Journal of Bio-Science
https: //doi.org/10.3329/jbs.v34i1. 89512
pISSN: 1023-8654 | eISSN: 2408-8595
Volume 34 | Issue 01 2026

RESEARCH ARTICLE

Analysis of Genetic Diversity Using Different Morphological Characteristics of Seven *Dendrobium* Orchid Species

Md. Ekhlas Hossain and S. M. Shahinul Islam*

OPEN ACCESS

Plant Biotechnology and Genetic Engineering Lab., Institute of Biological Sciences, University of Rajshahi, Rajshahi-6205, Bangladesh.

***Correspondence:**
Email: shahinul68@gmail.com

How to Cite the Article:
Hossain ME and Islam SMS (2026). Analysis of Genetic Diversity Using Different Morphological Characteristics of Seven *Dendrobium* Orchid Species. Journal of Bio-Science 34(1): 51-62.

Peer Review Process:
The Journal abides by a double-blind peer review process such that the journal does not disclose the identity of the reviewer(s) to the author(s) and does not disclose the identity of the author(s) to the reviewer(s).

Abstract

The aim of this study was to bring out the morphological diversity analysis based on the quantitative and qualitative morphological characters of seven species of *Dendrobium* namely *D. aggregatum, D. aphyllum, D. chrysotoxum, D. densiflorum, D. fimbriatum, D. nobile,* and *D. parishii.* The detailed morphological characterization and diversity are discussed and here the vegetative characters revealed variations among the species which can be differentiated from one another. Morphological characterization is an important step which can determine genetic relationships among orchid species in the same genus. Thirty seven characteristics on morphological parameters on the basis of quantitative and qualitative were assayed. There were 30 out of the 37 identified morphological characters (81.08%) that showed diversification in flowers, leaves, pseudobulbs, and roots. From the correlation analysis it was found that 8 out of 10 floral characters have significant positive correlation with themselves at 1% and 5% level. From the principal component analysis (PCA) values, it is exposed that the characters that have a large influence on grouping are the ratio of petal length, lip length and sepal length. The dendrogram topology is supported by the morphological character classification. The dendrogram revealed that *D. aphyllum* and *D. chrysotoxum* have the closest kinship between themselves with a similarity coefficient of 2.0 and hence they can be used as parents for cross-breeding and hybridization purpose to obtain new varieties. The results of this study are expected to provide scientific information about genetic diversity among *Dendrobium* orchid species and to help its conservation efforts in Bangladesh.

Keywords: Characterization, Conservation, *Dendrobium*, Diversity, Morphological characters, Orchids.

Copyright: © 2026 by the author(s). This is an open-access article distributed under the terms of the **Creative Commons Attribution 4.0 International License (CC BY-4.0)** which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

Received: 17 November 2025 | **Revised**: 08 December 2025 | **Accepted**: 28 January 2026 | **Published**: 30 June 2026

Introduction

Orchids belong to the family of Orchidaceae those are monocot plants. The Orchidaceae family provides several type of differentiation between populations at the genetic level (Kiran et al. 2013). The level of orchid's diversity is increasing towards tropical countries, where the epiphytic orchids dominate nearly 73% of the total species (Indraloka et al. 2019). It is considered to be one of the largest families of flowering plants with both terrestrial and epiphytic plants (Bhattacharjee and Islam 2014, Ayesha et al. 2024). It represents the most highly evolved family among monocotyledons that accounts for nearly 8% of the total species of flowering plants. Because of the wide variety of orchids in the world, currently orchids are rapidly developed as ornamental plants in Bangladesh. Unfortunately, many orchids are threatened by extinction because of environmental degradation, human occupation of natural habitats, and overexploitation for horticultural and ethno-botanical reasons (Coates and Dixon 2007). Habitat destruction due to road construction, fire, urbanization and other anthropogenic influences also directly affect (Cribb et al. 2003). The number of orchid species is rapidly and steadily declining now because of their low rate of propagation in nature and the ongoing inconsiderate collection from nature (Bektas et al. 2013, Bhattacharjee et al. 2015).

Dendrobium consists of 1600 species of sympodial epiphytic orchids. The common characteristic of this genera is long pseudobulbs or canes with soft leaves on entire length. But in some species, pseudobulbs are short or swollen. They are also valuable as pot plants or hanging baskets. In order to cover the bare space, some species are hanged on the walls or on tree branches. *Dendrobium* is a genus of orchids with diverse variations in the shape and color of the flowers. The genus has unique characteristics with segmented stems and pseudobulbs (Islam T et

al. 2015, Dehgahi and Joniyas 2017). Besides being an ornamental plant, *Dendrobium* is reported to be used as medicine (Teixeira da Silva et al. 2015, Zeng et al. 2020). For instance, *D. salaccense* leaves for reducing stomach pain (Silalahi et al. 2015) and *D. crumenatum* for treating acne (Gutiérrez 2010). The genus is widely diverse regarding morphological aspects and each species has different unique characteristics from one another.

Characterization is an activity to determine the morphological characteristics which can be used to distinguish germplasm, assess the degree of genetic diversity, identify the species, and to evaluate the number of germplasm (Rahman and Islam 2020a). Characterization is a method for qualitatively and quantitatively determining the plant traits. A characterization approach is necessary to identify the differences in the characters of each species (Rahman and Islam 2020b). Characterization is important for assessing the closeness of genetic relationships and diversity among orchid species in the same genus. Diversity in orchids have been studied from both morphological and anatomical aspects by Indraloka et al. (2019).

Morphological observations are easier to do because the dominant character can be found in several part of the plant. Morphological identification is the process of determining the phenotypic characteristics of plants by inspecting the leaves, stems and flowers of plants and understanding the genetic relation among the species. Morphological characterization activities are needed for the variety selection of native orchid germplasm. Morphological characterization includes the process of identification and documentation of plant phenotypic characters. Observation of morphological characters can be conducted on all parts of the plant which include stems, flowers, leaves, roots, seeds, and fruit (Rahman and Islam 2020a). Characterization based on morphological characters, such as leaves, stems, pseudobulbs, fruits and roots, is expected to be able to determine the type of utilization of the plants. Morphological characters are easy to observe visually, so their diversity can be assessed quickly compared to other characteristics. Moreover, morphological characterization can be used to assess the relationship and genetic diversity of orchids which are important for conservation programs and increase the utility of plant genetic resources (Wang et al. 2009). The dissimilarities in vegetative characteristics of plants are affected by environmental components and the germplasm ancestor habitats. Although environment has a strong influence on the analysis of genetic relationships based on morphological characters, adequate characterization of morphological characters is needed to facilitate the utilization of germplasm (Tuberosa et al. 2011). It is very important for the success of plant crossing. This characterization can be used not only to compose plant descriptions, but also to assess the genetic relationship among the species.

Morphological characterization may be used as the premise for phylogenetic studies to decide patterns of plant diversification (Freudenstein and Chase 2015). Moreover, the characterization outputs can be used as analytical data for various needs in hybridization, reproduction, germplasm preservation and genetic modification (Indraloka et al. 2019). To formulate a conservation strategy for cultivating, using, and managing plant genetic resources in a sustainable manner, it is necessary to understand plant genetic diversity information at the level of individual species or populations. The genetic diversity of orchids is visualized in the diversity of colors, shapes and sizes of flower bearing plants. The most important factor for the success of inter-species plant hybridization programs is the genetically related species. The morphological characteristics can be used as reference to study the genetic relationship among species. Therefore, the knowledge of the morphological diversity of orchids is of great significance to determine the protection or commercial purpose of orchid plants. The current study aimed to determine the morphological characteristics and relationships of the seven orchid species in the genus *Dendrobium* in Bangladesh. Due to its high economic value, steps must be taken to save the genus *Dendrobium* from extinction and further advance studies on biodiversity and hybridization purposes.

Materials and Methods

As plant materials seven *Dendrobium* species were used. Other materials used in this research include plastic bags, sacks, field books, descriptor books, label paper, newspapers, and ethanol 70%. While the tools used are meter, ruler, digital cameras, scissors, sliding hook and herbarium tools.

Direct observation of the orchid plant parts served as the basis for the descriptive identification of morphological features. Thirty-seven morphological traits from seven *Dendrobium* species were examined in this study that belongs to leaves (10 characters), flowers (22 characters) and stems/pseudobulbs (5 characters). *Dendrobium* species were quantitatively observed using 19 characteristics which are stem-length, stem-diameter, internode count, internode- length, leaf-length, leaf-width, leaf area, inflorescence-length, floret count in each inflorescence, length of flower, width of flower, floral bract, length of sepal, width of sepal, length of petal, width of petal, length of lip, width of lip and length of column. The data was collected and analyzed with the help of statistical computer tools.

Results and Discussion

Morphological characteristics

The major characters of orchids are roots, pesudobulbs, flowers and leaves where the most significant organ is flower. Castro and Singer (2019) mentioned that the petals, sepals, column, and lip make up almost all of an orchid's floral structure. According to the morphological observation of seven *Dendrobium* species thirty of the thirty-seven traits (81.08%) were found to have different outcome regarding leaf, flowers, pseudobulbs and root types.

Table 1: Qualitative morphological traits of *Dendrobium* species observed in this research.

Characters	*D. aggregatum*	*D. aphyllum*	*D. chrysotoxum*	*D. densiflorum*	*D. fimbriatum*	*D. nobile*	*D. parishii*
Stem shape	Pseudobulbous	Cylindrical	Pseudobulbous	Club shaped	Cylindrical	Cylindrical	Cylindrical
Leaf shape	Oblong	Lanceolate	Oblong	Oblong	Oblong	Oblong	Oblong
Leaf tip	Obtuse	Acuminate	Acute	Acute	Acute	Obtuse	Obtuse
Leaf edge shape	Entire	Entire	Entire	Entire	Entire	Entire	Entire
Leaf surface texture	Glabrous	Glabrous	Glabrous	Glabrous	Glabrous	Glabrous	Glabrous
Leaf symmetry	Symmetry	Symmetry	Symmetry	Symmetry	Symmetry	Symmetry	Symmetry
Leaf color	Green	Green	Green	Green	Green	Green	Green
Leaf arrangement	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate
Flowering position	Axillary	Axillary	Axillary	Axillary	Axillary	Axillary	Axillary
Inflorescence type	Raceme	Raceme	Raceme	Raceme	Raceme	Raceme	Raceme
Inflorescence nature	Pendulous	Pendulous	Pendulous	Pendulous	Pendulous	Sub-erect	Sub-erect
Inflorescence position	Nodal	Nodal	Base of leaf	Base of leaf	Base of leaf	Nodal	Nodal
Flowers 'shape	Round	Star	Round	Round	Round	Star	Star
Sepal shape	Ovate lanceolate	Sub-lanceolate	Oblong	Ovate	Oblong	Oblong	Ovate lanceolate
Sepal tip	Rounded	Apiculate	Obtuse	Obtuse	Obtuse	Obtuse	Obtuse
Petal shape	Elliptic	Elliptic	Sub lanceolate	Suborbicular	Oblong	Ovate	Elliptic
Petal tip	Acute	Cuspidate	Rounded	Rounded	Obtuse	Obtuse	Acute
Floral bract shape	Ovate	Ovate	Ovate	Oblanceolate	Ovate	Ovate	Ovate lanceolate

Flowers

Dendrobium is a genus of orchids (Orchidaceae family) with diverse variations in the shape and color of the flowers. In orchids, nearly every floral component has a different trait. Two flower types were evident in the overall floral pattern of seven *Dendrobium* species. They are star and round shape flowers (Fig. 2). Star-shape flowers were found in *D. aphyllum, D. nobile* and *D. parishii.* On the other hand, the flower shape of *D. aggregatum, D. chrysotoxum, D. densiflorum* and *D. fimbriatum* is round. Flowers' morphological differences make them useful for identifying orchid species within the same genus (Kuehnle 2007).

Some groups have flowers that are arranged in pairs or threes on a tiny peduncle throughout the whole length of the caduceus-leafed pseudobulbs. In certain species that have persistent leaves, the flowers alternately form upright or pendent thyrsus, or they are arranged in pairs or threes. Other groups have small and solitary flowers. From the leaf axils, they emerge. Sub-terminal or terminal inflorescences are grouped into one to dozens of flowers. The difference of sizes, color and dimensions is remarkable.

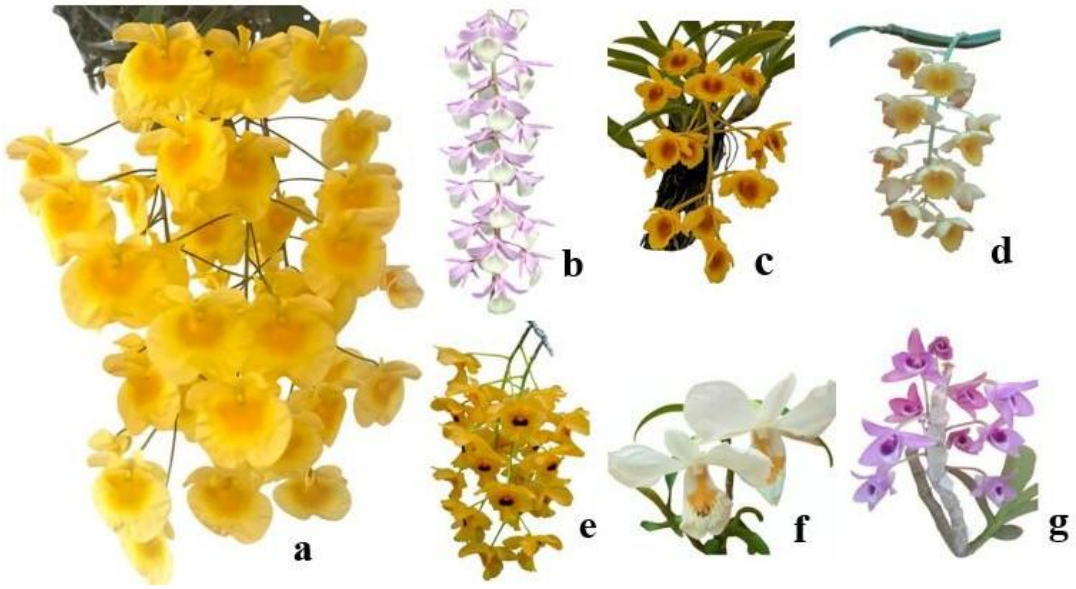

Fig. 1(a-g): Inflorescence of *Dendrobium* species. a) *D. aggregatum*, b) *D. aphyllum*, c) *D. chrysotoxum*, d) *D. densiflorum*, e) *D. fimbriatum*, f) *D. nobile*, and g) *D. parishii.*

Orchid flowers have a stem-like structure called a column (Johnson and Edwards 2000). At the apical part of the column is an anther where there is pollen called pollinarium. Also known as the rostellum, the stigma is situated subapically to the column. These organs' area is crucial for effective pollination (Azmi et al. 2016). Orchids are classified as monoandry (female and male genitals locate in the same place) and hermaphrodite (pollens and pistils locate in the flower). A unique characteristic of Orchidaceae is that the labellum or lip is a modified petal that comes in a variety of colors and shapes (Kurniawan and Semiarti 2021). Different lip-traits are seen in each orchid species (Fig. 2). The point in which *Dendrobium* differs from other orchids is that it features lateral lip flowers as well as sepals (Wang et al. 2017).

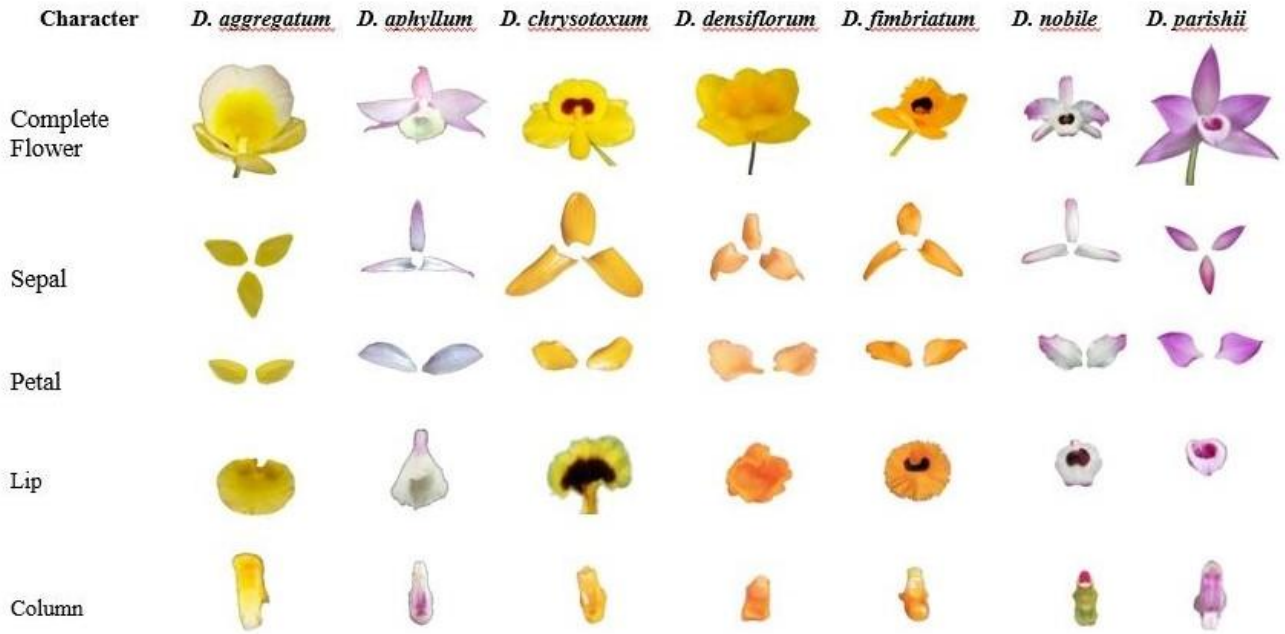

Fig. 2: Structure of flower and floral parts of seven *Dendrobium* species.

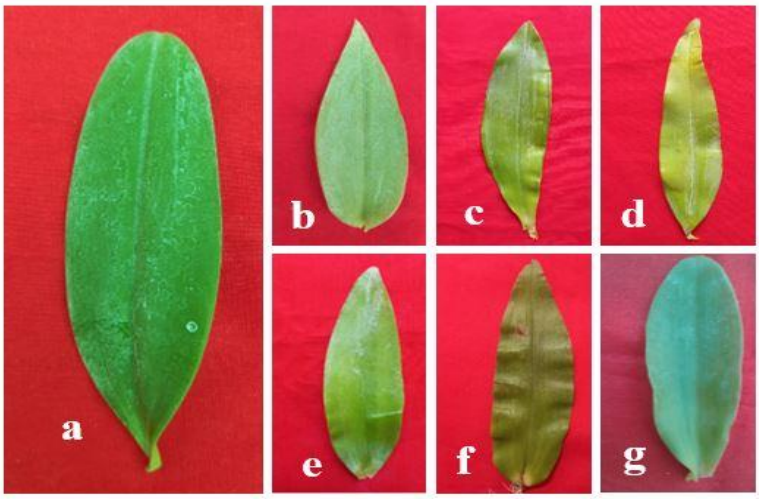

Fig. 3(a-g): Leaf structure of *Dendrobium* species. a) *D. aggregatum*, b) *D. aphyllum*, c) *D. chrysotoxum*, d) *D. densiflorum*, e) *D. fimbriatum*, f) *D. nobile*, and g) *D. parishii.*

Leaves

Dendrobium leaves are deciduous or evergreen of different sizes. The leaves are between 7.1 and 17.3 cm in size and leaf characterization included shape of leaf, tip of leaf, leaf edge shape, surface texture of leaf, symmetry of leaf, leaf color, leaf arrangement, length of leaf, width of leaf and leaf area. Leaf traits of seven *Dendrobium* species displayed a range of variations in terms of leaf tip and leaf shape (Table 1). *D. aggregatum, D. chrysotoxum, D. densiflorum, D. fimbriatum, D. nobile* and *D. parishii* have oblong leaf shapes, while *D. aphyllum* has lanceolate leaf shape. Three leaf tip forms were identified among the studied *Dendrobium* species; obtuse on *D. aggregatum, D.nobile,* and *D. parishii;* acuminate on *D. aphyllum* and acute on *D. chrysotoxum, D. densiflorum* and *D. fimbriatum.* Various shapes are found in orchid leaves namely elongated circular, roughly circular, and a few leaf bones create a spread grid that is collateral to the leaves. Leaf veins also exhibit diversity which includes thin and fleshy thick.

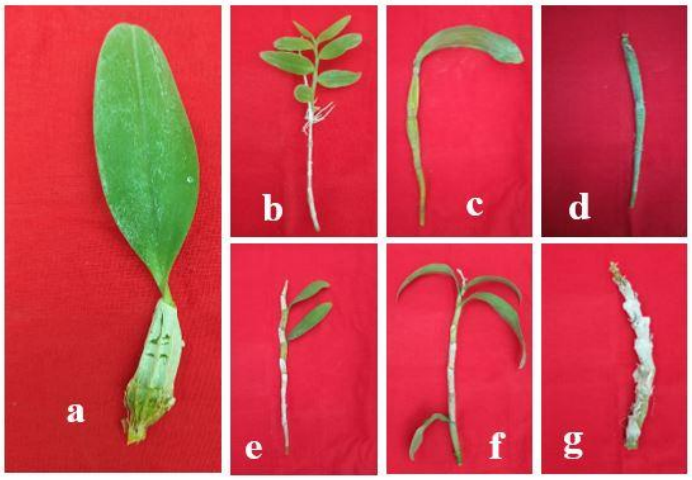

Fig. 4(a-g): Pseudobulb and stem structure of *Dendrobium* species. a) *D. aggregatum*, b) *D. aphyllum*, c) *D. chrysotoxum*, d) *D. densiflorum*, e) *D. fimbriatum*, f) *D. nobile*, and g) *D. parishii.*

Pseudobulbs and roots

Pseudobulb is a significant plant part to recognize the morphological traits of orchids (Miswarti et al. 2021). The characteristic of pseudobulbs is directly proportionate to the characteristic of leaves of each orchid. Pseudobulbs characteristics and its morphological benefits and *in vitro* cultures are reported by Bhattacharjee et al. (2022). The role of pseudobulbs is very important in reducing water scarcity when plants undergo drought as a result of water loss through their leaves due to evaporation (Tay et al. 2015). The chloroplast which is constructed

in pseudobulbs enables the plant to enhance intensive photosynthesis process other than leaves. Pseudobulbs also play a very important role as a medium for storing nutrients in the survival and growth of orchids (Ng and Hew 2000, Islam et al. 2025). In this study the identification of pseudobulbs resulted indifferent forms of them. Four types of pseudobulbs are found in orchids. They are cane woody, cane cylindric, cane clavate fleshy and bulbous round. *D. aphyllum, D. densiflorum, D. fimbriatum, D. nobile, D. parishii* have cane cylindric pseudobulbs. On the other hand, *D. aggregatum* and *D. chrysotoxum* have cane clavate fleshy types of pseudobulbs (Fig. 4).

Dendrobium species have different root types. Three different types of roots are found in orchids namely soil root, air root and sticky root. Air roots and sticky roots are utilized to secure the plant to its growing environment. In contrast, terrestrial orchids possess soil roots that absorb moisture and organic material from the ground. It was observed that *Dendrobium aphyllum, D. chrysotoxum, D. densiflorum, D. nobile* and *D. parishii* have an air root type while *Dendrobium aggregatum* and *D. fimbriatum* have sticky root type.

Table 2: Quantitative floral traits observed in *Dendrobium* orchid species.

Name of the species	Length of flower (cm)	Width of flower (cm)	Floral bract (cm)	Sepal length (cm)	Sepal width (cm)	Petal length (cm)	Petal width (cm)	Lip length (cm)	Lip width (cm)	Column length (cm)
D. aggregatum	7.74±0.15^{d}	3.02±0.99^{b}	0.29±0.05^{a}	2.09±0.07^{b}	0.66±0.05^{b}	2.11±0.07^{b}	1.02±0.05^{a}	2.11±0.07^{b}	1.07±0.04^{b}	0.39±0.04^{a}
D. aphyllum	4.93±0.08^{b}	3.02±0.99^{b}	0.30±0.05^{a}	2.11±0.07^{b}	0.32±0.03^{a}	2.19±0.06^{b}	1.01±0.05^{a}	2.98±0.10^{c}	2.21±0.06^{e}	0.30±0.03^{a}
D. chrysotoxum	4.59±0.14^{b}	2.78±0.14^{b}	0.30±0.04^{a}	1.51±0.05^{a}	0.61±0.04^{b}	1.45±0.05^{a}	1.01±0.04^{a}	2.13±0.05^{b}	2.02±0.06^{d}	0.32±0.03^{a}
D. densiflorum	3.35±0.07^{a}	2.67±0.13^{a}	1.29±0.06^{d}	2.10±0.06^{b}	1.06±0.04^{c}	2.10±0.06^{b}	1.13±0.04^{a}	2.11±0.06^{b}	1.08±0.05^{b}	0.33±0.03^{a}
D. fimbriatum	5.46±0.08^{c}	4.17±0.08^{d}	0.36±0.03^{a}	1.52±0.05^{a}	0.63±0.02^{b}	1.47±0.04^{a}	1.06±0.04^{a}	1.52±0.05^{a}	0.63±0.06^{a}	0.32±0.02^{a}
D. nobile	8.49±0.25^{e}	7.95±0.13^{e}	0.97±0.04^{c}	2.89±0.07^{c}	1.09±0.05^{c}	3.13±0.07^{c}	2.06±0.06^{b}	3.12±0.09^{c}	2.98±0.10^{f}	0.37±0.03^{a}
D. parishii	5.62±0.12^{c}	3.39±0.07^{c}	0.67±0.05^{b}	2.27±0.06^{b}	0.62±0.05^{b}	1.61±0.07^{a}	0.99±0.04^{a}	2.11±0.07^{b}	1.58±0.02^{c}	0.45±0.04^{b}

According to Table 2, variations are found in the size of the flowers, sepals, petals lips and columns of *Dendrobium* orchid species. Among other species, *D. nobile* seems to have highest average of flower length and width. On the other hand, the flower size of *D. densiflorum* appears to be the smallest of the seven species. In the genius *Dendrobium*, floral bract is practically very small. The largest floral bract (1.29 cm) is in *D. densiflorum.* In case of sepal length × width, *D. nobile* has the largest (2.89 × 1.09 cm) sepal size but the smallest (1.51 × 0.61 cm) sepal is in *D. chrysotoxum*. Petal size in *D. nobile* is the largest (3.13 × 2.06 cm) in average compared with other species. Whereas *D. chrysotoxum* has the tiniest (1.45 × 1.01 cm) petal size on average. Lip size in *D. nobile* is observed as the biggest (3.12 × 2.98 cm) and the smallest (1.52 × 0.63 cm) in *D. fimbriatum*. The highest (0.45 cm) column length is found in *D. parishii* whereas *D. aphyllum* has the shortest (0.30 cm) column length. The data on the table indicates that the flower size is not the only factor to determine the measurement of other floral parts.

Table 3: Quantitative morphological characters of *Dendrobium* orchid species.

Name of the species	Length of stem (cm)	Diameter of stem (cm)	Number of internodes	Length of internode (cm)	Length of leaf (cm)	Leaf width (cm)	Leaf area (cm)	Length of inflorescence (cm)	Number of florets in each inflorescence
D. aggregatum	4.5±0.08^{a}	1.2±0.04^{e}	3±0.04^{a}	1.5±0.02^{a}	7.1±0.06^{a}	2.2±0.01^{b}	13.74±0.04^{c}	12.0±0.02^{e}	7±0.05^{b}
D. aphyllum	55±0.02^{f}	0.6±0.11^{a}	39±0.11^{g}	3.0±0.13^{c}	8.3±0.03^{b}	3.1±0.06^{c}	17.29±0.02^{d}	0.20±0.01^{b}	2±0.03^{a}
D. chrysotoxum	19±0.12^{c}	0.9±0.09^{c}	5±0.02^{b}	5.2±0.07^{e}	17.3±0.05^{e}	3.2±0.03^{c}	39.13±0.16^{f}	0.14±0.12^{a}	12±0.01^{d}
D. densiflorum	28±0.06^{e}	1.0±0.08^{d}	7±0.14^{c}	4.6±0.04^{d}	12±0.02^{d}	2.4±0.14^{b}	17.86±0.03^{d}	21.3±0.5^{f}	13±0.13^{d}
D. fimbriatum	58±0.07^{g}	0.7±0.06^{b}	20±0.07^{f}	2.2±0.01^{b}	9.1±0.12^{c}	2.4±0.02^{b}	13.48±0.07^{b}	1.03±0.03^{c}	10±0.04^{c}
D. nobile	24±0.05^{d}	0.9±0.05^{c}	10±0.03^{d}	3.0±0.03^{c}	9.6±0.03^{c}	2.8±0.01^{b}	26.80±0.01^{e}	2.30±0.02^{d}	2±0.06^{a}
D. parishii	16±0.13^{b}	1.0±0.08^{d}	12±0.06^{e}	3.1±0.11^{c}	8.5±0.06^{b}	2.4±0.03^{a}	14.70±0.12^{a}	0.20±0.01^{b}	2±0.05^{a}

Table 3 shows the length and width of stem, leaf and measurement of other phenotypic characters. It is determined that they have diversity with each other. From the quantitative data on Table 3, *D. aphyllum* has the average longest (55 cm) stem while *D. aggregatum* has the shortest (4.5 cm). The thickness of *Dendrobium* spp. stems (pseudobulbs) which are measured is different. *D. aggregatum* has the bulkiest pseudobulb with the median thickness of 1.2 cm, while *D. aphyllum* has the thinnest pseudobulb with the median thickness of 0.6 cm. Average number of internodes is highest (39) in *D. aphyllum* and lowest (3) in *D. aggregatum.* Length of internodes also varies from species to species. *D. chrysotoxum* has longest (5.2 cm) internodes while *D. aggregatum* has the shortest (1.5 cm). Significant diversification was found in measurement of leaves of the species that were investigated in this study. The largest (17.3 × 3.2 cm) length × width of leaves was found in *D. chrysotoxum.* On the other hand, it is smallest (7.1 × 2.2 cm) in *D. aggregatum.* Similarly, leaf area is measured and found biggest (39.13 cm^2) in *D. chrysotoxum* and smallest (13.74 cm^2) in *D. aggregatum.* The larger the leaves, the overall value of the area covered by the leaves will rise and it affects the growth of vegetation. The net assimilation ratio is connected to leaf area, and a larger leaf area results in an enhanced assimilation ratio (Poorter and Remkes 1990). Longest (21.3 cm) inflorescence is observed in *D. densiflorum* and shortest (0.14 cm) in *D. chrysotoxum.* Number of florets in each inflorescence varied notably. The average number of florets is maximum in *D. densiflorum* and it was as many as 13. The minimum average number of florets is 2 and it was observed in multiple species *viz*. *D. aphyllum*, *D. nobile*and *D. parishii.* It is evident from the table that the area of leaves does not influence the quantity or dimensions of flowers.

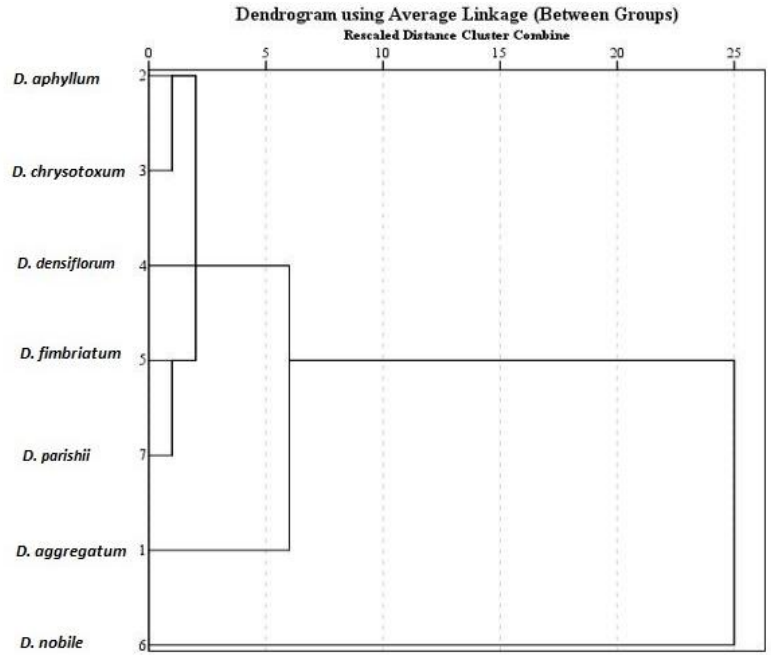

Fig. 5: Dendrogram of *Dendrobium* spp. according to the quantitative morphological features.

Cluster analysis

According to the quantitative morphological features of *Dendrobium* spp. dendrogram is shown in Fig. 5. Cluster analysis among seven species of *Dendrobium* revealed two clusters with a similarity coefficient ranging from 1.0 to 25.0. Cluster I consists of *D. nobile, D. aggregatum,* and *D. densiflorum*. It is made up of two smaller clusters, i.e. subcluster1of *D. nobile* and subcluster 2 of *D. aggregatum- D. densiflorum*. Cluster II consists of *D. aphyllum, D. chrysotoxum, D. fimbriatum* and *D. parishii* with a similarity coefficient of 2.0 (Fig. 5). Cluster II is made up of two smaller clusters, i.e. sub-cluster 1 of *D. aphyllum, D. chrysotoxum* and sub-cluster 2 of *D. fimbriatum* and *D. parishii.* The similarity co-efficient among germplasm illustrates the genetic relationship among the studied plants (Kumalwati et al. 2011). From the dendrogram it is found that the relationship among *D. aphyllum, D. chrysotoxum, D. fimbriatum* and *D. parishii* is the closest while *D. nobile* has a very distant kinship. The close association between plant species serves as a valuable resource for determining the parentage of two closely related species (Johnson 2018). The data can be utilized for cross-breeding in order to develop new varieties.

Table 4: Correlation among floral characters of *Dendrobium* species.

Characteristics	Length of flower	Width of flower	Floral bract	length of sepal	Width of sepal	Length of petal	Width of petal	Length of lip	Width of lip	Length of column
Flower length	1.00									
Width of flower	0.68**	1.00								
Floral bract	0.11	0.29*	1.00							
Sepal length	0.48**	0.62**	0.48**	1.00						
Sepal width	0.17	0.43**	0.63**	0.36**	1.00					
Petal length	0.54**	0.68**	0.41**	0.80**	0.41**	1.00				
Petal width	0.52**	0.83**	0.43**	0.59**	0.51**	0.69**	1.00			
Lip length	0.31**	0.45**	0.15	0.66**	0.10	0.69**	0.51**	1.00		
Lip width	0.33**	0.56**	0.10	0.55**	0.10	0.59**	0.60**	0.80**	1.00	
Column length	0.22	0.04	0.08	0.14	0.11	0.08	0.03	0.01	0.01	1.00

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed).

Correlation analysis

Correlation among key traits of *Dendrobium* species are presented in the (Table 4). Length of flower had a positive and significant correlation with width of flower, sepal length, petal length, petal width, lip length and lip width ($p<0.01$). Width of flower established a positive and significant correlation with floral bract ($p<0.05$) and sepal length, sepal width, petal length, petal width, lip length and lip width ($p<0.01$). Floral bract exhibited a positive and significant correlation with sepal length, sepal width, petal length and petal width ($p<0.01$). Sepal length showed a positive and significant correlation with sepal width, petal length, petal width, lip length and lip width ($p<0.01$). Sepal width demonstrated a positive and significant correlation with petal length and petal width ($p<0.01$). Petal length notified a positive and significant correlation with petal width, lip length and lip width ($p<0.01$). Petal width revealed a positive and significant correlation with lip length and lip width ($p<0.01$). Lip length exposed a positive and significant correlation with lip width ($p<0.01$).

Table 5: Principal component scores, eigenvalues and proportions of total and cumulative variations.

Characters	PC1	PC2	PC3	PC4	PC5	PC6
LF	-0.470	-0.382	1.586	-0.123	-0.936	-0.430
WF	-0.382	-2.152	-1.329	0.795	-0.439	0.290
FB	-1.757	-0.706	-0.746	-0.351	0.888	-0.536
SL	-0.260	2.552	-1.408	0.530	-0.366	-0.079
SW	-2.208	0.359	0.278	-1.611	0.000	0.475
PL	5.536	-0.106	-0.014	-0.574	0.208	0.021
PW	-0.459	0.436	1.633	1.333	0.644	0.260
LL	2.153	-1.216	0.328	-1.527	-0.213	0.864
LW	-0.592	1.537	-0.846	-1.864	0.524	0.995
CL	-0.528	-0.964	0.882	0.635	-0.119	-0.362
Eigenvalue	5.608	1.732	1.367	0.822	0.350	0.122
Variability (%)	56.076	17.315	13.669	8.217	3.500	1.223
Cumulative %	56.076	73.391	87.060	95.277	98.777	100.00

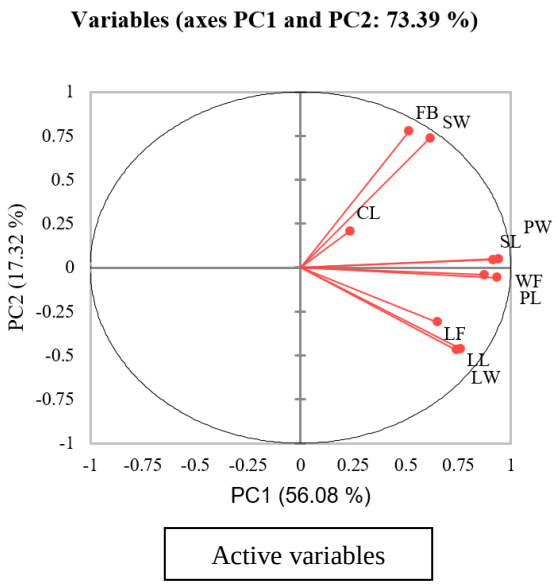

Fig. 6: Variables of principal component scores. LF = Length of flower, WF = Width of flower, FB = Floral bract, SL = Sepal length, SW = Sepal width, PL = Petal length PW = Petal width, LL = Lip length, LW = Lip width and CL = Column length.

Principal component analysis (PCA)

Principal component analysis (PCA) was studied following the standard protocol of Harun-Or-Rashid et al. (2020). The PCA results indicated that the first through sixth PCs contributed 56.07%, 17.31%, 13.66%, 8.21%, 3.50% and 6.86% of the total variance recorded in the study (Fig. 6). The first three PCs explained 87.06% of summation of variance. The highest values in PC1 were recorded for petal length (5.53). In PC2, maximum value was noted for sepal length (2.55). In PC3, petal width showed maximum value (1.63). PC4 suggests that petal width has got the maximum value (1.33). Floral bract has highest value (0.88) in PC5. However, in PC6 maximum value was found for lip width (0.99) (Table 5, Fig. 7). It was also exposed that most of the variances in PC1 was contributed by petal length and lip length which are the most important factors defining the traits.

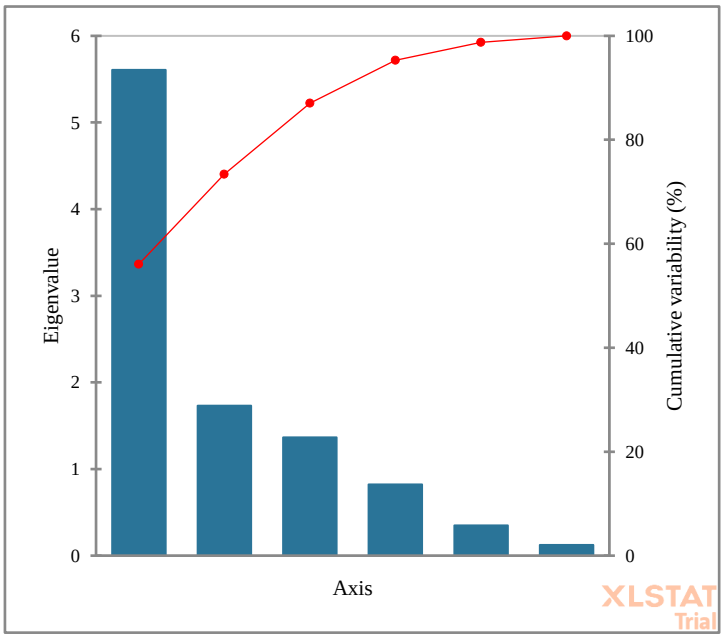

Fig. 7: Scree plot shows variables of principal component scores in comparison with Eigen values and cumulative variability.

Conclusion

The morphological diversity of seven species of *Dendrobium* native to Bangladesh was assessed using 37 characters. There was significant diversity and variation among the observed *Dendrobium* species for morphological traits. A total of 37 morphological characters were studied and 30 out of the characters (81.08%) exhibited results that varied regarding the traits of flowers, leaves, pseudobulbs and roots. Statistical analysis showed that some species *viz. D. aphyllum* and *D. chrysotoxum* have close kinship and can be used for further variety development. The dissimilarities that are found make particularities in vegetation.

Acknowledgements

The authors are thankful to the Ministry of Education (MoE) Bangladesh for the leave permission; Ministry of Science and Technology (MOST), Bangladesh and Institute of Biological Sciences, University of Rajshahi, Bangladesh for the fellowships, Lab and related other facilities to conduct this research.

Conflict of interest: It is declared by the authors that there is no conflicting interest.

Author's contribution: SMSI designed the experiment, supervised the study, and corrected the manuscript in every step. MEH conducted experiments, data collection and analysis and wrote the draft of the manuscript. Both authors have read and approved the final manuscript.

Funding source: No funding.

Data availability: All data generated in the study are reported in the article, and unprocessed data is with the corresponding author and available upon request.

References

Ayesha MN, Saha SR and Islam SMS (2024). *In vitro* micropropagation of *Erialasiopetala* (Willd.) Ormerod-A native medicinal orchid in Bangladesh. Journal of Bio-Science 32(2): 45-60. https://doi.org/10.3329/jbs.v32i2.75756

Azmi TK, Sukma D, Aziz SA and and Syukur M (2016). Polyploidy induction of moth orchid (Phalaenopsis amabilis (L.) Blume) by colchicine treatment on pollinated flowers. Journal of Agricultural Sciences (Sri Lanka): 14(2). doi: 10.4038/jas.v11i2.8118.

Bektaş E, Cüce M and Sökmen A (2013). *In vitro* germination, protocorm formation, and plantlet development of orchis coriophora (Orchidaceae), a naturally growing orchid species in Turkey. Turkish Journal of Botany 37(2): 336-342. doi: 10.3906/bot-1205-28.

Bhattacharjee B, Hossain ME, Ayesha MN and Islam SS (2022). Morphological diversity analysis of some existing and endangered dendrobium orchid species in Bangladesh. Journal of Bio-Science 30(2): 47-57. https://doi.org/10.3329/jbs.v30i2.68911.

Castro JB and Singer RB (2019). A literature review of the pollination strategies and breeding systems in Oncidiinae orchids. Acta Botanica Brasilica 33: 618-643. doi: 10.1590/0102-33062019abb0111.

Coates DJ and Dixon KW (2007). Current perspectives in plant conservation biology. Australian Journal of Botany 55(3): 187-193.https://doi.org/10.1071/BT07037.

Cribb PJ, Kell SP, Dixon KW and Barrett RL (2003). Orchid conservation: A global perspective. Orchid Conservation 124. https://www.researchgate.net/publication/234814294.

Dehgahi R and Joniyas A (2017). Review of research on Dendrobium sonia-28, a hybrid from Orchidacea family and mutation as somaclonal variation. International Journal of Bio-Science 10(6): 29-47. doi: 10.12692/ijb/10.6.29-47.

Freudenstein JV and Chase MW (2015). Phylogenetic relationships in Epidendroideae (Orchidaceae), one of the great flowering plant radiations: progressive specialization and diversification. Annals of Botany 115(4): 665-681. https://doi.org/10.1093/aob/mcu253.

Gutiérrez RMP (2010). Orchids: A review of uses in traditional medicine, its phytochemistry and pharmacology. Journal of Medicinal Plants Research 4(8): 592638.http://www.academicjournals.org/JMR

Indraloka AB, Dewanti P and Restanto DP (2019). Morphological characteristics and pollinia observation of 10 Indonesia native *Dendrobium* orchids. *BIOVALENTIA:* Biological Research Journal 5(2): 38-45. doi: https://doi.org/10.24233/BIOV.5.2.2019.140.

Johnson SD (2018). Natural hybridization in the orchid flora of South Africa: Comparisons among genera and floristic regions. South African Journal of Botany 118: 290-298. https://doi.org/10.1016/j.sajb.2018.01.011.

Johnson SD and Edwards TJ (2000). The structure and function of orchid pollinaria. Plant Systematics and Evolution 222: 243-269. https://doi.org/10.1007/BF00984105.

Kiran R, Kekuda TRP, Kumar PHG, Hosetti BB and Krishnaswamy K (2013). Biological activities of *Sarcanthus pauciflorus*. Journal of Applied Pharmaceutical Science 3(7): 105-110. doi: 10.7324/JAPS.2013.3720.

Kuehnle AR (2007). Orchids: Dendrobium. In: Flower Breeding and Genetics: Issues, Challenges and Opportunities for the 21st Century, Dordrecht: Springer Netherlands, pp. 539-560. https://link.springer.com/chapter/10.1007/978-1-4020-4428-1_20.

Kumalwati DA, Abdullah S, Mahfut M and Daryono BS (2011). Study on genetic diversity and conservation of orchids in Wonosadi forest, Gunungkidul based on molecular analysis study on genetic diversity and conservation of orchids, p. 54, http://repository.lppm.unila.ac.id/id/eprint/17362.

Kurniawan FY and Semiarti E (2021). Floral morphology and chromosome characteristics of bamboo orchid from Menoreh Hills, Kulonprogo. Journal of Agricultural Sciences (Sri Lanka) 16(3). http://doi.org/10.4038/jas.v16i03.9474

Miswarti, Calista I, Putra WE, Oktavia Y, Yuliasari S, Musaddad D and Sastro Y (2021). Morphology characteristics of orchids species in Bukit Barisan, Bengkulu province. doi: 10.1088/1755-1315/653/1/012149.

Ng CKY and Hew CS (2000). Orchid pseudobulbs–false' bulbs with a genuine importance in orchid growth and survival. Scientia Horticulturae 83(3-4): 165-172. https://doi.org/10.1016/S0304-4238(99)00084-9.

Poorter H and Remkes C (1990). Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. Oecologia 83(4): 553-559. https://doi.org/10.1007/BF00317209.

Silalahi M, Supriatna J and Walujo EB (2015). Local knowledge of medicinal plants in sub-ethnic Batak Simalungun of North Sumatra, Indonesia. Biodiversitas 16(1): 44-54. http://repository.uki.ac.id/id/eprint/198.

Tay S, He J and Yam TW (2015). Photosynthetic light utilization efficiency, water relations and leaf growth of C3 and CAM tropical orchids under natural conditions. American Journal of Plant Sciences 6(18): 2949. http://dx.doi.org/10.4236/ajps.2015.618290.

Teixeira da Silva JA, Cardoso JC, Dobránszki J and Zeng S (2015). *Dendrobium* micropropagation: A review. Plant Cell Reports 34: 671-704. https://doi.org/10.1007/s00299-015-1754-4.

Tuberosa R, Graner A and Varshney RK (2011). Genomics of plant genetic resources: an introduction. Plant Genetic Resources 9(2): 151154. https://doi.org/10.1017/S1479262111000700.

Wang HM, Tong CG and Jang S (2017). Current progress in orchid flowering/flower development research. Plant Signaling and Behavior 12(5): e1322245. https://doi.org/10.1080/15592324.2017.1322245

Wang HZ, Feng SG, Lu JJ, Shi NN and Liu JJ (2009). Phylogenetic study and molecular identification of 31 *Dendrobium* species using inter-simple sequence repeat (ISSR) markers. Scientia Horticulturae 122(3): 440447. https://doi.org/10.1016/j.scienta.2009.06.005.

Zeng J, Li D, Li Z, Zhang J and Zhao X (2020). *Dendrobium officinale* attenuates myocardial fibrosis via inhibiting EMT signaling pathway in HFD/STZ-induced diabetic mice. Biological and Pharmaceutical Bulletin 43(5): 864-872. https://doi.org/10.1248/bpb.b19-01073.