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Research Article

Phytochemical Screening of an Ethanolic Extract of *Spathodea campanulata* Leaf using GC-MS and LC-MS Technology

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Abstract

The African tulip tree (*Spathodea campanulata*), an invasive alien species, poses a significant ecological threat while offering pharmacological and medicinal opportunities. This study utilizes GC-MS and LC-MS analytical techniques to investigate the bioactive compounds present in the leaves of *S. campanulata* from Southern Bukit Barisan Selatan National Park. GC-MS identified three volatile compounds: benzenesulfonamide, 3,4-furandicarboxylic acid, and a flavonoid, while LC-MS revealed five non-volatile compounds, including alkaloids and flavonoids such as kaempferol. Despite a simpler phytochemical profile than other medicinal plants, the identified compounds exhibit potent biological activities, including anticancer, anti-inflammatory, and antibiotic properties. Additionally, two novel compounds were discovered, highlighting the untapped chemical diversity of this species. The findings underscore *S. campanulata's* dual potential for conservation management and pharmaceutical development. Leveraging its bioactive compounds could be utilized to address critical health challenges, including drug-resistant infections and chronic diseases. Future research should prioritize evaluating these compounds' biological activities through pre-clinical and clinical studies to unlock their full therapeutic potential. This work advances the understanding of invasive species' ecological and medicinal roles, providing a pathway for sustainable utilization while mitigating their environmental impact.

Keywords: *Spathodea campanulata*, GC-MS, LC-MS, bioactive compound

1. INTRODUCTION

The African tulip tree (*Spathodea campanulata* P. Beauv.), a member of the Bignoniaceae family, is an invasive alien species (IAS) with a highly aggressive invasion capacity, particularly in tropical and subtropical regions. As one of the most significant IAS, the presence of *S. campanulata* in conservation areas such as national parks poses a severe threat to biodiversity and natural ecosystems [1]. IAS often exhibits high adaptability and rapid dominating areas, displacing native species that play crucial roles in the food chain and ecosystem balance [2]. When native species are displaced, the habitats of dependent animals and insects are also at risk, leading to population declines and, in extreme cases, local extinctions [3].

S. campanulata, native to the tropical forests of West and Central Africa, is distributed from Ghana to Angola and extends into parts of East Africa, including Uganda and South Sudan, where it thrives in moist environments such as riverbanks, forest margins, and disturbed secondary growth areas [2]. Owing to its strikingly ornamental flowers, the species has been widely introduced as an ornamental plant throughout tropical and subtropical regions across the globe. However, its prolific reproductive capacity characterized by abundant seed production, efficient wind dispersal, and vigorous regeneration from root suckers has facilitated its rapid naturalization and expansion, rendering it invasive in various regions including the Pacific Islands, Southeast Asia, northern Australia, and the Caribbean [1]. In these non-native environments, *S. campanulata* often forms dense monospecific stands in disturbed habitats, abandoned plantations, and along roadsides, posing a significant threat to native biodiversity by outcompeting indigenous plant species and altering ecosystem dynamics [3].

S. campanulata currently poses a serious threat to several national parks in Indonesia, including the Southern Bukit Barisan National Park (SBBNP). *S. campanulata* and *Meremia peltata* are the most significant IAS in the SBBNP [4]. Ariq et al. reported that *S. campanulata* had invaded 0.16% of the utilization zone in the Pemerihan Resort of

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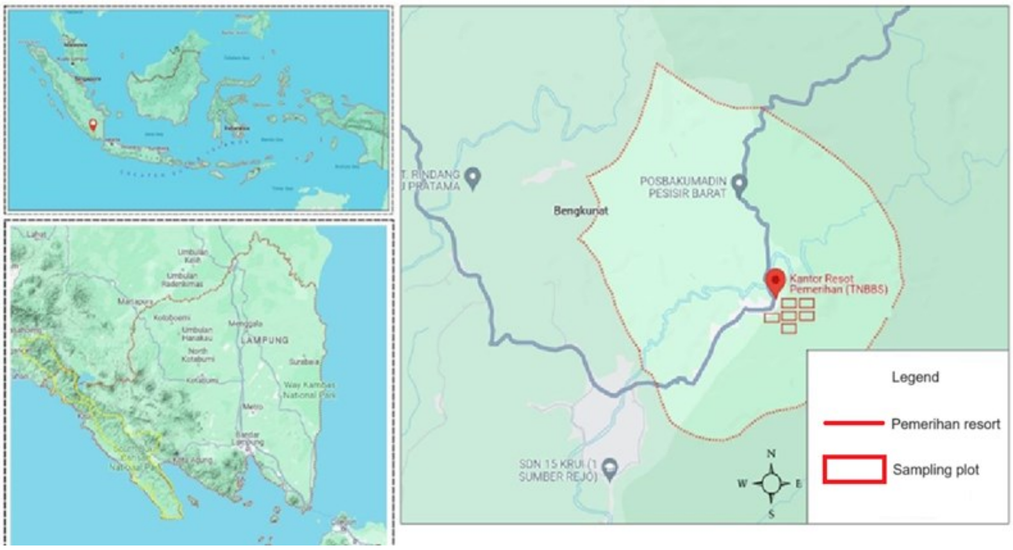


Figure 1. Research location*:* the Utilization Zone, Pemerihan Resort, SBBNP.

SBBNP [5]. This is particularly concerning as SBBNP is one of Indonesia's most important conservation areas, which is crucial in preserving biodiversity and maintaining ecosystem balance in Sumatra [6]. The park's unique flora, fauna, and invaluable tropical rainforest ecosystem have earned it recognition as a World Heritage Site [7]. SBBNP serves as a habitat for several rare and endemic species, including the Sumatran tiger (*Panthera tigris sumatrae*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*), and Sumatran elephant (*Elephas maximus sumatranus*), all of which are on the brink of extinction [8].

Despite being a threat, *S. campanulata* holds potential as a source of raw materials for pharmaceuticals, cosmetics, pesticides, and other industrial purposes. Leveraging invasive alien plants as a resource represents a wise approach to managing their populations while benefiting from their presence. Rather than focusing solely on eradication, which can be costly and environmentally damaging, integrating these species into local economies offers a sustainable solution for controlling their spread [1]. Utilizing invasive species in traditional medicine or as a food source can help alleviate pressure on native species and ecosystems while simultaneously managing invasive populations [9]. This combined strategy of control and utilization promotes a more balanced and economically viable conservation approach, minimizing the ecological impact of invasive species and providing tangible benefits to local communities [10]. *S. campanulata* contains a variety of bioactive compounds, including flavonoids, terpenoids, saponins, alkaloids, and phenolics, which have demonstrated potential as antioxidants [11], anti-inflammatory and antimicrobial agents [12], antidepressants [13] and anticancer agents [14]. These findings suggest that *S. campanulata* possesses a diverse range of secondary metabolites, providing a solid foundation for developing new, more effective drugs with minimal side effects [15]. Although *S. campanulata* shows significant potential in the pharmaceutical field, and numerous studies from various regions worldwide have substantiated this, the profiling of bioactive compounds from *S. campanulata* originating in SBBNP has not yet been reported.

As part of the effort to harness *S. campanulata* as a resource, bioprospecting through bioactive compound profiling is a crucial first step. Profiling bioactive compounds enables identifying and characterizing natural substances with potential medicinal properties. This process is essential for discovering new molecules that interact with biological targets uniquely, offering novel mechanisms of action that may be more effective or have fewer side effects than existing treatments [15]. Additionally, with the rise of drug-resistant pathogens and the growing need for more targeted therapies, exploring plant-derived compounds has become increasingly important, providing diverse chemical components for drug development [16]. Bioactive compounds are distributed across various plant organs, each exhibiting distinct phytochemical profiles [17]. This study focuses on the leaves of *S. campanulata*, selected for their central role in secondary metabolite production, ease of access, and suitability for sustainable harvesting [18]. Only healthy, mature, and disease-free leaves were collected to ensure data reliability [19]. Prior research has revealed the presence of flavonoids, alkaloids, terpenoids, saponins, and phenolics in the leaves, with demonstrated pharmacological activities [11][12]. While Świątek et al. reported 52 compounds from samples in Côte d'Ivoire, regional variations remain underexplored [20]. No phytochemical profiling has yet been conducted on S. campanulata leaves from SBBNP, which this study seeks to address.

In addition to their biochemical significance, leaves are more accessible and allow for non-destructive harvesting, thereby supporting sustainable sample collection [19]. To ensure data reliability and reduce variability, only mature, bright green, healthy, and disease-free leaves were selected from multiple randomly chosen trees. This selection criterion was intended to maintain sample consistency and to enhance the accuracy of compound identification and pharmacological assessment. Previous studies have identified various bioactive compounds in *S. campanulata* leaves, including flavonoids, alkaloids, saponins, terpenoids, and phenolics, many of which exhibit antioxidant, anti-inflammatory, and anticancer activities [11][12]. Świątek et al. reported 52 compounds from leaf and bark extracts collected in Côte d'Ivoire, highlighting significant chemical diversity [20]. However, the composition of these metabolites can vary across regions, and no such profiling has yet been conducted on specimens from the SBBNP. This study aims to obtain the profile and medical properties of the bioactive compounds found in the leaves of *S. campanulata* from the SBBNP.

2. MATERIALS AND METHODS

2.1. Time and Research Location

The research was conducted between February and March 2024. Leaves samples of *S. campanulata* were collected from the utilization zone at Pemerihan Resort, located within SBBNP area. Pemerihan Resort lies at coordinates 05°33'49.399" S and 104°24'50.176" E (see Figure 1). This site plays a vital role in conservation, supporting rich biodiversity and representing a key tropical forest ecosystem in Sumatra. The area's elevation ranges between 20 and 500 m above sea level, with an average annual rainfall of 2,500 to 3,000 mm and a mean temperature of approximately 31 °C. Around 43.35% of the terrain is classified as flat (0–8% slope), and the predominant soil types are red-yellow podzolic and alluvial soils [21]. The processes of sample preparation and extraction were undertaken at the Integrated Laboratory and Technology Innovation Centre (LTSIT) at the University of Lampung. Following this, LC-MS

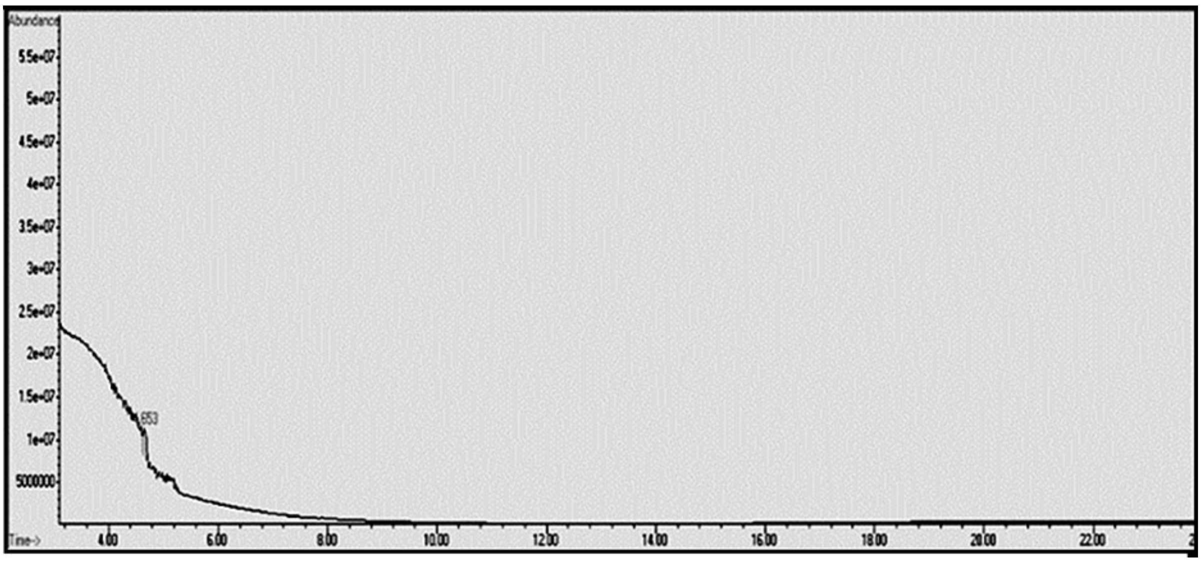


Figure 2. Chromatogram (GC-MS) of *S. campanulata* leaf.

Table 1. Table 1. Volatile Compounds in the leaf of *S. campanulata* extracted with 96% ethanol solvent and analysed using GC-MS.

No.	Tentative Identification	Molecular Formula	Molecular Weight (g/mol)	RT (min)	Classes
1.	benzenesulfonamide, 2 nitro-*N*-phenyl-	$C_{12}H_9N_3O_4S$	323.28	4.650	Sulfonamide
2	3,4-Furandicarboxylic acid, 2-(ethylthio)-5 (trifluoroacetyl)-, dimethyl ester	$C_{11}H_9F_3O_6S$	325.70	4.653	Triflic acid
3	4-Hydroxy-3-(2-oxo-2*H*-1-oxa-3-phenanthryl) 2(1*H*) quinolinone	$C_{22}H_{13}NO_4$	355.30	5.583	Flavonoid

and GC-MS analyses were meticulously performed at the Centre for Forensic Laboratory (Puslabfor) under the Criminal Investigation Agency of the Indonesian National Police, based in Depok City, Indonesia.

2.2. Object and Sampling

S. campanulata's taxonomic classification is as follows: Kingdom Plantae; Phylum Tracheophyta; Class Magnoliopsida; Order Lamiales; Family Bignoniaceae; Genus Spathodea [1]. Identification was confirmed based on morphological characteristics such as its distinctive trumpet-shaped flowers and compound leaves, following standard taxonomic keys simple random sampling (SRS) was employed as the sampling method. This approach was selected due to the verified stability and homogeneity of the location and the population of *S. campanulata* plants. Leaves samples were obtained from multiple randomly selected trees within a single designated sampling site.

2.3. Research Implementation

2.3.1. Collection of Leaves Sample

The leaves of *S. campanulata* were collected from the Utilization Zone, Pemerihan Resort, SBBNP. Only healthy, bright green and disease-free leaves were selected to ensure the integrity of the samples. The leaves were randomly harvested from several. In total, 2 kg of leaves were collected and carefully washed under running water to remove dirt and/or contaminants.

2.3.2. Sample Extraction

The washed samples were first air-dried to remove any residual moisture from the washing process. They were then sun-dried at 60 °C for about 3 days until they reached a consistent weight. After drying, the samples were cut into smaller pieces for easier grinding in a blender, reducing them to a fine powder. This powder was then passed through a 200-mesh sieve to produce a smooth and homogeneous flour. A total of 250 g of the leaf powder was accurately weighed and transferred into a maceration vessel. The sample was then immersed in 500 mL of 96% ethanol and macerated at room temperature for 72 hours. To enhance compound diffusion, gentle stirring was performed twice daily for 15 min each session. Upon completion of the maceration period, the extract was filtered using 2-micron filter paper to remove insoluble plant residues. Ethanol (96%) was chosen as the extraction solvent due to its proven efficacy in solubilizing a wide range of bioactive compounds, its low toxicity, and its acceptance in pharmaceutical-grade preparations. The resulting filtrate was subsequently concentrated under reduced pressure using a rotary evaporator at 40 °C for 24 h, yielding a viscous crude extract suitable for further chemical and pharmacological analysis. From 250 g of oven-dried *Spathodea campanulata* leaf powder, the extraction with 96% ethanol yielded 30.71 g of crude extract, corresponding to an extraction efficiency of 12.28%.

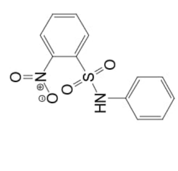
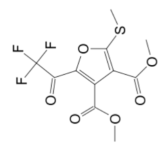
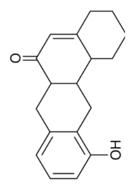
2.3.3. LC-MS and GC-MS Analyses

The LC-MS analysis utilized a liquid chromatography system (ACQUITY UPLC® H-Class System) integrated with mass spectrometry (MS Xevo G2-S QTof). The LC parameters were configured with a column temperature of 50 °C and an ambient temperature of 25 °C. A 0.2 mL/min flow rate was maintained for a 23-min runtime, with a 5-microliter injection volume passing through a 0.2-µm filter. The MS operated in positive ionization mode, covering a detection range of 50–1200 m/z. The ion source temperature was set to 100 °C, while the evaporation temperature was maintained at 350 °C. Low-energy scans were performed at 4 V, whereas high-energy scans ranged from 25 to 50 V. On the other hand, a gas chromatography system (Shimadzu® GCMS-QP2010 SE Single Quadrupole) was employed for GC-MS analysis. The initial column temperature was set at 60 °C using an Agilent 19091S-433 column, with a flow rate of 1 mL/min for 45 min. The MS operated in standard mode, with the ion source temperature set to 230 °C (a maximum of 250 °C) and the quadrupole temperature maintained at 150 °C (a maximum of 200 °C).

2.3.4. Data Analysis

The identification of bioactive compounds was conducted based on spectroscopic data using the Masslynx application and the Masshunter database. Masslynx is a software application utilized to control analytical instruments, including assisting in

Table 2. Molecular Structure and Medical Properties of Bioactive Compounds in *S. campanulata* Leaves.

No.	Tentative Identification	Molecular Structure	Medical Properties	References
1	benzenesulfonamide, 2 nitro-*N*-phenyl-		Anticancer, Antibiotic	1. Pubchem 2. Venkateswarlu [30] 3. Sharif [31]
2	3,4-Furandicarboxylic acid, 2-(ethylthio)-5 (trifluoroacetyl)-, dimethyl ester		Antibiotic	1. Pubchem 2. NIST 3. Sharif [31]
3	4-Hydroxy-3-(2-oxo-2H-1-benzopyran-3-yl)quinolin-2(1H)-one		Anticancer	1. PubMed 2. Theeramunkongch [32]

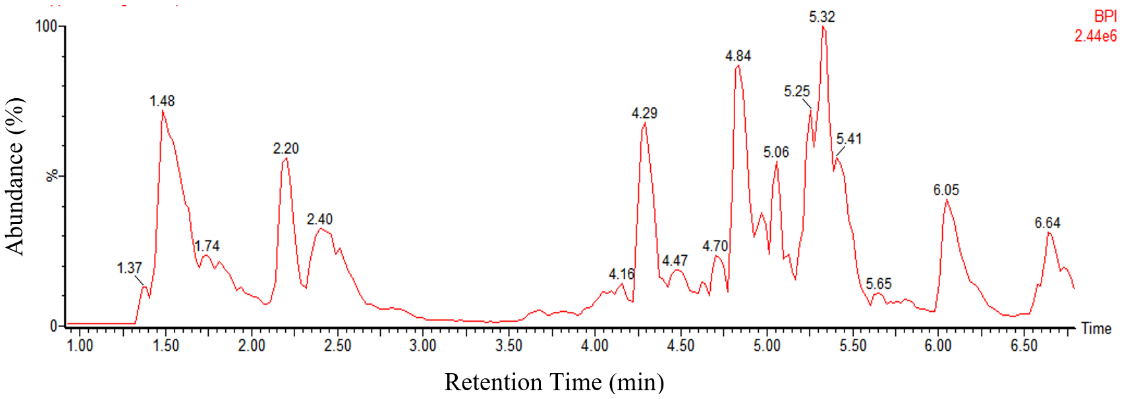


Figure 3. LC-MS Chromatogram of *S. campanulata* leaf.

acquiring and processing data generated by Waters Corporation. Bioactive compounds' chemical structure and medical properties were determined through a literature review approach, utilizing databases of PubChem, PubMed, the National Institute of Standards and Technology (NIST), ChemSpider, and Google Scholar. Data analysis was conducted by employing descriptive and analytical methods.

3. RESULTS AND DISCUSSIONS

3.1. GC-MS and LC-MS Analysis

The GC-MS and LC-MS analysis of *S. campanulata* leaf tissue yielded a chromatogram displaying several peaks and retention times (RT), indicating the presence of bioactive compounds within the leaves (Fig. 2). The results match the molecular weight and retention time data from the GC-MS analysis of *S. campanulata* leaves with the MassHunter database, which identified three bioactive compounds (Table 1).

The presence of only three bioactive compounds indicates that the leaves of *S. campanulata* exhibit a relatively simple phytochemical profile compared to many other plants. The leaves contain fewer bioactive compounds than several plant species widely used as herbal medicines and functional foods, such as moringa, green tea, soursop, red spinach, roselle, or certain species of mangrove *Avicennia marina*. For instance, moringa leaves (*Moringa oleifera*) contain over 20 types of polyphenols and 10 flavonoids; green tea leaves (*Camellia sinensis*) contain more than 30 catechins; soursop leaves (*Annona muricata*) possess at least 15 types of acetogenins and alkaloids; red spinach leaves (*Amaranthus cruentus*) have more than 15 types of carotenoids; roselle leaves (*Hibiscus sabdariffa*) contain at least 20 types of anthocyanins and flavonoids; while *A. marina* contains 13 bioactive compounds [22]-[27]. Although *S. campanulata* leaves possess only three bioactive compounds, which might suggest a limitation in their chemical diversity, this does not necessarily diminish their potential as a source of therapeutic agents. The number of bioactive compounds is not the sole determinant of a plant's therapeutic potential. Despite the limited bioactive compounds in *S. campanulata* leaves, these compounds may exhibit potent and specific pharmacological activities. For instance, single bioactive compounds have been shown to have significant therapeutic effects, such as the alkaloids vinblastine and vincristine derived from *Catharanthus roseus*, although the plant lacks chemical compound diversity [28]. Therefore, *S. campanulata* leaves still hold promise for exploration as a source of medicinal agents, especially if these compounds demonstrate high activity in preclinical or clinical studies [29]. Further research is needed to evaluate the potential of these compounds fully and understand their mechanisms of action in treating various diseases. Based on the various referenced databases, the molecular structure and medical properties of the bioactive compounds found in the leaves of *S. campanulata* were identified. These compounds exhibit two primary medical properties: anticancer and antibiotic (Table 2).

The bioactive compounds in *S. campanulata* exhibit notable properties as anticancer and antibiotic agents. These two medical properties are critically needed for future therapeutic applications. Cancer remains one of the most lethal diseases worldwide, with no currently effective treatment methods available for its complete cure [33]. While methods such as surgery and chemotherapy have been extensively applied for cancer eradication, their effectiveness is relatively low, and they are associated with side effects that can significantly reduce the quality of life and even increase mortality risk [34]. The rising global prevalence of cancer underscores the urgent need for anticancer drugs derived from herbal sources, the challenges posed by low efficacy, and the tendency of cancer cells to develop resistance to conventional therapies. Herbal materials generally have lower toxicity compared to synthetic drugs, making them a safer long-term alternative [15]. The potential synergistic effects of various compounds within herbal materials offer the advantage of enhanced anticancer activity and minimized resistance. Consequently, research focused on exploring and developing anticancer agents from *S. campanulata* should be a priority in the global effort to combat cancer [28].

The discovery of new antibiotics from herbal sources has become increasingly urgent in the face of the rapidly growing global antibiotic resistance crisis. Antibiotic resistance in bacteria is driven by the improper use of modern antibiotics and bacterial mutations [35]. This resistance has led to a reduction in the effectiveness of conventional antibiotics, complicating the treatment of bacterial infections that were previously manageable. Numerous studies have demonstrated that many plants can inhibit the growth of pathogenic bacteria, including strains resistant to modern antibiotics [36]. Sanandia et al. reported that certain herbal antimicrobials, such as cinnamon oil (*Cinnamomum burmanni*), carvacrol (*Origanum vulgare*), and ajwain oil (*Trachyspermum ammi*), are highly effective as antibiotics [37]. These findings suggest that *S. campanulata* has promising antibiotic potential for future pharmaceutical applications.

3.2. LC-MS Analysis

The LC-MS analysis of *S. campanulata* leaf tissue yielded a chromatogram displaying several peaks and RT, indicating the presence of bioactive compounds within the leaves (Fig. 3). The results match the molecular weight and retention time data from the LC-MS analysis of *S. campanulata* leaves with the MassHunter database, which identified five bioactive compounds (Table 3).

Identification of bioactive compounds using MassLynx revealed five bioactive compounds in the leaves of *S. campanulata* from SBBNP through LC-MS analysis. This number is significantly lower than the same species from Ivory Coast, which contained 52 bioactive compounds based on LC-MS analysis of its leaves and bark [37]. None of the 52 bioactive compounds identified in *S. campanulata* from the Ivory Coast were present in the species from SBBNP. These findings align with Deshmukh's assertion that a plant species can thrive under various biophysical and environmental statuses [38]. Differences in growing sites can result in considerable variations in the bioactive compound content. These differences are generally attributed to environmental factors such as climate, soil type, altitude, and sunlight exposure, all of which influence the production of secondary metabolites in plants. Furthermore, Padhy [12] stated that two populations of *S. campanulata* growing in West Africa and Southeast Asia exhibit significant variations in their bioactive compound profiles. The population in West Africa contains higher concentrations of iridoids and flavonoids due to environmental conditions that favour the production of these metabolites [12]. In contrast, the population in Southeast Asia may be richer in phenolic compounds due to adaptations to the more humid tropical climate [39].

Another noteworthy finding from this study is the detection of two bioactive compounds $C_{29}H_{41}N_4O_{19}S_2$ and $C_{45}H_{52}N_{11}O_{20}$ that, to the best of our knowledge, have not been previously reported in the literature. The identification of these putatively novel compounds represents a promising advancement in the fields of pharmacognosy and drug discovery [27], with the potential to contribute to the development of new therapeutic agents and expand our understanding of the chemical diversity present in *Spathodea campanulata* [19]. Given their unknown structural characteristics and unverified bioactivities, these compounds may possess unique molecular frameworks and mechanisms of action, positioning them as promising candidates for future pharmacological exploration [15]. Moreover, their presence highlights the importance of bioprospecting in underexplored regions such as the SBBNP, where environmental stressors may stimulate the synthesis of distinctive secondary metabolites [40]. It is important to emphasize, however, that the current identification of $C_{29}H_{41}N_4O_{19}S_2$ and $C_{45}H_{52}N_{11}O_{20}$ is based solely on high-resolution LC-MS data. Without complementary techniques such as NMR spectroscopy, infrared (IR) analysis, or X-ray crystallography, these structures remain tentative and should be interpreted with caution pending further confirmation. Based on the various referenced databases, the molecular structure and medical properties of the bioactive compounds found in the leaves of *S. campanulata* were identified. These compounds exhibit three primary medical properties: anticancer, anti-inflammation, and supplementary diet (Table 4).

Although they do not directly exhibit medical properties for disease prevention and treatment, ethyl *N*-acetyl-L-phenylalaninate and tert-butyl 1-benzyl-2-oxoethylcarbamate play crucial roles in drug synthesis. *Tert*-butyl 1-benzyl-2-oxoethylcarbamate is a compound commonly used as an intermediate in chemical synthesis, particularly in drug chemistry and the development of bioactive compounds [47]. This compound is often employed as a building block in synthesizing various molecules with pharmacological activity, particularly in the early stages of drug synthesis to introduce functional groups necessary for biological activity [48]. Additionally, *tert*-butyl 1-benzyl-2-oxoethylcarbamate is a protective group for amino functionalities during peptide synthesis or other amino-containing compounds [48]. The *tert*-butyl carbamate (Boc) group protects amino groups from undesired reactions during synthesis steps and can be removed afterwards to reveal the amino group [49]. Moreover, this compound is frequently used as an intermediate in organic synthesis for producing more complex molecules due to its carbamate functionality, which enables it to participate in various chemical reactions, including condensation and substitution reactions [48].

Ethyl *N*-acetyl-L-phenylalaninate is an intermediate in organic synthesis, playing a crucial role in producing various other chemical compounds. This compound often involves

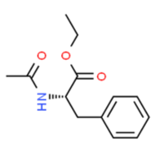
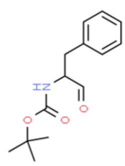
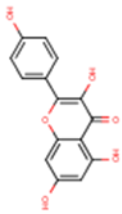
Table 3. Non-volatile bioactive compounds in the leaf of *S. campanulata* extracted with 96% ethanol solvent and analyzed using LC-MS.

No.	Tentative Identification	Molecular Formula	Molecular Weight (g/mol)	RT (min)	Classes
1	Not determined	$C_{29}H_{41}N_4O_{19}S_2$	Not determined	1.48	Not determined
2	Ethyl *N*-acetyl-L-phenylalaninate	$C_{13}H_{18}NO_3$	236.12	2.20	Alcaloid
3	*tert*-Butyl 1-benzyl-2-oxoethylcarbamate	$C_{14}H_{20}NO_3$	250.14	4.29	Alcaloid
4	Not determined	$C_{45}H_{52}N_{11}O_{20}$	Not determined	4.84	Not determined
5	Kaempferol (2-phenyl-1-benzopyran-4-one)	$C_{15}H_{11}O_6$	287.05	5.32	Flavonoid

esterification and amide formation reactions to create more complex molecules [42]. In the pharmaceutical industry, ethyl *N*-acetyl-L-phenylalanine serves as a raw material for the synthesis of bioactive compounds and drugs, with its primary application being the introduction of the phenylalanine acetyl group into drug molecules, which can significantly influence their biological activity [50]. Additionally, this compound is used in peptide and protein synthesis, where the *N*-acetyl group allows for introducing acetyl groups into peptides, thus modifying their chemical and biological properties [48]. It is also employed in structure-activity relationship studies to explore how modifications in molecular structure affect biological or pharmacological activity [49]. Furthermore, ethyl *N*-acetyl-L-phenylalaninate is used in research involving bioactive compounds to assess the biological activity and therapeutic potential of various phenylalanine-containing molecules [49].

Kaempferol has demonstrated potential as an anti-inflammatory agent [51], an anti-cancer compound [52], and even as a dietary supplement [53]. This finding suggests that *S. campanulata* leaves hold significant promise in developing health products and alternative therapies. Plants containing bioactive compounds with anti-inflammatory activity offer substantial potential for developing alternative therapies for chronic inflammatory diseases, such as arthritis, cardiovascular diseases, and autoimmune disorders [54]. Additionally, plants with bioactive compounds that function as dietary supplements positively affect body metabolism, digestive health, and the immune system. Dietary supplements can serve various functions, including acting as antioxidants, supporting digestive health, and regulating metabolism. Compounds such as vitamins C and E, as well as selenium, act as antioxidants, protecting cells from oxidative damage and environmental stress. These antioxidants are crucial in preventing various degenerative diseases [55]. Dietary fiber can enhance bowel motility and prevent constipation, while prebiotics like inulin supports the growth of healthy gut microbiota [56]. As metabolic regulators, compounds such as catechins from green tea or phenylalanine from cocoa beans can assist in regulating lipid and glucose

Table 4. Molecular structure and medical properties of bioactive compounds in *S. campanulata* leaves.

No.	Tentative Identification	Molecular Structure	Medical Properties	References
1	Ethyl *N*-acetyl-L-phenylalaninate		1. Intermediate in organic synthesis 2. Involved in esterification and amide formation 3. Used in peptide and protein synthesis	Adams [41] Brunner [42]
2	*tert*-Butyl 1-benzyl-2-oxoethylcarbamate		1. Intermediate in chemical synthesis 2. A protective group for amino functionalities 3. Intermediate in organic synthesis	Adams [41] Brunner [42] Combs [43]
3	Kaempferol (2-phenyl-1-benzopyran-4-one)		1. Anticancer 2. Anti-inflammatory 3. Diet Supplement	1. PubChem 2. Kiruthiga [44] 3. Ysrafil [45] 4. Butun [46]

metabolism, contributing to weight management and the prevention of type 2 diabetes [57].

The results of GC-MS and LC-MS analyses indicate that *S. campanulata* leaves contain various bioactive compounds with properties beneficial for cancer and anti-inflammatory applications. Plants that harbour bioactive compounds with such properties are of substantial interest in pharmaceutical and medical research due to their potential to develop novel therapeutic agents. Cancer and inflammation are closely interconnected conditions. Most cancer cases are linked to chronic infections, dietary factors, obesity, pollution, smoking, and autoimmunity [29]. Inflammation is a complex biological response to injury or harmful stimuli, and chronic inflammation is recognized as a key contributor to the development and progression of various diseases, including cancer [54]. Bioactive compounds with anti-inflammatory properties can modulate inflammatory pathways, reducing the risk of chronic inflammation and its associated health consequences. Compounds such as curcumin, found in turmeric, and resveratrol, found in grapes, have demonstrated significant anti-inflammatory effects by inhibiting key inflammatory mediators such as NF-kB and COX-2 [58]. These compounds help mitigate inflammation and show promise in cancer prevention and therapy. Chronic inflammation can lead to DNA damage, genetic mutations, and the activation of oncogenes, ultimately fostering an environment conducive to cancer development [54]. Therefore, reducing inflammation through bioactive compounds may be crucial in cancer prevention. Bioactive compounds exhibit direct anti-cancer effects by inducing apoptosis in cancer cells, inhibiting tumor growth, and preventing metastasis. For example, epigallocatechin gallate from green tea has been shown to possess potent anti-cancer properties through various mechanisms, including the modulation of cell signaling pathways and suppression of tumor angiogenesis [59]. By targeting both inflammation and cancer through a dual mechanism. These plant-derived compounds hold great promise in enhancing the efficacy of cancer therapies and improving patient outcomes.

4. CONCLUSIONS

The profiling of bioactive compounds in *Spathodea campanulata* leaves from the SBBNP, using 96% ethanol extract followed by GC-MS and LC-MS analyses, revealed a total of 8 compounds. GC-MS analysis identified 3 volatile compounds, including a sulfonamide, a triflic acid derivative, and a flavonoid, while LC-MS analysis detected 5 non-volatile compounds, primarily classified as alkaloids and flavonoids. Among these compounds, four compounds exhibit notable pharmacological properties such as anticancer, antibiotic, anti-inflammatory, and dietary supplement potential. Two other compounds, although lacking direct therapeutic properties, show promise as valuable intermediates in chemical and organic synthesis. Notably, the remaining two compounds $C_{29}H_{41}N_4O_{19}S_2$ and $C_{45}H_{52}N_{11}O_{20}$ are previously unreported and lack known structural or pharmacological data. The discovery of these putatively novel compounds not only enriches the phytochemical landscape of *S. campanulata* but also opens new avenues for drug discovery. However, their precise structures and biological activities of these compounds need to be elucidated. Future research should explore the use of alternative solvents, such as methanol, aqueous ethanol, or water, to assess their impact on the yield, diversity, and pharmacological relevance of extracted compounds, thereby enhancing reproducibility and extraction efficiency.

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Conflicts of Interest

The authors declare no conflict of interest.

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