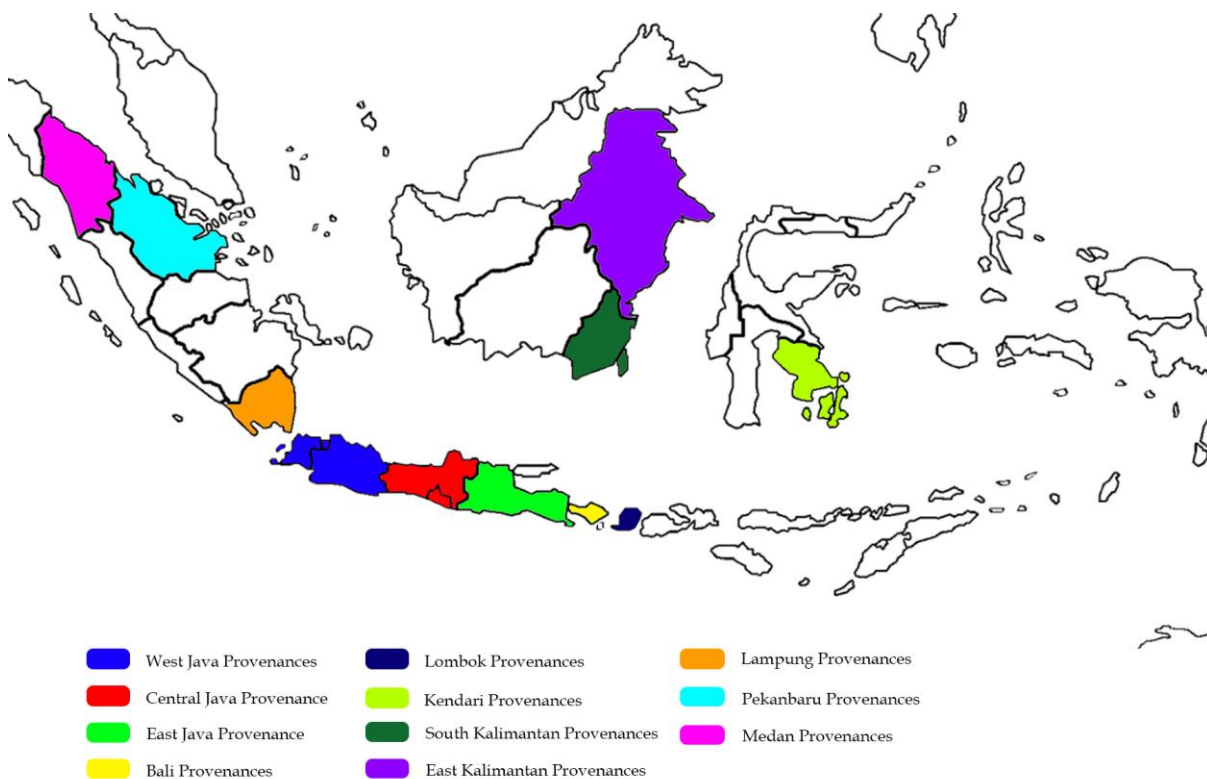
based on morphological characters was performed in West Kalimantan, Indonesia, by using 76 characters that were divided into three major groups through group analysis (Safitri *et al.*, 2017). This study aimed to evaluate the genetic diversity of jackfruit provenances in Indonesia by using morphological diversity. Morphological characterization would be highly helpful in the improvement of jackfruit cultivation and conservation.

## MATERIALS AND METHODS

### Study area

The jackfruit provenance samples used in this research were procured from the germplasm belonging to the Faculty of Forestry, Gadjah Mada University, Indonesia. This study was carried out on

the jackfruit germplasm planted at the forestry and plantation area of Gunungkidul Regency, Yogyakarta Province, Indonesia, during 2011–12. The collection area was utilized as an ex-situ area for the genetic conservation of jackfruit trees in Indonesia. The jackfruit samples were taken from an area of 35 ha that was divided into eight blocks and located in three subdistricts, i.e., Karangmojo, Semin, and Ngawen. The total jackfruit collection grown on the land comprised 360 provenances known as a seed lot (a group of trees grown from the same seed). However, in this study, the jackfruit seeds were taken from 11 regions of Indonesia, including East Java, Central Java, Special Region of Yogyakarta, West Java, Bali, Medan (North Sumatra), Pekanbaru (Riau), Lampung, East Kalimantan, South Kalimantan, Kendari (Southeast Sulawesi), and Lombok (West Nusa Tenggara) (Figure 1).



**Figure 1.** Map of 11 Indonesian provinces from which the jackfruit seeds originated.

## Morphological characters

The first step in the acquisition of morphological data was the selection and collection of the jackfruit provenance samples. The samples were collected by selecting the jackfruit trees with good quality and identical provenance numbers (seed lot). Three individual trees were repeatedly taken from each jackfruit provenance. The 71 morphological characters of the vegetative and generative parts, including the stem, leaf, flower, fruit, and seed organs of the jackfruit trees, of each sample were qualitatively and quantitatively observed and recorded in accordance with the parameters for jackfruit descriptors given by IPGRI (IPGRI, 2000). The samples were then documented in the form of photos and dried herbarium specimens.

The data obtained from the tabulated morphological characters were scored numerically, i.e., 0, 1, 2, and 3. The similarity indexes for the morphological characters were obtained through the Jaccard similarity coefficient and cluster (group) analysis by using the unweighted pair-group method using arithmetic mean (UPGMA) method to determine the phenetic relationship between operational taxonomic units shown in the form of a dendrogram. The data were then analyzed by using NTSYS software ver.2.1.

## RESULTS AND DISCUSSION

### Morphological characters

The morphological characters of 11 jackfruit provenances were observed. A total of provided 71 characters that consisted of 59 polymorphic characters and 12 monomorphic characters were provided (Tables 1–5). Typical characters were shown by the leaves, stems, fruit, and seeds of the 11 jackfruit provenances. These 11 jackfruit provenances could be distinguished on the basis of their phenotypic characters (Figures 2–5). The description of the jackfruit morphological

characteristics in each region is given as follows.

### East Java

Trees 6.0–6.4 m high, broadly pyramidal crown, round stem, rough, dark brown with white spots, no cracks, vertical branching. Leaves simple, broadly elliptic; petiole 1.4–1.7 cm long, yellowish green, lamina 14.1–14.7 cm × 7.4–7.9 cm, base obtusus, apex acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence unisexual flower; male flower yellowish green, position in secondary and tertiary branches; female flowers yellowish green, clusters, position in secondary and tertiary branches. Fruit ellipsoid, 44–47 cm long, greenish yellow, spiny; spine sharply pointed, dense; stalk 15.5–17 cm long; flake 6.5–8.0 cm × 3.4–4.7 cm, thickness 0.7–1.2 cm, reddish yellow, obovate, rectangular, oblong with curved tip irregular, soft texture, sweet taste, intermediate flavor, juicy. Rachis 35–38 cm long; *dami* yellow, less sweet taste. Seeds 2.5–3.0 cm × 1.7–2.3 cm, spheroid, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 2)

### Central Java

Trees 5.6–6.0 m high, broadly pyramidal crown, round stem, rough, brown with grayish spots, cracks, horizontal branching. Leaves simple, broadly elliptic; petiole 1.2–1.6 cm long, yellowish green; lamina 14.3–15.3 × 7.3–8 cm, base acuminate, apex acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position mainly on trunk and primary branches; female flowers yellowish green, clusters, mainly on trunk and primary branches. Fruit obloid, 42–54 cm long, yellow, reddish yellow, spiny; spine sharply pointed, dense; stalk 15–16 cm long. Flake 7.8–10 cm × 4.0–5.7 cm,

**Table 1.** Tree and stem morphological characters of 11 jackfruit provenances from Indonesia.

Provenances Characters	East Java	Central Java	West Java	Bali	Medan	Pekanbaru	Lampung	East Kalimantan	South Kalimantan	Kendari	Lombok
Habitus	Tree	Tree	Tree	Tree	Tree	Tree	Tree	Tree	Tree	Tree	Tree
Rod shape	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round
Tree height (m)	6.0–6.4	5.6–6.0	6.7–7.0	6.6–7.0	6.2–6.5	5.6–6.0	7.2–7.5	7.8–8.0	7.6–7.9	7.7–8.0	8.0–8.5
Trunk circumference (cm)	61–63	46–50	48–50	63–65	57–60	48–50	51–55	52–55	55–58	54–57	54–56
Trunk height (cm)	110–155	180–200	170–195	180–200	185–200	35–50	180–200	185–200	175–200	150–170	210–230
Trunk surface	Rough	Very rough	Rough	Rough	Rough	Rough	Very rough	Very rough	Very rough	Very rough	Rough
Bark color	Dark brown with white spots	Brown with grayish spots	Light brown with grayish spots	Dark brown with white spots	Brown with grayish spots	Grayish brown	Brown	Grayish white	Brown with grayish spots	Brown with grayish spots	Brown with grayish spots
Cracks in stem	Absent	Present	Absent	Absent	Absent	Absent	Present	Absent	Absent	Absent	Absent
Tree growth habit	Erect	Erect	Erect	Erect	Erect	Erect	Erect	Erect	Erect	Erect	Erect
Crown shape	Broadly pyramidal	Broadly pyramidal	Pyramidal	Pyramidal	Broadly pyramid al	Broadly pyramidal	Broadly pyramidal	Pyramidal	Pyramidal	Pyramidal	Pyramidal
Branching pattern	Erect	Horizontal	Horizontal	Horizontal	Erect	Erect	Erect	Horizontal	Erect	Erect	Erect

**Table 2.** Leaf morphological characters of 11 jackfruit provenances from Indonesia.

Provenances Characters	East Java	Central Java	West Java	Bali	Medan	Pekanbaru	Lampung	East Kalimantan	South Kalimantan	Kendari	Lombok
Leaf type	Simple	Simple	Simple	Simple	Simple	Simple	Simple	Simple	simple	simple	simple
Leaf blade length (cm)	14.1–14.7	14.3–15.3	12.8–13.3	12.0–12.6	9.3–9.7	14.1–14.7	9.8–11.5	12.7–14.0	13.0–13.8	11.0–12.5	12.0–12.8
Leaf blade width (cm)	7.4–7.9	7.3–8.0	7.0–7.3	5.4–6.0	5.3–6.0	7.4–7.9	4.3–5.0	7.8–8.6	7.0–7.9	6.0–6.5	6.0–6.8
Leaf blade shape	Broadly elliptic	Broadly elliptic	Broadly elliptic	Obovate	Broadly elliptic	Broadly elliptic	Elliptic	Broadly elliptic	Broadly elliptic	Obovate	Broadly elliptic
Leaf apex shape	Acuminat e	Acuminat e	Acuminat e	Acuminat e	Acuminat e	Acuminate	Acuminat e	Acuminate	Acuminate	Acuminat e	Acuminat e
Leaf base shape	Obtusus	Acuminat e	Acuminat e	Acuminat e	Unsymme trical	Obtusus	Unsymme trical, acuminat e	Obtusus	Unsymmetri cal, acuminate	Acuminat e	Acuminat e
Leaf blade margin	Undulate	Undulate	Undulate	Undulate	Entire	Undulate	Entire	Undulate	Undulate	Undulate	Undulate
Upper surface color	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Green
Lower surface color	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green
Upper surface texture	Nitidus	Nitidus	Nitidus	Nitidus	Nitidus	Nitidus	Nitidus	Scaber	Scaber	Nitidus	Nitidus
Lower surface texture	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber	Scaber
Petiole texture	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis	Laevis
Petiole length (cm)	1.4–1.7	1.2–1.6	2.1–2.5	1.6–2.0	1.2–1.7	1.5–1.8	1.5–1.9	1.5–1.8	1.7–2.2	1.6–2.0	2.2–2.7
Petiole color	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green
Grooves on petiole	Absent	Absent	Present	Absent	Absent	Present	Absent	Absent	Absent	Present	Present
Crotch angle of petiole	Acute	Acute	Acute	Obtuse	Acute	Acute	Obtuse	Acute	Acute	Acute	Acute
Venation	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s	Penninervi s

**Table 3.** Flower morphological characters of 11 jackfruit provenances from Indonesia.

Provenances Characters	East Java	Central Java	West Java	Bali	Medan	Pekanbaru	Lampung	East Kalimantan	South Kalimantan	Kendari	Lombok
Flower type	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence	Inflorescence
Female inflorescence colour	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green
Male inflorescence colour	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green	Yellowish green
Male inflorescence position	Secondary and tertiary branches	Mainly on trunk and primary branches	Mainly on trunk and primary branches	Mainly on trunk, primary and secondary branches	Primary and secondary branches	Mainly on trunk, primary, secondary, tertiary branches	Mainly on trunk and primary branches	Secondary and tertiary branches	Mainly on trunk	Primary and secondary branches	Primary and secondary branches
Female inflorescence position	Secondary and tertiary branches	Mainly on trunk and primary branches	Mainly on trunk and primary branches	Mainly on trunk, primary and secondary branches	Primary and secondary branches	Mainly on trunk, primary, secondary, tertiary branches	Mainly on trunk and primary branches	Secondary and tertiary branches	Mainly on trunk	Primary and secondary branches	Primary and secondary branches
Female flower clustering habit	Clusters	Clusters	Solitary	Solitary, clusters	Solitary, clusters	Clusters	Solitary, clusters	Solitary, clusters	Group	Solitary, clusters	Solitary, clusters
Number of female flowers per bunch	2-3	4-8	1	1-4	1-2	3-8	1-4	1-2	2-4	1-2	1-3

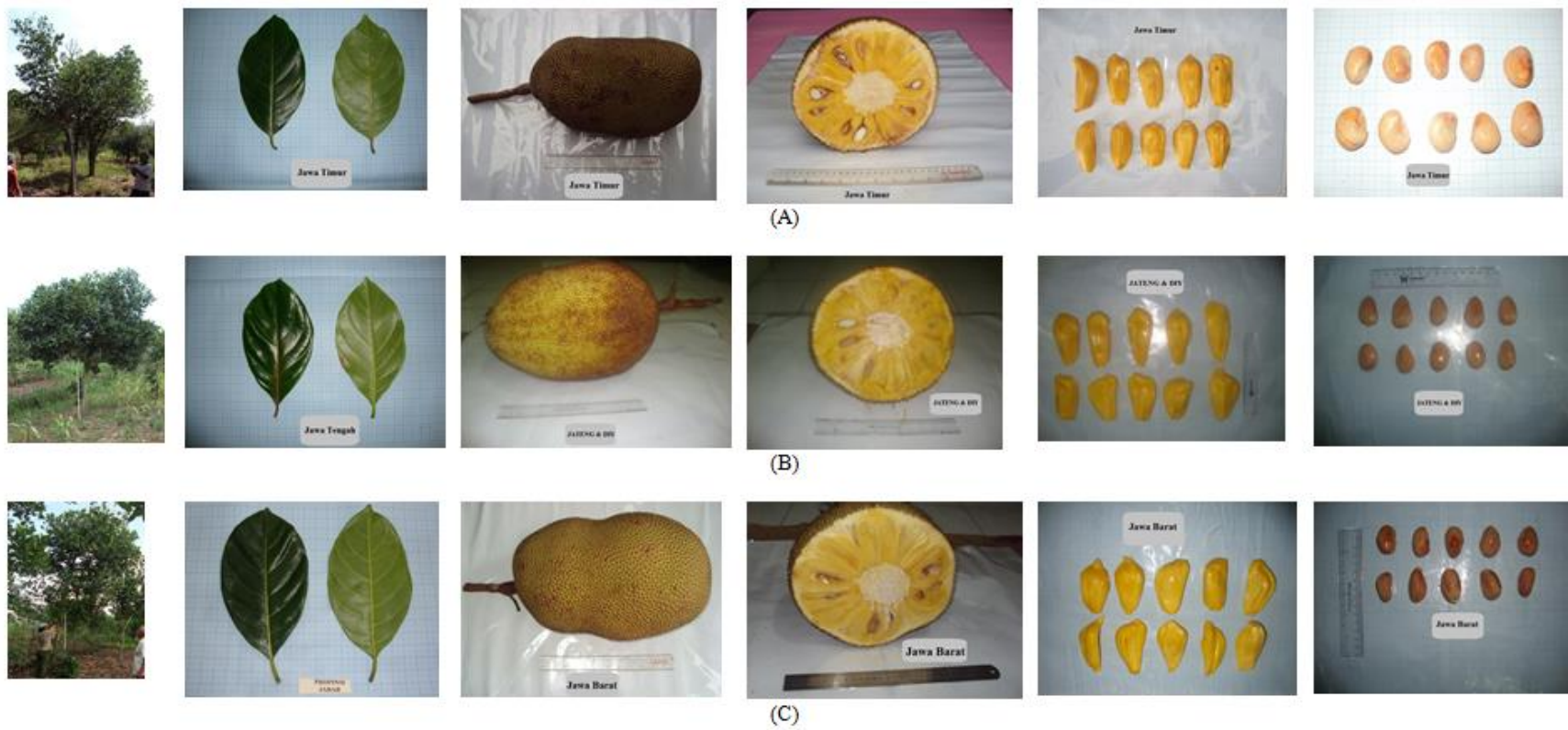
**Table 4.** Fruit morphological characters of 11 jackfruit provenances from Indonesia.

Provenances	East Java	Central Java	West Java	Bali	Medan	Pekanbaru	Lampung	East Kalimantan	South Kalimantan	Kendari	Lombok
Fruit length (cm)	44-47	42-54	38-42	34-35	40-54	45-47	38-43	40-42	35-36	34-37	43-45
Fruit diameter (cm)	24-27	30-36	25-27	26-27	26-29	25-27	25-27	23-24	21-22	21-23	24-25
Fruit shape	Ellipsoid	Obloid	Ovatus	Obloid	Ovatus	Ovatus	Ovatus	Ovatus	Ellipsoid	Ellipsoid	Ellipsoid
Fruit position	Clusters	Clusters	Solitary	Solitary, clusters	Solitary, clusters	Clusters	Mainly on trunk and primary branches	Secondary and tertiary branches	Mainly on trunk	Primary and secondary branches	Primary and secondary branches
Fruit rind colour	Greenish yellow	Yellow, reddish yellow	Greenish yellow	Reddish yellow	Greenish yellow, reddish yellow	Light green, Reddish green	Reddish yellow	Reddish green	Reddish green	Reddish yellow	Reddish yellow
Shape of spine	Sharp pointed	Sharp pointed	Sharp pointed	Intermediate	Intermediate	Sharp pointed	Sharp pointed	Flat	Intermediate	Sharp pointed	Intermediate
Spine density	Dense	Dense	Dense	Sparse	Intermediate	Dense	Intermediate	Sparse	Intermediate	Dense	Sparse
Latex exudation	Intermediate	High	High	High	Intermediate	High	High	Low	Low	High	Intermediate
Flake shape	Obovate, rectangular, oblong with curved tip irregular	Cordate, obovate, rectangular, irregular	Cordate, obovate, rectangular, irregular	Cordate, obovate, rectangular, irregular	Cordate, obovate, rectangular, irregular	Spheroid, cordate, obovate, rectangular, irregular	Cordate, obovate, rectangular, irregular	Obovate, rectangular, irregular	Spheroid, obovate, rectangular, irregular	Obovate, rectangular, irregular	Cordate, obovate, rectangular, irregular
Flake length (cm)	6.5-8.0	7.8-10	7.5-8.5	6.0-7.0	7.0-8.0	5.8-7.6	5.6-6.7	4.8-5.8	4.0-5.0	5.8-7.2	5.0-6.7
Flake width (cm)	3.4-4.7	4.0-5.7	3.8-5.0	3.4-4.5	3.5-5.0	3.6-4.8	3.5-4.6	2.8-3.5	2.3-3.2	3.4-4.3	2.7-3.7
Flake thickness	0.7-1.2	0.5-0.9	0,6 - 1,0	0.6-1.0	1.2-1.7	0.6-1.0	0.6-0.9	0.4-0.8	0.2-0.7	0.3-0.6	0.2-0.5
Flake texture	Soft	Soft	Soft	Soft	Soft	Soft	Soft	Soft	Soft	Soft	Soft
Pulp consistency	Soft	Soft	Soft	Firm	Firm	Soft	Soft	Soft	Soft	Soft	Slimy
Pulp taste	Sweet	Sweet	Sweet	Sweet, crunchy	Sweet, crunchy	Very sweet	Sweet	Sweet	Sweet	Sweet	Less sweet
Pulp flavor	Intermediate	Strong	Strong	Very sharp	Intermediate	Strong	Strong	Intermediate	Intermediate	Weak	Weak

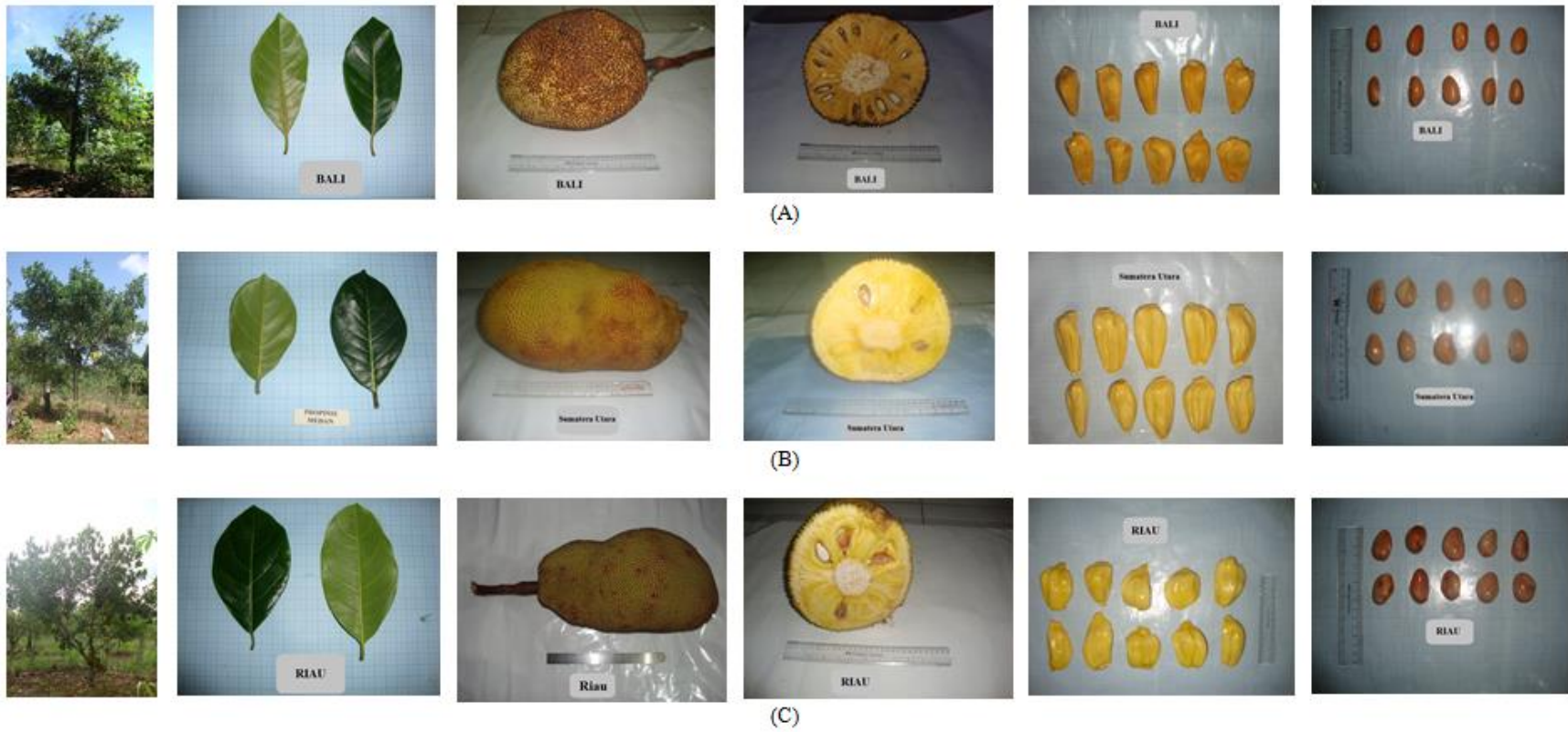


**Table 5.** Seed morphological characters of 11 jackfruit provenances from Indonesia.

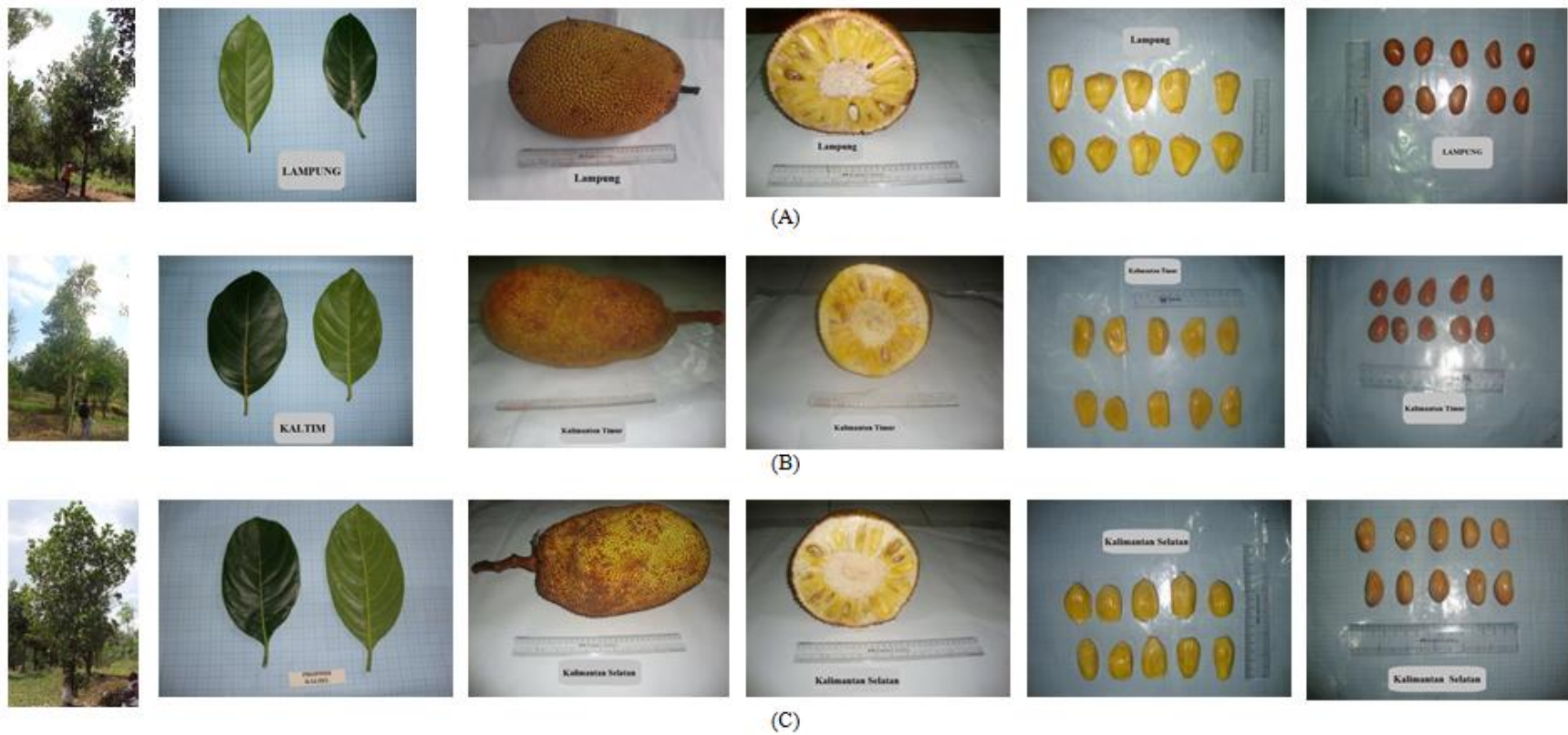
Provenances Characters	East Java	Central Java	West Java	Bali	Medan	Pekanbaru	Lampung	East Kalimantan	South Kalimantan	Kendari	Lombok
Seed length (cm)	2.5-3.0	3.3-4.2	3.5-4.0	2.8-3.7	2.6-3.6	2.6-4.0	2.5-3.5	2.5-3.2	2.8-3.4	2.8-3.4	2.8-3.7
Seed width (cm)	1.7-2.3	2.0-2.6	1.9-2.8	1.6-2.3	1.6-2.3	1.8-2.5	1.7-2.3	1.5-2.2	1.6-2.0	1.6-2.0	1.8-2.3
Seed shape	Spheroid, ellipsoid, ovatus, reniform, irregular	Spheroid, ellipsoid, ovatus, reniform	Ellipsoid, ovatus, reniform	Ellipsoid, ovatus, reniform, oblong	Ellipsoid, ovatus, reniform, irregular	Spheroid, ellipsoid, ovatus, reniform, irregular	Spheroid, ellipsoid, ovatus, irregular	Spheroid, ellipsoid, ovatus, reniform	Spheroid, ellipsoid, ovatus, irregular	Ellipsoid, ovatus, reniform	Spheroid, ellipsoid, ovatus, reniform
Adherence of seed coat to kerne	Easily separable	Easily separable	Easily separable	Difficult to separate	Easily separable	Difficult to separate	Easily separable	Easily separable	Easily separable	Easily separable	Striped
Seed surface pattern	Striped	Striped	Striped	Striped	Striped	Striped	Striped	Striped	Striped	Striped	Striped
Number of lines on seed coat	2-4	2-3	1-3	1-3	1-2	1-3	2-6	2-4	3-7	1-3	2-4
Seed coat colour	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown



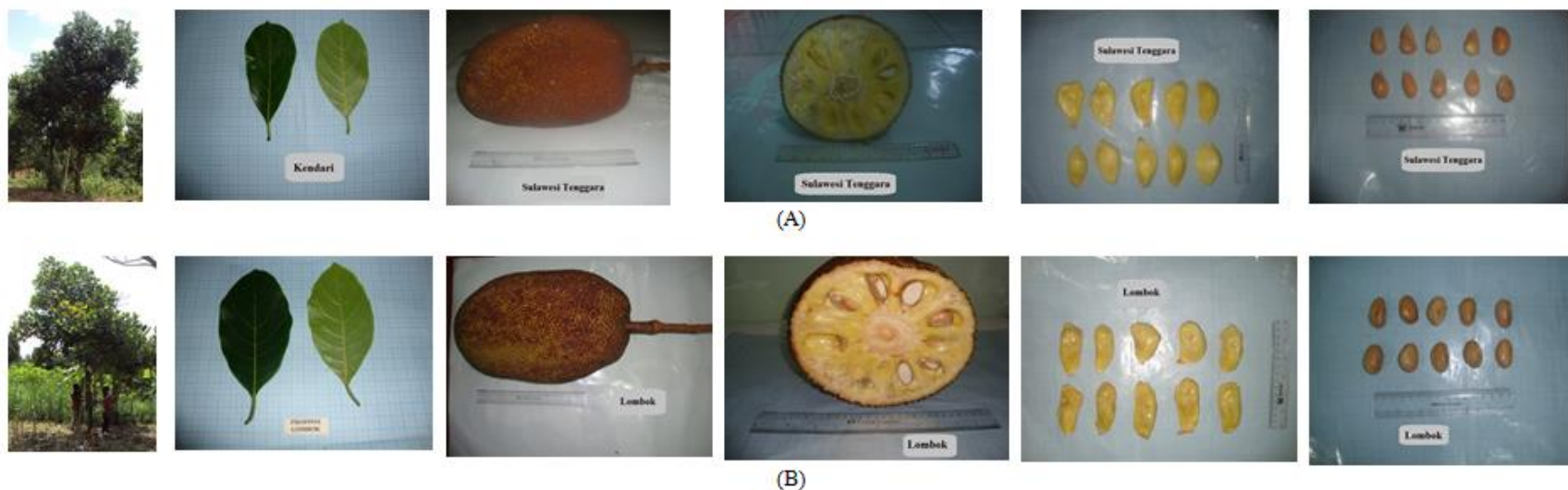
**Figure 2.** Morphological characters of Indonesian jackfruit provenances. A: East Java, B: Central Java, C: West Java.



**Figure 3.** Morphological characters of Indonesian jackfruit provenances. A: Bali, B: Medan, C: Pekanbaru.



**Figure 4.** Morphological characters of Indonesian jackfruit provenances. A: Lampung, B: East Kalimantan, C: South Kalimantan.



**Figure 5.** Morphological characters of Indonesian jackfruit provenances. A: Kendari, B: East Kalimantan, C: Lombok.

**Table 6.** Association coefficients (%) of Indonesian jackfruits originating from 11 regions based on morphological characters.

OTUs	1	2	3	4	5	6	7	8	9	10	11
1	100										
2	62.69	100									
3	61.19	74.63	100								
4	52.24	65.67	64.18	100							
5	65.67	52.24	56.72	59.70	100						
6	70.15	65.67	73.13	58.21	62.69	100					
7	52.24	65.67	58.21	49.25**	56.72	61.19	100				
8	61.19	53.73	55.22	49.25**	50.75	52.24	58.21	100			
9	61.19	59.70	52.24	55.22	50.75	49.25	58.21	70.15	100		
10	50.75	61.19	62.69	56.72	52.24	53.73	65.67	59.70	71.64	100	
11	61.19	53.73	58.21	52.24	62.69	52.24	70.15	64.18	76.12*	71.64	100

Description: OTU: Operational taxonomic units of various provenances, 1: East Java, 2: Central Java, 3: West Java, 4: Bali, 5: Medan, 6: Pekanbaru, 7: Lampung, 8: East Kalimantan, 9: South Kalimantan, 10: Kendari, 11: Lombok.

\*Jackfruit provenances that have the highest similarity.

\*\*Jackfruit provenances that have the lowest similarity.

thickness 0.5–0.9 cm, yellow, cordate, obovate, rectangular, irregular, soft texture, sweet taste, strong flavor, juicy; rachis 31.5–37 cm long; *dami* yellow, sweet taste. Seeds 3.3–4.2 cm × 2.0–2.6 cm, spheroid, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 2).

### West Java

Trees 6.7–7.0 m high, pyramidal crown, round stem, rough, light brown with grayish spots, no cracks, horizontal branching. Leaves simple, broadly elliptic; petiole 2.1–2.5 mm long, yellowish green; lamina 12.8–13.3 cm × 7.0–7.3 cm, base acuminate, apex acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position mainly on trunk and primary branches; female flowers yellowish green, solitary, mainly on trunk and primary branches. Fruit ovatus, 38–42 cm long, greenish yellow, spiny; Spine sharp pointed, dense; stalk 14.5–15 cm long. Flake 7.5–8.5 cm × 3.8–5.0 cm, thickness 0.6–1.0 cm, yellow, cordate, obovate, rectangular, irregular, soft texture, sweet taste, strong flavor, juicy; rachis 31.5–37 cm long; *dami* yellow, sweet taste. Seeds 3.3–4.2 cm × 2.0–2.6 cm, spheroid, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 2).

### Bali

Trees 6.6–7.0 m high, pyramidal crown, round stem, rough, dark brown with white spots, no cracks, horizontal branching. Leaves simple, obovate; petiole 1.6–2.0 cm long, yellowish green; lamina 12.0–12.6 cm × 5.4–6.0 cm, base acuminate, apex acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position mainly on trunk, primary and secondary branches; female flowers yellowish green, solitary,

clusters, mainly on trunk, primary and secondary branches. Fruit obloid, 34–35 cm long, reddish yellow, spiny; spine intermediate, sparse; stalk 16 - 18 cm long. Flake 6.0–7.0 cm × 3.4–4.5 cm, thickness 0.6–1.0 cm, yellow, cordate, obovate, rectangular, irregular, soft texture, firm, sweet taste, crunchy, very strong flavor, less juicy; rachis 26–27 cm long; *dami* yellow, sweet taste. Seeds 2.8–3.7 cm × 1.6–2.3 cm, ellipsoid, ovatus, reniform, oblong; seed coat striped, difficult to separate, brown (Figure 3).

### Medan

Trees 6.2–6.5 m high, broadly pyramidal crown, round stem, rough, brown with grayish spots, no cracks, vertical branching. Leaves simple, broadly elliptic; petiole 1.2–1.7 cm long, yellowish green; lamina 9.3–9.7 × 5.3–6.0 cm, base unsymmetrical, apex acuminate, margin entire; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position primary and secondary branches; female flowers yellowish green, solitary, clusters, primary and secondary branches. Fruit ovatus, 40–54 cm long, greenish yellow, reddish yellow, spiny; spine intermediate sharp, intermediate density; stalk 16–18 cm long. Flake 7.0–8.0 cm × 3.5–5.0 cm, thickness 1.2–1.7 cm, yellow, cordate, obovate, rectangular, irregular, soft texture, firm, sweet taste, crunchy, intermediate flavor, less juicy; rachis 29.3–37 cm long; *dami* yellow, less sweet taste. Seeds 2.6–3.6 cm × 1.6–2.3 cm, ellipsoid, ovatus, reniform, irregular; seed coat striped, easily separable, brown (Figure 3).

### Pekanbaru

Trees 5.6–6.0 m high, broadly pyramidal crown, round stem, rough, grayish brown, no cracks, vertical branching. Leaves simple, broadly elliptic; petiole 1.5–1.8 cm long, yellowish green; lamina 12.7–13.5 cm × 6.6–7.8 cm, base acuminate, apex

acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence unisexual; male flower yellowish green, position mainly on trunk, primary, secondary, tertiary branches; female flowers yellowish green, clusters, mainly on trunk, primary, secondary, tertiary branches. Fruit ovatus, 45–47 cm long, light green, reddish green, spiny; spine sharp pointed, dense; stalk 17–18 cm long. Flake 5.8–7.6 cm × 3.6–4.8 cm, thickness 0.6–1.0 cm, yellow, spheroid, cordate, obovate, rectangular, irregular, soft texture, very sweet taste, strong flavor, juicy; rachis 36–40 cm long; *dami* yellow, less sweet taste. Seeds 2.6–4.0 cm × 1.8–2.5 cm, spheroid, ellipsoid, ovatus, reniform, irregular; seed coat striped, difficult to separate, brown (Figure 3).

### Lampung

Trees 7.2–7.5 m high, broadly pyramidal crown, round stem, very rough, brown, cracks, vertical branching. Leaves simple, elliptic; petiole 1.5–1.8 cm long, yellowish green; lamina 9.8–11.5 cm × 4.3–5.0 cm, base unsymmetrical, acuminate, apex acuminate, margin entire; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position mainly on trunk, primary branches; female flowers yellowish green, solitary, clusters, mainly on trunk, primary branches. Fruit ovatus, 38–43 cm long, reddish yellow, spiny; spine sharp pointed, intermediate density; stalk 20–23 cm long. Flake 5.6–6.7 cm × 3.5–4.6 cm, thickness 0.6–0.9 cm, yellow cordate, obovate, rectangular, irregular, soft texture, sweet taste, strong flavor, juicy; rachis 38–43 cm long; *dami* white, insipid. Seeds 2.5–3.5 cm × 1.7–2.3 cm, spheroid, ellipsoid, ovatus, irregular; seed coat striped, easily separable, brown (Figure 4).

### East Kalimantan

Trees 7.8–8.0 m high, pyramidal crown, round stem, very rough, grayish white, no cracks, horizontal branching. Leaves simple, elliptic; petiole 1.5–1.8 cm long, yellowish green; lamina 12.7–14.0 cm × 7.8–8.6 cm, base obtusus, apex acuminate, margin undulate; upper surface dark green, scaber; lower surface yellowish green, scaber; penninervis. Inflorescence unisexual flower; male flower yellowish green, position secondary and tertiary branches; female flowers yellowish green, solitary, clusters, secondary and tertiary branches. Fruit ovatus, 40–42 cm long, reddish green, spiny; spine flat, sparse; stalk 18–21 cm long. Flake 4.8–5.8 cm × 2.8–3.5 cm, thickness 0.4–0.8 cm, yellow, obovate, rectangular, irregular, soft texture, sweet taste, intermediate flavor, juicy; rachis 40–42 cm long; *dami* white, insipid. Seeds 2.5–3.2 cm × 1.5–2.2 cm, spheroid, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 4).

### South Kalimantan

Trees 7.6–7.9 m high, pyramidal crown, round stem, very rough, brown with grayish spots, no cracks, vertical branching. Leaves simple, broadly elliptic; petiole 1.7–2.2 cm long, yellowish green; lamina 13.0–13.8 cm × 7.0–7.9 cm, base unsymmetrical, acuminate, apex acuminate, margin undulate; upper surface dark green, scaber; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position mainly on trunk; female flowers yellowish green, clusters, mainly on trunk. Fruit ellipsoid, 35–36 cm long, reddish green, spiny; spine intermediate sharp, intermediate density; stalk 18–20 cm long. Flake 4.0–5.0–5.8 cm × 2.3–3.2 cm, thickness 0.2–0.7 cm, yellow, spheroid, obovate,

rectangular, irregular, soft texture, sweet taste, intermediate flavor, juicy; rachis 35–38 cm long; *dami* white, insipid. Seeds 2.8–3.4 cm × 1.6–2.0 cm, spheroid, ellipsoid, ovatus, irregular; seed coat striped, easily separable, brown (Figure 4).

### Kendari

Trees 7.7–8.0 m high, pyramidal crown, round stem, very rough, brown with grayish spots, no cracks, vertical branching. Leaves simple, obovate; petiole 1.7–2.2 cm long, yellowish green; lamina 11.0–12.5 cm × 6.0–6.5 cm, base acuminate, apex acuminate, margin undulate; upper surface dark green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence unisexual flower; male flower yellowish green, position primary and secondary branches; female flowers yellowish green, solitary, clusters, primary and secondary branches. Fruit ellipsoid, 34–37 cm long, reddish yellow, spiny; spine sharp pointed, dense; stalk 18–20 cm long. Flake 5.8–7.2 cm × 3.4–4.3 cm, thickness 0.3–0.6 cm, yellow, spheroid, obovate, rectangular, irregular, soft texture, sweet taste, weak flavor, juicy; rachis 34–37 cm long; *dami* white, insipid. Seeds 2.8–3.4 cm × 1.6–2.0 cm, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 5).

### Lombok

Trees 8.0–8.5 m high, pyramidal crown, round stem, rough, brown with grayish spots, no cracks, vertical branching. Leaves simple, broadly elliptic; petiole 2.2–2.7 cm long, yellowish green; lamina 12.0–12.8 cm × 6.0–6.8 cm, base acuminate, apex acuminate, margin undulate; upper surface green, nitidus; lower surface yellowish green, scaber; penninervis. Inflorescence, unisexual flower; male flower yellowish green, position primary and secondary branches; female flowers yellowish green, solitary, clusters, primary and secondary branches. Fruit ellipsoid, 12.0–12.8 cm long, reddish

yellow, spiny; spine intermediate sharp, sparse; stalk 23–25 cm long. Flake 5.0–6.7 cm × 2.7–3.7 cm, thickness 0.2–0.5 cm, yellow, cordate, obovate, rectangular, irregular, soft texture, slimy, less sweet taste, weak flavor, very juicy; rachis 43–45 cm long; *dami* white, insipid. Seeds 2.8–3.7 cm × 1.8–2.3 cm, spheroid, ellipsoid, ovatus, reniform; seed coat striped, easily separable, brown (Figure 5).

The jackfruit germplasm showed morphological diversity in terms of fruit shape, skin color, spike sharpness and density, fruit color, fruit flesh character, flesh thickness, fruit flesh taste, fruit flesh aroma, *dami* color, and *dami* taste. Past research on jackfruit genetic diversity reported on the morphological diversity of 30 jackfruit accessions based on 21 characters, including fruit shape, fruit skin color, and fruit flesh color (Sulassih *et al.*, 2015). Morphological observations revealed that cultivated jackfruit genotypes have greater variation for qualitative and quantitative characters than jackfruit that grows naturally in the forests (Chowdhury *et al.*, 1997; Khan *et al.*, 2010). The evaluation of 24 local jackfruit genotypes from Assam, India, by using morphological characters revealed variability in crown shapes, such as irregular, elliptical, oblong, and spherical. Wide variations in leaf blade shape, i.e., elliptic, obovate, oblong, broadly elliptic, and narrowly elliptic, were observed. Fruit shapes included ellipsoid, spheroid, oblong, clavate, oblong, and irregular. Flake texture and flake flesh color also showed wide variation. Seeds presented different shapes, such as ellipsoid, irregular, reniform, spheroid, and oblong (Dey and Baruah, 2019).

### Relationship among jackfruit provenances based on morphological characters

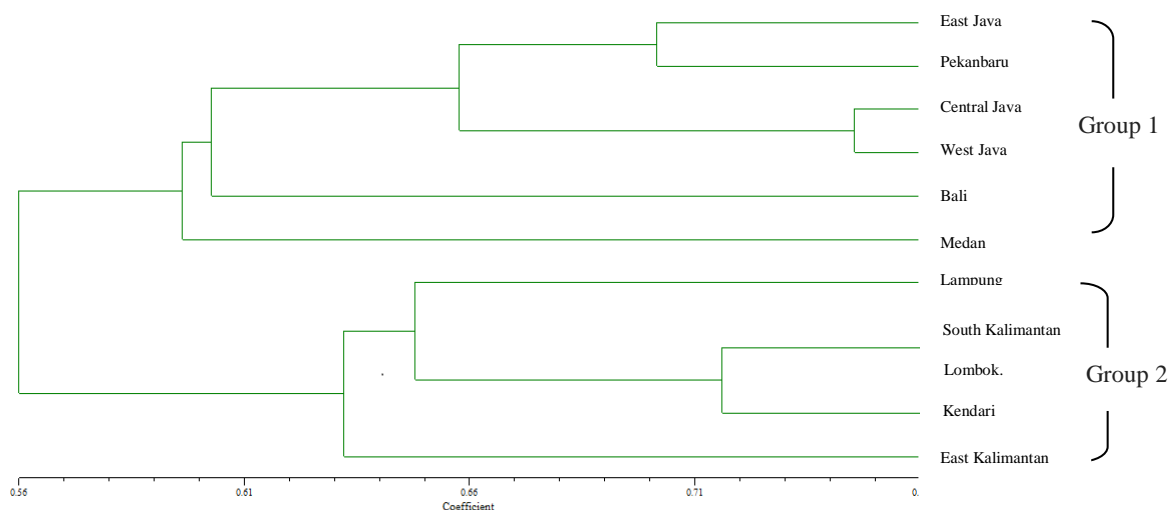
The observed morphological characters were then analyzed to determine the association coefficient and similarity index of the jackfruit provenances by using the coefficient of the Jaccard formula. The



similarity coefficients ranged from 49.25% to 76.12% (Table 6). On the basis of the values of the association coefficient, a dendrogram was compiled through cluster analysis with UPGMA. The similarity relationship between the 11 jackfruit provenances was based on morphological characters as can be seen in the dendrogram (Figure 6). Singh (1999) stated that in general, if the germplasm has a similarity index of 85% or more, then the germplasm can be grouped as the same species.

The dendrogram of the morphological characters showed that the 11 jackfruit provenances were divided into two major groups with the association coefficient of 56%. Group I consisted of six jackfruit origins, i.e., East Java, Pekanbaru, Central Java, West Java, Bali, and Medan. Group II contained five jackfruit provenances, namely, Lampung, South Kalimantan, Lombok, Kendari, and East Kalimantan. All the jackfruit genotypes in group I had yellow *dami* colors and sweet or less sweet taste, whereas group II genotypes had white *dami* colors and plain taste. The jackfruits

that originated from South Kalimantan and Lombok had the highest similarity (76.12%). This result showed that both provenances had the highest morphological similarities although they belonged to different geographical regions. The morphological similarities of the 11 jackfruit provenances were sufficiently high with similarity coefficients of 50.75% to 76.12%. South Kalimantan and Lombok had high similarity because they shared the characters of tree canopy shape, stem branching pattern, leaf shape, fruit shape, thorn sharpness, fruit flesh, and *dami* color and taste. Nonetheless, both provenances had differences, especially in the character of the form of stalk penetration. South Kalimantan had more similarities with Lombok than with East Kalimantan. South Kalimantan and East Kalimantan had a similarity of 70.15%. Morphological traits can be more easily measured than other characters (Moncur, 1985; Jones and Luchsinger, 1986) and are influenced by environmental and physiological factors (Zhao *et al.*, 2007).



**Figure 6.** Relationship of Indonesian jackfruits originating from 11 regions based on morphological characters.

The Central Java provenance shared 74.63% similarities with the West Java provenance. The characters of stem branching pattern, leaf shape, flower position, fruit length and diameter ratios, fruit stalk penetration, *nyamplung* (flesh and seeds) shape, fruit taste, fruit flesh aroma, and *dami* color and taste were the characters shared by the Central Java and West Java provenances. These two provenances differed greatly in terms of fruit shape traits. Several flexible phenotypic variations have emerged in response to environmental factors, and such a type of response is a reaction caused in an individual on the basis of physiological needs (Davis and Heywood, 1973; Musa, 2004).

East Java and Pekanbaru had a similarity of 70.15%. The characters of the shape of the tree canopy, the pattern of branching stems, the ratio of the length and diameter of the fruit, the penetration of fruit stalks, and the color of the *dami* were the common characters that belonged to both provenances. The distinguishing character between East Java and Pekanbaru was fruit taste. However, the *dami* taste of the jackfruits of East Java and Pekanbaru shared 65.67% similarity with that of the jackfruits with Central Java and West Java origins. The characters of the edge shape of the leaves, the sharpness of spikes, the density of spikes, the penetration of fruit stalks, the water content of the fruit flesh, and the color of the *dami* accounted for the relationship of jackfruits from East Java and Pekanbaru with those from the regions of Central Java and West Java. The character that distinguished the four provenances was mainly the branching pattern of the trunk. A large number of morphological traits, including fruit shape, the color of the fruit skin, and the color of fruit flesh, were responsible for genetic diversity and variations among jackfruit accessions (Sulassih *et al.*, 2015).

Bali had a similarity of 60.07% with East Java, Pekanbaru, Central Java, and West Java. The shared traits included leaf margin, leaf stalk texture, fruit stalks penetration, and *dami* color. The leaf

shape, spike sharpness, spike density, and fruit flesh character were the distinguishing characters between Bali and other provenances, i.e., East Java, Pekanbaru, Central Java, and West Java. The origin Medan joined the provenance group of East Java, Pekanbaru, Central Java, West Java, and Bali with an association coefficient of 59.40%. The characters of *dami* color and *dami* taste caused the Medan provenance to join with East Java, Pekanbaru, Central Java, West Java, and Bali provenances in group I, whereas the leaf margin distinguished the Medan provenance from five other provenances. Widyastuti (1993) also reported that jackfruit and cempedak possess undeveloped fleshy petals, which are known as *dami*, that are thick, large, sweet, and edible.

Kendari joined the group of South Kalimantan and Lombok with an association coefficient of 71.64% on the basis of stem branching pattern and fruit shape. The character spike sharpness distinguished Kendari from two other provenances. The Lampung provenance joined the provenance groups of South Kalimantan, Lombok, and Kendari with an association coefficient of 64.68%. Tree canopy shape was the character that distinguished Lampung from three other provenances. East Kalimantan joined South Kalimantan, Lombok, Kendari, and Lampung with an association coefficient of 63.2%, forming group II. The character of stem branching pattern distinguished East Kalimantan from the provenance group of South Kalimantan, Lombok, Kendari, and Lampung. The morphological diversity of jackfruit genotypes planted in different regions was based on morphological markers and isoenzymes (Adelina *et al.*, 2006) and may be attributed to cross pollination and seed propagation (Jagadeesh *et al.*, 2007).

A dendrogram was used to describe and identify the highest percentage of similarities between jackfruit provenances. However, the dendrogram did not show the differentiating characters among the provenances that accounted for similarity

percentages. Distinguishing characters can be known from the typical characters of each provenance. Chaveerach *et al.* (2008) stated that dendrograms can be used to explore and present the results of phenotypic analysis for the grouping of OTUs and the degree of similarity among the OTUs in a cluster or group. This study indicated that the jackfruit accessions with 11 provenances from Indonesia showed morphological variations and could be used for further improvement in cultivation and conservation purposes. The variations exhibited by the jackfruit accessions were due to genetic and environmental factors.

## CONCLUSIONS

The Indonesian jackfruit germplasm with different origins showed morphological variations in terms of fruit shape, fruit skin color, spike sharpness, spike density, and fruit flesh. The dendrogram based on morphological characters revealed that the jackfruit genotypes that originated from 11 origins grouped into two major groups with the highest similarity value shown by the accessions obtained from South Kalimantan and Lombok provenances. Morphological variation among jackfruit provenances will be helpful for the sustainable utilization of the germplasm in future jackfruit breeding programs and the conservation of germplasm for future generations.

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## REFERENCES

Adelina E, Tambing Y, Budiarti T, Murniati E (2006). Identifikasi keragaman kultivar nangka berdasarkan ciri morfologi, dan

- analisis isoenzim. *Agrisains* 7(3): 150-155.
- Chaveerach A, Sudmoon R, Tanee T, Mookamul P, Sattayasai N, Sattayasai J (2008). Two new species of *Curcuma* (Zingiberaceae) used as cobra-bite antidotes. *J. Syst. Evol.* 46(1): 80-88.
- Chowdhury FA, Raman MA, Mian J (1997). Distribution of free sugars and fatty acids in jackfruit (*Artocarpus heterophyllus* L.). *Food Chem.* 60: 25-28.
- Davis PH, Heywood VH (1973) Principles of Angiosperm Taxonomy. Krieger Publishing Company. Huntington, New York.
- Dey B, Baruah K (2019). Morphological characterization of jackfruit (*Artocarpus heterophyllus* Lam.) of Assam India. *Int. J. Curr. Microbiol. Appl. Sci.* 8(11): 1005-1016.
- Elevitch CR, Manner HI (2006). *Artocarpus heterophyllus* (jackfruit). Species profiles for Pacific Island agro-forestry. pp. 1-25.
- Haq N (2006). Jackfruit, *Artocarpus heterophyllus*. Southampton Centre for Underutilized Crops, University of Southampton, Southampton, UK.
- IPGRI (2000). Descriptors for jackfruit (*Artocarpus heterophyllus* Lam.). IPGRI, Rome. ISBN 92-90423-450-3.
- Jagadeesh SL, Reddy BS, Basavaraj N, Swamy GSK, Gorbak K, Hedge L, Raghavan GSV, Kajjidoni ST (2007). Inter tree variability for fruit quality in jackfruit selections of Western Ghats of India. *Scien. Hort.* 112: 382-387.
- Jones SB, Luchsinger AE (1986). Plant systematic. 2nd Edition. McGraw Hill Book Company, New York.
- Kavya K, Shyamamma S, Gayatri S (2019). Morphological and molecular genetic diversity analysis using SSR markers in Jackfruit (*Artocarpus heterophyllus* Lam.) genotypes for pulp colour. *Indian J. Agric. Res.* 53(1): 1-8.
- Khan R, Zerega N, Hossain S, Zuberi MI (2010). Jackfruit (*Artocarpus heterophyllus* L.) diversity in Bangladesh: Land use and artificial selection. *Eco. Bot.* 64(2): 124-136.
- Madrugá MS, de-Albuquerque FSM, Silva IR, do Amaral DS, Magnani M, Neto VQ (2014). Chemical, morphological and functional properties of Brazilian jackfruit (*Artocarpus heterophyllus* L.) seeds starch. *Food Chem.* 143: 440-445.

- Moncur MW (1985). Floral ontogeny of the jackfruit, *Artocarpus heterophyllus* L. (Moraceae). Division of Water and Land Resources, CSIRO Canberra. Australia.
- Mursyidin DH, Khairullah I (2020). Genetic evaluation of tidal swamp rice from South Kalimantan, Indonesia based on the agro-morphological markers. *Biodiversitas J. Biol. Divers.* 21(10): 4795-4803.
- Musa S (2004). Isolation and characterization of flavonoid compounds from methanol extracts ethyl acetate fraction bark fractions on jackfruit (*Artocarpus heterophylla* L.). [Thesis]. Universitas Negeri Gorontalo, Gorontalo, Indonesia.
- Rahman AM, Nahar N, Mian AJ, Mosihuzzaman M (1999). Variation of carbohydrate composition of two forms of fruit from jack tree (*Artocarpus heterophyllus* L) with maturity and climatic conditions. *Food Chem.* 65: 91-97.
- Safitri NB, Palupi T (2017). Identifikasi Keragaman Genetik Dengan Karakter Morfologi *Artocarpus heterophyllus* Lamk Nangka Kalimantan Barat, Indonesia. *Agrovigor: J. Agroekoteknol.* 10(1): 49-55.
- Singh G (1999). Plant systematics. Science Publishers, Inc. New Hampshire. pp. 164-195.
- Sulassih, Sobir, Santosa E, Tirtawinata MR (2015). Variability genetic analysis for jackfruit (*Artocarpus heterophyllus* L.) based on morphological markers. Prosiding Seminar Nasional Buah Tropika Nusantara II. Balai Penelitian Tanaman Bah Tropika, Indonesia.
- Suprpti ML (2004). Appropriate Technology Chips, Confectionery, and Jackfruit Syrup. Kanisius, Yogyakarta, Indonesia.
- Widyastuti YE (1993). Jackfruit and Cempedak: Variety of types and cultivation. Penebar Swadaya, Jakarta, Indonesia.
- Zhao K, Zhou M, Chen L (2007). Genetic diversity and discrimination of *Chimonathus praecox* (L.) link germplasm using ISSR and RAPD markers. *HortSci.* 42(5): 1144-1148.