Morphological Diversity of Local Sugar Apple (*Annona squamosa*) Germplasm from Madura

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Abstract. This study aimed to identify the morphological diversity of local sugar apple (Annona squamosa) germplasm and evaluate the potential of selected accessions from Madura Island, Indonesia, as prospective superior cultivars. A total of ten local sugar apple germplasm samples were collected from three regencies in Madura: Sumenep, Pamekasan, and Bangkalan. Morphological characterization was carried out using the official descriptor for Annona squamosa, encompassing both vegetative traits (such as leaf shape, stem characteristics, and tree architecture) and generative traits (including fruit size, skin texture, pulp thickness, and seed count). Descriptive analysis revealed substantial phenotypic variation among the observed germplasm. Notably, several accessions from Sumenep exhibited larger fruit size and thicker pulp, indicating potential for improved fruit quality. Meanwhile, accessions from Pamekasan demonstrated strong vegetative vigor and promising productivity traits, such as a higher number of fruits per tree. These variations highlight the wide genetic diversity present within the local sugar apple populations in Madura. The findings suggest that local sugar apple germplasm from Madura possesses valuable traits that can be utilized for future breeding and cultivar development.

Keywords. Germplasm diversity ; Madura Island ; Morphological characterization ; Sugar Apple; Superior cultivar potential

1 Introduction

Indonesia is known as one of the countries with the highest biodiversity in the world, encompassing an extensive variety of tropical fruit species that play important ecological, cultural, and economic roles. The country's wide range of agroecological zones—from coastal lowlands to upland areas—creates diverse environmental conditions that support the growth of numerous local fruit genotypes with unique characteristics, high adaptability, and potential for genetic improvement. This richness of fruit biodiversity not only contributes to food security but also serves as a valuable genetic resource for breeding and conservation programs [1][2]. One of the regions recognized for its remarkable diversity of local fruits is Madura Island, located in East Java Province. The island's dry climate and distinct soil composition allow several fruit species to thrive under marginal conditions. Among the fruits commonly found in this area, Annona squamosa L., known as sugar apple, stands out as one of the most widely cultivated and favored by local communities for its sweet flavor, nutritional value, and market potential [3][4][5].

Sugar apple (Annona squamosa L.) is a tropical fruit species belonging to the *Annonaceae* family, widely

recognized for its distinctive sweet flavor and high nutritional content. The fruit is rich in carbohydrates, vitamins, minerals, and natural antioxidants that contribute to its value as a functional food. Beyond its edible parts, other plant components such as leaves, bark, and seeds have long been utilized in traditional medicine due to their bioactive compounds with antimicrobial, anti-inflammatory, and antioxidant properties [6][7]. In addition to its nutritional and pharmacological benefits, sugar apple holds considerable economic potential, particularly for smallholder farmers, as it can serve as both a source of fresh fruit production and raw material for processed food and herbal industries. Its high adaptability to dry and nutrient-poor soils allows this species to thrive in marginal agricultural lands, making it a strategic crop for promoting sustainable and climate-resilient farming systems [8][9]. This adaptability, combined with its local popularity and market demand, positions sugar apple as an important horticultural commodity in arid regions such as Madura.

Despite its abundance and potential, studies on sugar apple in Madura are still very limited. Most previous research has focused on other fruit crops, leaving a lack of scientific data regarding the morphological and genetic characteristics of local sugar apple accessions.

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Morphological characterization plays an essential role in plant breeding programs to identify potential superior genotypes of sugar apple that can serve as prospective mother trees [10]. The development of new and improved varieties requires a broad range of phenotypic and genotypic variability, which can be assessed through morphological evaluation. This process enables the identification of accessions exhibiting desirable traits, providing valuable information for selecting the most promising sugar apple lines [11][12]. This research contributes to the identification and selection of superior sugar apple genotypes through comprehensive morphological characterization. It provides valuable insights into the phenotypic variability among accessions, supporting future breeding programs aimed at developing improved varieties.

2 Methods

This study used descriptive explorative research method through field survey. The results were analyzed using a descriptive analysis method based on the species descriptor. Morphological observations were conducted directly in the field on plants growing in the Pamekasan and Sumenep regions of Madura Island. This study applied purposive random sampling with the type of snowball sampling observation made on 10 plants that have been fruitful. Observation on morphological character in this research was done on vegetative and generative organs which include qualitative and quantitative characters based on sugar apple descriptor.

Each character was described and compared among accessions to determine the level of morphological variation. The data were analyzed by constructing a resemblance matrix using the SIMQUAL (Similarity for Qualitative Data) procedure, followed by cluster analysis through the SAHN (Sequential Agglomerative Hierarchical and Nested) algorithm employing the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) approach. All analyses were performed using the Numerical Taxonomy and Multivariate Analysis System (NTSYS-pc) version 2.10 [13][14]. The clustering results were displayed in the form of a dendrogram, which was subsequently interpreted and described to explain the relationships among accessions [15].

3 Results and Discussion

3.1 Morphological of sugar apple vegetative organs

Observations of 10 sugar apple accessions on Madura Island show that several growth characteristics are 100% similar, such as canopy shape, stem shape, and branching pattern. Several other growth characteristics vary widely [16][17].

Other vegetative observations were made on the morphology of sugar apple leaves. There were three categories of leaf shape, namely 20% obovate, 50% elliptical, and 30% lanceolate. Vegetative organ observations focused on the leaves, and the results of these observations are presented in Figure [2].

The leaf edge and leaf tip characteristics were uniform across the 10 accessions observed. 20% are obovate, 50% are elliptical, and 30% are lanceolate. However, 30% of the leaf bases are round, and 70% are flat. The leaf colors observed included the color of the leaf stalk, the color of the upper leaf surface, and the color of the lower leaf surface. The color of the leaf stalk was dominated by dark green, with 10% dark green, 80% green, and 10% pale green. Meanwhile, the color of the upper leaf surface was more diverse, with 30% dark green, 30% green, and 40% light green. The color of the lower leaf surface was 20% yellowish green, 20% green, and 60% light green [18][19][20].

(a) **(b)** **(c)**

Fig. 1. (a) Canopy shape (b) Branching pattern (c) Stem shape

The variation in leaf morphology and coloration among the observed accessions indicates the existence of phenotypic diversity within the sugar apple population in Madura. Although several traits, such as leaf edge and tip shape, appear relatively uniform, differences in leaf shape and color intensity suggest possible genetic variability or environmental influences affecting pigment expression and leaf structure. The predominance of green to light-green coloration on both leaf surfaces may reflect the adaptive response of the plants to the dry and high-radiation conditions typical of Madura's agroecological environment [21][22]. Such variation can serve as an important indicator for

(a) **(b)** **(c)**

Fig. 2. (a) Ovate leaf shape (b) Elliptic leaf shape (c) Lanceolate leaf shape

selecting accessions with better photosynthetic efficiency and adaptability, which are essential criteria in identifying potential superior genotypes for further breeding programs [23][24].

3.2 Morphological of sugar apple generative organs

Observations of generative characteristics in 10 sugar apple plant accessions included flower, fruit, and seed characteristics. In the observation of flower characteristics, namely flower position and number of petals, the 10 accessions showed uniformity, with 100% of flowers located in the leaf axils (floss axilaris) and 80% having 3 petals and 20% having 4 petals. In terms of fruit shape, 50% were oval and 50% were round. Meanwhile, fruit weight varied considerably. ellipsoid shape, and 30% had a spheroid shape. The number of seeds and total seed weight in the 10 accessions observed varied [27][28][29].

The diversity in fruit-related traits among the observed accessions demonstrates a wide range of phenotypic variability within the sugar apple population. The high variation in fruit weight and sweetness level suggests differences in genetic potential and environmental adaptability, which are important parameters for identifying superior genotypes. Although the fruit circumference and flesh thickness were relatively uniform, the variation in sweetness indicates the influence of both genotype and microenvironmental factors such as sunlight exposure, soil fertility, and water availability. The predominance of light green skin color and blunt scale shape reflects a common morphological feature among local accessions, while differences in seed number, shape, and weight highlight

(a) **(b)** **(c)** **(d)**

Fig. 3. (a) 3 flower crowns (b) 4 flower crowns (c) Oval fruit shape (d) Round fruit shape

Unlike fruit circumference, which was 100% above 24 cm, the thickness of sugar apple fruit flesh was fairly uniform, with an average thickness above 3 mm. The color of the fruit skin is also quite uniform, with 90% being light green and 10% green. The shape of the scales on all accessions is blunt, but the number of scales on the 10 accessions varies considerably. The sweetness level of all accessions observed varies considerably, but is relatively high. Fifty percent of accessions had a sweetness level of 25.6–27.4 Brix, 30% had a sweetness level of 23.3–25.5, 10% had a sweetness level above 27.4 Brix, and 10% had a sweetness level of 18.6–20.9 Brix [25][26]. In terms of seed shape, 70% had an potential variability in reproductive and fruit development traits. These variations are valuable for selecting accessions with desirable fruit quality, sweetness, and seed characteristics that can be further developed in breeding or propagation programs aimed at improving local sugar apple cultivars.

3.3 Analyze of vegetative organs

Analysis of kinship based on the vegetative characteristics of sugar apple plants produced a dendrogram showing the morphological similarity between ten accessions (MDR001–MDR010). The

similarity coefficient values ranged from 0.70 to 1.00, indicating significant morphological variation among the accessions observed. The higher the similarity coefficient value (approaching 1.00), the more similar the vegetative characteristics between the accessions. Based on the dendrogram resulting from the UPGMA (Unweighted Pair Group Method with Arithmetic Average) method, the ten sugar apple accessions can be grouped into three main clusters at a similarity level of around 0.85.

Cluster I consists of accessions MDR001, MDR002, and MDR003, which are grouped at a high similarity level (around 0.93–0.97). This indicates that these three accessions have strong similarities in vegetative characteristics, especially in leaf morphology traits such as leaf blade shape, leaf margin, and upper leaf surface color.

Cluster II includes accessions MDR004, MDR005, and MDR006, which also have a relatively high similarity level (around 0.90). The differences between accessions in this group are relatively small, perhaps only in leaf size or petiole length.

Cluster III consists of accessions MDR007, MDR008, MDR009, and MDR010, which are grouped at a slightly lower similarity level (around 0.82). This indicates that this group has greater vegetative morphological variation compared to the other two clusters.

If the similarity threshold is lowered to around 0.75, the three large clusters merge into one large group, indicating that all of the sugar apple accessions analyzed still have a fairly close morphological relationship. Thus, the variation between accessions is more quantitative than qualitative, i.e., differences in the degree of a trait (e.g., size, color intensity, or shape) rather than the presence or absence of a character. This grouping pattern shows that vegetative characters, especially those related to leaves, are quite effective in distinguishing the morphological diversity of sugar apple.

The similarity of characteristics between accessions in a cluster is likely influenced by similarities in their region of origin or similar genetic factors. Conversely, the differences between clusters illustrate genetic variation or different environmental influences at the time of observation. In general, a high similarity coefficient value (≥0.85) indicates that the sugar apple accessions observed have relatively low vegetative diversity, suggesting they may originate from closely related populations. However, the separation into several clusters still indicates the presence of phenotypic variation that could potentially be utilized in breeding activities or the selection of superior genotypes [30].

The clustering pattern obtained from the analysis provides valuable insight into the relationship among accessions and their potential for selection. The relatively high similarity coefficient value suggests that most accessions share common morphological traits, possibly due to the exchange of planting materials among farmers or the limited introduction of new genetic sources in the region. Nevertheless, the presence of distinct clusters implies that certain accessions have undergone adaptive differentiation influenced by local environmental conditions, such as soil type, temperature, or water availability [31][32]. This residual variability is important for breeding purposes, as it represents a genetic resource that can be utilized to enhance specific traits such as fruit quality, yield

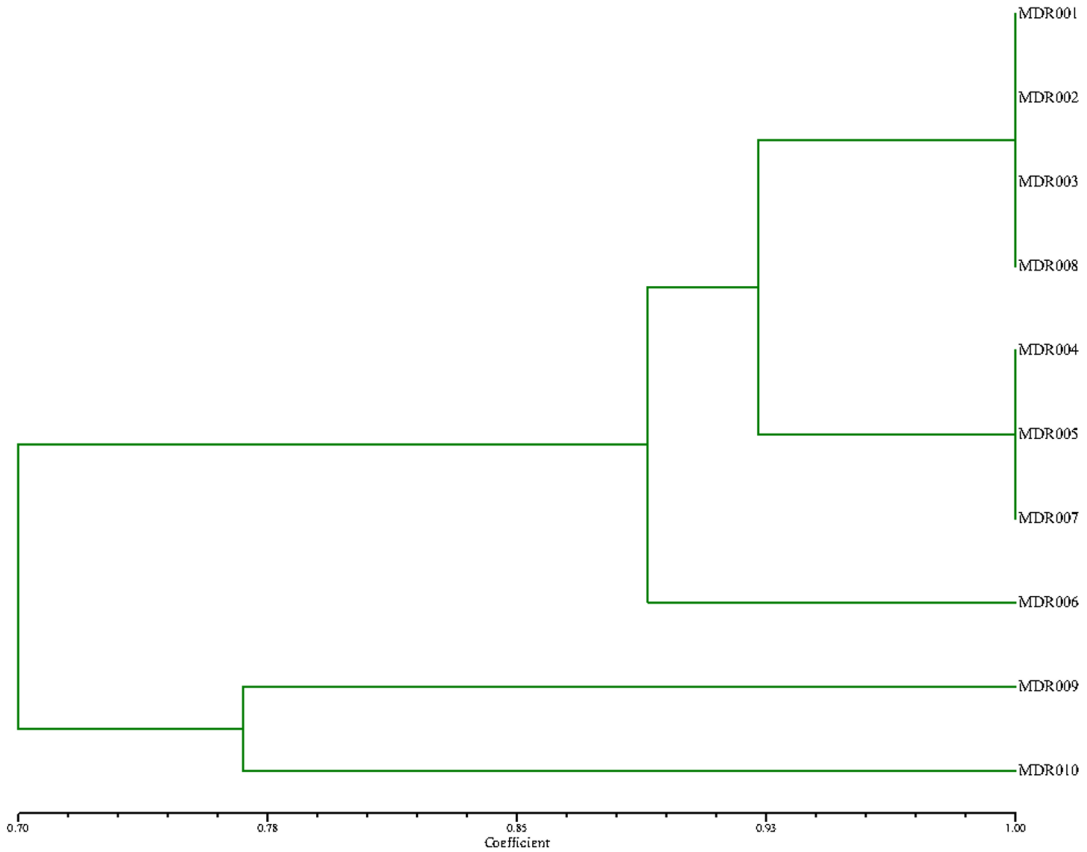

Fig. 4. Dendogram grouping of vegetative organ characters

potential, or tolerance to environmental stress [33]. Therefore, even though the overall diversity appears moderate, the observed clustering still provides an important foundation for germplasm management and future selection of superior sugar apple accessions in Madura.

3.4 Analyze of generative organs

Analysis of kinship based on the generative characteristics of sugar apple plants produced a dendrogram with similarity coefficient values ranging from 0.68 to 1.00. This range indicates that among the ten accessions observed, there was a fairly significant level of variation in flower and fruit morphology, but in general, their kinship was still relatively close. High similarity values (close to 1.00) indicate strong similarities in generative characteristics, while low values indicate greater phenotypic differences.

Based on the results of the UPGMA (Unweighted Pair Group Method with Arithmetic Average) clustering method, the ten sugar apple accessions can be grouped into three main clusters at a similarity level of around 0.84:

Cluster I consists of accessions MDR001, MDR010, and MDR002, which are grouped at a high similarity level (around 0.92–0.95). Accessions in this group share similarities in flower and fruit characteristics, such as petal color, flower shape, and fruit size, which are almost uniform.

Cluster II includes accessions MDR003, MDR004, and MDR005, which show moderate relatedness with a similarity level of approximately 0.86–0.88. Differences between accessions in this group are thought to originate from variations in fruit size or number of seeds per fruit.

Cluster III consists of accessions MDR006, MDR007, MDR008, and MDR009, which are grouped at a lower similarity level (around 0.78–0.82). These accessions have considerable diversity in generative characteristics, such as fruit shape, fruit skin color, and skin surface texture.

If the similarity threshold is lowered to 0.70, the three clusters begin to merge into one large group, indicating that all accessions are still within a relatively morphologically homogeneous group. Thus, the variation between accessions better reflects differences in the expression levels of quantitative traits rather than significant genetic differences.

This clustering pattern shows that generative characters such as flowers and fruits play an important role in distinguishing sugar apple accessions, even though the kinship between accessions is generally still close. Similarities in generative characters among accessions within a cluster may indicate genetic similarities or similar environmental conditions during the flowering and fruiting phases. Conversely, differences between clusters are likely due to more diverse genetic factors or different microenvironmental influences at the growth locations of each accession.

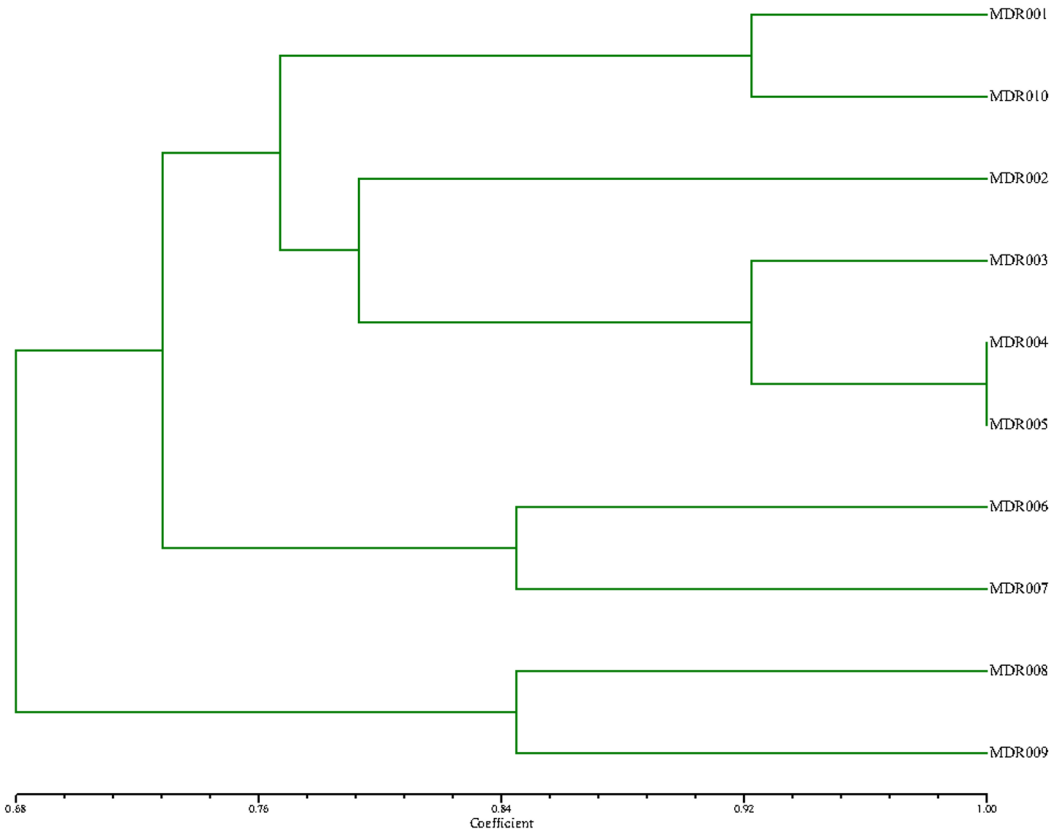

Fig. 5. Dendogram grouping of generative organ characters

Overall, the high similarity coefficient value (≥ 0.84) indicates that the sugar apple accessions collection has relatively narrow generative diversity, but there is still

sufficient variation to be used as a source of selection in breeding programs. Differences in these generative characteristics can be used to identify superior varieties based on desired fruit traits, such as size, skin color, or number of seeds.

The relatively narrow generative diversity observed among the accessions suggests that the existing population may have originated from a limited genetic base or experienced long-term vegetative propagation from similar parent trees. Despite this, the remaining variation in fruit-related traits provides a valuable opportunity for selection and genetic improvement. The observed differences in fruit size, skin color, sweetness level, and seed number can serve as practical indicators for identifying promising accessions with superior yield and market potential. These characteristics not only play a role in consumer preference but also serve as important selection criteria in breeding programs aimed at developing high-quality and well-adapted sugar apple cultivars suitable for the agroecological conditions of Madura. Thus, even with a relatively high similarity index, the collection still holds significant potential for genetic enhancement and varietal development.

4 Conclusion

The morphological characterization of ten sugar apple (*Annona squamosa* L.) accessions from Madura revealed moderate phenotypic diversity in both vegetative and generative traits. Vegetative organs such as leaves exhibited relatively uniform characteristics, with minor variations in shape and color that likely reflect adaptive responses to local environmental conditions. In contrast, generative traits showed wider variation, particularly in fruit weight, sweetness, and seed characteristics, indicating potential for selection and genetic improvement. Cluster analysis based on both vegetative and generative data demonstrated that most accessions share a close morphological relationship, yet distinct grouping patterns still highlight the existence of valuable variability within the population. Overall, although the observed diversity is relatively narrow, it remains sufficient to support the identification and development of superior sugar apple genotypes that are well adapted to the agroecological conditions of Madura.

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