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RESEARCH ARTICLE

Morphophysiological adaptations and fragrance profile analysis of two relocated orchid species

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Abstract

This study investigates the morpho-physiological adaptations and fragrance profiles of 2 relocated orchid species, *Cattleya aclandiae* x *Brassavola* Little star (V_1) and *Dendrobium var.* Meesangnil (V_2), following their translocation from Nagercoil to Coimbatore, India. The research aims to elucidate the mechanisms underlying successful acclimatization of these fragrant orchids to a new environment, with implications for horticulture, conservation and therapeutic applications. Comprehensive analyses were conducted on vegetative growth parameters, flowering characteristics, physiological responses and volatile organic compound (VOC) profiles. Morphological assessments revealed distinct adaptive strategies between the 2 species, with *Dendrobium* exhibiting superior vertical growth (39.13 cm) and leaf production (9 leaves/plant), while *Cattleya* developed larger leaves (30.483 cm length, 7.178 cm breadth) and longer internodes (5.061 cm). Flowering characteristics also differed significantly, with *Cattleya* demonstrating earlier spike emergence and floret opening. Physiological analyses using a CI-340 Handheld Photosynthesis System showed higher photosynthetic rates, transpiration rates and stomatal conductance in *Dendrobium*, suggesting a more resource-acquisitive strategy. Gas chromatography-mass spectrometry (GC-MS) analysis identified unique VOC profiles for each species, with 30 compounds detected in both varieties, including notable compounds such as n-Hexadecanoic acid, Octadecanoic acid and beta-Sitosterol. The study also explored potential applications in therapeutic horticulture, highlighting the diverse sensory and educational value of these orchid species. This comprehensive analysis of morphological, physiological and biochemical adaptations provides valuable insights into orchid acclimation processes and their potential for conservation and horticultural applications, contributing to our understanding of plant adaptability in the face of environmental changes and offering a foundation for future studies on orchid biology, ecology and therapeutic uses.

Keywords

Fragrant orchids; Relocation; Morphophysiological plasticity; Therapeutic horticulture; Gas chromatography-mass spectrometry

Introduction

Orchidaceae, one of the largest and most diverse families of flowering plants, has long captivated human interest due to its remarkable morphological diversity, ecological adaptability and aromatic properties. Within this expansive family, fragrant orchids hold a position of particular significance for their horticultural value and scientific interest. Genera such as *Dendrobium*, *Cattleya* and *Brassavola* have garnered substantial attention in both research and commercial horticulture due to their distinctive fragrances and adaptability to various environmental conditions (1). *Dendrobium*, a genus comprising over 1500 species, is renowned for its diverse array of floral scents, ranging from sweet and fruity to spicy and complex. Many *Dendrobium* species, such as *D. nobile* and *D. anosmum*, have been the subject of extensive phytochemical studies, revealing a rich tapestry of volatile organic compounds (VOCs) that contribute to their characteristic fragrances (2). These VOCs, including various terpenes, phenylpropanoids and benzenoids, not only serve ecological functions in pollinator attraction but also contribute to the genus's horticultural appeal (3). Cattleya orchids, often referred to as the "queen of orchids," are celebrated for their large, showy flowers and intense fragrances. Species like *C. labiata* and *C. dowiana* are particularly noted for their complex scent profiles, which can vary diurnally and throughout the flower's lifespan (4). The aromatic bouquet of *Cattleya* species typically includes compounds such as linalool, geraniol and various esters, which collectively contribute to their alluring and often citrusy or vanilla-like scents (5). The genus's ability to produce such compelling fragrances has made it a cornerstone of the orchid hybridization industry. *Brassavola*, a genus comprising approximately 20 species, is renowned for its night-fragrant flowers, most notably exemplified by *B. nodosa*, the "Lady of the Night" orchid. The nocturnal emission of strong, sweet fragrances by *Brassavola* species represents an evolutionary adaptation to attract night-active pollinators, primarily moths. The chemical composition of *Brassavola* fragrances typically includes high concentrations of monoterpenes and sesquiterpenes, with some species producing complex blends of over 40 different volatile compounds (6).

The relocation of fragrant orchids from their native habitats to new environments presents both challenges and opportunities for horticulturists and researchers alike. Environmental factors such as temperature, humidity, light intensity and substrate composition can significantly influence not only the growth and morphology of orchids but also their fragrance production and chemical composition (7). Understanding the adaptive responses of fragrant orchids to new environments is crucial for their successful cultivation and conservation. Recent advances in analytical techniques, particularly gas chromatography-mass spectrometry (GC-MS), have revolutionized our ability to characterize and quantify the complex mixture of volatile compounds that contribute to orchid fragrances (8). This technology allows for the precise identification of individual components within a fragrance profile, facilitating comparative studies across species and environmental conditions. Such detailed chemical analyses, when combined with morphological and physiological observations, provide a comprehensive understanding of how fragrant orchids adapt to new environments. The ability of orchids to adapt to new environments is not only of horticultural interest but also has significant implications for conservation efforts. As natural habitats face increasing threats from climate change and human activities, understanding how these plants respond to environmental changes becomes crucial for developing effective conservation strategies. Moreover, the study of orchid adaptation can provide insights into the broader mechanisms of plant acclimation and evolution. In light of these considerations, this study aims to evaluate the performance and adaptability of 2 fragrant orchid species, with a particular focus on representatives from the genera *Dendrobium*, *Cattleya* and *Brassavola*, when relocated to a new environment. By examining morphological changes, physiological adaptations and alterations in fragrance profiles, we seek to elucidate the mechanisms underlying successful acclimatization. Through a combination of detailed morpho-physiological analyses and advanced GC-MS characterization of volatile compounds, this research endeavors to contribute to our understanding of orchid biology, ecology and conservation. The findings of this study have the potential to inform horticultural practices, guide conservation efforts and enhance our appreciation of the remarkable adaptability of fragrant orchids. By investigating how these plants respond to environmental changes, we can gain valuable insights into their resilience and plasticity, which may prove crucial in predicting and mitigating the impacts of global environmental changes on orchid populations.

Materials and Methods

Experimental site and planting material

The present study was carried out at the Department of Floriculture and Landscaping, Tamil Nadu Agricultural University, Coimbatore (Latitude of 11000'N, Longitude of 77000'E and an elevation of 412 m above MSL), Tamil Nadu during 2023-2024.

Relocation of Fragrant orchids

Orchid species *Cattleya aclandiae* x *Brassavola* Little Star (V_1) (Fig. 1(A)) and *Dendrobium var.* Meesangnil (V_2) (Fig. 1 (B)) were relocated from Perumchilambu village, Nagercoil to Botanical Garden, TNAU, Coimbatore and it is crucial to consider the climatic variations between these locations. Nagercoil, situated in the southernmost part of Tamil Nadu, experiences a tropical climate with higher humidity and rainfall due to its coastal proximity. In contrast, Coimbatore, located in the western part of the state, has a more moderate climate characterized by lower humidity and less precipitation.

Vegetative and flowering parameter analysis

Vegetative characteristics studied in the present study include plant height, leaf dimensions (length and breadth),

Fig 1 (A)

Fig 2 (B)

Fig. 1(A) and 1(B). Florets of *Cattleya aclandiae* x *Brassavola* Little star (V_1) and *Dendrobium var.* Meesangnil (V_2).

internode metrics (length and diameter) and leaf count per plant. Flowering parameters were meticulously recorded, focusing on temporal aspects such as days to first spike emergence and initial floret opening. Floral morphology was quantified through measurements of floret length and diameter, spike and rachis length and spike longevity. Additionally, the study documented the number of flowers per spike and spikes per plant, providing a holistic view of the orchids' reproductive output.

Physiological parameters analyzed

Photosynthesis and transpiration rates were determined using a CI-340 Handheld Photosynthesis System manufactured by CID Bio-Science, Inc. This device was utilized to analyze leaf samples by placing them individually in the instrument's chamber and allowing them to adjust to the light conditions for 2 min prior to analysis. The CI-340 Handheld Photosynthesis System automatically calculated photosynthesis and transpiration rates by comparing carbon dioxide and water vapor levels respectively, between the chamber and the surrounding atmosphere. Each analysis comprised 5 consecutive measurements taken over a period of approximately 10 min. These readings were taken between 09:00 and 11:30 h to minimize the impact of diurnal variations. The system's design, which directly links the leaf chamber to the CO_2/ H_2O differential gas analyzer, enables the measurement of photosynthesis, transpiration, stomatal conductance and internal CO_2 with minimal sample degradation. This configuration reduces the risk of leaks, water vapor changes or temperature fluctuations, thereby preserving the integrity of the sample. The CI-340 Handheld Photosynthesis System is capable of measuring multiple parameters, including:

1. Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})
2. Transpiration rate (m mol H_2O m^{-2} s^{-1})
3. Stomatal conductance (mol H_2O m^{-2} s^{-1})

This methodology allows for comprehensive, non-destructive analysis of leaf gas exchange parameters, providing insights into the physiological responses of the studied orchid species to their environment.

SPAD value

Foliar chlorophyll content was quantified utilizing a SPAD-502 Spectrophotometric analyzer (Soil-Plant Analysis Development Division, Minolta Corporation, Japan). This instrument assesses chlorophyll levels by measuring the differential light transmittance at 650 nm and 940 nm wavelengths. For each experimental condition, 5 discrete measurements were recorded and their mean was calculated following the protocol reported (9). The resulting values, expressed in arbitrary SPAD units, served as a non-destructive proxy for leaf chlorophyll concentration.

Gas-Chromatography Coupled with Mass Spectroscopy (GC-MS) Analysis

Gas chromatography-mass spectrometry (GC-MS) analysis was employed to characterize the secondary metabolites present in the methanolic leaf extracts of *Catteleya aclandiae* x *Brassavola* Little star and *Dendrobium var.* Meesangnil with a method (10). Prior to analysis, each extract was solubilized in 100 % methanol. The GC-MS analysis was performed using an Agilent GC 7890A coupled with an MS 5975C detector. Separation was achieved on an Agilent DB5MS capillary column (30 m length, 0.25 mm internal diameter, 0.25 µm film thickness). Sample introduction was accomplished via split-mode injection, with helium serving as the carrier gas. Compound identification was based on the comparison of retention times and mass spectral fragmentation patterns with those in the National Institute of Standards and Technology (NIST) spectral library. This approach allowed for the tentative identification of bioactive constituents present in the orchid petal extracts. The chromatogram of the samples was examined by comparing their mass with spectral database (https://www.nist.gov/).

Statistical analysis

The statistical analysis for this study was conducted using R software version 4.4.1, employing a comprehensive approach to data evaluation. A one-way analysis of variance (ANOVA) was performed to assess statistically significant differences between treatments, with significance thresholds set at $p \leq 0.05$, 0.01 and 0.001. To further elucidate the intricate relationships between the observed variables, a Pearson correlation matrix was constructed using R. Visual representations of the data, including correlation plots and descriptive statistics were generated using Prism10 software (GraphPad Software, Inc., La Jolla, California, USA).

Results and Discussion

Morphological Adaptations

The 2 orchid varieties exhibited distinct differences in their vegetative growth parameters, indicating divergent strategies for resource allocation and structural development (Fig. 2). *Dendrobium var.* Meesangnil demonstrated superior vertical growth, attaining a mean plant height of 39.13 cm, which was approximately 41.9 % more than *Cattleya aclandiae* x *Brassavola* Little star, which reached an average height of 27.582 cm. This difference was statistically significant ($p < 0.05$, CD = 1.944).

In terms of foliage development, *Dendrobium var.* Meesangnil produced a higher number of leaves per plant, with an average of 9 leaves, compared to 6 leaves for *Cattleya aclandiae* x *Brassavola* Little star, as observed 150 days after planting. This 50 % increase in leaf production was statistically significant ($p < 0.05$, CD = 0.588), indicating a potentially greater photosynthetic capacity for the *Dendrobium* variety.

Leaf morphology varied considerably between the 2 orchid varieties. *Cattleya aclandiae* x *Brassavola* Little star exhibited longer and broader leaves, with mean leaf length and breadth of 30.483 cm and 7.178 cm respectively. In contrast, *Dendrobium var.* Meesangnil produced shorter and narrower leaves, measuring 14.987 cm in length and 5.187 cm in width on average. The difference in leaf length was particularly pronounced, with *Cattleya aclandiae* x *Brassavola* Little star leaves being approximately 103.4 % longer than those of *Dendrobium var.* Meesangnil. This difference was statistically significant ($p < 0.05$, CD = 0.721). Leaf breadth also differed significantly between the 2 varieties ($p < 0.05$, CD = 0.525), with *Cattleya aclandiae* x *Brassavola* Little star leaves being about 38.4 % wider.

Internode characteristics showed inverse relationships between length and diameter for the 2 orchid varieties. *Cattleya aclandiae* x *Brassavola* Little star displayed longer internodes, with a mean length of 5.061 cm, which was approximately 58.2 % greater than the average internode length of 3.199 cm observed in *Dendrobium var.* Meesangnil. This difference was statistically significant ($p < 0.05$, CD = 0.159). Conversely, *Dendrobium var.* Meesangnil exhibited thicker internodes, with a mean diameter of 1.720 cm, compared to 1.445 cm for *Cattleya aclandiae* x *Brassavola* Little star (Table 1). This represents a 19 % increase in internode diameter for *Dendrobium var. Meesangnil*, which was statistically significant ($p < 0.05$, CD = 0.077).

These distinct morphological growth attributes suggest that the 2 orchid varieties have adopted different strategies for resource allocation and structural support in response to their relocation. *Dendrobium var.* Meesangnil appears to prioritize vertical growth and leaf production, potentially maximizing light interception through numerous smaller leaves. In contrast, *Cattleya aclandiae* x *Brassavola* Little star seems to invest in fewer, larger leaves with more substantial internodes, possibly indicating a strategy

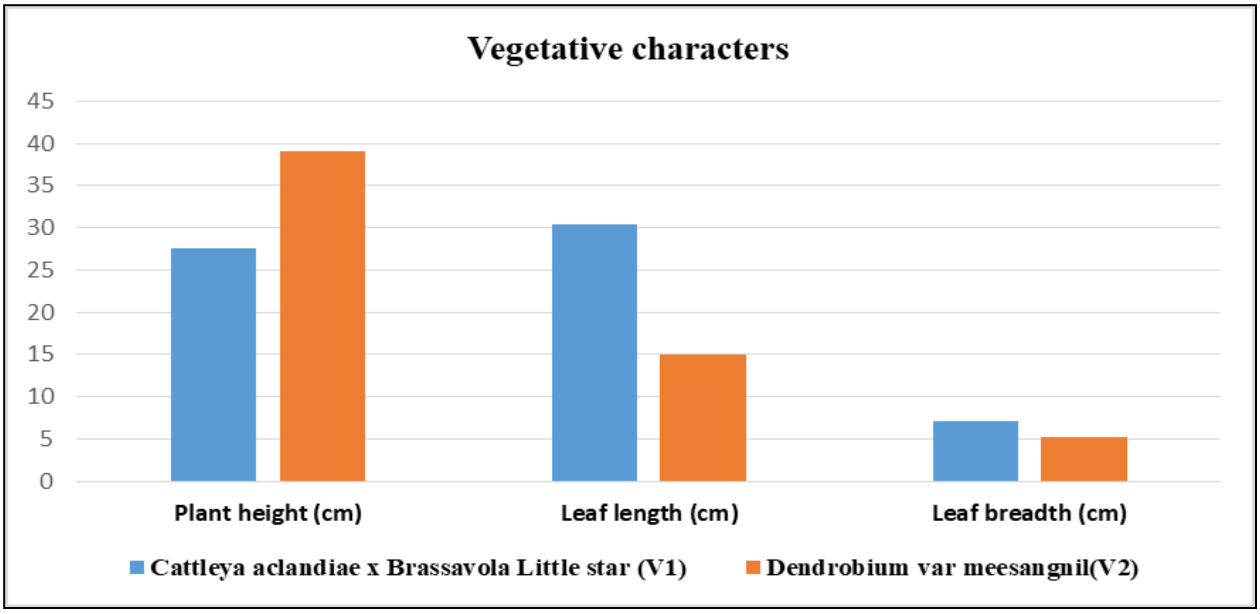

Fig. 2. Vegetative parameters of orchid varieties of V_1 and V_2.

Table 1. Variation of growth parameters in orchid varieties.

Varieties	Plant height (cm)	Leaf length (cm)	Leaf breadth (cm)	No. of leaves / plant	Internode length (cm)	Internode Diameter (cm)
Cattleya aclandiae x *Brassavola*	27.582	30.483	7.178	6.00	5.061	1.720
Dendrobium var. Meesangnil (V_2)	39.13	14.987	5.187	9.00	3.199	1.445
SEd	0.682	0.253	0.184	0.206	0.056	0.027
CD (0.05)	1.944	0.721	0.525	0.588	0.159	0.077

focused on efficient resource utilization and structural stability. This approach may be advantageous in environments with limited resources or during periods of stress (11). These data are in line with the works done (12) on reproductive phenology and morphological analysis of Indian *Dendrobium* Sw. (Orchidaceae) from the Northeast region. It was observed that the growth and flowering parameters were in the same trend with the original location from which the plants were collected.

Flowering Characteristics

The 2 orchid varieties exhibited notable differences in their flowering phenology and morphology, suggesting distinct reproductive strategies in response to their new environment (Fig. 3). *Cattleya aclandiae* x *Brassavola* Little star demonstrated earlier spike emergence, with the first spike appearing on average at 330.54 days. In contrast, *Dendrobium var.* Meesangnil required a longer period of 380.9 days for initial spike emergence. This variation in flowering time aligns with observations (13), who reported significant interspecific differences in flowering initiation among relocated orchid species. The trend continued for floret opening, with *Cattleya aclandiae* x *Brassavola* Little star reaching this stage at 367.05 days, while *Dendrobium var.* Meesangnil took 421.74 days (Table 2). This difference of approximately 54 days in floret opening time could have important implications for pollination and reproductive success in their new environment. Such variations in flowering timing can significantly impact orchid conservation efforts and adaptation to new habitats (14).

Dendrobium var meesangnil produced larger florets compared to *Cattleya aclandiae* x *Brassavola* Little star. The average floret length for *Dendrobium* was 9.853 cm, while *Cattleya* measured 6.968 cm. Similarly, floret diameter was greater in *Dendrobium* (6.64 cm) compared to *Cattleya* (4.68 cm). These differences in floret size could influence pollinator attraction and reproductive success, as larger flowers often serve as stronger visual cues for pollinators in terms of inflorescence architecture, *Dendrobium var.* Meesangnil developed longer spikes and rachises compared to *Cattleya aclandiae* x *Brassavola* Little star. The average spike length for *Dendrobium* was 29.694 cm, with a rachis length of 14.868 cm. In contrast, *Cattleya* produced shorter spikes (10.533 cm) and rachises (6.533 cm). This difference in inflorescence architecture could affect the display of flowers and consequently, pollinator behavior. Inflorescence structure plays a crucial role in orchid pollination success, and these differences may influence the reproductive strategies of the relocated species (15).

Dendrobium var. Meesangnil produced a higher number of flowers per spike, averaging 5 flowers compared to 2.91 for *Cattleya aclandiae* x *Brassavola* Little star. However, *Cattleya* compensated with a higher number of spikes per plant (2.00) compared to *Dendrobium* (1.24). These contrasting strategies in flower production align with findings (16), who observed diverse reproductive allocation

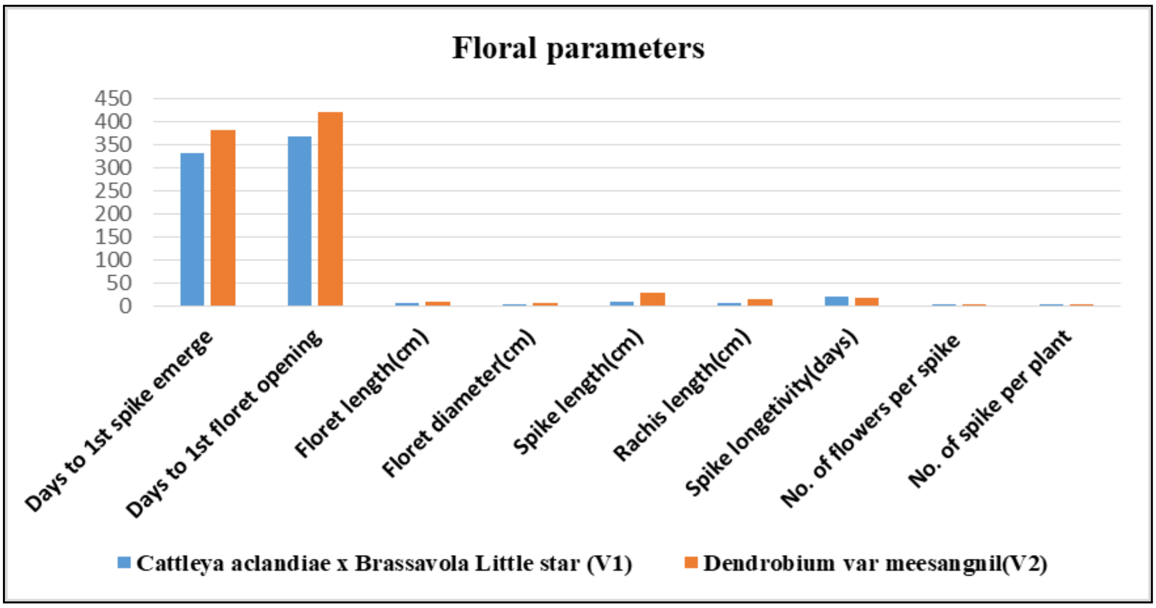

Fig. 3. Floral parameters of orchid varieties V_1 and V_2.

Table 2. Variations of flowering parameters in orchid species.

Varieties	Days taken for 1st spike to emerge	Days taken for 1st floret opening	Floret length (cm)	Floret diameter (cm)	Spike length (cm)	Rachis length (cm)	Spike longetivity (days)	No. of flowers per spike	No. of spike per plant
Cattleya aclandiae x *Brassavola* Little star (V_1)	330.54	367.05	6.968	4.68	10.533	6.533	19.47	2.91	2.00
Dendrobium var. Meesangnil (V_2)	380.9	421.74	9.853	6.64	29.694	14.868	18.17	5	1.24
SEd	9.296	7.899	0.250	0.131	0.735	0.305	0.328	0.087	0.045
CD (0.05)	26.502	2.517	0.712	0.375	2.095	0.869	0.936	0.249	0.127

patterns among orchid species in response to environmental changes. Interestingly, *Cattleya aclandiae* x *Brassavola* Little star exhibited slightly longer spike longevity (19.47 days) compared to *Dendrobium var.* Meesangnil (18.17 days). This extended flowering duration could potentially increase the chances of successful pollination (17). Flower longevity is a critical factor in orchid reproductive success, especially in environments with unpredictable pollinator activity. The observed differences in flowering parameters between the 2 orchid varieties suggest distinct reproductive strategies in response to their new environment. The earlier flowering and higher spike production of *Cattleya aclandiae* x *Brassavola* Little star may represent an adaptation to maximize reproductive opportunities, while the larger and more numerous flowers of *Dendrobium var.* Meesangnil could indicate a strategy focused on increased visual attraction to pollinators. These data are in line with the works done (18) on evaluation of floral characters of selected indigenous sympodial epiphytic orchids of Western Ghats. It was observed that the flowering parameters were in the same trend with the original location from which the plants were collected. These findings contribute to our understanding of how relocated orchid species adjust their reproductive phenology and morphology in new habitats. Such adaptations are crucial for the long-term survival and establishment of translocated orchid populations (19).

Physiological Adaptations

The physiological parameters measured in this study reveal distinct functional strategies between the 2 orchid varieties, providing insights into their adaptive mechanisms in response to relocation (Fig. 4 and 5). The SPAD values, which serve as a proxy for chlorophyll content, showed notable

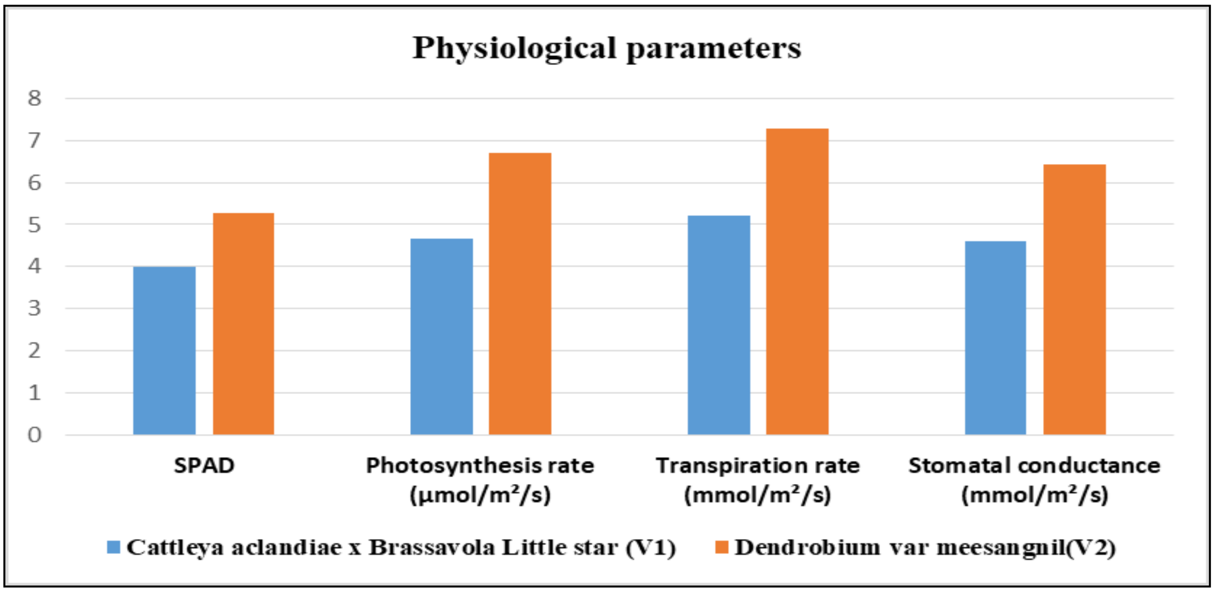

Fig. 4. Physiological parameters of orchid varieties V_1 and V_2.

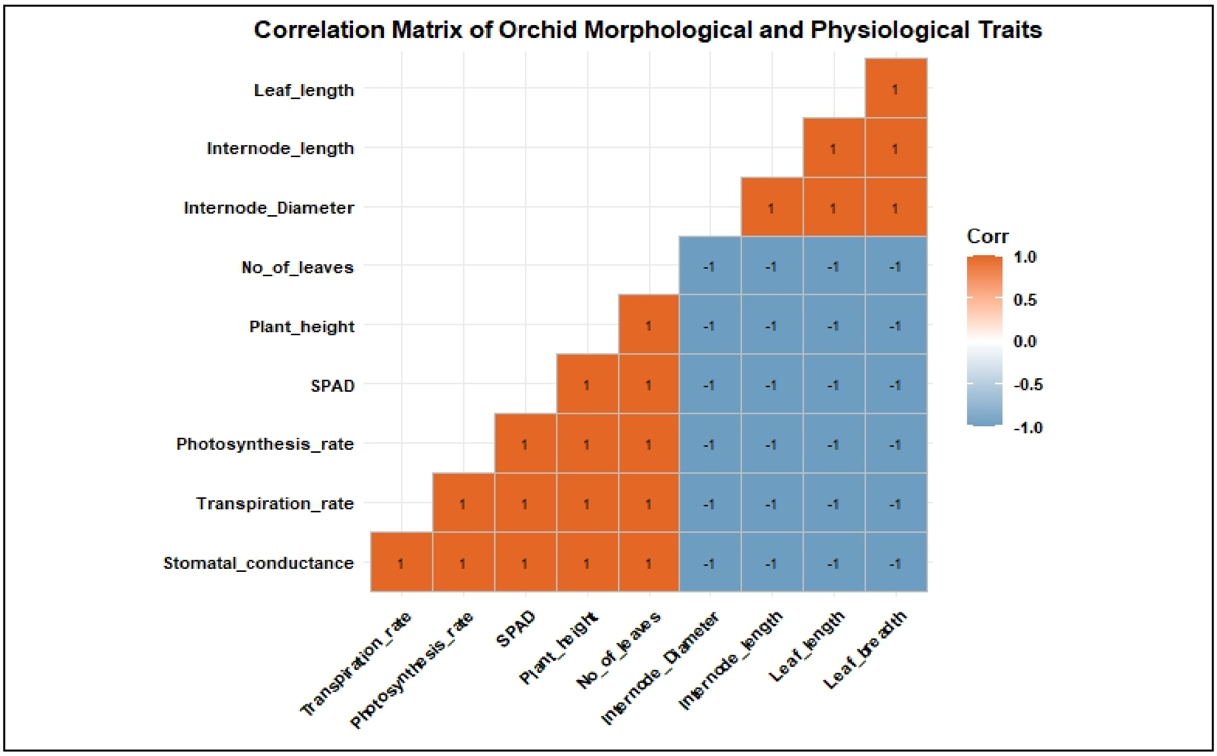

Fig. 5. Pearson correlation matrix between vegetative and morphological characters of V_1 and V_2.

differences between the 2 orchid varieties. *Dendrobium var.* Meesangnil exhibited a higher SPAD value of 5.284 compared to 3.989 for *Cattleya aclandiae* x *Brassavola* Little star. This suggests that *Dendrobium* may have a greater chlorophyll concentration in its leaves, potentially indicating improved adaptability to varied light conditions in new environment and species with higher chlorophyll content often demonstrate greater plasticity in response to changes in light intensity (20). *Dendrobium var.* Meesangnil displayed a superior photosynthetic rate of 6.712 µ mol/m^2/s, compared to 4.652 µ mol/m^2/s for *Cattleya aclandiae* x *Brassavola* Little star. This higher photosynthetic capacity in *Dendrobium* could indicate a more efficient carbon assimilation process. Orchid species with higher photosynthetic rates often show better acclimation to new habitats (21), potentially due to their ability to maintain carbon balance under varying environmental conditions.

The transpiration rate was notably higher in *Dendrobium var.* Meesangnil (7.283 m mol/m^2/s) compared to *Cattleya aclandiae* x *Brassavola* Little star (5.203 m mol/m^2/s) (Table 3). This increased transpiration could indicate a more active water transport system in *Dendrobium*, which might be advantageous in certain environmental conditions. Higher transpiration rates can also lead to increased water loss (22), suggesting a potential trade-off between water use efficiency and carbon gain that may influence the species' adaptation to their new environment.

Stomatal conductance measurements revealed higher values for *Dendrobium var.* Meesangnil (6.426 m mol/m^2/s) compared to *Cattleya aclandiae* x *Brassavola* Little star (4.615 m mol/m^2/s). This increased stomatal conductance in *Dendrobium* corresponds with its higher photosynthetic and transpiration rates. Higher stomatal conductance often exhibit greater plasticity (23), in response to environmental changes, potentially facilitating their adaptation to new habitats.

The physiological parameters observed in this study reveal distinct functional strategies between the 2 orchid varieties. *Dendrobium var.* Meesangnil appears to adopt a more resource-acquisitive strategy, characterized by higher chlorophyll content, photosynthetic rate, transpiration rate and stomatal conductance. This approach may allow for rapid resource capture and growth, potentially beneficial in environments with abundant resources or during favorable seasons. In contrast, *Cattleya aclandiae* x *Brassavola* Little star exhibits lower values across all measured physiological parameters, which might indicate a more conservative resource-use strategy. This approach could be advantageous in environments with limited resources or during periods of stress. Such physiological diversity among orchid species can contribute to their overall resilience and adaptability in the face of environmental changes (24). The observed differences in physiological parameters between these 2 orchid varieties provide valuable insights into their potential acclimation strategies in their new environment. The higher photosynthetic capacity and stomatal conductance of *Dendrobium var.* Meesangnil suggest it may be better equipped to take advantage of favorable conditions, while the more conservative approach of *Cattleya aclandiae* x *Brassavola* Little star might confer greater stress tolerance. These findings contribute to our understanding of the physiological basis of orchid adaptation to new environments and support the idea that such physiological plasticity is crucial for the successful establishment and long-term survival of relocated orchid populations.

Biochemical Profile Analysis

The GC-MS analysis of methanolic extracts from *Brassavola* ‘Little star’ (V_1) and *Dendrobium var.* Meesangnil (V_2) revealed complex and distinct phytochemical profiles, providing insights into the biochemical adaptations of these orchid species to their new environment. For *Cattleya aclandiae* x *Brassavola* Little star (V_1), notable compounds detected include Silane, Thymine, 4H-Pyran-4-one, 1,2-Benzenediol, Benzofuran, 4-Mercaptophenol and 2-Methoxy-4-vinylphenol, among others. The presence of these diverse compounds suggests a rich biochemical repertoire that may contribute to the species' adaptive capacity. For instance, 2-Methoxy-4-vinylphenol has been associated with antioxidant properties in plants (25), which could play a role in stress tolerance mechanisms. The *Dendrobium var.* Meesangnil extract (V_2) exhibited a different phytochemical profile, featuring compounds such as Butane, 4,5-Diamino-2-hydroxypyrimidine, 4H-Pyran-4-one, Benzofuran, 2-Furancarboxaldehyde and 2-Isopropoxyethyl propionate. This unique profile may reflect species-specific adaptations to environmental stress or contribute to the characteristic fragrance of the respective orchid variety.

Both extracts contained a range of organic compounds including aromatic hydrocarbons, phenols, fatty acids and sterols. The presence of these diverse phytoconstituents suggests potential biological activities that require additional study. Compounds such as Benzofuran, found to be present in both species (V_1 and V_2), and 2-Methoxy-4-vinylphenol in V_1, are known for their aromatic properties and may contribute to the characteristic fragrances of these orchid species (Table 4 and 5), (Fig. 6 and 7). These volatile organic compounds (VOCs) could play important roles in plant-pollinator interactions (26). Notably, both species comprised significant proportion of n-Hexadecanoic acid and Octadecanoic acid, with V_1 showing higher relative abundances (6.67 % and 9.70 % respectively) compared to V_2 (2.45 % and 3.55 % respectively). These fatty acids have been reported to be associated with anti-inflammatory and antimicrobial properties in previous studies (27), suggesting potential applications in aromatherapy or topical treatments within therapeutic horticulture programs.V_2 exhibited higher levels of beta-Sitosterol 19.42 % vs. 15.40 % in V_1, a compound known for its potential role in reducing cholesterol and improving immune function (28). This discovery indicates the possible applications in holistic wellness programs incorporating medicinal plants. The presence of Vitamin E (4.18 % in V_1, 3.67 % in V_2) in both species underscores their potential antioxidant properties, which could be leveraged in educational programs about plant-based nutrition and health within therapeutic horticulture settings.

The phyto-chemical profiling of both the orchid

Table 3. Variation of physiological parameters in V_1 and V_2.

Varieties	SPAD	Photosynthesis rate (μ mol/m²/s)	Transpiration rate (m mol/m²/s)	Stomatal conductance (m mol/m²/s)
Cattleya aclandiae x *Brassavola* Little star (V_1)	3.989	4.652	5.203	4.615
Dendrobium var. Meesangnil (V_2)	5.284	6.712	7.283	6.426
SEd	0.105	0.116	0.171	0.105
CD (0.05)	0.301	0.331	0.487	0.298

Table 4. Volatile organic compound study profile of the variety (V_1).

Peak no	Name of the compound	RT time	Peak Area %	Molecular weight	Molecular formula
1	Silane	4.420	1.79	32.12	H_4Si
2	Thymine	5.542	1.77	126.12	$C_5H_6N_2O_2$
3	4H-Pyran-4-one	6.320	2.58	96.08	$C_5H_4O_2$
4	1,2-Benzenediol	6.720	5.30	110.11	$C_6H_6O_2$
5	Benzofuran	6.987	3.61	118.14	C_8H_6O
6	4-Mercaptophenol	7.076	1.54	126.18	C_6H_6OS
7	4-Pentylbenzonitrile	7.198	0.97	173.25	$C_{12}H_{15}N$
8	2-Methoxy-4-vinylphenol	7.953	5.15	164.20	$C_{10}H_{12}O_2$
9	Phenol	8.264	0.94	94.11	C_6H_6O
10	Piperidine-4-carboxylic acid	8.731	1.09	129.16	$C_6H_{11}NO_2$
11	Benzene	9.020	0.92	78.11	C_6H_6
12	3,4-Dimethoxythiophenol	10.775	1.04	186.24	$C_8H_{10}O_2S$
13	n-Hexadecanoic acid	12.941	6.67	256.42	$C_{16}H_{32}O_2$
14	1-Pentadecyne	14.041	1.04	208.27	$C_{15}H_{28}$
15	Octadecanoic acid	14.219	9.70	284.48	$C_{18}H_{36}O_2$
16	Toluene	14.830	3.61	92.14	C_7H_8
17	Eicosane	15.030	1.38	282.55	$C_{20}H_{42}$
18	Furazano [3,4-b] pyrazine-5,6-diamin 102046 1000263-74-8 38 e, N-(1-phenylethyl)	15.386	1.39	269.32	$C_{14}H_{15}N_5$
19	Nonadecane	16.130	1.15	268.52	$C_{19}H_{40}$
20	n-Hexylamine	16.208	1.42	101.19	$C_6H_{15}N$
21	2,7-Dimethoxyphenazine	16.597	3.36	240.26	$C_{14}H_{12}N_2O_2$
22	Tetrapentacontane	17.141	3.18	759.46	$C_{54}H_{110}$
23	Triacontyl acetate	18.274	4.00	480.86	$C_{32}H_{64}O_2$
24	gamma. -Tocopherol	19.396	3.38	416.68	$C_{28}H_{48}O_2$
25	Heptacosyl acetate	19.774	6.56	438.77	$C_{29}H_{58}O_2$
26	Vitamin E	20.063	4.18	430.71	$C_{29}H_{50}O_2$
27	Campesterol	21.196	0.88	400.68	$C_{28}H_{48}O$
28	Stigmasterol	21.474	4.75	412.69	$C_{29}H_{48}O$
29	Octacosyl acetate	21.874	1.26	452.80	$C_{30}H_{60}O_2$
30	beta-Sitosterol	22.207	15.40	414.71	$C_{29}H_{50}O$

Table 5. Volatile organic compound study profile of the variety (V_2).

Peak no	Name of the compound	RT time	Peak Area %	Molecular weight	Molecular formula
1	Butane	4.454	1.51	58.12	C_4H_{10}
2	4,5-Diamino-2-hydroxypyrimidine	5.542	1.97	141.14	$C_5H_7N_3O$
3	4H-Pyran-4-one	6.320	2.65	96.08	$C_5H_4O_2$
4	1,2-Benzenediol	6.731	1.16	110.11	$C_6H_6O_2$
5	Benzofuran	6.987	5.20	118.14	C_8H_6O
6	2-Furancarboxaldehyde	7.075	2.37	96.08	$C_5H_4O_2$
7	Silane	7.187	1.08	32.12	H_4Si
8	Ethanone	7.953	7.48	44.05	C_2H_4O
9	Phenol	8.275	1.45	94.11	C_6H_6O
10	Benzene	8.731	0.91	78.11	C_6H_6
11	2-Isopropoxyethyl propionate	9.286	5.86	174.24	$C_9H_{18}O_3$
12	2,4,7(1H,3H,8H)-Pteridinetrione	10.097	1.93	184.13	$C_6H_4N_4O_3$
13	n-Hexadecanoic acid	12.930	2.45	256.42	$C_{16}H_{32}O_2$
14	Octadecanoic acid	14.208	3.55	284.48	$C_{18}H_{36}O_2$
15	Benzyl isopentyl ether	14.830	0.90	178.27	$C_{12}H_{18}O$
16	Eicosane	15.030	1.02	282.55	$C_{20}H_{42}$
17	Pentacosane	16.130	2.03	352.69	$C_{25}H_{52}$
18	Palmitoyl chloride	16.208	1.17	274.87	$C_{16}H_{31}C_l$
19	1,8,9-Anthracenetriol	16.596	4.98	226.23	$C_{14}H_{10}O_3$
20	Heneicosane	17.141	4.22	296.58	$C_{21}H_{44}$
21	Octacosane	17.663	1.10	394.77	$C_{28}H_{58}$
22	2-Methoxy-4-nitroacridone	17.985	0.92	254.23	$C_{14}H_{10}N_2O_3$
23	Hexadecane	18.252	6.88	226.44	$C_{16}H_{34}$
24	Tetratriacontane	18.918	1.58	478.93	$C_{34}H_{70}$
25	Nonadecane	19.707	4.10	268.52	$C_{19}H_{40}$
26	Vitamin E	20.063	3.67	430.71	$C_{29}H_{50}O_2$
27	Campesterol	21.196	1.49	400.68	$C_{28}H_{48}O$
28	Stigmasterol	21.474	5.85	412.69	$C_{29}H_{48}O$
29	Octacosyl acetate	21.862	1.12	452.80	$C_{30}H_{60}O_2$
30	Beta–Sitosterol	22.207	19.42	414.71	$C_{29}H_{50}O$

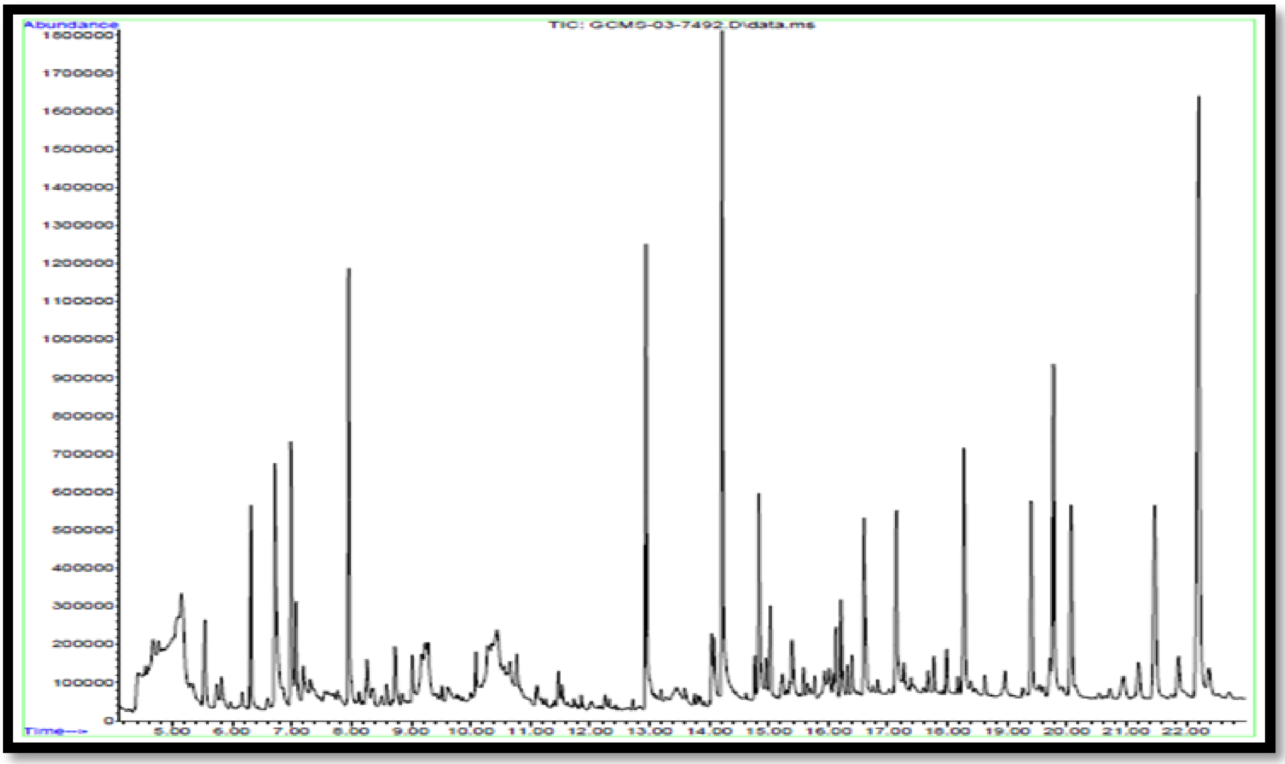

Fig. 6. GC- MS chromatogram of methanolic extract of *Cattleya aclandiae* x *Brassavola* Little star (V_1).

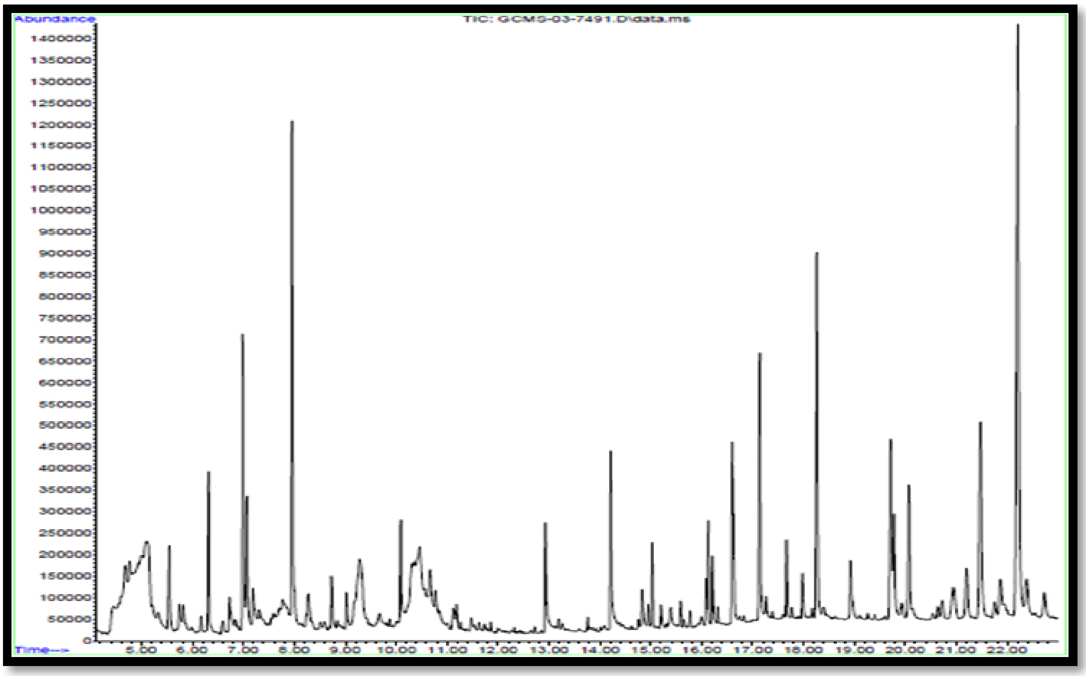

Fig. 7. GC- MS chromatogram of methanolic extract of *Dendrobium var. Meesangnil* (V_2).

species also revealed presence of specific phyto-compounds in each species which were not present in other. For instance, V_1 contained gamma-Tocopherol (3.38 %), known for its antioxidant properties, and Furazano [3,4-b] pyrazine-5,6-diamine (1.39 %), which has potential antimicrobial effects. V_2 uniquely contained 4H-Pyran-4-one (2.65 %), associated with neuroprotective benefits and 2-Furancarboxaldehyde (2.37 %), noted for its anti-inflammatory activity. These unique biochemical profiles indicate that each species may offer distinct sensory and therapeutic benefits in horticultural therapy programs. The diverse phytochemical compositions observed in this study align with the growing body of research on orchid biochemistry and its ecological significance. The chemical diversity in orchid fragrances plays a crucial role in pollinator attraction (29). The unique biochemical profiles of V_1 and V_2 may reflect adaptations to different pollinator assemblages in their native habitats, which could have implications for their reproductive success in the new environment. Moreover, the presence of compounds with potential medicinal properties in both orchid species supports the growing interest in exploring orchids as sources of bioactive compounds. Many orchid species contain compounds with antioxidant, anti-inflammatory and antimicrobial properties. The identification of such compounds in V_1 and V_2 opens avenues for further research into their potential therapeutic applications. The biochemical differences between V_1 and V_2 reveal their distinct strategies for coping with environmental stressors in their new habitat. For instance, the higher levels of beta-Sitosterol in V_2 could contribute to membrane stability under stress conditions. Similarly, the higher levels of antioxidant compounds like Vitamin E in both species could play a role in mitigating oxidative stress associated with environmental changes. Studies on antioxidant and cytotoxic activities of *Dendrobium moniliforme* extracts done (30) revealed that plant extracts have significant amounts of total polyphenol and flavonoid contents which is in trend with current study . It's important to note that while GC-MS analysis provides valuable insights into the biochemical profiles of these orchid species, further research is needed to fully elucidate the functional significance of these compounds in the context of adaptation to new environments. Future studies could explore how these biochemical profiles change over time as the orchids acclimate to their new habitat and how they compare to profiles of the same species in their native environments.

Implications for Therapeutic Horticulture

The diverse adaptive strategies and biochemical profiles of *Cattleya aclandiae* x *Brassavola* Little star and *Dendrobium var.* Meesangnil present exciting possibilities for their integration into therapeutic horticulture programs. Their contrasting growth habits and flowering characteristics offer opportunities for diverse visual and tactile experiences. *Cattleya aclandiae* x *Brassavola* Little star's more compact form and earlier flowering could be ideal for space-constrained settings or programs focusing on seasonal changes. Its larger leaves could provide tactile stimulation for participants with sensory processing challenges (31). The early flowering of this species could be particularly beneficial in therapeutic programs designed around seasonal rhythms and the anticipation of change, which has been shown to have positive effect on mental health (32). *Dendrobium var.* Meesangnil taller stature and larger flowers might be more suitable for visually-oriented therapies or programs emphasizing plant structure and development. The higher number of flowers per spike could provide opportunities for fine motor skill practice in deadheading activities, which are found to be beneficial for individuals with cognitive impairments. The species' different physiological strategies could be incorporated into educational programs about plant adaptation and stress responses. *Dendrobium var.* Meesangnil more active physiological profile could be used to demonstrate rapid plant responses to environmental changes, while *Cattleya aclandiae* x *Brassavola* Little star's more conservative approach could illustrate stress tolerance mechanisms.

These concepts could be particularly valuable in therapeutic programs aimed at building resilience and coping skills in participants and for people with mental health conditions (33). The unique biochemical profiles of each species open avenues for multisensory therapeutic experiences. The varied volatile compounds could be utilized in aromatherapy sessions, potentially offering stress-reduction benefits (34). The presence of potentially beneficial compounds like fatty acids and sterols could be integrated into educational programs about plant-based medicines and nutrition, aligning with the growing interest in plant-based health interventions (35). Moreover, the cultivation requirements and adaptive responses of these orchids could be leveraged in horticultural therapy programs focused on patient empowerment and skill development. Caring for these plants with their specific needs could foster a sense of responsibility and achievement in participants, while observing their adaptive responses could provide lessons in resilience and flexibility (36). The contrasting characteristics of these 2 orchid species also provide opportunities for comparative studies within therapeutic settings. Participants could observe and document the different growth rates, flowering times and sensory attributes of the 2 species, encouraging scientific thinking and observational skills. This type of engagement could be particularly beneficial for educational therapy programs or cognitive rehabilitation. Furthermore, the relocation aspect of these orchids' stories could be used metaphorically in therapy sessions, particularly for individuals dealing with major life transitions or adjustments. The orchids successful adaptation to a new environment could serve as a powerful symbol of resilience and the potential for positive change.

Future scope

To fully explore the therapeutic potential of these Orchidaceae species in horticultural therapy, several research avenues merit further exploration. Longitudinal phenotypic stability studies should be conducted to evaluate the consistency of observed traits across successive cultivation cycles in the novel environmental context. Comprehensive phytochemical profiling, employing gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS) technique is necessary to elucidate the full spectrum of volatile organic compounds (VOCs) emanating from floral and foliar tissues, with particular emphasis on their potential applications in aromatherapy. Investigation of the bioavailability, pharmacokinetics and potential therapeutic effects of identified phytochemicals should focus on their topical and aromatic applications within clinical settings. Randomized controlled trials in therapeutic horticulture need to be designed and implemented to quantify the psychophysiological impacts of structured interactions with these orchid species, utilizing validated outcome measures for both mental and physical well-being. Finally, the development and optimization of *in vitro* propagation techniques tailored for therapeutic horticulture environment is crucial to ensure a consistent and ethically sourced supply of plant material for long-term interventional programs.

Conclusion

Comprehensive analysis of *Cattleya aclandiae* x *Brassavola* Little star and *Dendrobium* var meesangnil reveals a rich tapestry of adaptive strategies and biochemical diversity. Their distinct morphological, physiological and biochemical profiles not only shed light on orchid adaptation mechanisms but also open new avenues for innovative applications in therapeutic horticulture. Therapeutic horticulture programs can provide participants with enriched, multifaceted experiences by utilizing the unique characteristics of these species. These experiences engage participants on sensory, educational and potentially physiological levels. As we continue to unravel the complex relationships between plants and human well-being, these orchid species stand as promising candidates for advancing the field of therapeutic horticulture.

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Authors' contributions

- **M. Dinesh Kumaar** carried out the experiment, took observations and analysed the data.
- **S. Karthikeyan** guided the research by formulating the research concept, helped in securing research funds and approved the final manuscript.
- **D. Keisar Lourdusamy** contributed by developing the ideas, reviewed the manuscript and helped in procuring research grants.
- **A. Senthil** contributed by imposing the experiment, helped in editing, summarizing and revising the manuscript.
- **S. Vellaikumar** helped in summarizing and revising the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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