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Anatomy of *Goniocaulon indicum* (J. G. Klein ex Willd.) C. B. Clarke: A Promising Wild Leafy Vegetable from Family Asteraceae

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***Goniocaulon indicum*; Asteraceae; wild leafy vegetable; root; stem; leaf: anatomy; secondary growth; vascular bundles; pharmacognosy**

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Abstract

Goniocaulon indicum (J. G. Klein ex Willd.) C. B. Clarke, a prominent wild leafy vegetable of the family Asteraceae, is traditionally utilized as a food resource in parts of Nanded District. The present study was undertaken to characterize the anatomy of the root, stem and leaf to establish diagnostic features useful for botanical identification and pharmacognostic standardization. The root exhibited prominent secondary growth, with a distinct outer protective region, narrow parenchymatous cortex, secondary phloem, vascular cambium and extensive secondary xylem containing numerous circular to oval vessel lumina, xylem fibers and parenchyma. The centrally positioned primary xylem was comparatively inconspicuous and exhibited an exarch arrangement. The stem showed a single-layered epidermis, broad parenchymatous cortex, numerous collateral, conjoint and open vascular bundles arranged predominantly in a ring, prominent secondary xylem, medullary rays and a broad parenchymatous pith. The leaf possessed single-layered epidermis, distinctly differentiated palisade and spongy mesophyll and collateral, closed vascular bundles comprising a prominent central bundle and smaller lateral bundles. The central leaf bundle exhibited adaxial xylem and abaxial phloem. The findings provide baseline information for quality assessment and standardization and may serve as a reference for future taxonomic and multidisciplinary investigations of this underexplored wild leafy vegetable.

1. INTRODUCTION

Goniocaulon indicum (J. G. Klein ex Willd.) C. B. Clarke is a lesser-known wild leafy vegetable belonging to the family *Asteraceae*. The species is distributed from Sudan and Ethiopia through India to Myanmar, occurring predominantly in seasonally dry tropical environments. The genus *Goniocaulon* is currently recognized as monotypic, with *G. indicum* as its accepted species (POWO, 2026). In India, the plant is locally utilized as a seasonal wild leafy vegetable and is associated with traditional food practices. Its relatively limited representation in modern botanical, anatomical and pharmacognostic literature makes systematic scientific documentation of the species particularly relevant. Anatomy provides an important level of evidence for plant identification because tissue organization, cell shape, epidermal characteristics, vascular architecture and other microscopic features can remain diagnostically useful. Recent studies have emphasized that microscopic characteristics can provide species-specific diagnostic markers and can be effectively integrated with physicochemical, phytochemical and molecular approaches for authentication and quality control of herbal materials (Harinarayanan et al., 2024; Intharuksa et al., 2024).

The taxonomic importance of anatomical and micromorphological characters is particularly relevant within *Asteraceae*, a large and morphologically diverse family in which closely related taxa may exhibit similarities in vegetative and reproductive morphology. Leaf epidermal characteristics, stomatal features, trichomes, mesophyll organization and vascular architecture have been demonstrated to provide useful additional characters for distinguishing taxa of *Asteraceae*. In pharmacognosy, characteristic anatomical markers can provide a reproducible basis for the authentication of crude plant materials and can assist in detecting substitution or adulteration. A recent pharmacognostic study of medicinal plant materials demonstrated that anatomical characters, together with other botanical and phytochemical parameters, can contribute to the development of reliable quality-control standards (Harinarayanan et al., 2024). Likewise, Intharuksa et al. (2024) demonstrated that microscopic examination, chemical analysis and DNA barcoding can be combined to improve the authentication and quality control of herbal materials. Thus, anatomical characterization represents an

important first-level scientific approach before extending investigations toward phytochemical profiling and biological evaluation.

The recent reports concerning the phytochemical composition and biological activities of *G. indicum* (Raut et al., 2025; Raut et al., 2026), anatomical information on the root, stem and leaf of the species remains comparatively limited. Particular attention to epidermal structure, cortex, mesophyll differentiation, vascular bundle organization, xylem and phloem arrangement, cambial activity, medullary rays and pith organization can provide useful information for species authentication and comparative anatomical studies. Accordingly, the present study was undertaken to investigate the anatomy of *Goniocaulon indicum* through microscopic examination of the root, stem and leaf. The study aims to document the major anatomical features and tissue organization of these vegetative organs, identify potentially diagnostic microscopic characters and establish a reference anatomical profile for the species. The resulting anatomical information is intended to contribute to the botanical authentication, pharmacognostic characterization and future standardization of *G. indicum*, while providing a structural basis for subsequent phytochemical and biological investigations.

2. METHODOLOGY

2.1 Study Area

A plant material Goniocaulon indicum, a wild leafy vegetable was collected from Therban village, Taluka- Bhokar, District- Nanded, Maharashtra, India for the anatomical study. Nanded District (extends approximately between 18°16′-19°55′ N latitude and 76°56′-78°19′ E longitude) is situated in the eastern part of the Marathwada region of Maharashtra state. The district encompasses a geographical area of approximately 10,502 km^2 and is characterized by a predominantly plateau landscape with undulating terrain, low hills, gentle slopes and river valleys (Groundwater Surveys and Development Agency, Maharashtra, 2025; Government of Maharashtra, 2025). The region experiences a tropical to subtropical climate, characterized by hot summers, relatively cool winters and seasonal rainfall predominantly associated with the southwest monsoon. Approximately 89% of the annual precipitation is received during the southwest monsoon season, generally extending from June to September. The district receives an average annual rainfall of approximately 700 – 900 mm, although considerable temporal and spatial variations may occur (Groundwater Surveys and Development Agency, Maharashtra, 2025). Recent meteorological observations reported by the India Meteorological Department further demonstrate variability in monsoon rainfall across Maharashtra, emphasizing the influence of seasonal climatic fluctuations on regional environmental conditions (India Meteorological Department, 2025).

2.2 Plant Collection and Authentication

A mature and healthy specimens of *Goniocaulon indicum* (Klein ex Willd.) C. B. Clarke, belonging to the family *Asteraceae*, were collected from their natural habitats in Nanded District, Maharashtra, India. The collected specimens were processed using standard herbarium preparation techniques, including pressing, drying, mounting and labelling, following the procedures described by Bridson and Forman (1999). The specimens were mounted on standard herbarium sheets to facilitate preservation and future taxonomic reference. Taxonomic identification and authentication were carried out in the BAMU Herbarium, Department of Botany, Dr. Babasaheb Ambedkar Marathwada University, Chhatrapati Sambhajinagar. The identification was further supported by regional floristic literature, particularly The Flora of Marathwada (Naik, 1998), and the published account of the species in the Flora of Maharashtra State (Shirodkar & Lakshminarasimhan, 2001). To ensure nomenclatural accuracy, the scientific name was cross-verified using authoritative online taxonomic resources (POWO, 2026; WFO, 2026; IPNI, 2026 and IFO, 2026).

2.3 Taxonomy of *Goniocaulon indicum* (Klein ex Willd.) C. B. Clarke (Karat-Kusumba)

Goniocaulon indicum commonly known as *Karat-Kusumba* in Marathi language, belongs to the family *Asteraceae*. It is an erect, glabrous annual herb, generally attaining a height of 40–120 cm. The stem is distinctly angular and longitudinally grooved. Leaves are alternate, sessile or subsessile, oblanceolate, measuring approximately 6–15 × 1–2 cm, with deeply serrated margins, acute apices and a glabrous surface (Figure 1: A-B). The inflorescence consists of narrow, few-flowered capitula, approximately 1–2 cm long, arranged in compound corymbs. The associated bracts are linear and the pedicels are very short. The receptacle is convex and paleaceous, bearing linear-oblong, lustrous paleae. The involucre is multiseriate, consisting of lanceolate, acute involucral bracts, which are whitish with pinkish or brownish apices. The florets are tubular, pink and five-lobed, with corollas exceeding the length of the involucre. The corolla segments are linear. Anthers are sagittate at the base and possess short basal tails, while the style branches are filiform. The fruits are oblanceolate achenes, approximately 5–6 mm long, glabrous and closely ribbed. The pappus consists of markedly unequal, linear-oblanceolate scales (Figure 1: C-F). The species is reported to flower and fruit predominantly during November–December in parts of peninsular India, although the phenological period may vary geographically in response to local environmental conditions (Naik, 1998; Karthikeyan et al., 2009; Shirodkar & Lakshminarasimhan, 2001; POWO, 2026; WFO, 2026).

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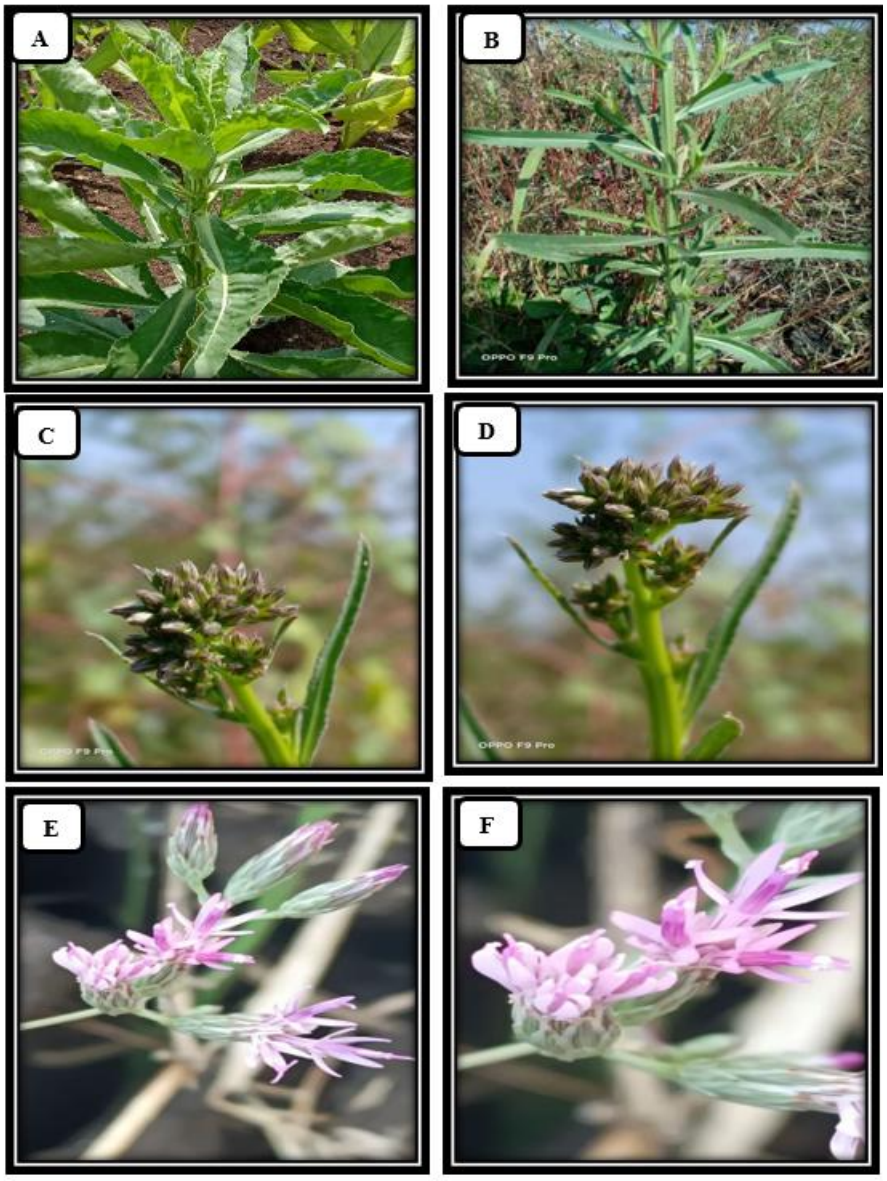


Figure 1: Goniocaulon indicum: Plant Habitat (A-B); Inflorescence (C-D) and flowers (E-F)

2.4 Anatomy of *Goniocaulon indicum*

Freshly collected root, stem and leaf specimens of *G. indicum* were thoroughly washed with distilled water to remove adhering soil particles and other surface contaminants. The specimens were maintained in the fixative for 24–48 hours to preserve tissue architecture and minimize cellular degradation (Johansen, 1940; Sass, 1958). Following fixation, the specimens were subjected to dehydration through a graded ethanol series comprising 50%, 70%, 90% and 100% ethanol to facilitate the gradual removal of water from the tissues. The dehydrated materials were subsequently preserved in 70% ethanol until further anatomical processing (Sass, 1958).

The transverse sections (T. S.) of the root, stem and leaf were prepared using a sharp razor blade. Thin and uniform sections were selected to ensure adequate visualization of the internal tissue organization. The sections were subjected to a double-staining procedure using safranin and fast green. Initially, the sections were stained with safranin to enhance the visibility of lignified tissues, followed by rinsing and counterstaining with fast green to differentiate the non-lignified cellular components. Excess stain was removed through treatment with 70% ethanol, following established botanical micro technique procedures (Johansen, 1940; Sass, 1958; Megías et al., 2024). The stained sections were carefully mounted on clean glass slides covered with coverslips to obtain suitable preparations for microscopic observation. The prepared slides were examined under a compound light microscope. Particular attention was given to the anatomical organization of the epidermis, cortex, vascular tissues, trichomes and secretory structures in the respective plant organs. Photomicrographs of the anatomical sections were captured using a microscope-mounted digital camera to document the structural characteristics and facilitate subsequent interpretation. The microscopic imaging enabled the observation and documentation of tissue organization and cellular features in the root, stem and leaf of Goniocaulon indicum (Baldacci-Cresp et al., 2020; Histological Methods for Plant Tissues, 2025).

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3. RESULTS AND DISCUSSION

3.1 Plant Collection and Authentication

The systematic collection, taxonomic identification and authentication of plant material constitute essential prerequisites for ensuring the reliability, reproducibility and scientific validity of phytochemical, pharmacognostic and pharmacological investigations. Accurate botanical identification is particularly important when wild-collected plants are investigated because closely related taxa, synonyms or morphologically similar species may otherwise result in erroneous attribution of biological or chemical properties. The World Health Organization emphasizes that botanical identity should be verified and documented using the scientific name, author citation, family, source and where appropriate, a voucher specimen. Macroscopic and microscopic examination, supported by authenticated reference material, provides an important basis for establishing the identity and quality of medicinal plant materials (WHO, 2018).

Extensive field visits were undertaken in Therban village, Bhokar Taluka, Nanded District, Maharashtra, India, during the appropriate growing season to document locally available wild edible vegetation. During the visits, a wild leafy vegetable belonging to the family *Asteraceae* was collected from its natural habitat. Healthy, mature and disease-free individuals displaying the characteristic morphological features of the species were preferentially selected to obtain representative plant material. Particular attention was given to the vegetative and reproductive characters required for reliable taxonomic identification. Preliminary identification of the collected material was based on detailed morphological examination of diagnostic characters, including habit, stem morphology, leaf arrangement and morphology, inflorescence structure, capitulum characteristics, involucral bracts, florets, fruits, and other distinguishing features. Regional floristic literature, particularly Flora of Marathwada (Naik, 1998), was consulted for comparison with published taxonomic descriptions and identification keys. The observed morphological characters were consistent with those described for *Goniocaulon indicum*.

A voucher specimen was prepared from the collected plant material following standard herbarium procedures. The authentication of voucher specimen (Figure 2) has been done from the BAMU Herbarium, Department of Botany, Dr. Babasaheb Ambedkar Marathwada University, Chhatrapati Sambhajinagar, Maharashtra having Accession number- 01397.



Figure 2: Herbarium preparation of selected wild leafy vegetable.

3.2 Anatomy of *Goniocaulon indicum*

Unlike several external morphological characteristics, many anatomical features, particularly the organization of vascular tissues, epidermal structures, secretory elements and supporting tissues, provide relatively consistent diagnostic information when specimens are examined under standardized conditions. Consequently, anatomical investigations are widely used as complementary evidence for establishing the identity and quality of plant-derived materials (WHO, 2011, 2018; Evert, 2006; Metcalfe & Chalk, 1979).

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The anatomical examination of *G. indicum* revealed a distinct organization of the root, stem and leaf tissues, consistent with the general anatomical pattern observed in herbaceous dicotyledonous members of the family *Asteraceae*. The three vegetative organs exhibited clearly differentiated tissue systems comprising the epidermal, ground and vascular tissues.

3.3 T. S. of root of *Goniocaulon indicum*



Figure 3: T. S. of root of *G. indicum*

The T. S. of the root revealed a well-differentiated anatomical organization with prominent secondary growth. The section showed a distinct outer protective region, cortical tissues, secondary phloem, vascular cambium, extensive secondary xylem and a relatively inconspicuous central primary xylem region (Figure 3). The predominance of secondary xylem indicated substantial radial development of the root.

3.4 Periderm / outer protective region

The outermost portion of the root section appeared as a relatively compact and darkly stained protective region. The development of secondary growth results in the replacement of the original epidermal and cortical tissues by a periderm in mature roots. The formation of periderm provides a protective barrier against mechanical injury, desiccation and external biotic and abiotic stresses. In roots undergoing secondary growth, development of the periderm is closely associated with radial expansion and progressive modification of the original primary tissues (Evert, 2006; Smetana et al., 2019; Wang, 2024).

3.5 Cortex

It is present below the outer protective region; a relatively narrow zone of parenchymatous cortical tissue was observed. The cortical cells were predominantly thin-walled and parenchymatous. In roots with pronounced secondary growth, much of the original cortex may become compressed or displaced as secondary tissues increase in radial extent. Therefore, the comparatively narrow cortical region observed in the present section may reflect the advanced development of secondary vascular tissues (Evert, 2006; Wang, 2024).

3.6 Secondary phloem

The secondary phloem occurred external to the vascular cambium and was composed of relatively smaller and less conspicuous cells than those of the secondary xylem. The comparatively limited visual prominence of the secondary phloem was attributable to the much greater accumulation of secondary xylem toward the centre of the root. During secondary growth, the vascular cambium produces secondary phloem centrifugally, i.e., toward the outer side, while producing secondary xylem centripetally, toward the inner side (Smetana et al., 2019; Wang, 2024).

3.7 Vascular cambium

A distinct cambial region was observed between the secondary phloem and secondary xylem. The vascular cambium represents a lateral meristem responsible for radial or secondary growth of the root. Its activity produces secondary phloem toward the outside and secondary xylem toward the inside. Continued cambial activity consequently results in the progressive increase in root diameter and accumulation of secondary vascular tissues (Evert, 2006; Wang, 2024). Recent studies have further established that cambial activity is regulated by coordinated developmental, hormonal, and environmental signals and is central to the formation of secondary vascular tissues (Wang, 2024).

3.8 Secondary xylem

The secondary xylem constituted the most prominent portion of the root section. Numerous circular to oval openings, corresponding predominantly to xylem vessel lumina, were distributed throughout the xylem region. The vessel elements possessed strongly stained, lignified walls and varied considerably in diameter, comprising large, medium-sized and smaller vessels. In addition to vessels, xylem fibres and xylem parenchyma were

also evident. The extensive development of secondary xylem accounted for the major proportion of the root's radial thickness. Secondary xylem is produced by the vascular cambium and consists of conducting vessel elements together with supporting fibres and living parenchymatous tissues. The lignification and differentiation of xylem elements are essential for efficient water transport and mechanical support (Evert, 2006; Fischer et al., 2019; Wang, 2024).

3.9 Primary xylem

The primary xylem was located toward the central region of the root. Because of the extensive accumulation of secondary xylem, the original primary xylem appeared comparatively small and inconspicuous. The central position of the primary xylem is characteristic of root vascular organization, while the development of secondary xylem progressively surrounds and increases the radial extent of the central vascular region. The primary xylem observed in the present section exhibited an exarch developmental arrangement, with the protoxylem positioned toward the periphery relative to the later-formed metaxylem (Evert, 2006; Harrison & Morris, 2018).

3.10 Central region

The central portion of the root was occupied by the primary xylem, which formed a relatively small central vascular structure in comparison with the extensive secondary xylem. The predominance of secondary xylem and the displacement of the primary tissues toward the centre are characteristic consequences of secondary vascular development in mature dicotyledonous roots (Evert, 2006; Smetana et al., 2019).

3.11 Secondary growth

The anatomical organization of the root section clearly indicated substantial secondary growth. The most conspicuous feature was the massive accumulation of secondary xylem, accompanied by numerous vessel elements of different sizes and a distinct vascular cambial region. The cambium had produced secondary xylem internally and secondary phloem externally, resulting in considerable radial thickening of the root. Concurrent development of the outer protective tissue was also evident. The original primary tissues, particularly the primary xylem and cortical region, were comparatively inconspicuous because of the extensive development of secondary tissues. Such radial expansion is a characteristic consequence of vascular cambial activity in roots undergoing secondary growth and enhances both the conducting capacity and mechanical stability of the root (Smetana et al., 2019; Wang, 2024).

3.12 T. S. of stem of *Goniocaulon indicum*

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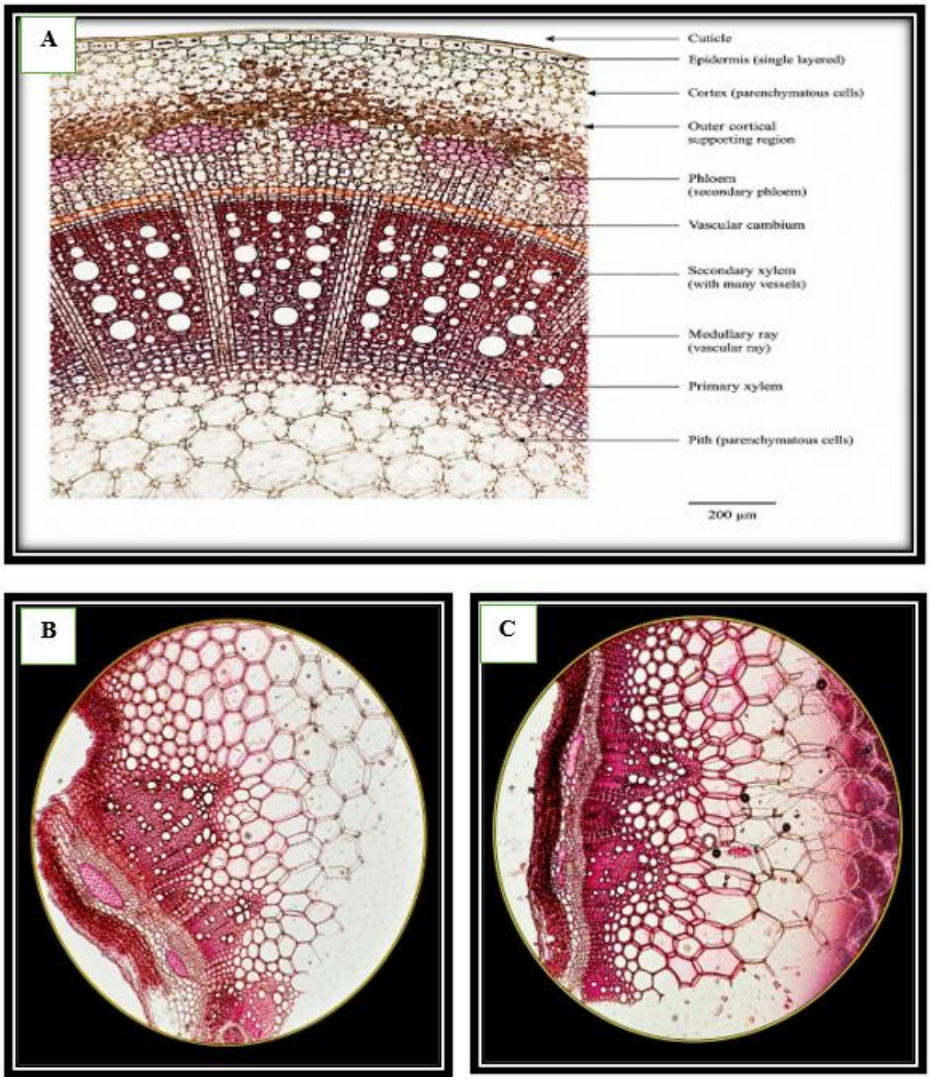


Figure 4: T. S. of stem of *G. indicum* (A-C)

The T. S. of stem revealed a well-differentiated tissue organization consisting of an epidermal layer, cuticle, cortex, vascular region, medullary rays and a prominent central pith. The vascular system exhibited conspicuous secondary xylem and a continuous or relatively well-developed cambial region, indicating secondary thickening of the stem (Figure 4). The major anatomical features observed in the stem section are described below.

3.13 Cuticle

The outer surface of the stem was covered by a thin, continuous cuticular layer overlying the epidermis. The cuticle appeared as a narrow, relatively dark-staining layer at the external surface. The cuticle constitutes an important protective interface between the plant and its surrounding environment and contributes to limiting uncontrolled water loss and protecting the underlying epidermal tissues from environmental stresses (Evert, 2006; Taiz et al., 2015).

3.14 Epidermis

The stem was externally bounded by a single-layered epidermis. Epidermal cells were compactly arranged without conspicuous intercellular spaces and were predominantly rectangular to polygonal in outline. The outer tangential walls appeared cutinized and were covered by the thin cuticle. The compact arrangement and cutinization of the epidermal cells provide structural protection to the underlying tissues and form the primary surface barrier of the young stem (Evert, 2006; Beck, 2010).

3.15 Hypodermal region

Immediately below the epidermis, certain regions exhibited relatively compactly arranged cells compared with those of the deeper cortex. This subepidermal region appeared more intensely stained and may represent a mechanically supportive tissue zone. Depending on the degree of cell-wall thickening observed in the sections, the region may comprise collenchymatous or sclerenchymatous elements. Such subepidermal strengthening is particularly relevant in herbaceous stems because it contributes to mechanical support while allowing continued stem expansion (Evert, 2006; Beck, 2010).

3.16 Cortex

The cortical region occurred between the epidermis and the vascular tissues and constituted a relatively broad zone of

predominantly parenchymatous tissue. The cortical cells were comparatively large, thin-walled, and polygonal to rounded in outline. They were loosely to moderately compactly arranged, with discernible intercellular spaces in several regions. Some peripheral portions contained smaller and more densely stained cells. The cortical parenchyma may participate in storage and radial transport, while chloroplast-containing cortical cells of young green stems can also contribute to photosynthetic activity (Evert, 2006; Taiz et al., 2015).

3.17 Vascular region

The vascular region occupied a substantial proportion of the stem cross-section. Numerous vascular bundles and extensive secondary vascular tissues were evident. The vascular bundles were collateral, conjoint, and open, with xylem positioned toward the inner side and phloem toward the outer side, while vascular cambium occurred between them. The vascular bundles were arranged predominantly in a ring surrounding the central pith. The development of secondary xylem and the presence of vascular cambium indicated active secondary growth and radial thickening of the stem (Evert, 2006; Fischer et al., 2019; Wang, 2024).

3.18 Phloem

The phloem was situated external to the vascular cambium and was considerably less conspicuous than the secondary xylem. The phloem consisted predominantly of relatively small cells and was observed as a comparatively narrow region toward the outer side of the vascular cylinder. Its principal components include sieve elements, companion cells, phloem parenchyma, and, where differentiated, phloem fibres. The functional role of the phloem is the translocation of photoassimilates and other organic substances from source tissues to growing or storage organs (Evert, 2006; Taiz et al., 2015).

3.19 Vascular cambium

A narrow zone of meristematic cells was observed between the phloem and xylem. This region represents the vascular cambium, which is responsible for secondary vascular growth. Cambial activity produces secondary xylem toward the inner side and secondary phloem toward the outer side, resulting in progressive radial expansion of the stem. The development and activity of the cambium are regulated by complex developmental, hormonal, and environmental signals (Fischer et al., 2019; Smetana et al., 2019; Wang, 2024).

3.20 Secondary xylem

The secondary xylem constituted the most conspicuous component of the vascular region. Numerous circular to oval, strongly stained structures were observed throughout the xylem; these corresponded predominantly to vessel lumina. The vessels possessed thick, lignified walls and varied in diameter from relatively large to smaller elements. Numerous smaller xylem cells occurred between the vessels. The secondary xylem comprised vessel elements, other tracheary elements, xylem fibres, xylem parenchyma, and radially arranged parenchymatous tissues forming xylem rays. The conspicuous development of secondary xylem accounted for much of the radial thickness of the vascular region. In addition to conducting water and mineral nutrients, the lignified xylem provides mechanical support to the stem (Evert, 2006; Fischer et al., 2019).

3.21 Primary xylem

Toward the inner portion of the vascular cylinder, remnants of the primary vascular system were observed. The primary xylem was situated toward the central region and was relatively less conspicuous than the extensively developed secondary xylem. In a typical dicotyledonous stem, the primary xylem exhibits an endarch arrangement, in which the protoxylem is positioned toward the pith and the metaxylem toward the peripheral side. The observed arrangement was consistent with the development of secondary vascular tissues around the original primary xylem (Evert, 2006; Beck, 2010).

3.22 Medullary rays

Radially oriented rows or bands of parenchymatous cells extending through the vascular region were observed and were interpreted as medullary rays. These rays traversed the secondary vascular tissues and provided a radial pathway between the central pith and peripheral tissues. In stems undergoing secondary growth, rays play important roles in radial transport and storage and contribute to the organization of the secondary vascular system (Evert, 2006; Fischer et al., 2019).

3.23 Pith

The central region of the stem consisted predominantly of a broad and conspicuous pith composed of large, thin-walled parenchymatous cells. The cells were polygonal to rounded in outline and were relatively loosely arranged in some regions, with discernible intercellular spaces. The pith represented a substantial portion of the central stem region and is primarily associated with storage and internal tissue organization. The presence of a large parenchymatous pith, together with the surrounding vascular cylinder and extensive secondary xylem, contributed to the characteristic anatomical organization observed in the stem of *G. indicum* (Evert, 2006; Beck, 2010).

3.24 T. S. of leaf of *Goniocaulon indicum*

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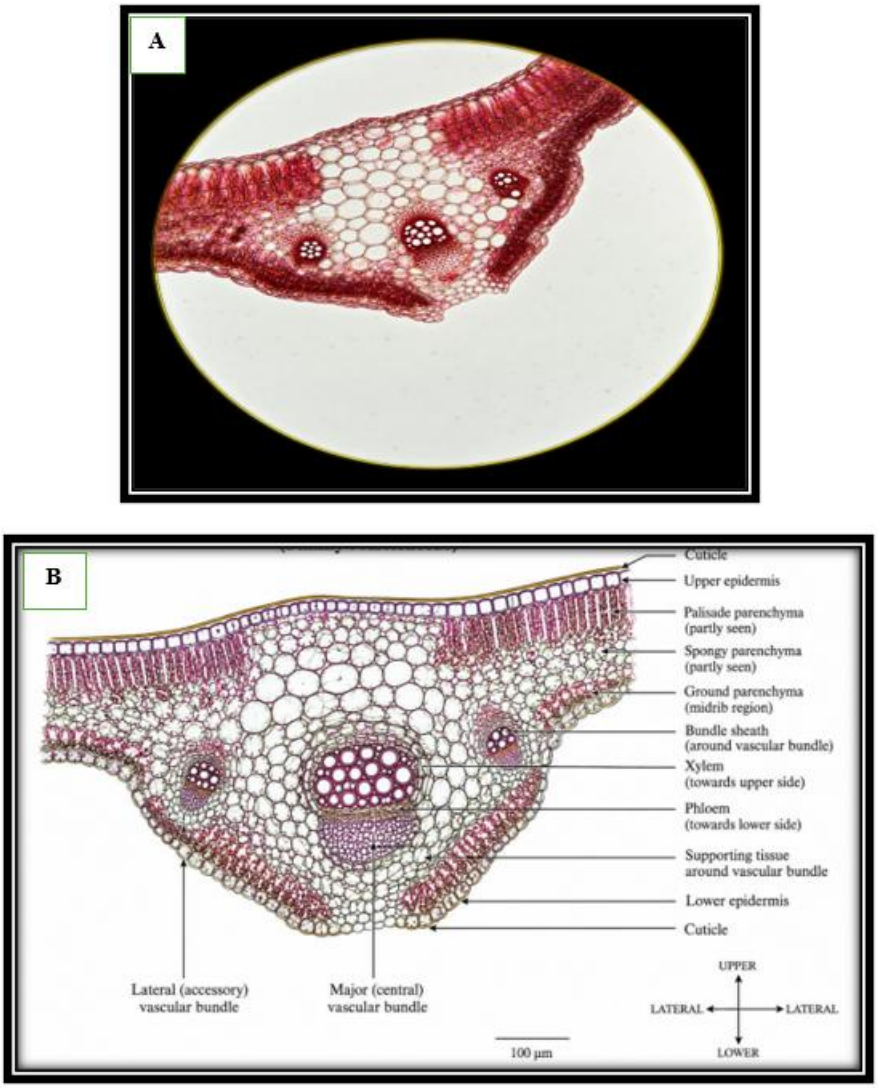


Figure 5: T. S. of leaf of *G. indicum* (A-B)

The T. S. of the leaf revealed a well-organized dorsiventral anatomical structure comprising a thin cuticle, single-layered upper and lower epidermis, differentiated mesophyll, parenchymatous ground tissue, and a distinct vascular system (Figure 5). The mesophyll was clearly differentiated into palisade and spongy parenchyma, whereas the vascular system consisted of a prominent central vascular bundle accompanied by smaller lateral or accessory bundles. The vascular bundles were collateral and closed, with xylem oriented toward the adaxial surface and phloem toward the abaxial surface. Similar combinations of uniseriate epidermis, differentiated mesophyll and collateral vascular bundles have been documented in anatomical studies of several Asteraceae taxa, although considerable interspecific variation occurs in bundle arrangement, bundle sheath development, secretory structures and mesophyll organization (González & Baran, 2019; Dörken & Parsons, 2023).

3.25 Cuticle

A thin, continuous cuticular layer was observed over the epidermis. In transverse section, the cuticle appeared as a narrow, relatively dark-staining line external to the epidermal cells. The cuticle constitutes the outer interface between the leaf and its environment and contributes to the regulation of water loss and protection against environmental stresses. Contemporary studies describe the plant cuticle as a dynamic protective structure associated with the epidermal cell wall and composed predominantly of cutin and waxes (Bhanot et al., 2021; Heredia et al., 2024).

3.26 Upper epidermis

The upper or adaxial surface of the leaf was bounded by a single layer of compactly arranged epidermal cells. In transverse section, the cells were generally polygonal to rectangular, with little or no conspicuous intercellular space. Their outer tangential walls appeared comparatively thickened and cutinized and were covered by the thin cuticular layer. The compact arrangement of the upper epidermal cells provides a continuous protective boundary for the underlying tissues. The leaf epidermis functions as an important interface between the plant and its surrounding environment and contributes to protection, regulation of water relations and coordination of specialized epidermal structures such as stomata and trichomes (Zuch et al., 2022).

3.27 Lower epidermis

The lower or abaxial surface was also composed of a single layer of compactly arranged epidermal cells. The cells were predominantly rounded to polygonal in outline and formed a continuous protective boundary around the leaf. Although the cellular appearance differed slightly from that of the upper epidermis, both surfaces retained a compact, single-layered organization. The differentiation of adaxial and abaxial surfaces is a fundamental feature of bifacial leaf development. Such polarity is associated with differential tissue organization across the leaf lamina, including the preferential development of palisade tissue toward the adaxial surface and spongy tissue toward the abaxial surface in many dorsiventral leaves (Zuch et al., 2022; Dörken & Parsons, 2023).

3.28 Mesophyll

The mesophyll constituted the principal internal photosynthetic tissue between the upper and lower epidermis. In the examined leaf, the mesophyll was distinctly differentiated into palisade and spongy parenchyma, confirming a dorsiventral organization. Comparable dorsiventral mesophyll differentiation has been reported in several Asteraceae species, although the number of cell layers, relative proportions and degree of differentiation vary among taxa (González & Baran, 2019).

3.29 Palisade parenchyma

The palisade parenchyma occurred immediately below the upper epidermis. The cells were elongated, closely packed and predominantly oriented perpendicular to the epidermal surface. The cells were chloroplast-rich and constituted the principal photosynthetic tissue of the adaxial region of the leaf. The compact arrangement of palisade cells increases the concentration of photosynthetically active tissue toward the adaxial surface and is a common structural feature of dorsiventral leaves. Comparable palisade differentiation has been documented in several Asteraceae species (González & Baran, 2019).

3.30 Spongy parenchyma

The spongy parenchyma occurred below the palisade region toward the lower epidermis. Its cells were irregular in shape and comparatively loosely arranged, with conspicuous intercellular spaces. These spaces provide an internal pathway for gaseous diffusion within the mesophyll and facilitate movement of carbon dioxide and water vapour. The clear differentiation between compact palisade tissue and loosely arranged spongy tissue therefore supports the classification of the leaf as dorsiventral. Anatomical comparisons within Asteraceae demonstrate that mesophyll organization is variable among species, ranging from distinctly dorsiventral to more homogeneous arrangements (González & Baran, 2019).

3.31 Ground tissue

The tissue surrounding the vascular bundles consisted predominantly of parenchymatous ground tissue. The cells were relatively large, thin-walled and approximately isodiametric to polygonal. They were loosely to moderately compactly arranged, with some comparatively large parenchymatous cells occurring around the major vascular bundle. This parenchymatous region provides structural continuity between the mesophyll and vascular tissues and contributes to the internal organization of the midrib and lamina. Comparable parenchymatous regions surrounding vascular bundles have been reported in anatomical investigations of Asteraceae leaves (González & Baran, 2019).

3.32 Vascular bundles

Numerous vascular bundles were observed within the leaf, including a prominent central vascular bundle and smaller lateral or accessory bundles. The vascular bundles were collateral and closed, with xylem positioned toward the adaxial side and phloem toward the abaxial side. The absence of a conspicuous vascular cambium between xylem and phloem supports their interpretation as closed collateral bundles. The smaller lateral bundles occurring on either side of the central bundle represent components of the leaf vascular system and contribute to the distribution of water and mineral nutrients to the lamina and the transport of photo assimilates away from photosynthetically active tissues. Vascular tissues are fundamental to long-distance transport and provide an integrated network for the movement of water, nutrients and assimilates throughout the plant (Hunziker & Greb, 2024). Collateral vascular bundles are also widely documented in Asteraceae, although their number, size, arrangement, bundle sheath and associated supporting tissues vary considerably among taxa (González & Baran, 2019).

3.33 Central vascular bundle

A large and conspicuous vascular bundle occurred in the central region of the leaf and was associated with the midrib. The bundle contained prominent xylem elements and a comparatively less conspicuous phloem region. The large circular to oval, strongly stained structures within the vascular bundle were interpreted predominantly as xylem vessel lumina. The central vascular bundle was substantially larger than the lateral bundles and therefore constituted the principal vascular supply of the midrib and adjacent laminar regions. The occurrence of smaller lateral bundles on either side of the central bundle indicates a differentiated vascular organization associated with the lateral expansion of the leaf blade. Comparable variation in the number and arrangement of central and lateral vascular bundles has been reported among Asteraceae species (González & Baran, 2019).

3.34 Xylem

The xylem occupied the adaxial or upper side of the vascular bundles. It consisted of prominent vessel elements together with other tracheary elements, xylem parenchyma and associated supporting tissues. The vessel elements appeared as relatively large circular to oval lumina surrounded by strongly stained, thick and lignified walls. The observed adaxial orientation of the xylem and abaxial position of the phloem represents the characteristic polarity of collateral vascular bundles in bifacial leaves. This arrangement is consistent with the general organization of leaf vascular bundles described for numerous Asteraceae taxa (González & Baran, 2019; Dörken & Parsons, 2023).

3.35 Phloem

The phloem occurred on the abaxial or lower side of the vascular bundle, opposite the xylem. It appeared comparatively less conspicuous because its cells were generally smaller and less strongly stained than the prominent xylem vessel elements. The phloem comprises conducting and associated living cells, including sieve elements, companion cells and phloem parenchyma. Functionally, phloem provides the principal pathway for the transport of photoassimilates from source tissues to developing, growing and storage organs, whereas xylem is primarily responsible for the transport of water and mineral nutrients. The observed adaxial–abaxial differentiation of xylem and phloem is consistent with the organization of collateral vascular bundles in bifacial leaves (Evert, 2006; Taiz et al., 2015; Hunziker & Greb, 2024).

3.36 Anatomical Significance and Pharmacognostic Implications

The anatomical characteristics recorded in the present study provide supportive evidence for the botanical identity and taxonomic placement of *Goniocaulon indicum*. The observed combination of epidermal characteristics, mesophyll

differentiation, vascular-bundle organization, xylem–phloem polarity and other tissue features constitute a useful set of microscopic diagnostic characters for the identification and pharmacognostic evaluation of the species. Microscopic examination is particularly valuable in the authentication of herbal materials because characteristic tissue organization and cellular features can assist in distinguishing genuine plant material from substituted or adulterated materials, especially when diagnostic external morphological characters are altered or lost during drying and processing. Recent studies have likewise demonstrated the value of microscopic characterization as an important component of an integrated approach to herbal-material authentication and quality assessment (WHO, 2020; Harinarayanan et al., 2024).

Anatomical standardization therefore represents an important component of pharmacognostic quality control. It contributes to the establishment of reproducible botanical identity, assists in detecting substitution and adulteration, and provides reference characteristics against which future samples can be compared. Current approaches to herbal quality control increasingly emphasize the complementary use of morphological, anatomical, physicochemical, phytochemical, chromatographic, and molecular parameters rather than reliance on a single authentication method. WHO guidance on herbal quality control recognizes the importance of appropriate identification and testing procedures, while recent studies have shown that microscopic analysis can be effectively integrated with chemical and DNA-based methods to improve the reliability of herbal-material authentication (WHO, 2020; Intharuksa et al., 2024; Raclariu-Manolică et al., 2023).

The anatomical profile established in the present investigation may therefore serve as a reference for future taxonomic, pharmacognostic, phytochemical and pharmacological studies of *G. indicum*. The recorded features—including the single-layered epidermis, thin cuticle, dorsiventric mesophyll, differentiated palisade and spongy tissues, prominent central vascular bundle, smaller lateral vascular bundles, collateral and closed vascular organization, and characteristic xylem–phloem arrangement—provide a reproducible microscopic framework for the identification of the investigated plant material. The integration of anatomical observations with phytochemical profiling and biological activity assessment can further strengthen the characterization of medicinal plants. Recent pharmacognostic investigations have demonstrated that the combined application of botanical, microscopic, physicochemical and phytochemical parameters can provide a more comprehensive basis for standardization and authentication than any individual parameter alone (Harinarayanan et al., 2024). Similarly, integrated microscopic, chemical, and DNA-based approaches have been shown to improve confidence in the identification of medicinal plant materials and in the detection of potential substitution or adulteration (Intharuksa et al., 2024).

Accordingly, the anatomical findings of the present study should be considered complementary to the phytochemical and biological investigations presented in subsequent sections. Such multidisciplinary characterization is consistent with the current emphasis on strengthening the evidence base, quality, safety, and appropriate standardization of traditional and herbal medicines (WHO, 2025). The integration of these anatomical findings with phytochemical composition, chromatographic profiling, and biological activity data may contribute to the development of a scientifically supported quality-control framework for *G. indicum* and facilitate future investigations into its potential as a standardized herbal resource.

4. CONCLUSION

The present investigation provides a comprehensive scientific characterization of *Goniocaulon indicum*, a traditionally utilized wild leafy vegetable. The plant material collected from the study area was botanically authenticated and subjected to anatomical, phytochemical and biological investigations using the root, stem and leaf. The anatomical study revealed distinct and reproducible microscopic features, including characteristic epidermal organization, cuticular differentiation, cortical and mesophyll tissues, collateral vascular bundles, vascular tissues, medullary rays and a well-developed central pith in the stem. The leaf exhibited a dorsiventric mesophyll differentiated into palisade and spongy tissues, together with a prominent central vascular bundle and smaller lateral bundles. These characteristics provide useful microscopic diagnostic features for the authentication and pharmacognostic evaluation of *G. indicum*. The anatomical observations obtained in the present study provide a useful microscopic reference profile for *G. indicum*. Such anatomical information can complement chemical and molecular approaches for reliable botanical authentication and quality control of plant materials. Therefore, the anatomical profile established in the present investigation may serve as a baseline for future taxonomic, pharmacognostic and quality-control studies of *G. indicum*.

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