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Comparative Characterization of Morphological, Physiological, and Phytochemical Traits among Four *Allamanda* Species

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ABSTRACT

Allamanda species are widely cultivated as ornamental plants and have attracted increasing interest due to their potential medicinal properties. However, comparative information on their morphological, physiological, and phytochemical characteristics remains limited. This study examines four *Allamanda* species based on morphological traits, stomatal distribution, chlorophyll content, and phytochemical analysis: specifically, *A. cathartica* L., *A. cathartica (Hendersonii); A. blanchetii* (Purple); and *A. blanchetii* (Brown Bud). The study aimed to find out the lack of comparative data among *Allamanda* species, which limits their botanical and pharmacological potential uses. The blooms of A. *cathartica* are yellow, while those of *A. blanchetii* cultivars range from purple to brown. According to the stomatal study, all species exhibited a hypostomatic pattern, and *A. cathartica "Hendersonii"* had the highest stomatal density (2.983 mm^{-2}). Chlorophyll content analysis showed that A. *blanchetii* (purple) had the highest chlorophyll a/b ratio (0.448), and *A. cathartica* L. had the highest total chlorophyll content (119.649 mg/L). In line with earlier research that emphasizes the genus's diverse secondary metabolite profile, phytochemical analysis confirmed the presence of alkaloids, steroids, terpenoids, saponins, flavonoids, and phenolic compounds in all species. These findings demonstrate the potential of *Allamanda* species in pharmacological applications and support further investigation into their bioactive constituents.

Keywords: *Allamanda;* chlorophyll content; medicinal plants; phytochemicals; stomatal density

INTRODUCTION

Allamanda is a genus that belongs to the Apocynaceae family and approximately consists of 15 species of flowering plants native to the South of America, spreading from Mexico to Argentina (The Plant List, 2025; Tajram et al., 2024). It's renowned for the vibrant, trumpet-shaped flowers and commonly cultivated as ornamental plants worldwide. Allamanda*,* often referred to as the trumpet flower, stands out due to its striking blooms and widespread use in traditional medicine, being well known for its ability to treat a wide range of diseases in many countries around the world (Petricevich & Abarca-Vargas, 2019).

The leaves and flowers are used to treat fevers, coughs, inflammation, and skin diseases, while its roots have been used as an emetic and laxative and exhibit wound-healing capabilities (Matignon et

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al., 2023). *Allamanda cathartica L.* and *Allamanda blanchetti* L. are two plants that are well-known from this genus. In folk medicine, they are utilized to treat skin infections, colds, coughs, and other types of inflammation (Chen et al., 2024; Wagmare et al., 2024). Most medicines and health care products for humans are derived from plants (Torimbanu et al., 2024), medicinal plants play a pivotal role in healthcare, medical research, and the preservation of cultural heritage (Tsurayya et al., 2025). The plant contains various secondary metabolites, including flavonoids, polyphenols, iridoids, tannins, and alkaloids (Matignon et al., 2023).

Despite these promising findings, research involving all species of *Allamanda* is still limited. The majority of studies have mainly concentrated on *A. cathartica* (Petricevich & Abarca-Vargas, 2019; Tomar et al., 2024), resulting in a lack of information concerning the phytochemical characteristics and antioxidant properties of other species in the genus. The inconsistencies in extraction techniques, the specific plant parts analyzed, and assay conditions in various studies complicate the ability to reach clear conclusions about their relative effectiveness. Integrated research on the morphological traits, stomatal density, chlorophyll, and phytochemical variation among these species also remains limited.

Plant leaves have stomatal spaces that mediate water loss through transpiration and CO_2 uptake for photosynthesis. Conversely, lower stomatal density is associated with greater drought tolerance and water use efficiency. Therefore, knowing how stomata function in leaves could be useful in breeding for more productive or water-efficient varieties (Caine et al., 2019; Jalakas et al., 2024). This manuscript aims to bridge existing gaps by exploring the botanical features (morphology, stomatal density, and chlorophyll content) and phytochemical constituents of selected *Allamanda* species.

MATERIALS AND METHODS

Study area

The research was conducted using a descriptive, exploratory, and comparative experimental approach and was carried out in Banda Aceh from March to April 2025. The laboratory experiments were conducted at the Biology Department laboratory, Islamic Faculty of Universitas Muhammadiyah Aceh, and Biology Department, Science and Technology Faculty of Universitas Islam Negeri Ar-raniry, Banda Aceh.

Plant Materials and Morphological Features

Four species of *Allamanda* were collected from the garden around Banda Aceh are *Allamanda cathartica L., Allamanda chatartica (Hendersoni), Allamanda blanchetti (purple),* and *Allamanda blanchetti (brown bud*) (Figure 1). The morphological features of Allamanda species were studied by comparing the similarities in characteristics possessed by each plant species, using the book "Plant Morphology" written by Tjitrosoepomo (2006) as a guideline.

Stomatal density calculation

The third leaf from the top of each Allamanda species was used to calculate stomatal density, which was conducted three times using leaves from three different plants of each species. The replica method was employed to prepare the slide in calculating the number of stomata. The procedure consisted of the following steps: (1) Cleaning both the upper and lower leaf surfaces, (2) Applying nail polish and allowing it to dry for 10 minutes, (3) Flattening and affixing the dried spreads with transparent tape, (4) Gently removing the transparent tape from the leaf surfaces and attaching it to the glass slide, (5) Labeling the slide with a description of the plant species, and finally, (6) Determining the stomatal density using a light microscope at the same magnification (40x) (Haryanti, 2010). Calculate it with the following formulas (Salisbury, 1927):

$$Stomatal\ density = \frac{number\ of\ stomata}{field\ of\ view\ under\ the\ microscope} \quad (1)$$

The number of stomata was calculated under the microscope with 10x magnifications, while the field of view was calculated using the standard formula for the area of a circle.

Field of view under microscope = $\pi \times r^2$. r = 0.25 mm² for 10x magnifications (Lestari, 2006; 19; Zahara, 2020).

Chlorophyll content measurement

The fresh leaves of four *Allamanda* species were weighed, homogenized, and extracted with 80% acetone in dark condition. The extract was centrifuged, and the supernatant was collected. Chlorophyll content was analyzed using a Perkin Elmer Lambda 365 UV/Vis spectrophotometer at wavelengths of 663 nm and 645 nm, involving the application of specific formulas for chlorophyll a, chlorophyll b, and the total chlorophyll content based on Arnon's (1949) formulas as follows:

Chlorophyll a = 12.7 λ663 – 2.69 λ645
Chlorophyll b = 22.9 λ645 – 4.68 λ663
Total Chlorophyll = 20.2 λ645 + 8.02 λ663 (Arnon, 1949).

The procedures were conducted three times using leaves from three different plants of each species.

Phytochemical content analysis

Plant materials preparation

Fresh leaves of *Allamanda* species were collected and washed to remove any contaminants and shade-dried at room temperature to preserve heat-sensitive phytochemicals. Once completely dried, the leaves were ground into a fine powder using a mechanical grinder (Arundhina et al., 2014).

Extraction

The ground *Allamanda* leaves were soaked in the ethanol solvent for 24-72 hours. After maceration, the mixture was filtered to separate the liquid extract from the plant residue and concentrated under reduced pressure using a rotary evaporator at temperatures between 40 and 50°C to obtain a semi-solid crude extract (Madhiri et al., 2023).

Phytochemical analysis

The concentrated leaf extract is then subjected to qualitative phytochemical screening to identify the presence of various bioactive constituents such as alkaloids, steroids, terpenoids, saponins, flavonoids, and phenolics.

To detect alkaloids in *Allamanda* leaves, an acidic extract of the powdered leaves was prepared, and a few drops of Mayer's, Wagner's, or Dragendorff's reagent were added separately; the formation of white (Mayer), brown (Wagner), or orange (Dragendorff) precipitates indicates the presence of alkaloids (Jha et al., 2012). To detect the steroid and terpenoid content in *Allamanda's* leaf, the Libermann-Buchard method was used. Mix 2 mL of the Allamanda's leaf extract with 2 mL of acetic anhydride and 2 mL of concentrated sulfuric acid. The formation of a blue-green ring indicates the presence of steroids, while the formation of a red or purple ring indicates the presence of the terpenoid (Sari, 2021).

Detecting the presence of saponins in *Allamanda* leaves, mixed 2 mL of the aqueous extract was mixed with 10 mL of distilled water in a test tube and shaking vigorously for about 5 minutes. The formation of stable, persistent foam indicates the presence of saponins (Sari, 2021). Methodology used to detect the availability of flavonoids in *Allamanda* leaves was Shinoda test by adding a few fragments of magnesium ribbon to the ethanolic extract, followed by a few drops of concentrated hydrochloric acid. A pink to red color indicates the presence of flavonoids (Tajram etal., 2024). Detecting the availability of phenolic compounds in *Allamanda* leaves were doing by few drops of 1% ferric chloride were added to the ethanolic extract of the *Allamanda* leaves, the presence of a green, blue, or violet color indicates the presence of phenolic compounds (Arundhina et al., 2014). Those analysis was conducted at Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, Banda Aceh.

Statistical Analysis

Data obtained from stomatal density and chlorophyll content were analyzed using one-way analysis of variance (ANOVA) to determine significant differences among *Allamanda* species, followed by Tukey's test at a significance level of $p < 0.05$. All analyses were performed using SPSS.

RESULTS AND DISCUSSION

Taxonomical and morphological feature identification

Among the four *Allamanda* species examined, morphological differences were observed in their flowers, colors, shapes, leaves, and stems. *Allamanda cathartica* features bright yellow, trumpet-shaped flowers with oval-shaped leaves. While A. cathartica 'Hendersonii' produces larger, often golden-yellow flowers that open from bronze-tinted buds, this variety adds a distinctive hue to its appearance (Rejitha & Devi, 2023). *A blanchetti (purple)*, *A blanchetti (brown bud*) commonly have the same characteristics, only differing in the flower color (Figure 1; Table 1).

Allamanda sp. belongs to the Apocynaceae family, which encompasses approximately 415 genera and around 4,555 species. It is widely distributed across various regions of the world. Members of this family include perennial shrubs or woody vines, often exhibiting a climbing or twining growth habit. These plants are characterized by their abundant milky latex and typically possess multiple branches, with lengths generally ranging from 3 to 9 meters.

Morphological features have consistently been the primary source of knowledge in plant taxonomy (Sandepogu & Somineni, 2024). The main technique for taxonomic identification of angiosperms

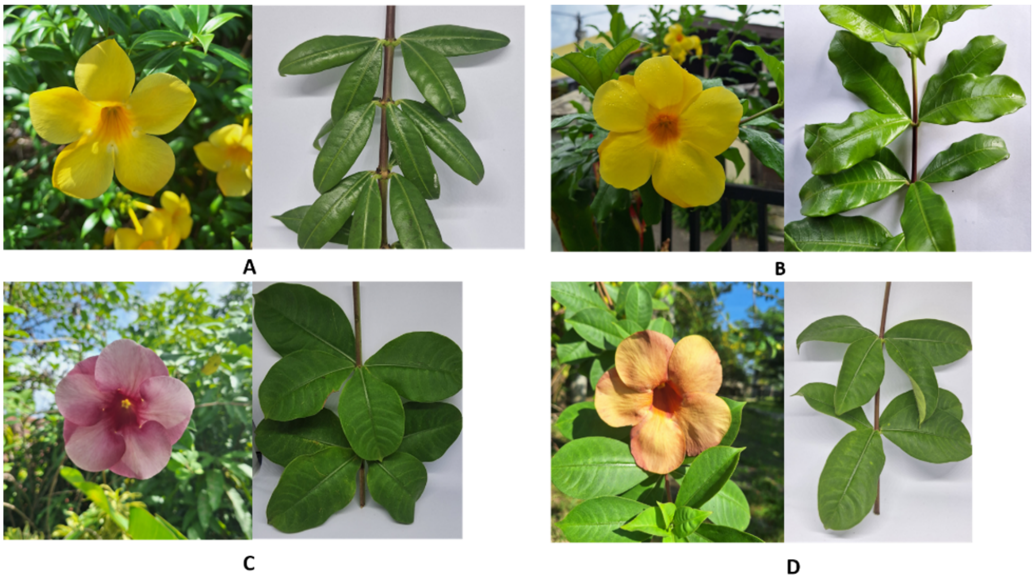

Figure 1. *Allamanda* species: (A) *Allamanda chatartica* L, (B) *Allamanda chatartica "Hendersonii"*, (C) *Allamanda blanchetti "purple"*, (D) *Allamanda blanchetti "brown bud"* (Photos taken by Author)

Table 1. Comparative morphological traits of four *Allamanda* species (Tjitrosoepomo, 2006; Zahara & Win , 2019 ; Rejitha & Devi, 2023).

No	Species	Flower		Leaves				Stem	
		Color	Shape	Form	Edge	Color	Surface's texture	Color	Shape
1	*Allamanda chatartica* L	Yellow	elongated	elliptic to lanceolate	flat	green	glossy	brown	round
2	*Allamanda chatartica "Hendersonii"*	Yellow	Obovate	elliptic to lanceolate	flat	green	glossy	brown	round
3	Allamanda blanchetti "purple"	Purple	Obovate	ovate to elliptic	flat	dark green	rough texture	brown	round
4	*Allamanda blanchetti "brown bud"*	Brown	Obovate	ovate to elliptic	flat	dark green	rough texture	brown	round

relies on the plants' visually evident physical features and traits. Floral morphology is acknowledged by most taxonomic groups (Chen et al., 2025). Morphological analysis is crucial for a thorough understanding of a taxon's position within the plant kingdom. It also provides a precise method for identifying the agronomic characteristics of plants (Sofiyanti et al., 2022).

A. cathartica L. produces a bright golden-yellow flowers with a typical trumpet or funnel-shaped corolla of five lobes. The petals are broadly obovate, forming a flaring bloom roughly 5–6 cm across, with a smooth and glossy, slightly waxy throat as shown in Figure 1A. The leaves of *Allamanda cathartica* are typically arranged in whorls of four around the stem. Each leaf is simple, lanceolate (up to 7 cm long and 2,5 cm wide with a thick) leathery lamina. The leaf surface is glossy green , with entire margins and pinnate venation (a prominent midrib with fine lateral veins) *Allamanda cathartica* is a perennial, evergreen plant characterized by its woody stems and vigorous climbing habit. Under optimal conditions, it can reach up to 6 meters (approximately 20 feet) in length.

Although naturally inclined to climb, it can be pruned and maintained as a shrub, making it versatile for various landscaping purposes (Tjitrosoepomo, 2006; Rejitha & Devi, 2023).

The flowers of the cultivar A. cathartica (Hendersonii) are similar in shape but larger than those of *A. cathartica* L., bright yellow, trumpet-like flowers (about 7 cm wide) also with a deepening golden-orange center. The petals slightly overlap. The corolla is glabrous and leathery, and the overall flower shape is identical, reflecting their close relationship. The leaves of '*Hendersonii'* are likewise arranged in whorls: they are dark green, smooth-edged, and thick, but larger than those of *A. cathartica* L. Thus, both the standard and Hendersonii forms share the same glossy, leathery foliage characteristic of *A. cathartica* (Figure 1B). The leaf surface of *Allamanda blanchetii* exhibits a coarse texture due to the presence of trichomes on both the upper (adaxial) and lower (abaxial) surfaces, indicating a rough texture (Table 1) (Rejitha & Devi, 2023).

The floral traits of *Allamanda blanchetii (purple* and *brown bud)* differ even further. In addition, 'Brown Bud' stands out for its warm apricot-orange blossoms that develop from brownish buds, providing a distinctive color shift as the flowers age. Both cultivars retain the trumpet-shaped, five-lobed, slightly leathery blooms that are characteristic of the genus. Their glossy, dark-green leaves, which are similarly grouped in whorls, have complete margins, an oval to elliptic form, and an attractive appearance.

Differences in the flower colors among those species could be associated with the pigment composition, such as flavonoids and anthocyanins, which contribute to floral coloration and pollinator attraction. These traits may also increase the value of ornamental plants (Mekapogu et al. 2020). While the leaf morphology reflected the adaptive responses to environmental conditions such as light intensity, temperature, and water availability. The difference in leaf structure is often associated with transpiration and photosynthesis (Yao-Qi and Zhi-Heng, 2021).

Stomatal density

Analysis of the stomatal density in four *Allamanda* species showed that the adaxial (top) leaf surface was completely devoid of stomata. In contrast, there was significant species heterogeneity in the presence of stomata, which were only found on the abaxial (lower) surface. At 2.983 mm^{-2}, *A. chatartica "Hendersonii*" had the highest abaxial stomatal density (Figure 2), whereas *A. chatartica* L came in second with 2.505 mm^{-2}. The densities of *A. blanchetti "purple*" and *A. blanchetti "brown bud,"* on the other hand, were significantly lower, measuring 1.401 mm^{-2} and 1.265 mm^{-2}, respectively. These results demonstrate that *Allamanda* leaves have a uniform hypostomatic leaf pattern, with stomata restricted to the abaxial surface and differing in density among cultivars (Table 2).

Table 2. Stomatal density on the leaf surfaces of four *Allamanda* species

No	Species	Stomatal density (mm^{-2})	
		Adaxial	Abaxial
1	*A. chatartica* L	0	2.505±0.003[b]
2	A. chatartica "Hendersonii"	0	2.983±0.011[c]
3	A. blanchetti "purple"	0	1.401±0.004[a]
4	A. blanchetti "brown bud"	0	1.265±0.005[a]

Data are means±standard error of 3 replicates. Different letters indicate significant differences at p<0.05 (independent t-test).

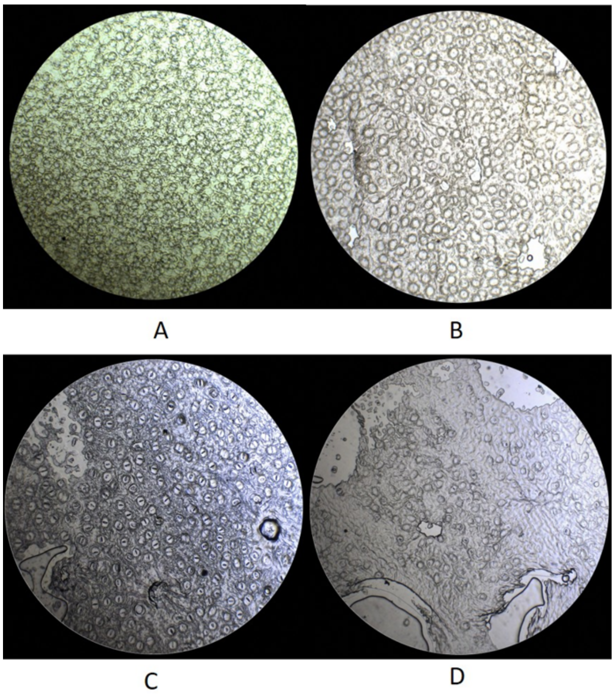

Figure 2. Stomatal density of *Allamanda* species: (A) *Allamanda chatartica* L, (B) *Allamanda chatartica "Hendersonii"*, (C) *Allamanda blanchetti "purple"*, (D) *Allamanda blanchetti "brown bud"* (ocular and objective lens of 10x magnifications (total magnification 100×). The field of view 0.196 mm²; Scale bar = 200 µm) (Photos taken by Author)

The distribution of stomata in the *Allamanda* species under study shows a regular hypostomatic leaf pattern, as stomata occur only on the abaxial (lower) leaf surface. This structural characteristic, common in dicotyledonous plants, is considered to be an adaptive trait that reduces water loss by transpiration, particularly in hot and light-intensive environments. The adaxial (top) surface's lack of stomata minimizes direct sunlight exposure, conserving water while allowing for effective gas exchange through the abaxial stomata (Jalakas et al., 2024).

The *Allamanda* species under study showed clear interspecific variation in abaxial stomatal density. *A. cathartica "Hendersonii"* recorded the highest value at 2.983 mm^{-2} (Figure 2), whereas that of *A. cathartica* L was the second highest at 2.505 mm^{-2}. In contrast, the densities of *A. blanchetii "purple"* and "*brown bud*" were 1.401 mm^{-2} and 1.265 mm^{-2}, respectively. These differences could be the result of species-specific adaptations to their natural environments, which would affect their ability to photosynthesize and how efficiently they use water. Greater water loss may result from higher stomatal density, which can also improve CO_2 uptake and possibly increase photosynthetic rates. The observed variations, therefore, represent an ecological trade-off between maximizing photosynthesis and limiting transpiration (Caine et al., 2019; Jalakas et al., 2024).

Under drought stress, *A. blanchetii* may demonstrate an adaptive response by reducing the stomatal size (Driesen et al., 2023). Types of stomata that were commonly found are anisocytic, paracytic (more abundant), and tetracytic, clearly characterizing a polymorphic behavior. Research on *Allamanda cathartica* has demonstrated that temperature and humidity levels can affect stomatal density and dispersion (Idris et al., 2019). According to studies, tropical climbers can reduce the effects of urban heat islands (Shekanino et al., 2023). *A. cathartica* has a high stomatal density, which increases evapotranspiration rates and contributes to cooling urban areas.

In this study, the highest stomatal density obtained in *A. cathartica* "Hendersonii" may indicate a greater capacity for gas exchange and transpiration, which could support higher photosynthetic activity under favorable conditions. While lower stomatal density obtained in *A. blanchetti* may represent an adaptive strategy in reducing water loss (Caine et al., 2019; Jalakas et al., 2024).

Chlorophyll content

The chlorophyll content measurement of these four *Allamanda* species showed that *A. cathartica* L. had the highest total chlorophyll content at 119.649 mg/L, suggesting a potentially higher photosynthetic capacity compared to the other varieties. Chlorophyll b concentrations were higher than chlorophyll a in all species. Since chlorophyll b increases the spectrum of light wavelengths that plants can use for photosynthesis, this distribution may have an impact on how well the plants absorb light (Table 3) (Thornton et al., 2023). The ratios indicate a higher concentration of chlorophyll b relative to chlorophyll a across all species.

Table 3. Chlorophyll content in the leaves of four *Allamanda* species

No	Species	Chlorophyll content (Mg/L)			
		Chlorophyll a	Chlorophyll b	Chlorophyll a/b ratio	Total Chlorophyll
1	*A. chatartica* L	36.008±0.016[c]	83.369±0.099[c]	0.432±0.012[ab]	119.649±1.16[c]
2	A. chatartica "Hendersonii"	31.227±0.002[a]	82.478±0.009[b]	0.3790.011[a]	110.934±1.17[bc]
3	A. blanchetti "purple"	33.358±0.001[b]	74.525±0.005[a]	0.448±0.002[b]	108.135±0.49a
4	A. blanchetti "brown bud"	32.491±0.001[ab]	78.662±0.007[b]	0.413±0.003[ab]	111.359±1.04[bc]

Data are means±standard error of 3 replicates. Different letters indicate significant differences at $p<0.05$ (independent t-test).

Chlorophyll (Chl) is the most important part for the photosynthetic reaction in plants, which is the primary pigment that directly converts light energy into chemical energy, making it a necessary component of photosynthesis. Another statement mentioned that in oxygenic photosynthesis, chlorophyll a (Chl a) has two functions: it harvests light and transforms absorbed photon energy into chemical energy (Thornton et al., 2023). As an accessory pigment, Chl b absorbs additional light energy and transfers it to Chl a, enabling the plant to exploit a wider spectrum of wavelengths (Angeles et al., 2025). Chl a/b, or the ratio of chlorophyll a to b, is a crucial indicator of how well a plant has adapted to its light environment. Plants exposed to high light intensities tend to have a higher Chl a/b ratio because it maximizes the photosynthetic capability of the plant by reflecting a larger proportion of chlorophyll a than Chl b. On the other hand, shade-adapted plants typically have a lower Chl a/b ratio, which suggests that they have more Chl b to optimize light absorption under low light conditions (Lichtenthaler & Babani, 2021).

A study on A. *blanchetii* found that the tissue had a total chlorophyll content of 4.90 mg/g, with levels of chlorophyll a and b being 2.78 and 2.71 mg/g, respectively. Similarly, studies on A. *cathartica* showed that the leaf tissues had a chlorophyll a level of 161 mg/g and a total chlorophyll content of

267 mg/g (Doddavarapu et al., 2021), which has a different number compared to this study (Table 3). The concentration of chlorophyll may vary in different regions and seasons. It may also change due to environmental stress and pollution (Talebzadeh & Valeo, 2022). Although certain studies have measured chlorophyll levels in particular species like *A. blanchetii* and *A. cathartica*, there is still a lack of extensive data throughout the genus.

The differences in chlorophyll content among these species may indicate the variation in photosynthetic efficiency and physiological adaptation. Species with higher chlorophyll content possess greater light-harvesting capacity, which may contribute to growth and biomass production (Taiz and Zeiger, 2002).

Phytochemical content

Alkaloids, steroids, terpenoids, saponins, flavonoids, and phenolic compounds are the six main phytochemical groups found in four *Allamanda* species that were subjected to phytochemical screening: *A. cathartica L., A. cathartica "Hendersonii," A. blanchetii "Purple,"* and *A. blanchetii "Brown Bud*." Based on previous studies confirming these species' potential for therapeutic use, this consistent identification indicates that they have a rich profile of bioactive components overall (Table 4) (Dokhe et al., 2023).

In the case of phytochemicals, analysis of the current study (Table 4) showed the presence of important secondary metabolites, including alkaloids, steroids, terpenoids, saponins, flavonoids, and phenolic compounds. These phytochemicals have been consistently found in a variety of *Allamanda* species and cultivars, which indicates that the genus has a conserved potential for biosynthesis. This homogeneity could account for the similar therapeutic use of these plants in conventional medicine, including the treatment of inflammation, infections, and other conditions (Dokhe et al., 2023).

Table 4 Qualitative phytochemical compounds detected in the leaves of four *Allamanda* species

Phytochemical compounds	*A. chatartica* L	*A. chatartica "Hendersonii"*	*A. blanchetti "purple"*	*A. blanchetti "brown bud"*
Alkaloid (Mayer, Wagner, Dragendorff)	+	+	+	+
Steroid	+	+	+	+
Terpenoid	+	+	+	+
Saponin	+	+	+	+
Flavonoid	+	+	+	+
Phenolic	+	+	+	+

Petricevich and Abarca-Vargas (2019) mentioned that the majority of phytochemical, pharmacological, and toxicological research has been conducted on *A. cathartica* out of the 15 species of *Allamanda*. Numerous medical conditions are treated with these plants. Hydrocarbons, alcohols, esters, ethers, aldehydes, ketones, fatty acids, phospholipids, volatile chemicals, phenolic compounds, flavonoids, alkaloids, steroids, terpenes, lactones, and carbohydrates have all been found in plants from the *A. cathartica* family, according to numerous phytochemical analyses. Various studies have proven that extracts and active compounds extracted from the A. cathartica have multiple pharmacological actions. An emerging source of traditional medicine for human health is the species *A. cathartica.* It is advised that more research be done on the phytochemical, pharmacological, and toxicological characteristics of the *Allamanda* species as well as their mechanisms of action, safety, and effectiveness.

The persistent identification of these bioactive chemicals in many Allamanda species highlights their possible pharmacological importance. While flavonoids and phenolic compounds have potent antioxidant qualities, alkaloids are well-known for their analgesic and antibacterial characteristics. Terpenoids and saponins have immune-modulating and anti-inflammatory properties (Petricevich & Abarca-Vargas, 2019; Reethu & Satapathy, 2024). However, quantitative differences in the concentration of these compounds among species and cultivars could influence efficacy and potency, warranting further comparative studies.

The presence of flavonoids, phenolics, alkaloids, and saponins suggests potential antioxidant and pharmacological properties in all *Allamanda* species. These secondary metabolites are important for plant defense mechanisms and may contribute to the medicinal value of ornamental plants (Petricevich & Abarca-Vargas, 2019; Reethu & Satapathy, 2024).

CONCLUSION

The four *Allamanda* species showed significant variations in morphological traits, stomatal density, chlorophyll, and phytochemical content. The morphological features proved the differences in flower color, shape, and form, in leaf color, edge, and surface and also in stem color. Stomatal analysis indicated variability in density and index, suggesting adaptations to different environmental conditions. Chlorophyll content measurements showed significant differences, with some species exhibiting higher levels of chlorophyll a and b, which may correlate with their photosynthetic efficiency. Phytochemical screening identified the presence of bioactive compounds such as flavonoids, saponins, tannins, and alkaloids in all species. These findings highlight their potential as sources of natural antioxidants and potential for medicinal plant research and ornamental and pharmacological studies. Further studies involving quantitative phytochemical analaysis and antioxidant activity evaluation are recommended.

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AUTHORS' CONTRIBUTIONS

MZ was the principal researcher and was responsible for designing the study, data collection, data analysis and interpretation, as well as drafting the manuscript. MH assisted in data collection, data analysis, and manuscript revision. NAS provided sample collection, documentation, and manuscript revision. All authors contributed to providing the final version of the manuscript.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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