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Exploration of bioactive compounds in invasive plant *Spathodea campanulata* flower originating from Bukit Barisan National Park, Lampung, Indonesia

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Abstract. *Duryat, Ghozali RI, Saragih YJ, Rodiani, Maryono T, Pardilawati CY, Ismanto. 2025. Exploration of bioactive compounds in invasive plant* Spathodea campanulata *flower originating from Bukit Barisan National Park, Lampung, Indonesia. Biodiversitas 26: 366-376.* The African tulip tree (*Spathodea campanulata*), an invasive alien species, poses a significant ecological threat but offers promising bioactive compounds with therapeutic potential. This study aimed to profile the bioactive compounds present in the flowers of *S. campanulata* sourced from the Utilization Zone of Pemerihan Resort, Bukit Barisan Selatan National Park (BBSNP), Lampung, Indonesia. Using ethanol extraction followed by LC-MS and GC-MS analysis, 11 bioactive compounds were identified, comprising six volatile and five non-volatile compounds. These compounds, categorized into flavonoids, alkaloids, amino acids, and iridoids, exhibited 13 notable medical properties, including anti-inflammatory, anticancer, antimicrobial, antioxidant, and anticholinergic activities. The findings highlight the potential of *S. campanulata* flowers in addressing some of the world's deadliest diseases, such as cancer, chronic obstructive pulmonary disease (COPD), respiratory infections, and coronary artery disease. Despite these promising results, further research is essential to translate these findings into practical applications. Future studies should focus on in vitro and in vivo pharmacological evaluations, toxicity assessments, clinical trials, and compound synthesis and dosing optimization. The discovery of these bioactive compounds underscores the dual role of invasive species as both ecological challenges and valuable resources for pharmaceutical development.

Keywords: Bioactive compound, Bukit Barisan Selatan National Park, GC-MS, LC-MS, *Spathodea campanulata*

INTRODUCTION

The African tulip tree (*Spathodea campanulata* Beauverd), a member of the Bignoniaceae family, is a highly invasive alien species (IAS) that spreads aggressively, particularly in tropical and subtropical regions. Its presence in conservation areas, such as national parks, threatens biodiversity and ecosystem balance (Shackleton et al. 2019). By rapidly adapting and dominating its environment, *S. campanulata* displaces native species essential for maintaining food chains and ecosystem stability. This displacement can result in cascading ecological effects, including population declines in dependent animal and insect species, potentially leading to local extinctions (Bellard et al. 2016; Avalos et al. 2021).

S. campanulata threatens many critical ecosystems in Indonesia, including Bukit Barisan Selatan National Park (BBSNP), a UNESCO World Heritage Site. Alongside *Merremia peltata*, it is one of the most impactful IAS in the park (Duryat et al. 2023). Recent studies have reported that *S. campanulata* has invaded 0.16% of the Utilization Zone in the Pemerihan Resort of BBSNP, concerning development given the park's critical role in preserving biodiversity and maintaining ecosystem balance on the island of Sumatra (Ariq and Dewi 2022). BBSNP is a World Heritage Site recognized for its unique flora, fauna, and invaluable tropical rainforest ecosystem. The park is a habitat for several rare and endemic species, including the Sumatran tiger (*Panthera tigris* subsp. *sumatrae* Pocock 1929), Sumatran rhinoceros (*Dicerorhinus sumatrensis* G.Fischer 1814), and Sumatran elephant (*Elephas maximus sumatrensis* Temminck 1847), all of which are on the brink of extinction (Pusparini et al. 2018).

Managing IAS like *S. campanulata* is challenging, as eradication can be expensive and environmentally damaging. An alternative approach is utilizing invasive species for economic and industrial purposes, integrating them into local economies to mitigate their spread and provide benefits (Shackleton et al. 2019). Such species can serve as resources for pharmaceuticals, cosmetics, pesticides, and traditional medicines (Reed et al. 2016). This strategy reduces ecological pressure and aligns conservation with economic incentives, benefiting both biodiversity and local communities.

Spathodea campanulata is known to contain a wide array of bioactive compounds, including flavonoids, terpenoids, saponins, alkaloids, and phenolics. These secondary metabolites have demonstrated significant potential for therapeutic applications, such as antioxidants (Bajaj et al. 2021), anti-inflammatory and antimicrobial agents (Imran et al. 2019), anti-malarial compounds (Geevarghese et al. 2024), and anticancer treatments (Venkateswarlu et al. 2015). Such properties make the species a promising candidate for pharmaceutical development. The diverse range of bioactive compounds found in *S. campanulata* highlights the importance of bioprospecting as a tool for drug discovery, particularly in the face of rising drug resistance and the need for more targeted therapies (Atanasov et al. 2015). Despite these promising findings, there has been little research specifically profiling the bioactive compounds of *S. campanulata* from BBSNP, which could offer unique chemical constituents adapted to local environmental conditions.

Bioactive compounds are distributed across plant tissues such as leaves, stems, roots, and flowers. Flowers are particularly noteworthy due to their ecological and medicinal importance. As reproductive organs, flowers contain secondary metabolites that attract pollinators, deter pests, and protect against environmental stressors (Singh et al. 2019). These compounds often exhibit pharmacological properties, making flowers key targets for phytochemical research. Moreover, harvesting flowers can serve as a strategy to control *S. campanulata*'s spread by reducing seed production (Harvey et al. 2015). Flowers are easier to collect and process than other plant parts, making them an efficient and less destructive resource.

This study aimed to profile the bioactive compounds present in the flowers of *S. campanulata* from BBSNP. The findings are expected to contribute to both conservation and bioprospecting efforts, highlighting the species' pharmaceutical potential while addressing its ecological impact. This research seeks to balance ecological protection with sustainable resource utilization by integrating bioprospecting with conservation strategies.

MATERIALS AND METHODS

Study area

Samples of *S. campanulata* flowers were gathered from the Utilization Zone at Pemerihan Resort within Bukit Barisan Selatan National Park (05°33'49.399"S, 104°24'50.176"E), Pesisir Barat District, Lampung Province, Indonesia (Figure 1). The sample preparation and extraction processes were carried out at the Integrated Laboratory and Technology Innovation Centre (LTSIT) at Universitas Lampung. Subsequent LC-MS and GC-MS analyses were performed at the Centre of Forensic Laboratory (Puslabfor) under the Criminal Investigation Agency of the Indonesian National Police in Depok City, West Java, Indonesia.

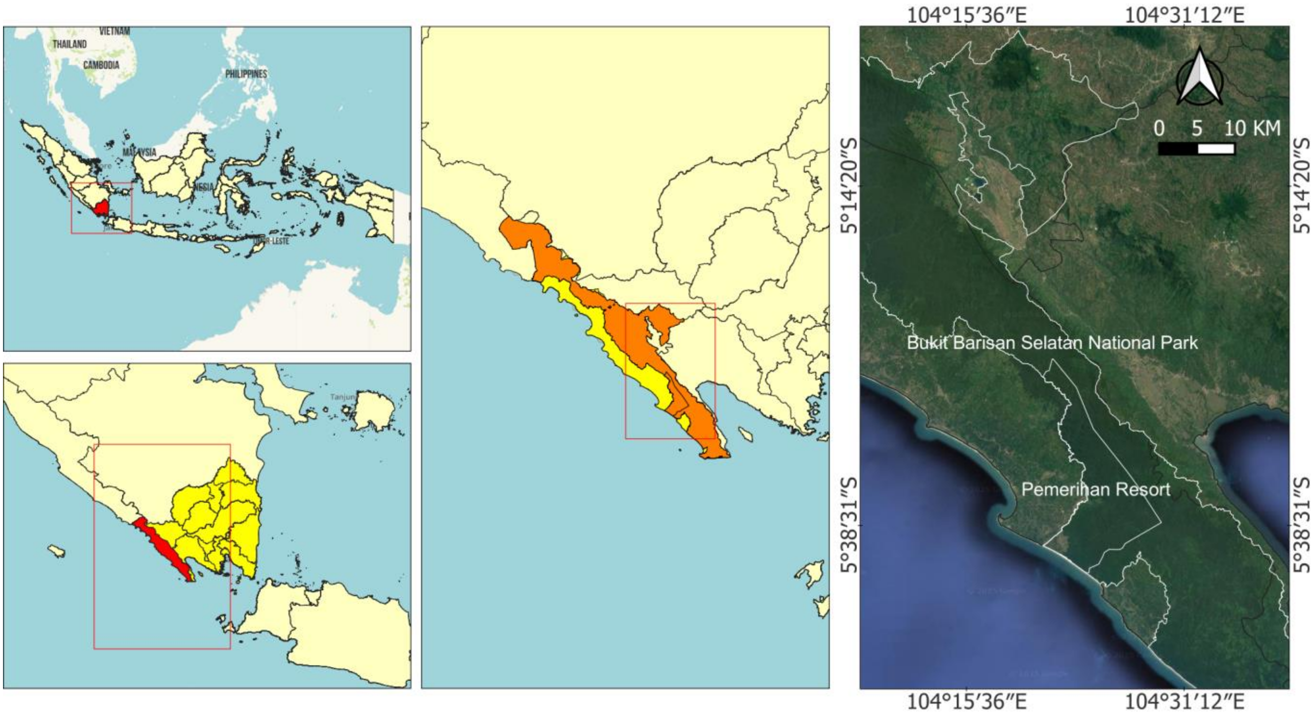


Figure 1. The Utilization Zone at Pemerihan Resort within Bukit Barisan Selatan National Park, Pesisir Barat District, Lampung Province, Indonesia, indicating the sampling sites of *Spathodea campanulata* flowers

Procedures

Flower sample gathering

The sample was procured from the flowers of S. campanulate (Figure 2). Flower specimens were gathered within the Utilization Zone, Pemerihan Resort, BBSNP. The samples were carefully selected to ensure they were healthy and devoid of any diseases. The flowers were collected randomly from various *S. campanulata* trees (Figures 3 and 4), with the sampling area defined by the central presence of a dominant tree. A total of 2 kg of samples were obtained, which were then thoroughly washed under running water to remove any dirt or contaminants.

Sample extraction

The washed samples are subsequently air-dried to eliminate residual moisture from the washing procedure. They are then subjected to oven drying at 80°C for approximately three days until a constant weight is achieved. The samples are cut and then ground using a blender until they are reduced to a fine powder. This powder is then sieved through a 200-mesh sieve to yield a smooth and homogeneous flour.

Maceration is conducted by weighing 250 g of the sample flour. The sample is then placed in a maceration vessel and immersed in 500 mL of 96% ethanol for 72 hours (3 days) at room temperature. During the maceration period, the sample is stirred for 15 minutes daily. After 72 hours, the solution is filtered through 2-micron filter paper. The filtered solution is subsequently evaporated using a rotary evaporator under vacuum at 40°C for one day. This evaporation process yields a highly concentrated solution, which can be dissolved at elevated concentrations. Before analysis, the concentrated extract was further filtered using a 0.2-µm membrane syringe filter to ensure the removal of any residual particulates.

LC-MS analysis

(i) Sample preparation: 250 g of flower powder was dissolved in 500 mL of 96% ethanol for maceration over 72 hours. The resulting solution was filtered using a 2-micron filter paper before being subjected to evaporation under reduced pressure with a rotary evaporator at 40°C. Before analysis, the concentrated extract was further filtered using a 0.2-µm membrane syringe filter to ensure the removal of any residual particulates; (ii) Column specification: a C18 reverse-phase column (Waters ACQUITY UPLC® BEH, 2.1 mm × 50 mm, 1.7 µm particle size) was employed.

Figure 3. African tulip tree (*Spathodea campanulata*)

Figure 4. New *Spathodea campanulata* stem growing from fallen trunk

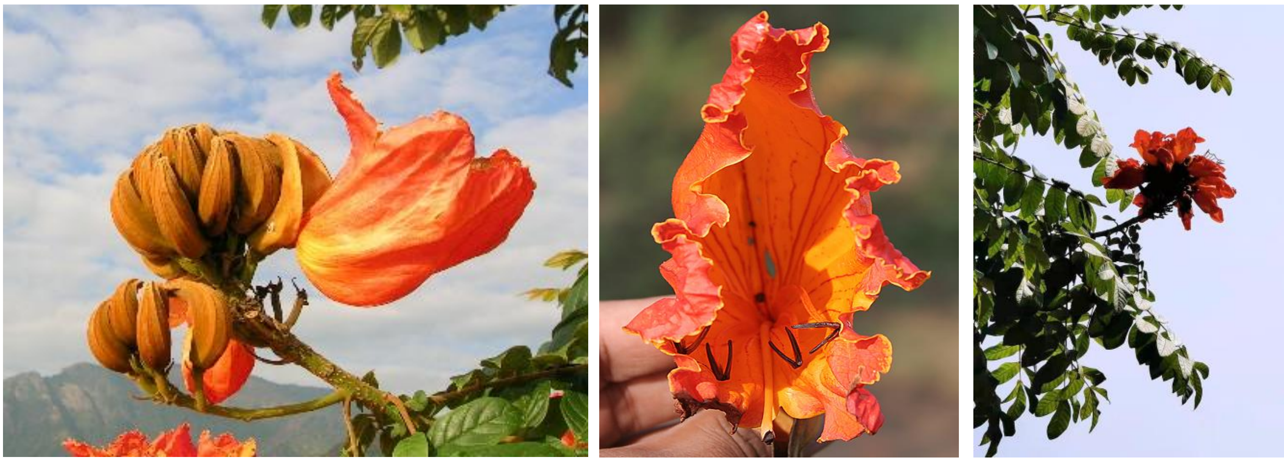


Figure 2. African tulip tree (*Spathodea campanulata*) flowers

The column temperature was maintained at 50°C during the analysis to ensure optimal separation; (iii) Mobile phase composition: The solvent system consisted of 0.1% formic acid in water (Solvent A) and 0.1% in acetonitrile (Solvent B). The method utilized a gradient elution approach, starting with 90% Solvent A and 10% Solvent B and gradually transitioning to 10% Solvent A and 90% Solvent B over a runtime of 23 minutes, with a flow rate of 0.2 mL/min; (iv) Additional parameters and detailed procedures: 5 µL of filtered sample extract was injected into the LC-MS system. The mass spectrometer operated in positive ion mode with an analysis range of 50-1200 m/z. The ion source temperature was set to 100°C, while the evaporation temperature was maintained at 350°C. The mobile phase gradient transitioned from 90% Solvent A (0.1% formic acid in water) and 10% Solvent B (0.1% formic acid in acetonitrile) to 10% Solvent A and 90% Solvent B over 23 minutes, with a flow rate of 0.2 mL/min.

GC-MS analysis

(i) Sample preparation. The samples were extracted using direct solvent extraction (DSE). A total of 250 g of flower powder was macerated in 500 mL of 96% ethanol for 72 hours at room temperature, with occasional stirring to ensure uniform extraction. After maceration, the extract was filtered using 2-micron filter paper and concentrated under reduced pressure using a rotary evaporator at 40°C. For GC-MS analysis, the extract underwent fractionation using liquid-liquid partitioning with n-hexane, ethyl acetate, and water, resulting in distinct polar and non-polar fractions. No derivatization was performed as the compounds were adequately volatile for GC-MS analysis; (ii) Injection mode and conditions. The injection mode was set to splitless mode to maximize sensitivity when detecting trace compounds. The injection port temperature was maintained at 250°C to ensure rapid vaporization of the sample. A volume of 1 µL of the concentrated sample extract was injected into the system for each run; (iii) Oven temperature program. The oven temperature was programmed to start at 60°C, held for 2 minutes, then increased at a rate of 10°C per minute to reach 230°C, where it was held for 5 minutes. This gradient ensured the optimal separation of volatile compounds while maintaining peak resolution; (iv) Column and mobile phase. A capillary column (Agilent DB-5MS, 30 m × 0.25 mm i.d., 0.25 µm film thickness) was utilized. The stationary phase comprised 5% phenyl and 95% dimethylpolysiloxane, well-suited for separating a wide range of volatile and semi-volatile compounds. The mobile phase consisted of helium gas as the carrier, with a constant flow rate of 1 mL/min to ensure efficient and consistent compound separation during the analysis; (v) Quantification and Qualification. The mass spectrometer was operated in positive ion mode, with the mass range set between 50 and 1200 m/z to capture a broad spectrum of compounds. The NIST Mass Spectral Library (NIST 17) supported compound identification, accurately matching mass spectra for reliable identification of the detected bioactive compounds.

Data analysis

The molecular structure and medical properties analysis of the bioactive compounds identified was conducted using spectral data and verified through comparison with established chemical databases such as the NIST Mass Spectral Library, PubChem, ChemSpider, and Google Scholar. These databases provided comprehensive information on each compound's chemical composition, structural configurations, and known biological activities. Cross-referencing the identified compounds with multiple data sources ensured a robust understanding of their pharmacological potential, including known interactions with key biological pathways and mechanisms. This database-driven approach supports the preliminary findings of this study. It underscores the importance of further experimental validation, such as in vitro and in vivo studies, to confirm these bioactive compounds' therapeutic efficacy and safety in clinical applications.

RESULTS AND DISCUSSION

GC-MS analysis

The GC-MS chromatogram reveals several peaks at specific Retention Times (RT), which, when correlated with the unique mass spectrum for each compound, indicate the presence of multiple bioactive compounds in the flowers of *S. campanulata* (Figure 5). Identifying bioactive compounds at each detected peak and retention time (RT) resulted in six volatile compounds. Bioactive compounds: formula, molecular mass, retention time, molecular structure, and medical properties in the flowers of *S. campanulata* extracted with 96% ethanol based on GC-MS analysis are presented in Table 1.

Table 1 demonstrates that *S. campanulata* flowers contain diverse bioactive compounds. The bioactive compounds offer a wide range of benefits that support human well-being. In cosmetics, bioactive compounds such as saponins and essential fatty acids are extensively used in skin and hair care products due to their moisturizing, anti-inflammatory, and anti-aging properties (Desam and Al-Rajab 2021). In the food industry, bioactive compounds serve as natural additives to enhance nutritional value and extend the shelf life of products (Hosseini and Jafari 2020).

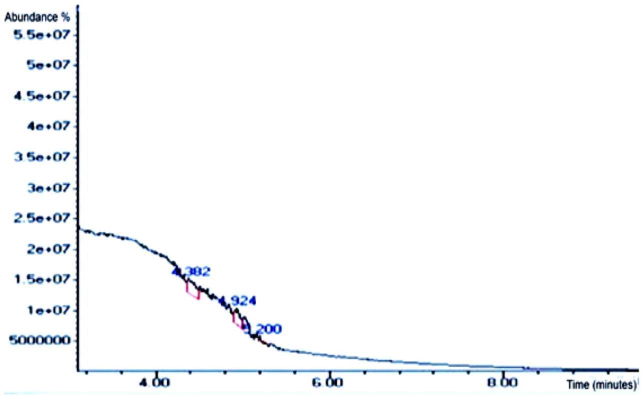
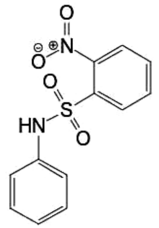
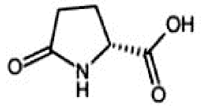
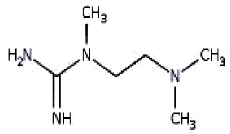
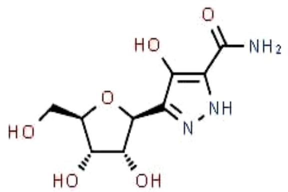
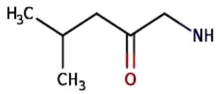


Figure 5. Chromatogram (GC-MS) of *Spathodea campanulata* flower

Table 1. Tentative identification of compounds, formula, molecular mass, retention time, molecular structure, and medical properties in the flowers of *Spathodea campanulata* extracted with 96% ethanol based on GC-MS analysis

Tentative identification of compounds	Formula	Cal. molecular mass (g/mol)	R. time (min)	Molecular structure	Compound class	Medical properties	Reference
Benzenesulfonamide, 2 Nitro-*N*-Phen Yl- 6-Oxa-1 Azabicyclo[3.1.0]Hexane, -Methoxy-	$C_{12}H_{10}N_2O_4S$	336.37	4.77		Sulfonamide	Mefenamic acid is a nonsteroidal anti-inflammatory, analgesic, and antipyretic agent.	Sokolsky et al. (2022)
8,9,9,10,10,11 Hexafluoro-4,4 Dimethyl -3,5 Dioxatetracyclo[5. 4.1.0(2,6).0(8,11)] Dodecane	$C_5H_7NO_3$	129.11	4.77		Fluorinated cyclic	Anti-inflammatory	Krishnan (2016)
6-Oxa-1Azabicyclo[3.1.0] Hexane, -Methoxy- Alpha.-*D* Glucopyranoside, Methyl 3,6-Anhydro- (Cas)	$C_6H_{13}N$	99.17	5.01	-	Bicyclic ethers	Antioxidant, antimicrobial, antibacterial, and antifungal	Zengin et al. (2016)
1,2,4,5 Tetramethyl 1,2,4,5 Tetraazinane	$C_6H_{16}N_4$	144.22	5.13		Aziridines	Antiseptic and disinfectant	Bijekar et al. (2015)
1,2,4,5-Tetrazine, Hexahydro-1,2,4,5 Tetramethyl-	$C_6H_{16}N_4$	231.21	5.13		Tetrazines	Antibacterial, anticancer, and anti-inflammatory	Rao et al. (2012)
1,2,2-Trimethylcyclopropylamine	$C_6H_{13}NO$	115.17	4.87		Amine Cyclopropane	Anticholinergic	Zalivatskaya et al. (2021)

These compounds act as eco-friendly biopesticides in the agricultural sector, reducing reliance on synthetic chemicals (Khursheed et al. 2022). In healthcare, compounds like flavonoids and polyphenols are recognized for their antioxidant capabilities, which are crucial in preventing degenerative diseases and boosting the immune system (Mutha et al. 2021). Moreover, in the pharmaceutical industry, compounds such as alkaloids and terpenoids have formed the foundation for developing essential medications, including analgesics and anticancer agents (Ansari and Akhtar 2019; Men et al. 2024). Specifically in healthcare, based on literature studies, the bioactive compounds in *S. campanulata* flowers show potential as anti-inflammatory, analgesic, antipyretic, antioxidant, antimicrobial, antifungal, antiseptic, disinfectant, anticancer, and anticholinergic agents.

The bioactive compounds in *S. campanulata* are crucial in treating and preventing common diseases worldwide, including both degenerative and infectious diseases. Chronic inflammatory diseases such as arthritis and cardiovascular disorders can be managed with the plant's anti-inflammatory and antioxidant properties, which help reduce inflammation and oxidative damage (Fernandes et al. 2024). Plants with analgesic and antipyretic properties effectively alleviate pain and fever, common symptoms in conditions like influenza and migraines (Cock et al. 2023). Antimicrobial and antifungal agents derived from *S. campanulata* help combat bacterial and fungal infections, the primary causes of infectious diseases such as tuberculosis and candidiasis (Ahmadi et al. 2023). Anticancer agents from this plant play a pivotal role in cancer therapy by inhibiting the growth of cancer cells (Yuan et al. 2016). Additionally, anticholinergic compounds show potential in treating asthma and gastrointestinal disorders (Soler and Ramsdell 2014).

LC-MS analysis

The LC-MS chromatogram displays distinct peaks at defined retention times (RT), which, upon correlation with the unique mass spectra of each compound, confirm the presence of various bioactive compounds in the flowers of *S. campanulata* (Figure 6). Based on the chromatogram from the LC-MS analysis, bioactive compounds were identified using MassLynx software, revealing five bioactive compounds in the *S. campanulata* flowers. Unlike GC-MS, peak signals in LC-MS spectroscopy do not always indicate the presence of bioactive compounds.

The presence of bioactive compounds was only confirmed at the highest peak signals. The selection of compounds was based on the following criteria: (i) Peak intensity: We selected compounds with the highest peak intensity, indicating their higher abundance in the extract. These compounds are likely to contribute more significantly to the biological activity of the sample. (ii) Unique mass spectral fragmentation: The five selected compounds were chosen based on their distinct and well-defined mass spectral fragmentation patterns, which were easily distinguishable from background noise and other overlapping peaks. This ensured reliable identification using the NIST Mass Spectral Library (NIST 17) for accurate compound identification. (iii) Biological relevance: The selected compounds were also chosen for their potential biological significance based on their molecular structure and previously reported bioactivities. These compounds are known to exhibit important pharmacological properties such as antimicrobial, antioxidant, and anti-inflammatory activities, which are relevant to the objectives of this study, and (iv) Correlation with literature: We cross-referenced the detected compounds with relevant literature to ensure that the selected compounds were of particular interest in pharmacological studies, especially in the context of plant-based bioactive compound profiling tentative identification of compounds, formula, molecular mass, retention time, molecular structure, and medical properties in the flowers of *S. campanulata* extracted with 96% ethanol based on GC-MS analysis are presented in Table 2.

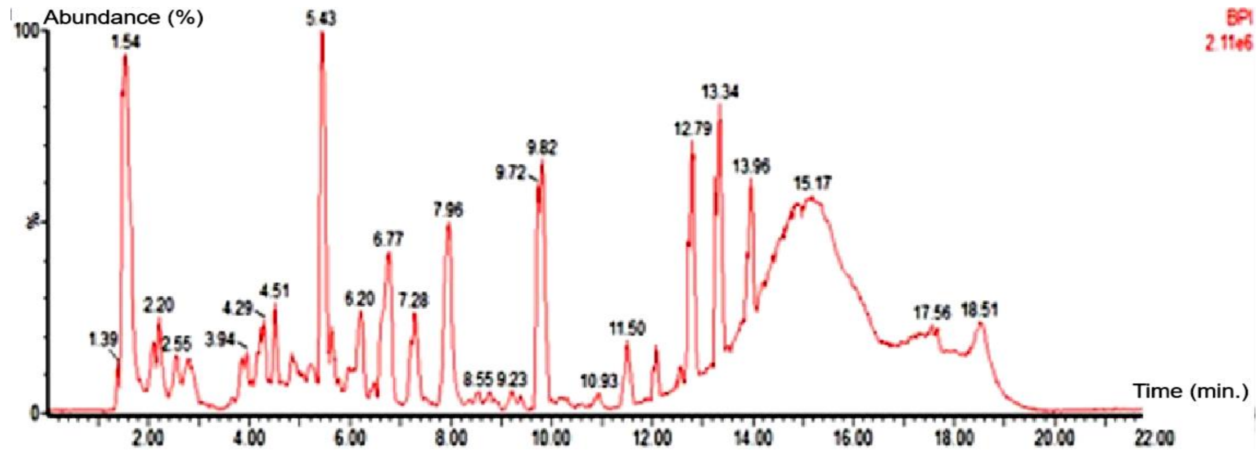


Figure 6. Chromatogram (LC-MS) of *Spathodea campanulata* flower

Table 2. Tentative identification of compounds, formula, molecular mass, retention time, molecular structure, and medical properties in the flowers of *Spathodea campanulata* extracted with 96% ethanol based on LC-MS analysis

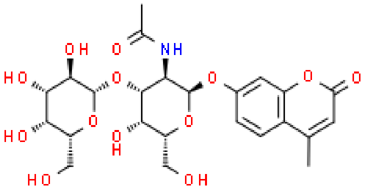
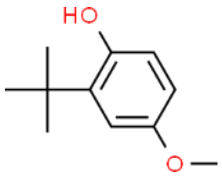
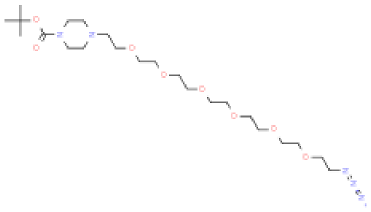
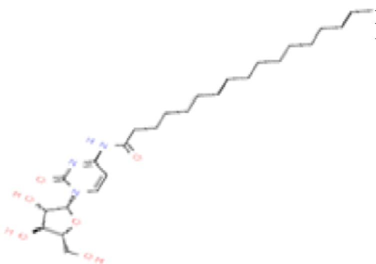
Tentative identification of compounds	Formula	Cal. molecular mass (g/mol)	R. time (min)	Molecular structure	Compound class	Medical properties	Reference
$C_7H_{21}N_6O_8S_2$	$C_7H_{21}N_6O_8S_2$	381.08	1.58	-	Sulfonamide	-	-
4-Methyl-2-oxo-2H- chromen-7-yl 2-acetamido-2-deoxy-3- O-β-D-galactopyranosyl-α- D-galactopyranoside	$C_{24}H_{32}NO_{13}$	542.18	5.43		Flavonoid Glycosides	Antibacterial	ChemSpider
3-BHA	$C_{11}H_{17}O_2$	181.12	9.82		Phenolic Antioxidants	- Antioxidant, - Anti- inflammatory, - Inhibitor of chemical carcinogen - Animal food additives	- Wattenberg (1986) - (Murakami et al. 2015) - (Rychen et al. 2018) - ChemSpider
2-Methyl-2-propanyl4-(20-azido-3,6,9,12,15,18-hexaoxaicos-1-yl)-1-piperazinecarboxylate	$C_{23}H_{46}N_5O_8$	520.33	12.79		Piperazine Carboxylates	Antibiotic	Shehab et al. (2014)
1-(β-D- Arabinofuranosyl)-4-(heptadecanoylamino)-2(1H)-pyrimidinone	$C_{26}H_{46}N_3O_6$	496.33	13.34		Nucleoside Pyramidine	Anticancer	Chemspider and PubChem

Table 2 reveals that at least five non-volatile bioactive compounds were identified in the flowers of *S. campanulata*. This finding suggests the potential for discovering new, effective, and safe drug sources from *S. campanulata* flowers. The unique chemical structures of these bioactive compounds can serve as a foundation for synthesizing more effective drugs and lower toxicity (Padhy 2021). Further exploration of the bioactive compounds in *S. campanulata* holds promise for discovering treatments for various diseases that are currently challenging to cure (Newman and Cragg 2020). The non-volatile bioactive compounds from *S. campanulata* flowers exhibit medical properties as antibacterial, antibiotic, antioxidant, anti-inflammatory, and anticancer agents, as well as inhibitors of chemical carcinogens, with potential use as animal food additives.

Discussion

The bioactive compounds in *S. campanulata* flowers exhibit distinct medical properties between volatile and non-volatile constituents. Volatile compounds uniquely possess analgesic, antipyretic, antimicrobial, antifungal, antiseptic, disinfectant, and anticholinergic properties. In contrast, non-volatile compounds are characterized by antibacterial, antibiotic, and inhibitors of chemical carcinogens and additives in animal feed. The significant differences in the medical properties of volatile and non-volatile compounds in the extract of *S. campanulata* arise from their differing chemical characteristics and mechanisms of action. Volatile compounds, such as essential oils, are often responsible for the plant's aromatic qualities and exhibit impressively rapid pharmacological effects, particularly as antimicrobial, anti-inflammatory, and analgesic agents. These compounds tend to evaporate quickly at room temperature, enabling swift interaction with biological systems and making them effective in treating acute conditions like infections or pain (Das et al. 2018). In contrast, non-volatile compounds, including flavonoids, alkaloids, and tannins, are more stable and frequently contribute to the plant's long-term therapeutic effects. Meanwhile, the properties found in both volatile and non-volatile compounds include anticancer, antioxidant, and anti-inflammatory effects. The complementary action of volatile and non-volatile compounds in *S. campanulata* underscores its potential as a multifunctional medicinal agent.

The flowers of *S. campanulata* originating BBSNP have been identified to possess 13 medical properties, including analgesic, antipyretic, antimicrobial, antifungal, antiseptic, disinfectant, antibacterial, antibiotic, anticancer, antioxidant, anticholinergic, anti-inflammatory and inhibitors of chemical carcinogens. These findings suggest that the bioactive compounds in *S. campanulata* flowers are more diverse than those found in commonly used medicinal plants. Zhang et al. (2022) reported that red ginger's ethanol and methanol extracts (*Zingiber officinale* var. *rubrum* Theilade rhizomes) contain only five bioactive properties, specifically as antioxidants, anti-inflammatory, and anticancer agents (Maulana et al. 2023) reported the GC-MS and phytochemical analysis of *Begonia hirtella*. flowers revealed only five compounds, including alkaloids, phenolics, saponins, and terpenoids, with antibacterial and antifungal properties. Furthermore, (Joseph et al. 2016) reported that the extract from the *Garcinia xanthochymus* fruit contains only four bioactive compounds with potential, antimicrobial, antifungal, antioxidant, anti-inflammatory properties. Similarly, Han et al. (2023) noted that the bioactive compound extract from teak flowers (*Tectona grandis*) revealed only two types of flavonoids with anti-inflammatory potential.

The flowers of *S. campanulata* originating BBSNP contain several bioactive compounds with antimicrobial properties. This finding aligns with the report by (Tsouh Fokou et al. 2015), which demonstrated that the flower extract of *S. campanulata* originating in Africa exhibits antimicrobial activity against bacterial and fungal pathogens. Similar findings were reported by Kumari et al. (2016), who discovered that the flower extract of *S. campanulata*, which originates in India, also possesses potential as an effective antibacterial agent against various pathogenic bacteria.

This study reveals that the flowers of *S. campanulata* from Bukit Barisan Selatan National Park (TNBBS) contain several bioactive compounds, including 6-Oxa-1-Azabicyclo[3.1.0]hexane, -Methoxy-α-D Glucopyranoside, Methyl 3,6-Anhydro-(Cas), and 1,2,4,5-Tetrazine, Hexahydro-1,2,4,5-Tetramethyl-, which are known for their antioxidant properties. These findings are consistent with the report by Santos et al. (2020) that the leaves and flowers of *S. campanulata* from Brazil possess a considerable amount of total phenolic content and exhibit strong antioxidant activity .

The flower of *S. campanulata* harbors an array of bioactive compounds with significant anticancer potential, including flavonoids, phenolics, 1,2,4,5-Tetrazine, Hexahydro-1,2,4,5-Tetramethyl-. These compounds have demonstrated the capacity to inhibit cancer cell proliferation through mechanisms such as apoptosis induction and modulation of molecular pathways, including p53 and NF-κB, which are critical in cell cycle regulation and inflammation (Geevarghese et al. 2024). Furthermore, the potent antioxidant activity of phenolic and flavonoid compounds mitigates oxidative stress, a major driver of carcinogenesis (Jomova et al. 2023). Flavonoids have also been reported to suppress angiogenesis, a process essential for tumor progression, by regulating growth factors such as Vascular Endothelial Growth Factor (VEGF) (Fernandes et al. 2024). These findings underscore the potential of secondary metabolites from *S. campanulata* as chemical carcinogen inhibitors, which could be instrumental in cancer prevention strategies (Das et al. 2018). With its diverse bioactive profile, *S. campanulata* is a promising candidate for developing novel anticancer therapies. The discovery of anticancer agents in Indonesia is of critical importance given the high prevalence of cancer in the country and the limited access to effective and affordable modern therapies. With more than 100,000 new cases annually and over 70,000 cancer-related deaths reported each year, Indonesia ranks as one of the countries with relatively high cancer mortality rates, particularly in Southeast Asia. Further research should prioritize in vivo evaluations, dose optimization, and toxicity assessments, ultimately progressing to clinical trials to ascertain the efficacy and safety of these bioactive compounds (Dehelean et al. 2021).

The flowers of *S. campanulata* originating TNBBS contain several bioactive compounds with anti-inflammatory properties, including Benzenesulfonamide, 2-Nitro-N-Phenyl-, 6-Oxa-1-Azabicyclo[3.1.0]hexane, -Methoxy-, 1,2,4,5-Tetrazine, Hexahydro-1,2,4,5-Tetramethyl-, and 8,9,9,10,10,11-Hexafluoro-4,4-Dimethyl-3,5-Dioxatetracyclo [5.4.1.0 (2,6).0(8,11)] dodecane. This finding is consistent with the report by (Wagh and Butle 2018), which identified several compounds from the flower extract of *S. campanulata* with potential anti-inflammatory effects that could be beneficial in treating conditions such as osteoarthritis and rheumatoid arthritis (Gulumian et al. 2018) stated that inflammation is significantly associated with coronary artery disease, caused by the blockage of blood vessels by cholesterol plaques, leading to an increased risk of coronary artery disease. According to the World Health Organization (WHO), cancer and coronary artery disease are among the deadliest diseases worldwide. The WHO reports that coronary artery disease and cancer have resulted in at least 27.7 million deaths globally from the year 2000 to 2021.

The flowers of *S. campanulata* contain bioactive compounds with anti-inflammatory and antioxidant properties that can alleviate inflammation symptoms and relieve respiratory disorders associated with Chronic Obstructive Pulmonary Disease (COPD) (Gholamnezhad et al. 2015). Furthermore, Bahramsoltani et al. (2015) reported that the bioactive compounds in *S. campanulata* can inhibit the production of pro-inflammatory cytokines and reduce oxidative stress in the respiratory tract (Das et al. 2018) also demonstrated that extracts of *S. campanulata* contain flavonoids and tannins with antimicrobial activity against several bacteria causing respiratory infections. Furthermore, (Jomova et al. 2023) found that extracts from the flowers of the African tulip tree contain anti-inflammatory compounds that can reduce respiratory tract inflammation and improve lung function in COPD patients.

The findings of this study indicate that the *S. campanulata* holds significant promise as a future medicinal plant due to its potential in addressing various life-threatening diseases globally. The bioactive compounds present in the flowers of *S. campanulata* have promising potential to treat four of the deadliest diseases worldwide: cancer, COPD, respiratory infections, and coronary artery disease. According to the WHO, cancer, coronary artery disease, stroke, respiratory infections, COPD, diabetes mellitus, and Alzheimer's disease have collectively caused 45 million deaths from the year 2000 to 2021.

The flowers of *S. campanulata* originating BBSNP contain 11 bioactive compounds, of which six are volatile and five are non-volatile. These eleven compounds fall into four categories: flavonoids, alkaloids, amino acids, and iridoids. The identified compounds exhibit 13 medical properties, including analgesic, antipyretic, antimicrobial, antifungal, antiseptic, disinfectant, anticholinergic, antibiotic, antibacterial, anticancer, antioxidant, anti-inflammatory, and inhibitors of chemical carcinogens. This finding aligns with the report by Wagh and Butle (2018), which identified several compounds in *S. campanulata* flower extracts with potential anti-inflammatory effects, suggesting their benefit in treating conditions such as osteoarthritis and rheumatoid arthritis. Additionally, Gulumian et al. (2018) noted that inflammation plays a significant role in the development of coronary artery disease, as it contributes to the blockage of blood vessels by cholesterol plaques, thereby increasing the risk of this condition. However, this research is limited to profiling bioactive compounds within *S. campanulata* flowers and their potential medical applications. Further studies are required to develop these compounds into standardized herbal medicines, including in vitro and in vivo pharmacological studies, toxicology and safety assessments, clinical efficacy testing, pharmacokinetic and pharmacodynamic studies, and compound structure and synthesis optimization.

This study indicates that *S. campanulata* flowers from BBSNP have significant potential for future therapeutic agents, given the substantial potential of their bioactive compounds in the prevention and treatment of some of the deadliest diseases, including cancer, infectious diseases, arthritis, coronary heart disease, and autoimmune disorders. Based on the findings of this study, further steps are required to develop *S. campanulata*-based drugs. The anticancer activity should be evaluated in vitro and in vivo using various cancer cell lines. Additionally, research must explore mechanistic studies, optimal dosing, and toxicity. Antibacterial and antimicrobial tests should be conducted against various pathogens, including antibiotic-resistant bacteria. Such studies are crucial for determining these compounds' antimicrobial spectrum and clinical efficacy. Preclinical and clinical trials are necessary to assess anti-inflammatory compounds' effectiveness, safety, and mechanism of action to treat chronic inflammation.

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