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Full Paper

Characterization and Phenotypic Trait Analyses of Five *Dendrobium* Species

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Phenotyping of 50 *Dendrobium* genotypes belonging to five *Dendrobium* species including *Dendrobium anosmum* (Lindl.)*, Dendrobium aphyllum* (Roxburgh) C.E.C Fisch., *Dendrobium crumenatum* Swartz, *Dendrobium profusum*, and *Dendrobium bullenianum* Rchb.f., and pollen fertility testing of selected *D. anosmum* genotypes was conducted to characterize and analyze them morphologically in terms of flower, leaf spike traits and growth habit. Principal Component Analysis (PCA) of the different quantitative traits evaluated grouped them into 16 principal components, wherein the first four components have Eigenvalues greater than one and, they have contributed 80.93% of the total cumulative variability. Fifteen phenotypic traits have high variances as shown by the four most important principal components, and these have significance to the different genotypes since they can be used as basis for selection in breeding work to improve the *Dendrobium* orchid. The relationship of the different quantitative traits was subjected to correlation circle analysis, and it revealed that flower width, flower length, petal length, dorsal and lateral sepal length, lip length, lip width, peduncle length, petal thickness and flower lifespan are positively correlated. Furthermore, Agglomerative hierarchal clustering analysis indicated that the 50 individual *Dendrobium* genotypes clustered into three classes with different class sizes. The dendrogram showed a highly branched structure indicating a high variability among the 50 *Dendrobium* genotypes, suggesting a wide window for selection of desirable genotypes. The *Dendrobium* selections that are floriferous with big flowers included: Genotype #3 from *D. anosmum*, Genotype #20 from *D. aphyllum* and Genotype #32 from *D. cremenatum*.

Keywords: Agglomerative hierarchal clustering analysis, *Dendrobium* species, morphological characterization, phenotype, principal component analysis

INTRODUCTION

One of the largest families of flowering plant in the world with over 30,000 species, is the family *Orchidaceae* (Johnson 2010). These plants can easily adapt to any type of environment and exist in various colors, shapes, scent and sizes. Orchids grow in either humid or cold environment, from marshlands to deserts. Except for black, the flowers appear in any color. With regards to shape, there are several species resembling the shape of insects, which tends to attract insect pollinators. The scent of the flower, on the other hand, ranges from odorless to pleasant to foul-smelling (Rittershausen 2006). In terms of size, species vary from minute to gigantic, with the tiniest recorded at two millimeters (Kaufman 2009), and the largest at 20 centimeters in diameter (Snakenberg, 2018).

Due to the wide variability in phenotypic traits of orchids, breeders exploited these variations to improve the characters by producing hybrids via varietal breeding. Orchid breeding aims to develop new flower colors, introduce disease-resistance, and prolong the lifespan of the flower for mass production purposes (De, 2017). In addition, breeding in orchids also aimed to develop heat-tolerant varieties due to the demand in the landscaping industry. (Zainol et al. 2015). There is an estimated 100,000 hybrid species of orchids recorded in the world in the past 150 years (Rittershausen 2006). The marketability of orchid cutflowers is worth billion dollars wherein the industry is considered one of the economic boosters in the global ornamental trade (Teixeira da Silva 2013).

In the Philippines, there are several orchid species that has been exploited in varietal breeding, and among them is from the *genus Dendrobium,* a large diverse genus of about 1,000 species occurring mainly in Asia, Polynesia, Malaysia to New Zealand and Australia. According to Valmayor (1984), 70 species are endemic to the Philippines. These species are used for the production of potted plants and cut flowers that are popular for their blossoming flowers, floral characteristics, year-long availability and longevity (De et al. 2014a).

Dendrobium hybrids can be produced through different breeding techniques like hybridization and selection (Khangjarakpam et al. 2014). Recently, both conventional breeding methods and biotechnology techniques have been employed aimed at developing varieties with pendant-like inflorescence, new flower colors, those that flower in almost all nodes of the pseudobulb, synchronous flowering habit, and compact plants with multiple terminal inflorescence (Cardoso et al. 2023). According to Goulet et al. (2017), hybridization is purposefully employed in the improvement of domesticated plants to take advantage of transient hybrid vigor, transfer desirable variation among lineages, and generate novel phenotypes. Before hybridization is conducted, parent plants with the most desirable characters are first evaluated and then selected for use in hybridization (De et al. 2014b). Generally, the reproductive biology particularly pollen viability and pollen germination are evaluated prior to hybridization (De Silva et al. 2023). In a recent study, six Indonesian *Dendrobium* species were evaluated for 21 quantitative and another 21 qualitative morphological traits including heritability of traits for breeding and selection purposes (Tini et al. 2025). This study aimed to: i) evaluate and characterize genotypes of different *Dendrobium* species, ii) analyze the different phenotypic characters of *Dendrobium*, and iii) select individual genotypes with attractive flower colors, big flowers and floriferous for future use in genetic improvement.

MATERIALS AND METHODS

Characterization and evaluation

Fifty genotypes belonging to five *Dendrobium* species were used for characterization and evaluation of various phenotypic traits. The *Dendrobium* species used for evaluation included: 26 genotypes of *Dendrobium anosmum*, 15 of *Dendrobium crumenatum*, seven of *Dendrobium aphyllum*, and one genotype each of *Dendrobium profusum* and *Dendrobium bullenianum.* The different genotypes belonging to the five species were collected from home gardens and orchid nurseries of enthusiasts in different places including: Marinduque, Mindoro, Ilocos Norte, Camarines Sur, Camarines Norte, Nueva Viscaya, Quezon, Batangas, Laguna and Cavite.

Genotypes of each species were characterized morphologically based on their growth, flower, leaf and spike characteristics. Twenty-five random flower samples per character were evaluated per plant. The different quantitative and qualitative traits were assessed, and the instrument used including the measurement procedures employed were presented in Table 1. The flower colors were assessed using the Royal Horticultural Color Chart (RHCC) of the Royal Horticultural Society (RHS) of London (1966). The descriptions of the flower characteristics were mostly based on the book “Philippine Native Orchid Species” (Cootes 2011).

Table 1. Quantitative and qualitative plant characters of five *Dendrobium* species evaluated, the measurement technique employed, the instrument and color chart used.

Plant Characters	Measurement Technique	Instrument Used
Flower Characters		
Flower width (cm)	Measured horizontally from the left to the right end of the petals	Ruler
Flower length (cm)	Measured vertically from the tip of the dorsal sepal to the tip of the labellum	Ruler
Petal length (cm)	Measured from its attachment to the flower to its tip	Ruler
Dorsal and lateral sepal length (cm)	Measured from its point of attachment to the flower to the tip of the sepal	Ruler
Labellum length (cm)	Measured from the point of attachment of the lip to the flower to the tip of the labellum	Ruler
Labellum width (cm)	Measured from the left to the right end	Ruler
Peduncle length (cm)	Measured as the distance between its point of attachment to the stem from the flower	Ruler
Thickness (mm)	The petal of the flower was placed between the anvil and the rachet of the micrometer caliper and was spun counterclockwise until the right thickness was observed	Micrometer caliper, Mitutuyo Co., Japan
Flower lifespan (days)	Observed by keeping track of the date when the flowers will wilt and fall off from the spike	Manual counting
Flower color	Visual assessment of flower color and matched with the color coordinates	RHS Color Chart (1966), London
Leaf Characters		
Leaf length (cm)	Measured from the point of attachment of the leaf to the stem to the tip of the leaf	Ruler
Leaf width (cm)	Measured by first observing the widest part of the leaf and then getting the distance of the left side to the right side of the leaf	Ruler
Thickness (mm)	Measured by placing a leaf between the anvil and spinning the rachet of the micrometer caliper counterclockwise until the right thickness was observed	Micrometer caliper, Mitutuyo Co., Japan
Leaf color	Visual assessment of leaf color and matched with the color coordinates	RHS Color Chart (1966), London
Spike Characters		
Number of spikes	Measured by counting the spikes present on the plant.	Manual counting
Length of spike (cm)	Measured from the point of attachment of the spike to the plant to the spike’s end	Ruler
Length of spike with flowers (cm)	Measured from where the first flower was located up to the last flower. It was measured based on the point of attachment of the flowers to the stem.	Ruler
Number of flowers per spike	Measured by counting the number of flowers present per spike.	Manual counting

Statistical Design and Analyses

Purposive sampling was used to assemble the 50 *Dendrobium* genotypes that were randomly selected. Different characteristics were observed and recorded for the characterization and evaluation of the *Dendrobium* genotypes. Sixteen of which are flower characteristics consisting of nine quantitative and seven qualitative traits. In terms of leaf characteristics, seven were quantitative while four were qualitative. The four other qualitative traits were spike characteristics.

The data were analyzed using XLSTAT. Sixteen quantitative traits were subjected to Principal Component Analysis (PCA). Qualitative traits including: flower and leaf colors were subjected to Multiple Correspondence Analysis (MCA). Through these, the resulting principal coordinates were placed alongside the other quantitative traits in order to cluster the genotypes using Agglomerative Hierarchical Clustering (AHC). AHC was used to group the *Dendrobium* species based on the class where they belong.

The variability of plant characters involving the different *Dendrobium* species was also evaluated using Shannon-Weaver Diversity Index (Tolbert et al. (1979) to estimate phenotypic diversity and guide to selecting the best genotypes. It was computed for the different plant characters using the formula:

$$H' = \frac{\sum pi(\log2pi)}{\text{Log}2n}$$

where pi = frequency of each descriptor state and n = the number of states per descriptor. It gives the result of H' = 0 - 1.0 having the value nearest to one to be the most diverse. For this diversity index, a value of 0.80-1.0 is arbitrarily considered high to indicate a wide variability, while a value of 0.20-0.79 is considered low, indicating a narrow variability. The mean, range, standard deviation and coefficient of variation (%) were also determined.

RESULTS AND DISCUSSION

Morphological characterization and evaluation

The morphological characteristics of 50 *Dendrobium* genotypes belonging to five different species varied considerably. Descriptions of each species are as follows:

***Dendrobium anosmum* Lindley and *Dendrobium anosmum var. dearie* (Rolfe) Ames and Quisumbing**

Dendrobium anosmum has varying flower colors such as amethyst violet (RHCC 84C, Figure 1), bishop's violet (RHCC 81B, Figure 2), light purple (RHCC 67C, Figure 3) and white (RHCC NN155A, Figure 4). It has a sympodial and pendulous growth. Its flowers develop into clusters having ovate petals and

Figure 1. The amethyst violet-colored petals (RHCC 84C) of seven genotype samples belonging to the species known as *Dendrobium anosmum* Lindley.

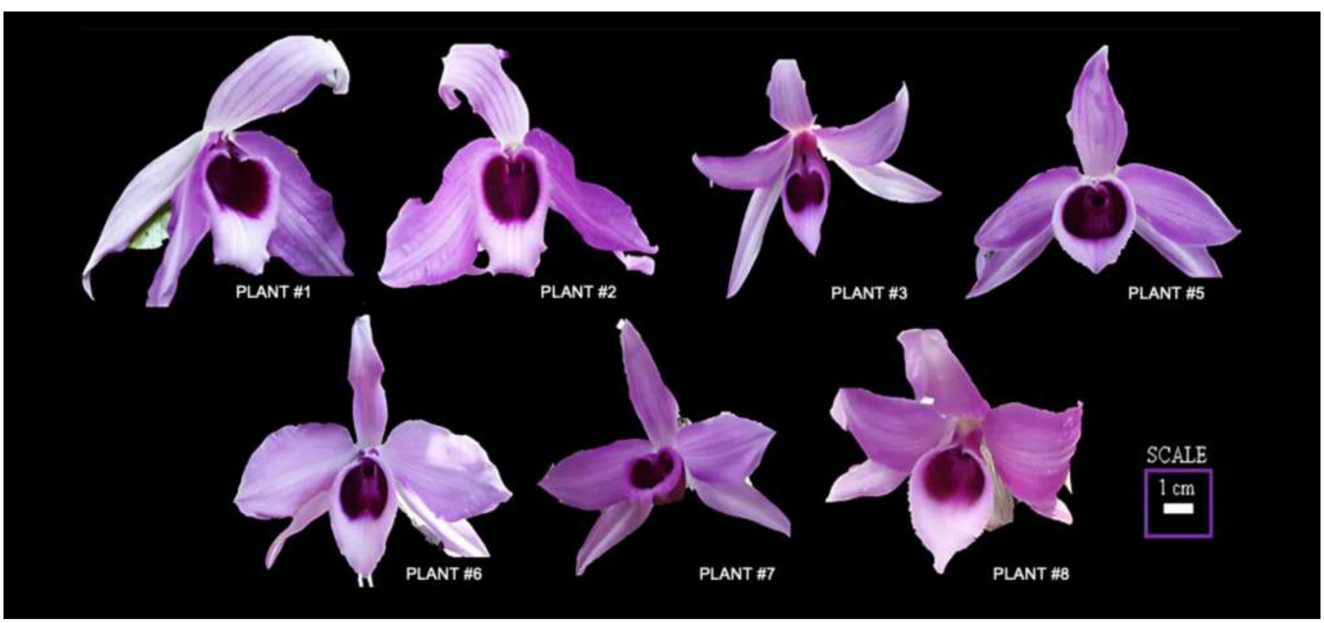

Figure 2. The bishop's violet-colored petals (RHCC 81B) of seven genotype samples belonging to the species known as *Dendrobium anosmum* Lindley.

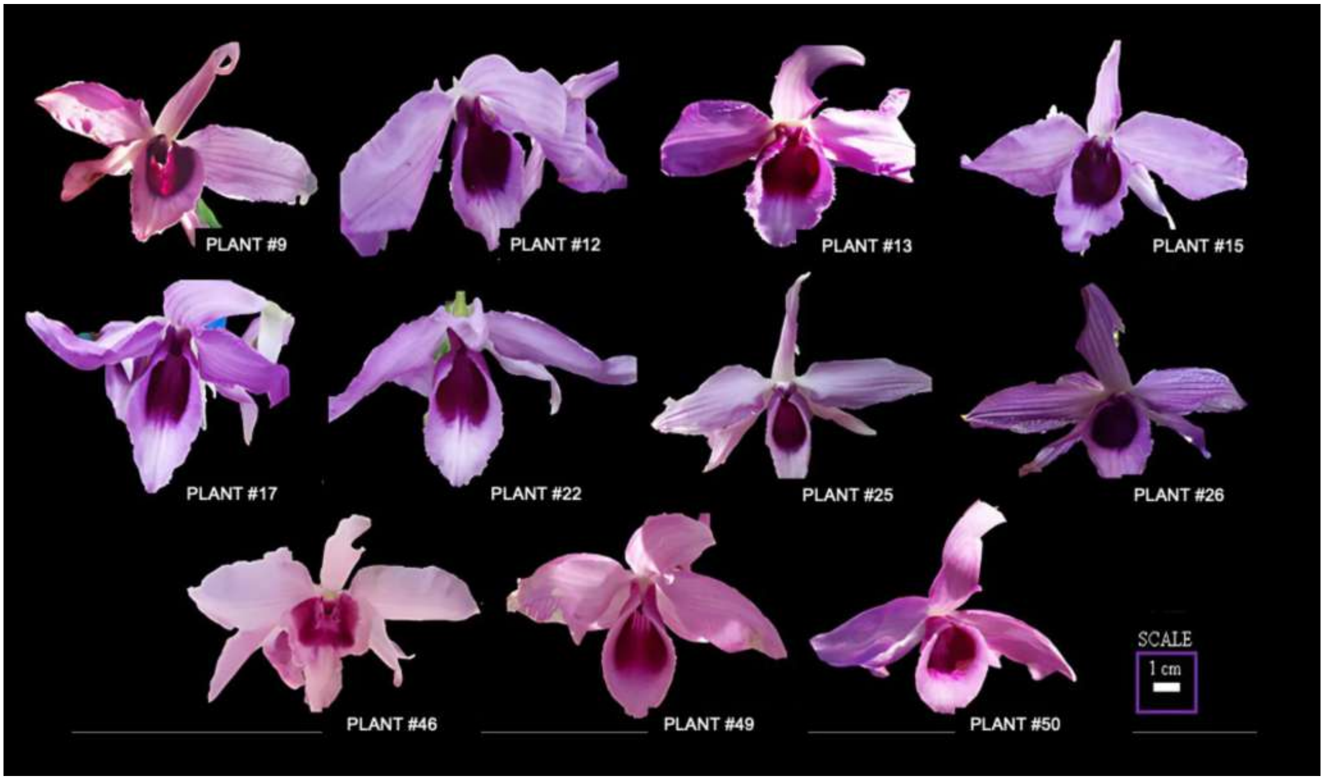

Figure 3. The light purple (RHCC 67C) colored petals of 11 genotype samples belonging to the species known as *Dendrobium anosmum* Lindley.

Figure 4. The white colored petal (RHCC NN155A) *Dendrobium anosmum* var. *dearie* (Rolfe) Ames and Quisumbing.

lanceolate sepals with a circular lip if flattened and a pointed tip. Flowers measure 10.1 ± 0.96 cm long and 13.2 ± 1.23 cm wide. The leaves are simple and have an entire margin that are arranged alternately. They measure 8.8 ± 2.54 cm long and 3 ± 0.87 cm wide. The plant can have 11 ± 8.35 flowers per spike that can last on the plant for up to 23 ± 3.44 days.

Dendrobium aphyllum **(Roxburgh) C.E.C. Fischer**
This species of *Dendrobium* has a light violet (RHCC 84C) colored petals with either a chartreuse yellow lip (RHCC 2D, Figure 5), or sap green lip (RHCC 150D, Figure 6). It has a pendulous and sympodial growth habit. The flowers measure 4.8 ± 0.15 cm wide and 3.7 ± 0.18 cm long. The petals are broadly oblong to elliptic, while the sepals are oblong to lanceolate with a circular lip, and a pointed tip if flattened. The leaves measure 6.24 ± 1.06 cm long and 1.8 ± 0.27 cm wide, which are generally smaller compared to the leaves of *D. anosmum*. There are 16 ± 11.82 flowers per spike that can last while on the plant for 14 ± 2 days.

Dendrobium crumenatum **Swartz**
The *Dendrobium crumenatum* species has three flower shapes namely: round (Figure 7), flying bird-like (Figure 8) and spear-like flowers (Figure 9) with white petals and sepals (RHCC 155C) and light-yellow labellum (RHCC 4A). It has an upright and sympodial growth habit. The flowers measure 3.5 ± 0.40 cm wide and 3.8 ± 0.55 cm long. The petals are oblanceolate, while the dorsal sepal is oblong to lanceolate, and the lateral sepals are lanceolate. The labellum is three-lobed and has scalloped edges. The leaves are 6.71 ± 1.52 cm long and 1.95 ± 0.47 cm wide. Among the *Dendrobium* species, it has the greatest number of flowers per spike having 37 ± 3.42 flowers, that last while on the plant for only one day.

Dendrobium profusum **Reichenbach f.**
Dendrobium profusum has light yellow flowers (RHCC 8C, Figure 10) and they are smaller compared to the flowers of the three species mentioned above. The flowers measure 2.44 ± 0.60 cm wide and 2.25 ± 0.30 cm long and can last up to seven days while on the plant. The petal and dorsal sepals are ovate, while the lateral sepal is triangular. The labellum is three-lobed and fiddle-shaped. The mid-lobe looks like an inverted heart, while the side lobe is semi-circular. It has also a pendulous and sympodial growth habit. The leaves measure 10 ± 1.50 cm long and 8 ± 1.62 cm wide with similar leaf characteristics with the other *Dendrobium* species.

Figure 5. The light violet (RHCC 84C) and chartreuse yellow (RHCC 2D) colored lips of five genotype samples belonging to the species *Dendrobium aphyllum* (Roxburgh) C.E.C. Fischer.

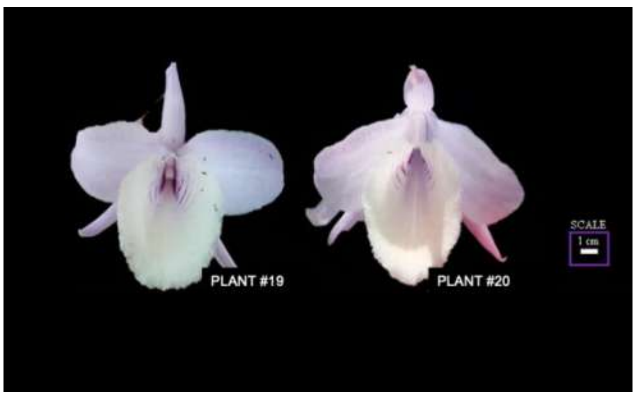

Figure 6. The mineral violet (RHCC 84D) petals with sapgreen colored lips (RHCC 150D) of two genotype samples belonging to *Dendrobium aphyllum* (Roxburgh) C.E.C. Fischer

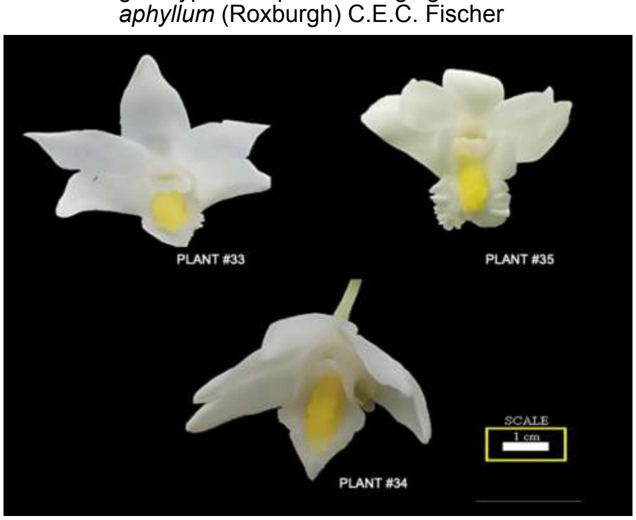

Figure 7. Rounded white flowers (RHCC 155C) with light yellow labellum (RHCC 4A) of three genotype samples belonging to the species *Dendrobium crumenatum* Swartz.

Table 2. The seven principal components of *Dendrobium crumenatum* and their Eigenvalues, proportion of variance, and cumulative portion.

Principal Components	Eigenvalues	Proportion of Variance (%)	Cumulative Proportion (%)
F1	2.57	36.75	36.75
F2	1.66	23.67	60.42
F3	1.57	22.47	82.89
F4	0.55	7.82	90.71
F5	0.36	5.16	95.87
F6	0.254	3.623	99.492
F7	0.04	0.51	100

Dendrobium bullenianum Reichenbach f.
Dendrobium bullenianum has the smallest flowers among the five species evaluated. The flower measures 1.3 ± 0.90 cm long and 1.5 ± 0.40cm wide. The flower is bright yellow orange (RHCC 23A) with red stripes (Figure 11). The petal and dorsal sepals are lanceolate, while the lateral sepal is ovate. The labellum is elliptic that is different from the other *Dendrobium* species. The plant has 33 ± 3.12 flowers per spike that can last up to seven days while on the plant. The leaves measure 10 ± 1.90 cm long and 2 ± 1.40 cm wide, but they are thinner compared to the leaves of the other *Dendrobium* species. The plant has a sympodial and pendulous growth habit.

Principal Component Analysis
The Principal Component Analysis (PCA) is a technique being used for analyzing large datasets that are difficult to interpret (Jolliffe and Cadina 2016). This analysis reduces the dimensionality of datasets and, thus it increases the interpretability of the data and minimizes information loss. This technique does so by creating new uncorrelated variables that

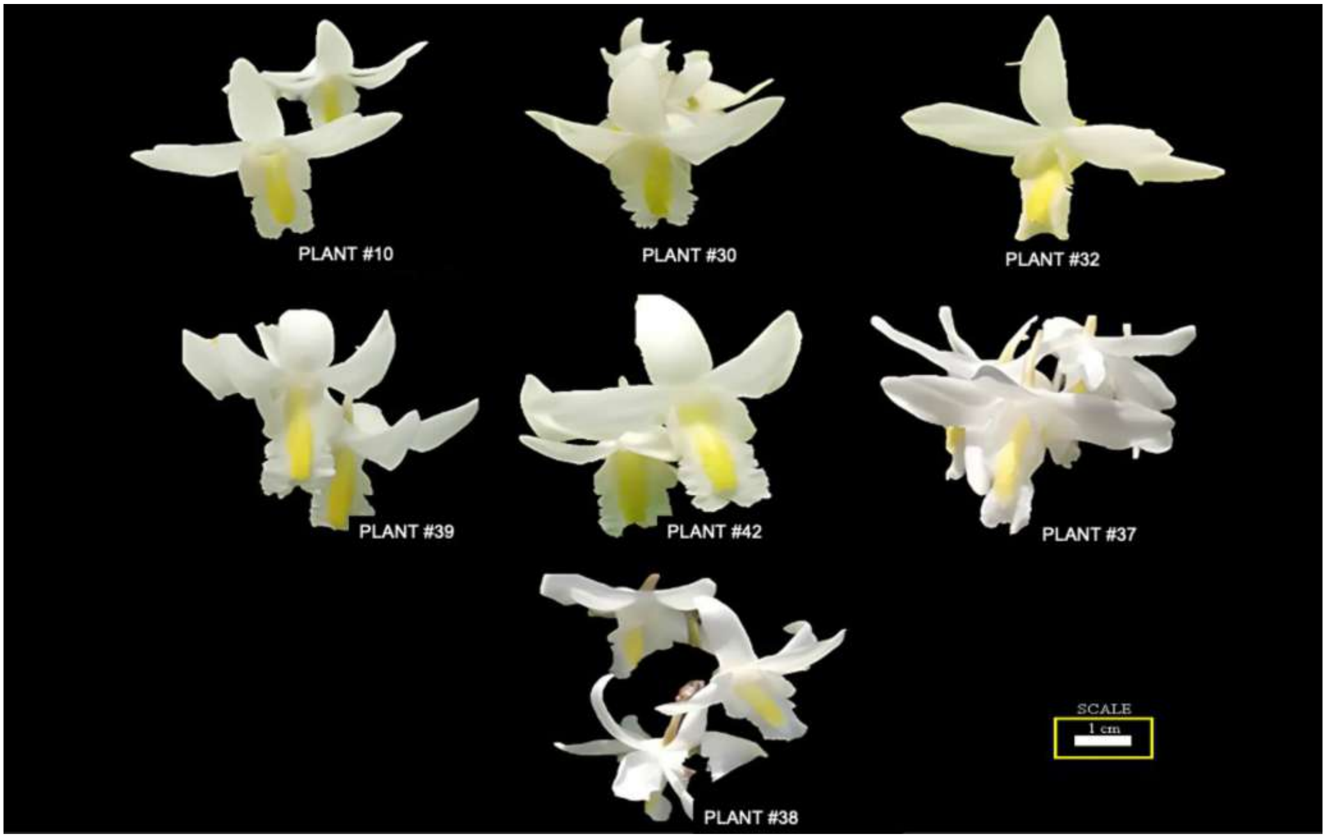

Figure 8. Flying bird-like white (RHCC 155A) flowers with light yellow labellum (RHCC 4B) of seven genotype samples belonging to the species *Dendrobium crumenatum* Swartz.

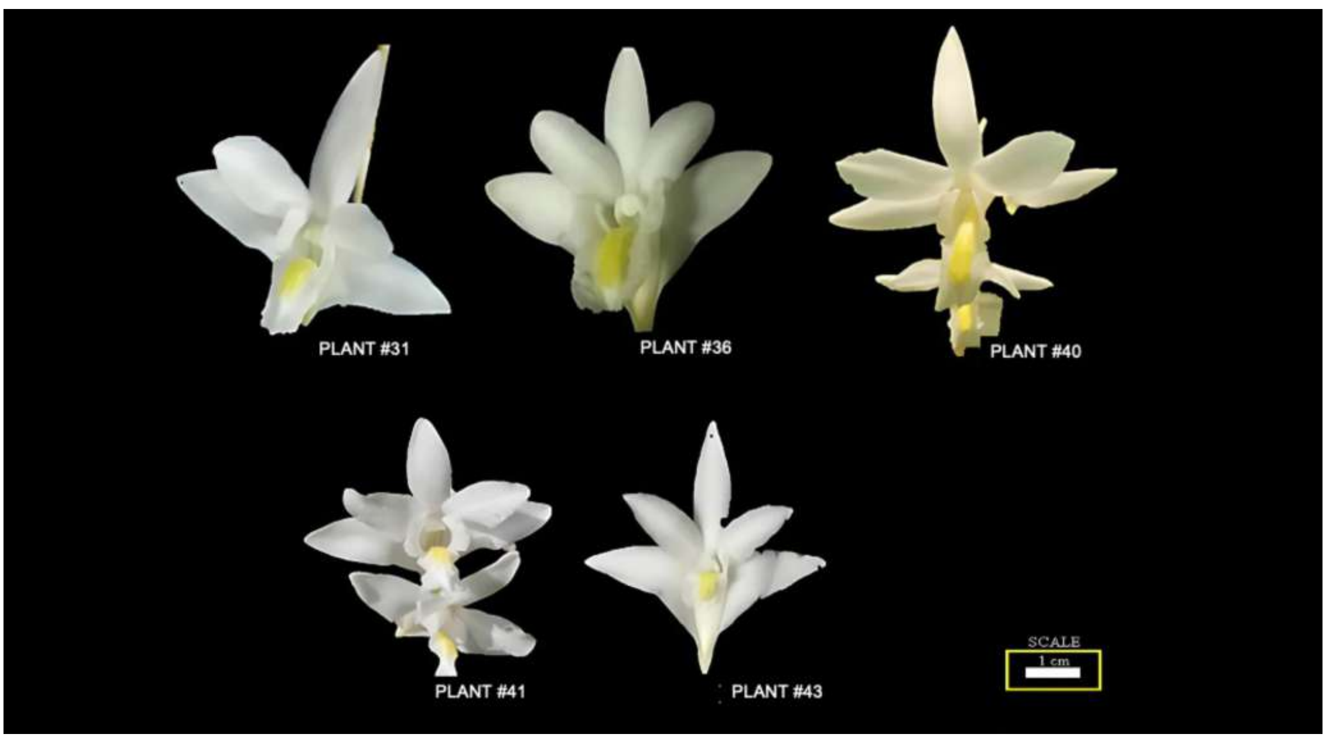

Figure 9. The spear-like white flowers (RHCC 155A) with light yellow labellum (RHCC 4C) of five genotype samples belonging to the species *Dendrobium crumenatum* Swartz.

successively maximize variance, and finding such new variables the PCA reduces to solving an Eigenvalue problem. In the present study on *Dendrobium*, the different data on quantitative traits of 50 *Dendrobium* genotypes were analyzed using PCA. The first three components namely: F1, F2, and F3 have Eigenvalues greater than 1 (>1), have a high proportion of variance, and they contributed 82.88% of the total cumulative variability out of the seven principal components for *D. crumenatum* (Table 2).

Table 3. Factor loading of the seven quantitative traits including flower width, flower length, number of spikes, spike length with flowers, leaf length, leaf width, and leaf thickness of *Dendrobium crumenatum* in each of the seven principal components.

Principal Components	F1	F2	F3	F4	F5	F6	F7
Flower width	0.72	0.64	0.06	-0.03	-0.14	0.19	-0.11
Flower length	0.78	0.59	-0.01	-0.14	-0.05	-0.08	0.13
Number of Spikes	0.26	-0.59	-0.59	-0.43	-0.15	0.19	0.02
Spike length with flowers	0.69	-0.11	-0.54	0.07	0.45	-0.07	-0.03
Leaf length	0.54	-0.4	0.6	-0.31	-0.04	-0.28	-0.05
Leaf width	0.44	-0.4	0.72	0.11	0.17	0.3	0.04
Leaf thickness	0.65	-0.46	-0.22	0.48	-0.29	-0.08	0.01

Table 4. Correlation of the seven quantitative traits of *Dendrobium crumenatum.*

	FW	FL	NS	SLF	LL	LW	LT
Flower width	1	0.92	-0.15	0.32	0.14	0.12	0.17
Flower length	0.92	1	-0.09	0.45	0.23	0.05	0.19
Number of Spikes	-0.15	-0.09	1	0.45	0.11	-0.09	0.39
Spike length with flowers	0.32	0.45	0.45	1	0.08	0.02	0.53
Leaf length	0.14	0.23	0.11	0.08	1	0.71	0.29
Leaf width	0.12	0.05	-0.09	0.02	0.71	1	0.29
Leaf thickness	0.17	0.19	0.39	0.53	0.29	0.29	1

FW – flower width; FL – flower length; NS – number of spikes; SLF – spike length with flowers; LL – leaf length; LW – leaf width; LT – leaf thickness

Figure 10. The light yellow (RHCC 8C) flowers of a genotype belonging the species known as *Dendrobium profusum.*

Figure 11. The bright yellow orange (RHCC 23A) with red stripes flowers of a genotype belonging to the species known as *Dendrobium bullenianum* Reichenbach f.

This suggests that F1, F2 and F3 principal components best explains the different qualitative characteristics of the species and contains the highest variance that is desirable for selection purposes.

The first principal component *(ie.* F1) showed positive factor loadings (Table 3) for all the traits which means that it measures all the traits. It shows high positive loadings for flower length and flower width which suggests that this component primarily represent variation in flower characteristics. The second principal component (*ie.* F2) has large negative factor loadings for leaf length, leaf width, leaf thickness and number of spikes while the third principal component (*ie.* F3) also has significant negative factor loadings for the number of spikes and spike length with flowers. This result suggests that F3 captures variation in spike characteristics, while F2 in leaf characteristics.

Figure 12 shows the correlation circle on the relationship of variables projected in the space. This relationship depends on the closeness of the variables to each other relative to the center of the circle. If the variables are close to each other, it means that they are significantly and positively correlated. If they are orthogonal, there are no correlation; and if they are on the opposite sides of the center, there is a significant negative correlation.

Flower width and length including leaf characteristics like leaf width, length and thickness are shown close to each other, thus, they are positively correlated. This means that the variables are directly proportional to each other. This proportionality is the same for the leaves. Moreover, the number of spikes is orthogonal to flower length and width, which means that these traits are not related with one another.

There are no other significant relationships shown with the variables used for *Dendrobium crumenatum*. There is a strong positive relationship between flower width and flower length (0.92) (Table 4) including leaf length and leaf width (0.71). The same observations were recorded for rambutan in which the fruit width shows positive correlation with seed weight (Magdalita and Valencia, 2004). This indicates that the evaluation of the quantitative characteristics of *D. crumenatum* could be limited to the length of the flower and the leaves, while the width of the flowers and leaves can be extrapolated. On the other hand, all other characters having medium and weak correlation need to be measured individually.

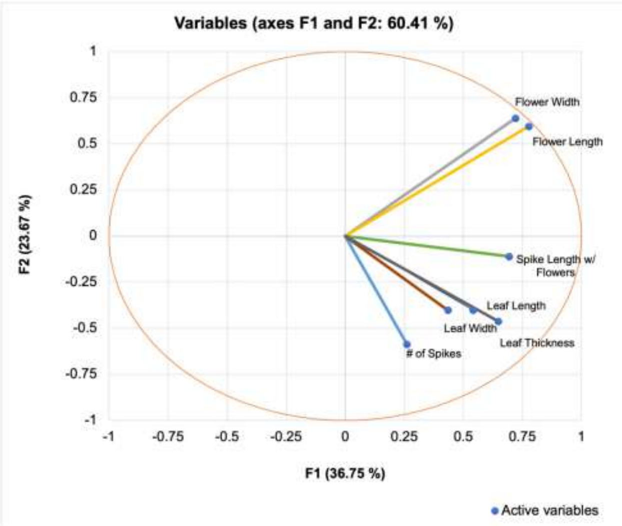

Figure 12. Correlation of the different qualitative traits of *Dendrobium crumenatum.*

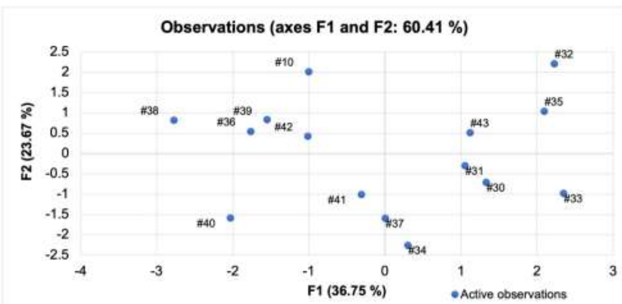

Figure 13. Chart of the two-dimensional map and their relationship with one another of the different qualitative traits of *Dendrobium crumenatum*.

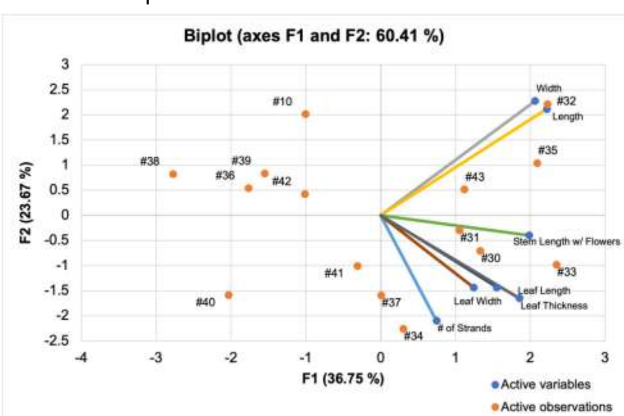

Figure 14. Observations and variables chart of the qualitative traits of *Dendrobium crumenatum* species.

The correlation circle also shows that the horizontal axis (*ie.* axis F1) was linked to the significant values of the flower and leaf measurements and the spike length with flowers (Figure 12). High quantitative measurements of the variables were found on the right side of the correlation circle while low measurements were on the left side. Meanwhile, important values for the number of spikes were linked to the vertical axis (*ie.* axis F2) in which a greater number of spikes were found at the bottom while a lower number was found at the top (Figure 12).

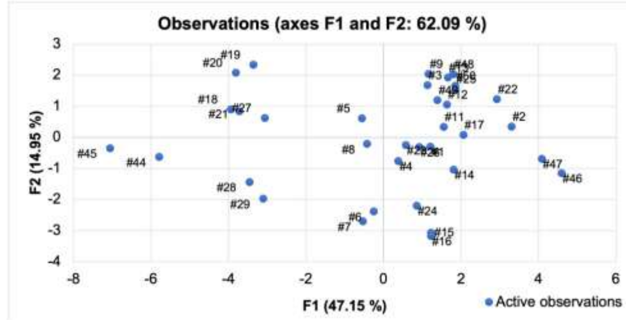

Figure 15. Observational chart of the different qualitative traits of *Dendrobium anosmum, Dendrobium aphyllum, Dendrobium profusum* and *Dendrobium bullenianum* species.

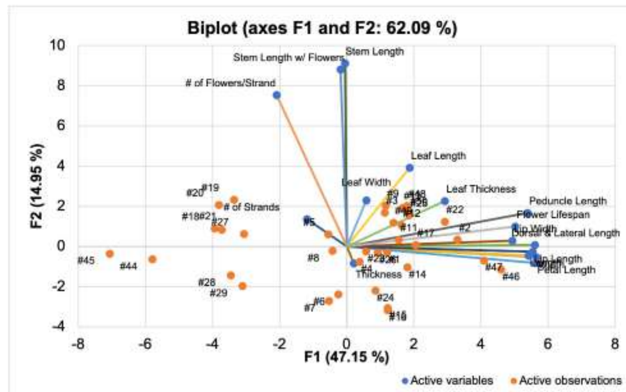

Figure 16. Observations and variables chart of the different qualitative traits of *D. anosmum, D. aphyllum, D. profusum* and *D. bullenianum.*

Figure 13 shows the observations on a two-dimensional map and their relationship with one another. The genotypes were divided based on their characteristics. Genotypes that were located on the same side of the chart have the same characteristics and were separated from other plants with different characteristics. For example, genotype #36 and genotype #39 have the same plant characters, while genotype #32 and plant #10 are distinctly different from each other.

To further show the relationship of the plants with the variables, the variables and observational chart was used (Figure 14). Collectively, the plants on the right side of the chart including genotype #32, #35, #43, #31, #30, #33, and #34 showed significant measurements of the variables like leaf length, leaf width, flower length and number of flowers as well as the spike number and length. These genotypes had both big flowers and leaves, and had the highest number and longest spikes. Meanwhile, the genotypes on the left side of the chart including genotype #10, #38, #39, #36, #42, #41, and #40 were much smaller in terms of morphological traits. The genotypes at the bottom of the chart had the highest number of spikes per plant, while the plants at the top of the chart had a lower number of spikes. Genotype #32, #35, and #43 had significantly larger flowers compared to the other plants (Figure 14). Genotype #31, #30, and #33 had significantly long spike with flowers while genotype #34 had significant number of spikes.

Table 5. The 16 principal components of , *Dendrobium aphyllum*, *Dendrobium profusum*, and *Dendrobium bullenianum* and their Eigenvalue, proportion of variance and cumulative portion.

Principal Component	Eigenvalue	Proportion of Variance (%)	Cumulative Proportion (%)
F1	7.54	47.15	47.15
F2	2.39	14.95	62.09
F3	1.82	11.37	73.46
F4	1.19	7.46	80.93
F5	0.96	6.01	86.94
F6	0.67	4.18	91.12
F7	0.44	2.77	93.89
F8	0.29	1.79	95.68
F9	0.2	1.23	96.92
F10	0.16	0.98	97.9
F11	0.11	0.69	98.58
F12	0.08	0.51	99.09
F13	0.08	0.47	99.56
F14	0.05	0.29	99.85
F15	0.02	0.13	99.98
F16	0	0.02	100

Principal component analysis (PCA) of sixteen (16) qualitative traits of the other four (4) *Dendrobium* species including: *D. anosmum, D. aphyllum, D. profusum* and *D. bullenianum* was also conducted.

The first four principal components (*ie.* F1, F2, F3, and F4) have Eigenvalues that are greater than 1 (>1), have a large proportion of variance and have contributed 80.93% of the total cumulative variability out of the 16 principal components (Table 5). This indicates that these four principal components can best explain the different qualitative characteristics and contains the highest variance that is desirable for selection purposes. The first principal component (*ie.* F1) showed significant positive factor loadings for almost all flower measurements including flower width, flower length, petal length, dorsal and lateral sepal length, petal length, lip length, lip width, peduncle length, and flower lifespan. This component primarily measures the flower characteristics. The second principal component *(ie.* F2) has positive factor loadings for spike characteristics including spike length, spike length with flowers, and number of flowers per spike which indicates that it measures spike characteristics. Meanwhile, the third principal component (*ie.* F3) has significant positive factor loadings for leaf width and leaf length and large negative factor loadings for the number of spikes. Lastly, the fourth principal component (*ie.* F4) had a significant factor loading for leaf thickness (Table 6). The correlation of these traits that were grouped in each principal component can be further seen in the correlation circle (Figure 15).

Flower characteristics such as flower width, flower length, petal length, dorsal and lateral sepal length, lip length, lip width, peduncle length, and flower lifespan, leaf width and leaf length, including spike length and spike length with flowers were positively correlated since the genotypes involved were closely related. This means that if the spike length increases, the spike length with flowers will also increase. Also, if the flower length increases, all the other flower characteristics will also increase.

Spike length and spike length with flowers is orthogonal with flower characteristics. This means that these variables are not related with each other. Meanwhile, the number of spikes and the number of flowers per spike and the flower characteristics were found on the opposite side of the circle with reference to the center and are considered negatively correlated. This means that they are inversely proportional with each other. If any of the flower characteristics increases, the number of spikes and the number of flowers per spike will decrease. Similarly, Magdalita and Valencia (2004) observed on rambutan, that there is a negative correlation between fruit weight and total soluble solids as well as the percent edible portion. In the present study, this means that flower characteristics and spike characteristics like the number of spikes and number of flowers per spike are distinct quantitative characters of *Dendrobium* species, and that they are independent of each other.

Moreover, there is a strong positive correlation between the flower characteristics such as flower width, flower length, petal length, dorsal and lateral sepal length, lip length, lip width, and peduncle length (Table 7). This relationship was also observed between the number of spikes and the above-mentioned flower characteristics including the leaf length and leaf width (**Table 7**). This result may imply that flower width, flower length, number of spikes, and leaf length are the only quantitative characters needed to be evaluated in *Dendrobium* species.

It is also shown that significant values of flower measurements and number of spikes were linked to the horizontal axis F1. High values of flower measurements were located on the right side of the chart, while high values of the number of spikes were on the left side. Meanwhile, important values of spike length with or without flowers were linked to the vertical axis F2. High values of spike length were on the top of the chart, while the low values were on the bottom. Variables like leaf measurements and number of flowers per spike were not specifically linked to an axis. High values of number of strands were located on the left side of the chart, while high values of leaf measurements were on the right.

To reveal the relationships of the plants from each other, an observational chart was presented. (Figure 16). The two-dimensional chart showed the separation of the genotypes based on the traits analyzed. Genotypes on the right side of the chart have the same characteristics as well as the genotypes on the left side. Genotypes #11 and #17 and genotypes #28 and #29 have the same morphological characteristics. However, genotypes #45 and #47 have different characteristics.

Moreover, Figure 16 presents the relationship of the genotypes with the variables. It can be observed that the genotypes on the right-side including Genotypes

Table 6. Factor loading of the 16 quantitative flower traits of *D. anosmum*, *D. aphyllum*, *D. profusum* and *D. bullenianum* in the 16 principal components.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
FW	0.98	-0.05	-0.06	-0.06	0.01	-0.05	-0.02	-0.11	-0.08	-0.04	-0.03	-0.04	-0.08	-0.04	-0.01	0.05
FL	0.94	-0.04	-0.07	0.18	-0.03	0.08	0.01	-0.07	-0.06	0.06	0.07	0.22	0.1	0	-0.02	0.01
PetL	0.98	-0.08	-0.08	-0.06	0.04	0	-0.03	-0.08	-0.08	-0.02	-0.02	-0.05	-0.04	-0.09	-0.09	-0.03
DLSL	0.97	0.01	0	-0.1	0.04	-0.11	-0.03	-0.08	-0.07	-0.09	-0.01	0	0.02	-0.08	0.11	-0.02
LL	0.96	-0.03	-0.04	0.01	-0.07	-0.11	0.04	-0.14	0	-0.06	0.03	0.01	-0.12	0.16	0.01	-0.01
LW	0.85	0.03	-0.25	0.19	-0.05	0.14	-0.09	0.31	0.05	0.07	0.19	-0.05	-0.06	-0.02	0.01	0
PedL	0.93	0.16	-0.1	0.04	-0.08	-0.15	-0.01	0.04	0.04	-0.06	-0.01	-0.13	0.19	0.06	-0.02	0.01
PT	0.04	-0.08	0.02	0.95	0.02	0.26	-0.05	-0.06	0.02	-0.05	-0.1	-0.03	-0.02	0	0.01	0
FLi	-0.21	0.13	-0.42	-0.02	0.86	0.01	-0.07	0.01	0	-0.11	0.03	0.02	0.01	0.02	-0.01	0
LeL	-0.01	0.89	-0.18	-0.05	-0.24	-0.01	-0.17	-0.04	0.24	-0.15	-0.01	0.06	-0.03	-0.04	-0.01	0
LeW	-0.03	0.86	-0.33	-0.07	-0.04	0.13	-0.23	0.02	-0.22	0.15	-0.09	-0.01	-0.01	0.04	0.01	0
LT	-0.36	0.74	-0.05	0.27	0.03	-0.17	0.44	-0.12	-0.06	0.03	0.11	-0.04	-0.01	-0.03	0	0
NS	0.87	0.1	-0.07	0.02	0.25	-0.17	0.17	0.08	0.2	0.21	-0.15	0.02	-0.03	-0.01	0.01	0
SL	0.32	0.38	0.77	0.08	0.09	-0.14	0.07	0.29	-0.11	-0.12	-0.06	0.05	-0.02	0.01	-0.01	0
SLF	0.1	0.22	0.86	0.07	0.25	-0.06	-0.27	-0.18	0.07	0.12	0.1	-0.04	0.01	0	0	0
NFS	0.51	0.22	0.3	-0.34	0.08	0.66	0.22	-0.04	0.05	-0.03	-0.01	-0.03	0.01	0.01	0.01	0

FW – flower width; FL – flower length; PetL – petal length; DLSL – dorsal and lateral sepal length; LL – lip length; LW – lip width; PedL – peduncle length; PT – petal thickness; FLi – flower lifespan; LeL – leaf length; LeW – leaf width; LT – leaf thickness; NS – numberof spikes; SL – stem length;SLF – stem length with flowers; NFS – numberof flowers per spike

Table 7. Correlation matrix of the 16 quantitative flower traits of *D. anosmum*, *D. aphyllum*, *D. profusum* and *D. bullenianum*.

	FW	FL	PetL	DLSL	LL	LW	PedL	PT	FLi	LeL	LeW	LT	NS	SL	SLF	NFS
FW	1	0.9	0.99	0.98	0.96	0.8	0.9	-0.01	-0.17	-0.05	-0.05	-0.39	0.83	0.24	0.05	0.45
FL	0.9	1	0.91	0.88	0.9	0.84	0.86	0.21	-0.2	-0.05	-0.04	-0.32	0.78	0.22	0.04	0.43
PetL	0.99	0.91	1	0.94	0.94	0.81	0.89	0	-0.15	-0.08	-0.06	-0.42	0.82	0.21	0.04	0.46
DLSL	0.98	0.88	0.96	1	0.94	0.76	0.91	-0.07	-0.16	0	-0.03	-0.35	0.83	0.32	0.12	0.45
LL	0.96	0.9	0.94	0.94	1	0.78	0.9	0.02	-0.24	0	-0.07	-0.31	0.82	0.26	0.06	0.4
LW	0.8	0.84	0.81	0.76	0.78	1	0.82	0.21	-0.1	0.06	0.09	-0.3	0.73	0.14	-0.13	0.36
PedL	0.9	0.86	0.89	0.91	0.9	0.82	1	0.02	-0.19	0.18	0.11	-0.19	0.83	0.31	0.03	0.37
PT	-0.01	0.21	0	-0.07	0.02	0.21	0.02	1	-0.02	-0.11	-0.1	0.11	-0.01	0.02	0.07	-0.15
FLi	-0.17	-0.2	-0.15	-0.16	-0.24	-0.1	-0.19	-0.02	1	0.01	0.22	0.18	0.04	-0.25	-0.13	-0.13
LeL	-0.05	-0.05	-0.08	0	0	0.06	0.18	-0.11	0.01	1	0.79	0.56	0.02	0.15	0.03	0.11
LeW	-0.05	-0.04	0.06	-0.03	-0.07	0.09	0.11	-0.1	0.22	0.79	1	0.53	0.01	0.04	-0.06	0.12
LT	-0.39	-0.32	-0.42	-0.35	-0.31	-0.3	-0.19	0.11	0.18	0.56	0.53	1	-0.16	0.16	0.03	-0.14
NS	0.83	0.78	0.82	0.83	0.82	0.73	0.83	-0.01	0.04	0.02	0.01	-0.16	1	0.3	0.08	0.38
SL	0.24	0.22	0.21	0.32	0.26	0.14	0.31	0.02	-0.25	0.15	0.04	0.16	0.3	1	0.71	0.37
SLF	0.05	0.04	0.04	0.12	0.06	-0.13	0.03	0.07	-0.13	0.03	-0.06	0.03	0.08	0.71	1	0.26
NFS	0.45	0.43	0.46	0.45	0.4	0.36	0.37	-0.15	-0.13	0.11	0.12	-0.14	0.38	0.37	0.26	1

FW – flower width; FL – flower length; PetL – petal length; DLSL – dorsal and lateral sepal length; LL – lip length;LW – lip width; PedL – peduncle length; PT – petal thickness; FLi – flower lifespan; LeL – leaf length; LeW – leaf width;LT – leaf thickness;NS – number of spikes;SL – stem length;SLF – stem length with flowers; NFS – number of flowers per spike

#2, #11, #22, etc. have higher flower measurements but have lower number of flowers per spike and number of spikes. Meanwhile, the genotypes on the left side including Genotypes #19, #20, #21, etc. have smaller flower measurements, but have higher number of flowers per spike and number of spikes. It is also shown that the genotypes on the right side like genotypes #2, #11, #22, etc. have bigger leaves compared to the genotypes on the left side including genotypes #19, #20, #21, etc.

Agglomerative Hierarchal Clustering

The 50 *Dendrobium* genotypes were clustered into different classes based on their morphological characteristics. Both qualitative and quantitative traits were used as basis to form the dendrogram using the Agglomerative Hierarchical Clustering. In terms of qualitative data, its corresponding principal coordinates were obtained using Correspondence Analysis.

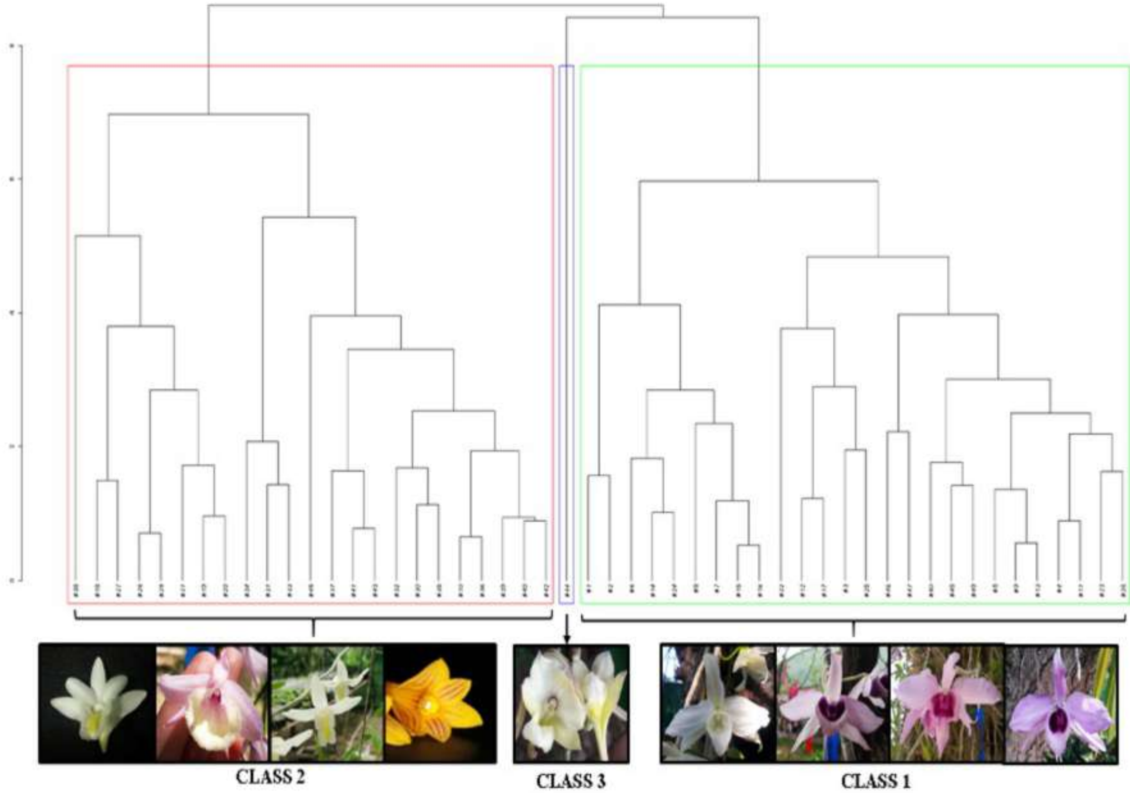

Figure 17. Agglomerative Hierarchical Clustering (AHC) analysis with Euclidean distance and Ward agglomeration resulting in three clusters.

Table 8. Distribution of *Dendrobium* plant genotypes in different classes.

Class	Individual Plant Number	Class Size
1	#1, #2, #3, #4, #5, #6, #7, #8, #9, #11, #12, #13, #14, #15, #16, #17, #22, #23, #24, #25, #26, #46, #47, #48, #49, #50	26
2	#18, #19, #20, #21, #27, #28, #29, #45, #10, #30, #31, #32, #33, #34, #35, #36, #37, #38, #39, #40, #41, #42, #43	23
3	#44	1

Table 9. Mean of quantitative characteristics of different *Dendrobium* genotypes per class.

Plant Characters	Class 1	Class 2	Class 3*
Width (cm)	9.27±1.23	3.87±0.84	2.44
Length (cm)	7.46±0.96	3.69±0.70	2.25
Number of Spikes	2±1.24	7±6.73	1
Spike Length with Flowers (cm)	32.67±18.72	32.81±17.51	12.2
Flower Lifespan (days)	23±3.44	6±6.07	7
Leaf Length (cm)	8.89±2.54	6.75±1.62	10.22
Leaf Width (cm)	2.97±0.87	1.93±0.42	7.68
Leaf Thickness (mm)	1.07±0.37	1.09±0.31	0.81

*Class 3 has no SD since it only contains one plant.

Figure 17 shows the dendrogram of the 50 *Dendrobium* genotypes that were grouped into three different classes and this dendrogram was cut at a Euclidean distance between 3 and 6 as a dissimilarity measure. It also shows that there is a high variability among the different genotypes of *Dendrobium* genotypes as shown by the highly branched structure of the dendrogram. This suggests that selection and evaluation of outstanding genotypes to be used as parents for breeding purposes can be done efficiently. Similar findings were revealed in hierarchal clustering of different pummelo genotypes (Magdalita and San Pascual 2020).

The cluster analysis divided the *Dendrobium* genotypes into three classes: Class 1, Class 2, and Class 3. Table 8 shows that Class 1 has the biggest class size where there are 26 genotypes including genotypes #1, #2, #3, #4, #5, #6, #7, #8, #9, #11, #12, #13, #14, #15, #16, #17, #22, #23, #24, #25, #26, #46, #47, #48, #49, and #50. It is then followed by Class 2 with 23 genotypes including genotypes #18, #19, #20, #21, #27, #28, #29, #45, #10, #30, #31, #32, #33, #34, #35, #36, #37, #38, #39, #40, #41, #42, and #43. Lastly, Class 3 is composed of only a single genotype which is genotype #44.

Class 1 is composed of genotypes belonging to *D. anosmum* and *D. anosmum* var. *dearie.* This class contains genotypes with significantly larger flowers compared to the two other classes with a mean flower width and length of 9.27 cm and 7.46 cm, respectively (Table 9). In addition, this class has the longest mean flower lifespan of 23 days. Meanwhile, Class 2 is composed of three different species of *Dendrobium* including *D. aphyllum, D. crumenatum,* and *D. bullenianum*. This class contains genotypes with the greatest mean number of spikes of seven (ie. 7 spikes per genotype), and has the longest mean spike length

Figure 18. Selected *D. anosmum* genotype #3 having medium sized flowers, high number of spikes and flowers per spike with 28 days floral longevity.

Figure 19. Selected *D. aphyllum* genotype #20 with high number of flowers per spike and number of spikes and has large flowers with 14 days floral longevity.

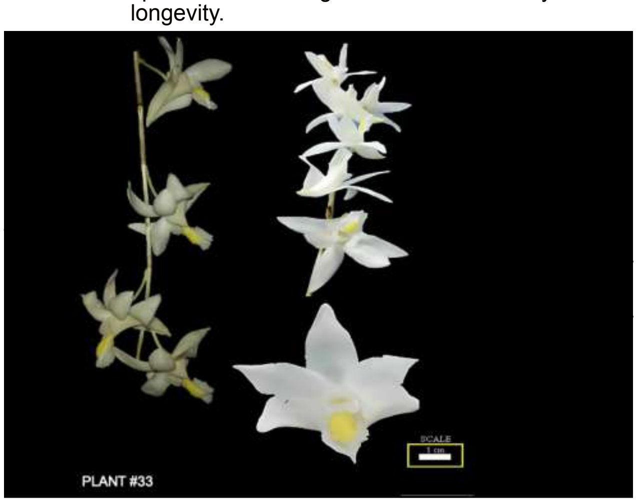

Figure 20. Selected *D. crumenatum* genotype #33 with high number of spikes and flowers per spike with only one day floral longevity.

Table 10. The mean, range, standard deviation, coefficient of variation (%) and Shannon Weaver diversity index (H') of some plant characters evaluated in 50 genotypes of *Dendrobium*.

Plant Characters	Mean	Range	H'	CV (%)
Flower width (cm)	6.65 ±2.95	1.54-13.2	0.23	44.36
Flower length (cm)	5.62±2.11	1.29-10.1	0.20	37.59
Number of spikes	4±5.30	1-25	0.06	132.38
Spike length with flowers (cm)	32.33 ±18.03	3.2-71.17	0.22	55.76
Flower lifespan (days)	14.16±9.83	1-28	0.33	69.45
Leaf length (cm)	7.93 ±2.39	3.86-12.3	0.24	30.13
Leaf width (cm)	2.59±1.16	1.22-7.98	0.20	44.70
Leaf thickness (mm)	1.07±0.34	0.51-1.80	0.24	31.29

Table 10 shows the mean, range, coefficient of variation and Shannon-Weaver diversity index (H') of the plant characters of *Dendrobium* genotypes. Wide variability in the characteristics can be observed if the value of H' is close to 1. The widest variability was observed in flower lifespan with H' = 0.33 (Table 10). This finding agrees with the previous report of Valmayor (1984) that the genus *Dendrobium* exhibits a tremendous diversity of structure both vegetative and floral characteristics. Similar results were also observed on avocado in which characters like fruit width, seed weight and peel thickness showed a wide variability (Magdalita and Valencia, 2004). Result of the present study may indicate that flower lifespan is the most important characteristic in a *Dendrobium* genotype to be considered when selecting desirable genotypes. This may suggest to the orchid breeders that elite genotypes to be considered in selection shall have a long flower lifespan regardless of the species. This flower trait to be considered as one of the selection criteria is commonly wanted in many flowers including anthurium, zinnia, globe amaranth, hibiscus, orchids like *Paphiopedilum*, etc. (Zhang et al. 2021; Magdalita et al. 2019; Jiang et al. 2011).

The second highest Shannon-Weaver diversity index (H') was revealed for leaf length, leaf thickness, flower width, spike length with flowers, flower length and leaf width with H'= 0.24, 0.24, 0.23, 0.22, 0.20 and 0.20, respectively.This result may suggest that these characteristics can be also used and considered in selecting desirable *Dendrobium* genotypes. Specifically, this implies that the selection of *Dendrobium* genotypes for breeding can be also focused on traits like large flowers, large leaves, and long spikes.

However, the lowest Shannon-Weaver diversity index (H') of 0.06 was revealed for the number of spikes indicating the narrowest diversity among the plant characters (H'=0.06). According to Magdalita and Valencia (2004), a narrow variability is caused by the distinct differences of the individual genotypes. Where a narrow variability of traits exists, this needs to be broadened by implementing either interspecific hybridization or induction of mutation via physical or chemical mutagenesis including somaclonal variation in tissue culture (Quiros et al. 2023; Oladosu et al. 2016).

Selection of desirable genotypes was also done based on its desirable morphological characteristics revealed through hierarchical clustering analysis and Shanon-Weaver Diversity Index. One desirable genotype in each *Dendrobium* species was selected. Specifically, the genotype was selected based on flower size, flower lifespan, number of strands and number of flowers per strand.

Among the 26 *D. anosmum* plants, genotype #3 was selected (Figure 18). This genotype has medium sized flowers, has the greatest number of spikes and contains a large number of flowers per spike (Table 8). It also has the longest flower lifespan of 28 days. In *D. aphyllum*, genotype #20 was selected among the 7 genotypes under this species (Figure 19). In comparison to other genotypes, this genotype has the greatest number of flowers with a relatively high number of spikes and large flowers (Table 8). The flower lifespan is 14 days.

Moreover, among the 15 genotypes belonging to the species *D. crumenatum*, genotype #33 was selected (Figure 20). It has the second highest number of strands with relatively high number of flowers per strand and large flowers (Table 8). All the flowers on the spike last only for one day.

SUMMARY AND CONCLUSION

Orchidaceae is among the largest flowering plant families in the world. It can easily adapt to any type of environment and exists in various colors, shapes, sizes and scent. Due to its various characteristics, breeders attempt to improve and develop its phenotypic traits, disease resistance, and flower lifespan through varietal breeding. This is done mainly for production and marketing purposes, since species like *Dendrobium* is popularly used as potted plants and cut flowers. This study characterized the five *Dendrobium* species and; identified the correlation between quantitative and qualitative traits of 50 *Dendrobium* genotypes.

The correlation between quantitative characters of *Dendrobium* species as well as the distribution of the genotypes per species were determined. It was ascertained that the set of traits that are related with one another shows positive correlation. Each parameter within flower, leaf, and spike characteristics are directly proportional to each other. Moreover, negative correlations existed between spike characteristics and flower characteristics as plants with bigger flowers have lower number of spikes or number of flowers. However, there are also traits without correlation. This relationship is mainly detected in leaf characteristics since its variation does not affect either the flower or spike characteristics.

The 50 *Dendrobium* genotypes were also divided into three classes based on their quantitative and qualitative traits. Class 1 contains *D. anosmum* and *D. anosmum* var. *dearie* and the genotypes are grouped based on flower size in which they were identified as having the biggest flowers and longest flower lifespan. Meanwhile, Class 2 contains *D. aphyllum, D. crumenatum,* and *D. bullenianum* genotypes and the genotypes were grouped based on the number of flowers per spike and they were detected collectively as having the highest number of spikes and longest spike with flowers but having the shortest flower lifespan. Lastly, Class 3 contains *D. profusum* in which it has the shortest flower length and narrowest width, lowest number of spikes and shortest spike length with flowers.

The phenotypic characters of the *Dendrobium* species were highly variable. Flower lifespan showed to be the most important characteristic of *Dendrobium* to be considered in selection alongside with the flower, leaf, and spike characteristics.

Genotypes were selected based on outstanding morphological characteristics such as attractive flower colors, big flowers and the plants are floriferous in each *Dendrobium* species. Among *D. anosmum* genotypes, genotype #3 was selected for having many flowers that are relatively large and longest flower lifespan. In *D. aphyllum* genotypes, genotype #20 was selected since it has also high number of flowers that are relatively large, and high number of spikes. In addition, among *D. cremenatum* genotypes, genotype #32 was selected for having large flower, and high number of flowers and spikes.

Overall, it was determined that phenotyping plant characters of *Dendrobium* species showed that traits belonging to the same set of characteristics for flower, leaf, or spike showeed positive correlation while those which do not, showed negative or no correlation. The *Dendrobium* species were grouped accordingly based on the plant characteristics that they share like flower sizes and number of flowers. Successful selection of parents was based on the identification of the most important phenotypic trait like prolificacy, flower color and size including long flower retention.

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