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Morphological Characterization of Purple Yam (*Dioscorea alata*) in Purwodadi Botanic Garden

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Abstract. *Dioscorea* spp. (Yam) is an edible tuber plant from the Dioscoreaceae family. There are around 600 species of *Dioscorea* spp., one of them is *Dioscorea alata*. *D. alata* has a wide range of morphological characteristics, including shape, size, skin color, flesh, and tuber texture. This research focused on *D. alata* with purple tuber flesh. This study aims to reveal the diversity of *D. alata* in Purwodadi Botanical Garden based on its morphological characteristics. Characterization is an important aspect of identifying *D. alata* diversity. Characterization was performed on six *D. alata* accessions from the Purwodadi Botanical Garden, DA 28, DA 36, DA 57, DA 86, DA-SB, and DA-Tr. Morphological characterization can be divided into qualitative and quantitative stem and leaf properties. The morphological feature data were processed using NTSys 2.11a software. The observation results showed that *D. alata* from different accessions had diverse morphological characteristics such as stem color, wing color, leaf margin color, leaf vein color, petiole color, and petiole wings color. The dendrogram results showed that DA 36 and DA SB accessions had a very close level of similarity. Meanwhile, the DA-Tr accession exhibited the most distinct character from the other accessions with the dominant color being purple covering stems, stem wings, leaf veins, leaf margins, petioles, and petiole wings.

1 Introduction

Dioscorea spp. (yam) is a perennial plant that reproduces vegetatively using tubers from the Dioscoreaceae family [1]. According to Massawe & Temu [2], *Dioscorea* spp. is a tuber crop that can be consumed, even included in the top 10 main tuber crops besides cassava, potatoes, and sweet potatoes with the fourth rank in the world. *Dioscorea* spp. is classified into more than 600 species. The species that are widely cultivated worldwide are *D. bulbifera, D. panthaica*, *D. esculenta*, *D. japonica*, *D. trifida*, *D. alata*, *D. pentaphylla*, and *D. rotundata*. *Dioscorea spp.* is grown in tropical and subtropical regions, especially in Southeast Asia, Africa, and America [1-3]. In the Southeast Asian region, especially Indonesia, *Dioscorea spp.* mostly grown in Java. Some species found are *D. alata, D. bulbifera, D. esculenta, D.*

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hispida, D. nummularia, and *D. pentaphylla*. These plants are widely used as food sources by the Javanese people [4, 5].

Dioscorea spp. considered to have superior nutritional content compared to other tuber crops. *Dioscorea* spp. contains high carbohydrates with low-fat content, crude fibre, minerals (calcium, iron, phosphorus), and vitamins (especially vitamins A and C). This plant contains about 63.31% starch, 6.66% protein, and 0.64% fat. The energy value of every 100 grams of tubers ranges from 320 to 470 calories and 2.0 to 2.7 grams of protein, making it potential as a local food source that can support national food security programs. In addition, *Dioscorea* spp. also contains water-soluble glycoproteins, polysaccharides, and dietary fibre, which is a hydrocolloid and useful for lowering blood glucose levels and total cholesterol in the body [4, 6, 7].

Several species of *Dioscorea* have purple tubers, one of which is *D. alata* or uwi. *D. alata* is often referred to as the 'winged yam'. This plant grows by vines or twisting at the place of growth, which can spread up to 10 m or more and will continue to branch freely. The tubers are large in size with purple flesh. Generally, *D. alata* grows for 8–10 months, then will be dormant for 2–4 months. *D. alata* is often mistaken for taro (*Colocasia esculenta*) and purple sweet potato (Okinawan), which are different even though they have almost similar characteristics [8].

The purple color in *D. alata* tubers is produced by a compound called anthocyanins. Anthocyanins are a natural source of antioxidants that act as an antidote to free radicals, which play a role in preventing ageing, cancer, and degenerative diseases. The amount of anthocyanin in *D. alata* is 31 mg/100 g of dry weight, which are cyanidin-based such as cyanidin 3-O-gentiobioside; alatanin 1 and 2; alatanin A, B, and C; and D, E, F, and G alatanins. Anthocyanins are known to be unstable and very susceptible to degradation by pH, temperature, oxygen, anthocyanin concentration, light, enzymes, ascorbic acid, sugars, and sulfites so that sometimes anthocyanins do not always produce purple color on tubers, but may appear red or blue depending on the surrounding environmental conditions (such as pH) [9, 10].

Indonesia has very abundant types of *D. alata*, in East Java, there are Uwi Perti, Uwi Ulo, Uwi Bangkulit, Uwi Kelopo, Uwi Ketan Putih, Uwi Biru, Uwi Budeng, Uwi Legi, Uwi Jaran, and Uwi Cemeng. *D. alata* also has found in Kalimantan as Ubi Alabio and in Sulawesi as Ubi Banggai. *D. alata* have high morphological variations in their tubers, especially in shape, size, skin color, as well as flesh and texture of tubers. The high diversity of *D. alata* makes this plant have many variants with diverse morphological characteristics, which are divided into qualitative and quantitative characteristics [6, 7].

One place in Indonesia that has a large collection of *D. alata* plants is Purwodadi Botanic Garden. Purwodadi Botanic Garden also known as Purwodadi Dry Climate Hortus, is one of the three branches of the Indonesian Botanic Garden (Bogor Botanic Garden), which has the duty and function of collecting plants that live in dry lowlands. The Purwodadi Botanic Garden stores various types of *D. alata* as a live collection [11]. Characterization is an important step in revealing the diversity of *D. alata,* which can provide benefits in various aspects, one of which is as a form of conservation activities and exploring the potential of *D. alata*. This study aimed to reveal the diversity of *D. alata* in Purwodadi Botanic Garden based on its morphological characteristics.

2 Materials and methods

2.1 Characterization

Characterization was carried out on six *D. alata* accessions located in the Purwodadi Botanic Garden nursery, namely DA 28, DA 36, DA 57, DA 86, DA SB (Situbondo) and DA Tr (Trawas). Morphological characterization is divided into qualitative and quantitative characteristics. Aspects observed in the stem are length, number of internodes, color, wax on the surface, wings, wing color, fine hair, spines, thorn color, and barky patches, and on the leaves includes number and leaf color, leaf margin color, leaf bone color, petiole color, and fine hair (trichomes) on the upper/lower surface of leaves. The morphological character data is collected and recapitulated on Microsoft Excel worksheets and then presented in the form of tables and bar charts. The morphological characters are compared with other uwi plants originating from Indonesia or abroad based on literature as a result of observations.

2.2 Dendrogram analysis and similarity distance

Analysis of the similarity distance of *D. alata* based on morphological characters was carried out using a dendrogram processed through NTSys 2.11a software. The morphological character data format that has been recapitulated is converted into an NTS File (.NTS) using "ntedit" application to be readable by NTSys 2.11a software. Characterization data with file format (.NTS) is incorporated into NTSys 2.11a software to be processed into dendrograms. Then, the results of the dendrogram that have been displayed are analyzed to obtain the similarity distance between uwi plants based on morphological characters.

3 Results and discussion

3.1 Morphological character of *D. alata* stem

The quantitative characters observed in stems can be in the form of length and the number of internodes. Table 1 shows the length and number of internodes of *D. alata*. The stem lengths of the ten *D. alata* accessions observed showed various internode lengths with the longest length is DA 86 accession (16.23 cm) and the shortest internode length is DA 36 accession (6.65 cm). In addition to the length of the internodes, the number of internodes was also counted for each accession of the *D. alata* observed in this study. Table 1 shows that DA SB has the highest number of internodes compared to the others at 73, while the accession with the least number of internodes is DA 57 (9 internodes). The number of internodes correlates with the number of leaves of a plant. The more nodes formed, the more leaves will develop. This is due to the activity of cell division in the shoot meristem. As a result, the number of internodes also increases [12, 13].

The results showed that accessions with a greater number of leaves also indicated a greater number of internodes. However, there is an interesting thing from the observation result. Although the number of internodes is large, this is not followed by a higher number of leaves. The DA 28 accession only had nine leaves but had 20 internodes. This was thought to be due to the stage of leaf development, which affected their size. Some of the leaves that appeared were not counted in this study because they were too small and young (just developing). Although the internodes have been formed, the leaves have not fully developed yet, and the characters are difficult to observe [14]. Therefore, immature leaves do not need to be counted when characterizing the morphology of a plant. The table of the number of leaves used as a comparison can be seen in Table 1.

Table 1. Observation results of the quantitative character of *D. alata*

Character	DA 28	DA 36	DA 57	DA 86	DA-SB	DA-Tr
Internodes lengths (cm)	10.25	6.65	9.65	16.23	11.5	7.83
Number of internodes	20	37	9	18	73	12
Number of leaves	9	25	6	19	80	11

D. alata has waxy stems and a variety of colors. There are three variations of stem color that can be found from observations which are purplish green (50%), green (40%), and purple (10%) (Fig. 1a). In addition, there are wings on the stems which in this observation are divided into three different colors, which are green with purple edges (70%), purple (20%), and green (10%) (Fig. 1b). In this observation, the stems of *D. alata* did not have fine hairs (trichomes) or spines on the stem surface. This is in accordance with the results of research by Pertiwa et al. [15], which stated that in general, *D. alata* does not have spines on the stem surface, so these characteristics can be used to distinguish between *D. alata* and other *Dioscorea* species. In addition, none of D. alata had barky patches on their stems in this observation.

In general, *D. alata* has green or purplish stems [15]. The most common wing colors are purple and green with purple edges. This was proven through research conducted by Rao et al. [16] at the RHRS farm, in Gujarat, India, in which of the 27 *D. alata* observed, the most common stem wing colors were purple and green with purple edges. Meanwhile, green wings are very rare and very few compared to other colors. This shows that the research that has been carried out is following the stem color that is generally found in *D. alata*.

The leaves of *D. alata* are single leaves arranged facing each other, the edges are flat, the tips are tapered, and there are no fine hairs (trichomes) on either the upper or lower surfaces [15]. In this observation, *D. alata* leaves had various characters between accessions, one of which was the number of leaves. The results showed that DA SB had the highest number of leaves, with 80 leaves (53.33%), while the plant with the least number of leaves was DA 57 accession, with six leaves (4%) (Table 1).

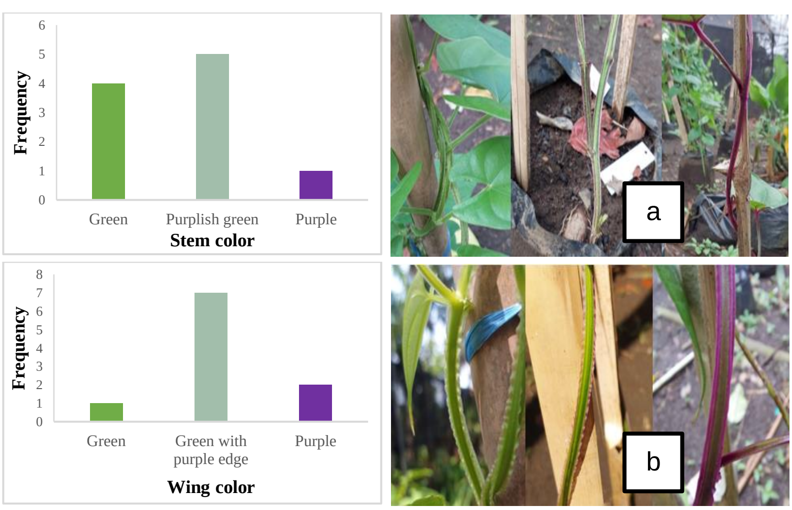

Fig. 1. Frequency and variation: (a) stem color and (b) stem wing color of *D. alata*

The difference in the number of leaves is closely related to the age of the plant. This is because the plants are getting more mature, the number of leaves will increase as the plant gets older [17]. *D. alata* in this observation had different sprouting times, which affected the age of the plants. This causes variations in the number of leaves in the observations (Fig. 2). In addition, the age difference also affects the number of plant internodes due to a correlation between the number of leaves and the number of internodes, where the more nodes are formed, the greater the number of leaves, as well as the number of internodes [13]. Water yams have different types of growth after harvest; the response to the shoot formation of rooted cuttings depends on the accession, and the growth conditions are influenced by high air and soil temperatures in the nursery [18].

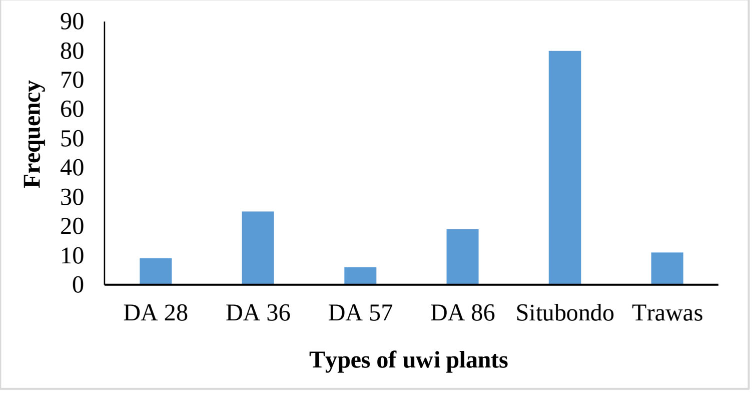

Fig. 2. Frequency of observed leaves of *D. alata*

Fig. 3a shows two leaf color variations in the six observed accessions of *D. alata* which are pale green (30%) and dark green (40%), while three accessions (30%) could not be identified because the leaf size was too small due to new development and the morphology is not clear yet [14]. The results showed that the color of the leaf margins was identified as two groups of variations which are green (60%) and purple (10%) (Fig. 3b). Variations in the color of the leaf veins observed were yellow (30%), green (20%), and purple (20%) (Fig. 3c). Apart from the leaves, the characters of the petiole were also observed, namely the color of the stalk and the wings. The identifiable petiole colors are green with purple tips (40%), green (20%), and purplish green with purple base color (10%) (Fig. 3d). The dominating petiole wing color in this observation was green with purple edges (40%) and purple (40%), while green wing color was only found in two accessions (20%) (Fig. 3e).

D. alata generally has pale green or dark green leaves. This was proven through research conducted by Yalindua et al. [19], in which the observed *D. alata* leaf color was pale green or dark green. Apart from these two colors, the color of the leaves of *D. alata* can also be purplish green and yellowish green [16]. According to a study conducted by Anokye et al. [20], the color of the leaf margin most often found on *D. alata* is green, besides that accessions with purple leaf margins are also found, and some leaves can also have a yellowish margin. This shows that the results of observations on leaf color, leaf margin, and leaf veins follow the results of observations in previous studies. However, there are differences in the color of the petiole wings between the observations and the results of previous studies.

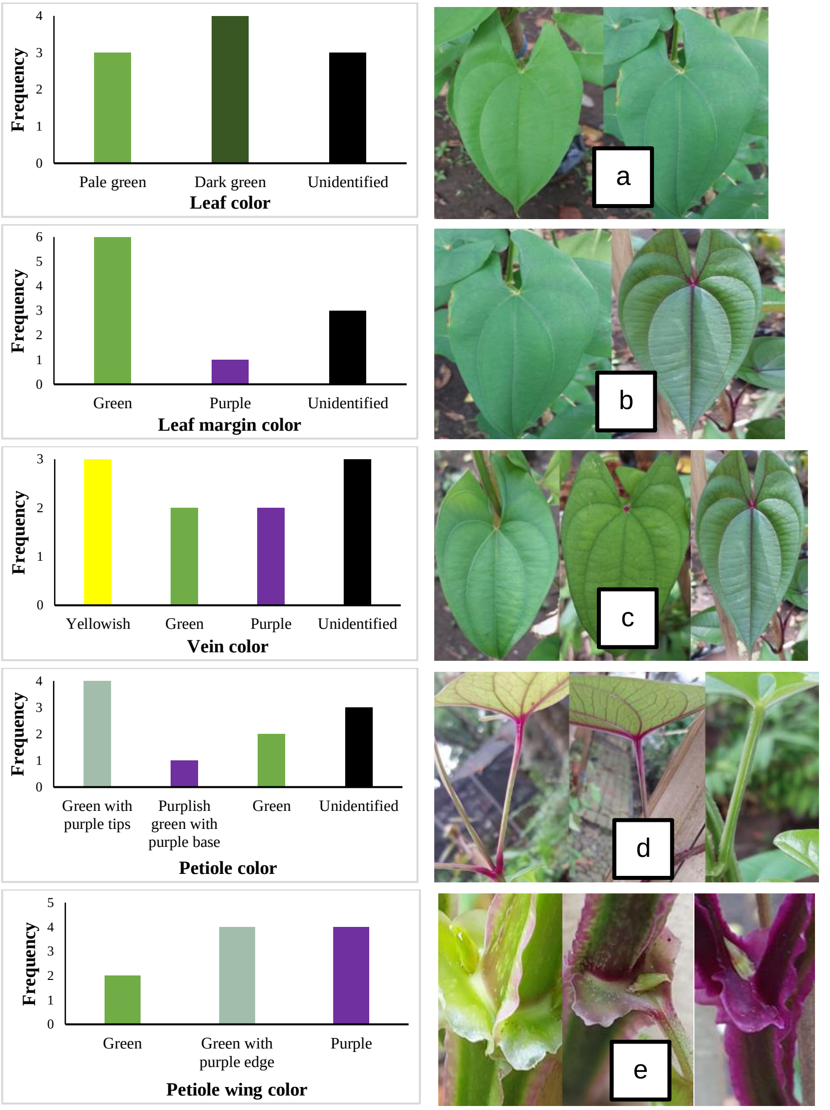

Fig. 3. Frequency and variation: (a) leaf color, (b) leaf edge color, (c) leaf vein color, (d) petiole, and (e) petiole wing color

The results of a previous study on *D. alata* in Ghana showed that *D. alata* with green petiole wings had the highest number which is 32 plants (65.3%) out of 49 plants, followed by purple with nine plants (18.4%) [20]. Green wing color with purple edge has the least frequency which is eight plants (16.3%) [20]. The differences in character could be caused by genetic and environmental factors between accessions planted in Purwodadi (Indonesia) and Ghana. Plants that grow in different geographical areas have different characteristics due to somatic mutations which can show variations in the morphology and appearance of these plants, including the *D. alata* [21, 22].

Environmental factors such as soil nutrients, light intensity, temperature, and water availability can affect the genetic and chemical diversity of plant populations. Different environmental conditions can provide strong selection pressure, even influencing the direction of the evolution of plant populations. As a result, several plant populations of one species may show different genetic and chemical variation patterns in different geographic areas [23]. According to Trimanto [6], plants that grow in different environments tend to adapt to their environment and produce morphological variations, which are supported by more dominant environmental factors that affect the genetic properties of these plants.

3.2 Similarity distances of *D. alata* based on morphological character

The *D. alata* observed in this study had various morphological characters. The distance of similarity between accessions can be analysed through a dendrogram. Based on the morphological characters, the results of the dendrogram of the similarity distance between *D. alata* accessions showed variation (Fig. 4). The cluster analysis results shown in Fig. 4 can be grouped into three different accession groups. The groupings produced by cluster analysis can indicate a genetic relationship based on the morphological characters of an accession or group [6]. The grouping results showed that there were three groups consisting of group 1 with three accessions, group 2 with one accession, and group 3 with two accessions (Table 2).

The DA 36 and DA SB accessions have a very close similarity (85%). This indicates that both accessions morphologically show a high degree of similarity. Based on the observations, it was shown that the DA 36 and DA SB accessions had the same morphological characters for almost all of the characters observed, only differing in the color of the stem wings and the color of the petiole wings. The DA 36 and the DA SB have green stems, green leaves, and green leaf margins. The DA 36 has purple stem wings and purple petiole wings, and the DA SB has green stem wings and green petiole wings. The similarity distance of an organism can be said to be far if the value is less than 60% (0.60) [6]. Therefore, a similarity distance above 60% indicates a close or large resemblance between organisms.

The DA 57 and DA 86 accessions have a similarity of 73.4% which indicates that the two accessions have close resemblance. The DA 57 tends to have green morphological characters. And DA 86 has a few purple morphological characters. The DA 28 accession has a similarity rate of 66.4% with DA 36 and DA SB accessions. This shows that these accessions have almost similar morphological characters because they still have a close level of similarity.

In this observation, DA Tr is one of the accessions with the most different characters from the other accessions. This was shown from the results of the characterization that only DA Tr had morphological characters with the dominant color being purple covering stems, stem wings, leaf veins, leaf margins, petioles, and petiole wings in contrast to other accessions which have a character with a dominant color of green. In addition, the dendrogram shows that only the DA Tr accession was out of the group to other accessions in its group. An accession group can be used as an indication of a genetic relationship [6]. This statement can also be strengthened through the dendrogram results in which the DA Tr accession has a small degree of similarity with other accessions in this study (<60%).

Table 2. Similarity distance of *D. alata* based on morphological characters

Group	Accessions
1	DA 28, DA 36, DA-SB
2	DA-Tr
3	DA 57, DA 86

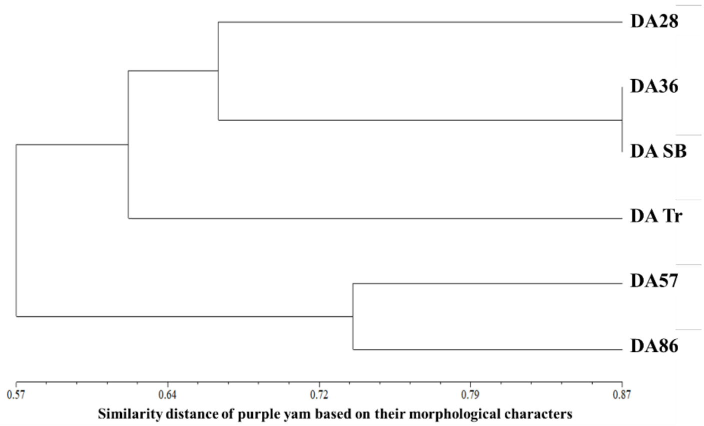

Fig. 4. Similarity distance of *D. alata* based on morphological characters

4 Conclusion

From the observations of the six observed *D. alata* accessions, it can be seen that *D. alata* from different accessions also have various morphological characters. The dendrogram formed based on morphological characters shows that DA 36 and DA SB accessions have a very close level of similarity. Meanwhile, DA Tr has the most different character from the other accessions.

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