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Analyzing the Secondary Metabolites and Pharmacological Activities of *Solanum ferox*: A Systematic Review

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Abstract
This study explores *Solanum ferox*, also known as *Solanum lasiocarpum* Dunal, as a rich source of secondary metabolites in herbal medicine. The main objective of this article is to highlight the secondary metabolites contained in *S. ferox*. The methodology employed is a Systematic Literature Review, following the PRISMA guidelines, which analyzes 8 selected articles published from 2018 onwards. These articles were sourced from Google Scholar, PubMed, and Mendeley databases, focusing on studies related to the phytochemistry of this plant. the results of the document analysis show *Solanum ferox* contains various compounds such as alkaloids, flavonoids, tannins, terpenoids, steroids, and saponins, which demonstrate significant potential in antioxidant, antibacterial, and anticancer activities. These results also indicate the possible structures of the identified compounds, providing a deeper understanding of their bioactivity. Moreover, this study highlights how the diverse phytochemical profile of *Solanum ferox* supports its traditional use in herbal remedies. These findings emphasize the importance of further research to optimize the utilization of *Solanum ferox* in the development of safe, effective, and sustainable herbal medicines.

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INTRODUCTION

Plants have long been a primary source of traditional medicine, and their popularity continues to rise alongside public interest in herbal remedies (Prasetyo et al., 2023; Savitri, 2016). The "back to nature" trend shows that more and more people are turning to more natural health solutions (Firmansyah et al., 2017). Therefore, exploring the potential of plants as a source of raw materials for medicine becomes very important for the development of effective and sustainable drugs.

Among various plants, those from the genus Solanum have many species, consisting of 2000 species (Chidambaram et al., 2022). Several species within this genus have been reported to possess anticancer activity (Balachandran et al., 2015; Helilusiatiningsih et al., 2019), anti-inflammatory properties (Elmitra et al., 2019; Priamsari et al., 2019), as well as antibacterial characteristics (Lajira et al., 2019; Nurmaulawati et al., 2024). This indicates that the diversity of species within the genus Solanum reflects a significant potential that can be explored for the development of herbal medicines.

Solanum lasiocarpum Dunal, previously known as *Solanum ferox*, is a synonym referring to a plant commonly called terong asam in the local language (Ibrahim et al., 2022). This plant is commonly found in the regions of Kalimantan and Sumatra (Syakirin et al., 2022) and is used as an ingredient in cooking (Budiarto et al., 2022; Syarpin et al., 2018). Among the many species in this genus, *Solanum ferox* is still relatively underexplored in terms of pharmacology, despite having a history of use in traditional medicine (Hazimah et al., 2018; Syakirin et al., 2022); Syarpin et al., 2018). Although the use of *S. ferox* as medicine is based solely on empirical experience (Syarpin et al., 2018), scientific research is available reporting its antioxidant, antibacterial, anticariogenic, and UV protection potential (Hazimah et al., 2023; Kalalinggi et al., 2024; Raduan et al., 2019) in both its leaves and fruits. These findings indicate that *S. ferox* possesses various properties that may not yet be fully explored, thus opening up opportunities for further research. The literature mentions that the phytochemicals contained in *S. ferox*, such as flavonoids and phenolics, potentially have significant biological effects, including as natural antioxidants and potential anti-inflammatory agents (Rahman et al., 2019). Additionally, previous studies successfully isolated stigmasterol from *S. ferox* (Hazimah et al., 2023), which has the potential to inhibit cancer cells (Bae et al., 2020; Zhao et al., 2021). Considering that potential, a more in-depth exploration of the secondary metabolite compounds in this plant is warranted.

The limitations of existing research indicate that there are still many aspects of the pharmacological activity of *S. ferox* that need further exploration. Therefore, this article systematically reviews existing of various secondary metabolite compounds of *S. ferox*, as well as to integrate the knowledge obtained from previous studies.

METHOD

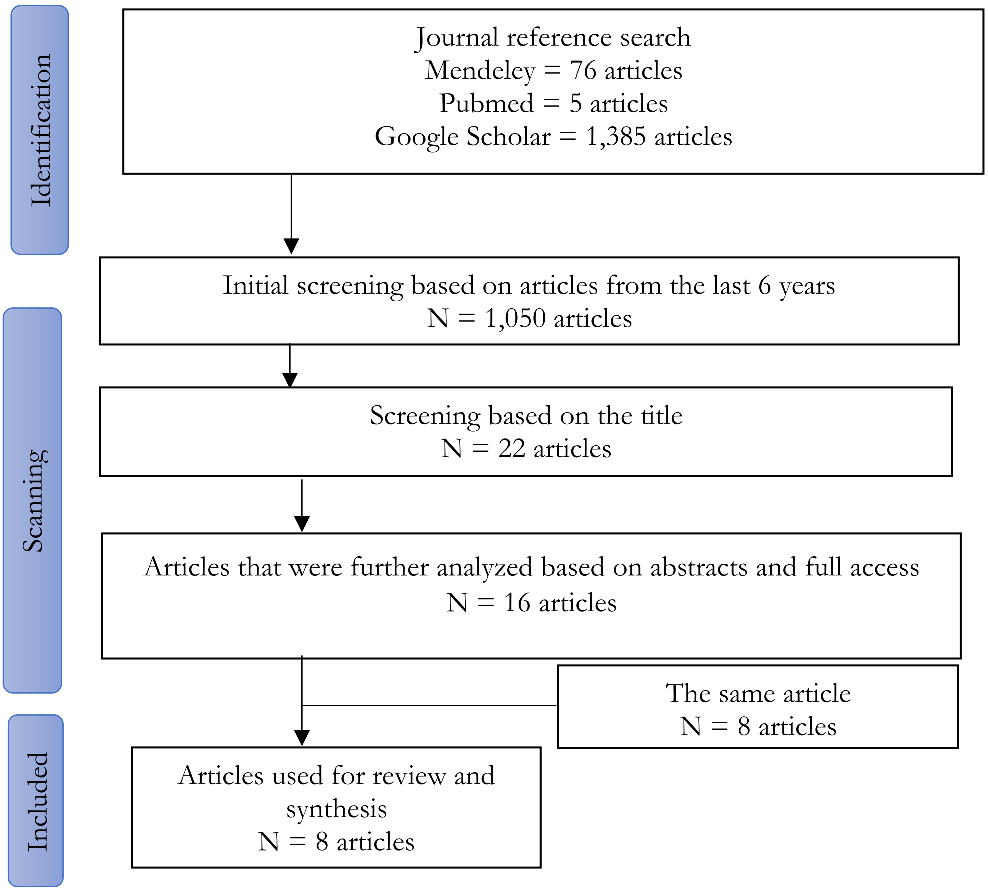

Figure 1. Diagram Illustrating the Literature Selection Process

This study adopted a systematic literature review framework guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. A comprehensive literature search was conducted across three major databases Mendeley (76 articles), PubMed

(5 articles), and Google Scholar (1,385 articles) using the keywords "*Solanum ferox*" and "*Solanum lasiocarpum*", yielding a total of 1,466 records. During the initial identification phase, articles were screened based on publication year (2018–2024), and duplicates were removed, resulting in 1,050 eligible records. The title screening phase then assessed the relevance of articles to the study focus, specifically phytochemical screening and metabolite identification in *Solanum ferox* and *S. lasiocarpum*, narrowing the selection to 22 articles. Subsequently, abstracts and full-texts were critically evaluated based on predefined inclusion criteria: studies that reported phytochemical analyses, metabolite profiling, or compound isolation using validated analytical techniques. Articles lacking full-text access, original data, or direct relevance to the topic, as well as non-research publications, were excluded, resulting in 16 eligible studies. A final duplication check identified 8 overlapping articles published across multiple platforms, leaving 8 unique and relevant articles for analysis.

RESULTS AND DISCUSSION

Based on the search results of articles from PubMed, Google Scholar, and Mendeley, only 8 articles were found that met the inclusion criteria set in this study. The literature review conducted identified secondary metabolite compounds found in the plants *Solanum ferox* and *Solanum lasiocarpum*. The secondary metabolites present in the plants *S. ferox/lasiocarpum* are summarized in Table 1.

Table 1. Secondary metabolites compounds reported in each research article

Species	Compounds	Solvent	Extraction Method	Plant Part	Reference
Solanum lasiocarpum	Alkaloids, terpenoids, steroids, saponins, flavonoids, and tannins.	Ethanol 96%	Maceration	Fruit	(Syukriah et al., 2022)
Solanum ferox	Alkaloids, steroids, terpenoids, flavonoids, and phenolics	Methanol 98%	Maceration	Fruit	(Nugroho et al., 2023)
	Alkaloids, flavonoids, and tannins	Ethanol 95%	Maceration	Leaves and fruit pulp	(Raduan et al., 2019)
	Alkaloids, terpenoids, flavonoids, phenolics	Ethanol 96%	Maceration	Fruit pulp	(Kalalinggi, 2024)
	Alkaloids, flavonoids	Ethanol	Maceration	Fruit	(Hazimah Hazimah et al., 2018)
	Terpenoids, steroids, and phenolics.			Leaves	
	Alkaloids, Tannins	Methanol	Maceration	Stem	(Noor et al., 2021)
	Alkaloids, Tannins			Root	
	Alkaloids, Flavonoids			Leaves	
	Alkaloids, Flavonoids, Tannins			Fruit	
	Flavonoids	Ethanol 96%	Maceration	Fruit	(Anggoro, 2022)

Species	Compounds	Solvent	Extraction Method	Plant Part	Reference
	Alkaloids, terpenoids, phenolics , flavonoids	Ethanol	Maceration	Fruit	(Syarpin et al., 2018)

Solanum ferox and *Solanum lasiocarpum* are types of plants recognized as sour eggplants. *Solanum ferox* and *Solanum lasiocarpum* have local names as terung asam or terung dayak. Dayak eggplant, which was previously classified as *Solanum ferox*, is now known as *Solanum lasiocarpum* (Ibrahim et al., 2022). This merging largely occurs due to two factors: first, local classification often treats these two plants identically, and second, the difficulty in distinguishing their morphology or physical characteristics. As a result, both *Solanum lasiocarpum* and *Solanum ferox* are often used in the same way (Meyer et al., 2014).

Alkaloids

Alkaloids are secondary metabolites most frequently identified in *S. ferox/lasiocarpum*, where these compounds function as nitrogen-containing secondary metabolites. Alkaloids play an important role in plant defense (Halimatussakdiah et al., 2016), with their toxic properties protecting against other organisms, including pest and disease control (Suryelita et al., 2017). Thus, alkaloids not only protect the plants but can also contribute to the sustainability of the surrounding ecosystem.

Previous research has shown that alkaloids can be found throughout all parts of the *S. ferox* plant using the maceration extraction method (Noor et al., 2021; Kalalinggi et al., 2024). The results of this study indicate that the distribution of alkaloids in *S. ferox* is quite extensive and easily found.

The suspected alkaloid in *S. ferox* is solasodine, which falls into the category of steroid alkaloids. Another study identified solasodine as an alkaloid, which was detected in fruit extracts using High-Performance Liquid Chromatography (HPLC) instrumentation (Hardi et al., 2021). Additionally, several genera within the Solanum family are also known to contain solasodine compounds, indicating that the distribution of this compound is very widespread not only in plant parts but also in the Solanum genus (Pondini et al., 2023; Makmur, 2019).

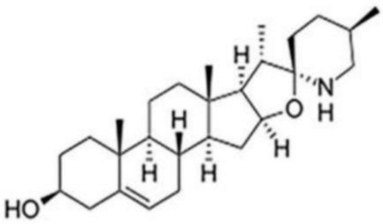

Figure 2. Structure of the solasodine compound
(Image Source: Khandani et al., 2019)

Solasodine is produced from solamargin or solasonin, which belong to the category of steroid alkaloids. The hydrolysis process of this compound produces two components: the aglycone part (solasodin) and the glycoside part, which consists of mannose, glucose, and galactose (Kousar et al., 2022). As a member of steroid alkaloids, solasodine exhibits important chemical properties and biological activities, particularly in anticancer properties (Waddell et al., 2021), immunomodulation, antimicrobial, and anti-inflammatory effects (Kumar et al., 2019). These findings indicate that *S. ferox* has the potential to be a source of compounds with significant pharmacological activity, opening up opportunities for further research that can explore the clinical and therapeutic applications of these compounds.

Phenolics, Flavonoids & Tannins

Phenolic compounds are secondary metabolites commonly found in various types of plants (Diniyah et al., 2020), including *Solanum ferox*. This compound has a basic structure consisting of an aromatic ring bound to one or more hydroxyl groups on the carbon atoms in the ring (Adawiah et al., 2015). Phenolic compounds are known for their antioxidant properties (Mukhriani et al., 2019) and have significant antibacterial activity. For example, research (H Hazimah et al., 2019) reported that *S. ferox* leaf extract in n-hexane solvent was able to provide antibacterial effects against Escherichia coli at a concentration of 5.7%, resulting in an inhibition zone of 12.93 mm. However, the effectiveness of this extract against *Staphylococcus aureus* and *Bacillus subtilis*, which are Gram-positive bacteria, is lower.

The difference in the effectiveness of phenolics on gram-negative and gram-positive bacteria can be explained by the unique chemical structure and cell wall composition of each bacterium. Phenolic compounds, with their conjugated aromatic ring structure (Prasiddha et al., 2016) and hydrophobic properties (Pramushinta, 2021), have the potential to interact with lipids in bacterial membranes, especially in gram-negative bacteria that have a lipopolysaccharide (LPS) layer on their outer membrane. This interaction can cause damage to the lipid layer, which ultimately triggers cell content leakage and bacterial death. On the other hand, gram-positive bacteria such as *S. aureus* and *B. subtilis* have thicker cell walls, consisting of a peptidoglycan layer that can provide better protection against external disturbances (Mahmudah et al., 2016). Phenolic compounds, such as flavonoids and tannins, are examples of compounds that play an important role in antibacterial activity.

Flavonoids and tannins are part of phenolic compounds because they have an aromatic ring (benzene), although not all flavonoids have a hydroxyl group (-OH) in their structure. Flavonoids and tannins are widely distributed throughout all parts of the sour eggplant plant through the method of maceration extraction. Flavonoids, as part of this group, have a basic structure (C6-C3-C6) consisting of two phenyl rings connected by three carbon atoms. This structure forms an oxygenated heterocyclic ring, where the three rings are labeled A, B, and C (Nugrahani et al., 2016). Flavonoids often act as antioxidants by neutralizing free radicals in the body, preventing cell damage due to oxidative stress. On the other hand, tannins are phenolic compounds with a larger molecular weight and generally, the chemical properties of tannins include phenolic groups and colloidal characteristics (Nofita et al., 2021). Tannins are usually found in the bark, leaves, and seeds of plants, and are often used for medical and industrial purposes, such as leather tanning. Biologically, tannins can precipitate proteins, allowing them to function as antibacterial agents by disrupting essential protein functions in bacterial cells. The antibacterial properties of tannins usually work by binding to cell wall proteins and microbial enzymes, thereby inhibiting bacterial growth.

Steroids & Terpenoids

Steroids and terpenoids originate from the same biosynthesis, as they both use the isoprene precursor (C_5H_8). Terpenoids are compounds with an isoprene backbone that have undergone modification. Steroids are organic compounds based on fat that belong to the sterol group, cannot be broken down through hydrolysis, and are soluble in fat, with a basic structure of sterane, which consists of 17 carbon atoms arranged in four rings (Akhmadi et al., 2022; Yasser et al., 2022). Several literatures indicate the presence of steroids and terpenoids in the *S. ferox/lasiocarpum* plant, particularly in the fruit and leaf parts, which are extracted through maceration using ethanol or methanol solvents. Compounds from the terpenoid group have the potential to act as feeding inhibitors for insects, function as larvicides, and serve as insect repellents, thereby helping to prevent chronic diseases such as cancer (Fransiska et al., 2021). Another study successfully isolated the n-hexane extract of *S. ferox* leaf, where the main compound identified was stigmasterol with the chemical formula $C_{29}H_{48}O$. This compound was analyzed using UV, IR, and NMR spectroscopy methods (Hazimah Hazimah et al., 2023).

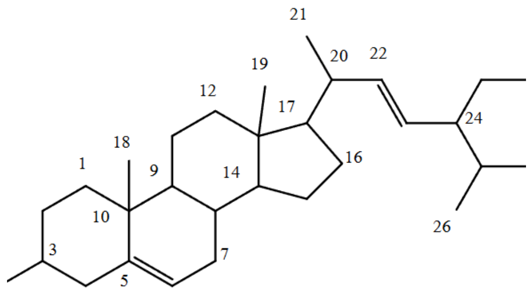

Figure 3. Structure of the compound stigmasterol
(Image Source: Hazimah et al., 2023)

Saponins

Saponin is a glycoside compound that contains an aglycone in the form of steroids and triterpenoids (Firdaus et al., 2013). This compound is soluble in water and can be identified through a simple test such as shaking, which produces foam as an indicator of its presence (Ernawita, 2022). Saponin has various potential applications, such as being used as a natural pesticide on shrimp and having antifungal properties. In its function as an antifungal, saponin works by reducing the surface tension of the cell wall and disrupting membrane permeability (Putri et al., 2023). Several other species from the genus Solanum, such as *Solanum lycopersicum* L., *Solanum torvum* Swartz, and *Solanum nigrum* L., have successfully detected the presence of saponins (Artanti et al., 2018; Rizkita et al., 2021). In *S. ferox*, saponins were not detected in the leaves, fruits, stems, or roots. On the other hand, in *S. lasiocarpum*, saponin was detected. This difference is most likely due to the very low concentration of saponins in *S. ferox*, making them undetectable in the test. This is supported by research (Singh et al., 2019), which shows that the foaming ability of saponin from the tested plant parts is lower compared to standard saponin. The low foam formation activity may be due to the extract being less pure compared to pure saponin. These findings support the hypothesis that low saponin concentration or suboptimal extract purity can affect the results of phytochemical tests, including foaming ability.

CONCLUSION

Solanum ferox (sour eggplant), also known as *Solanum lasiocarpum* Dunal, is a local plant commonly found in the regions of Kalimantan and Sumatera. This plant is widely recognized for its richness in secondary metabolite compounds, including alkaloids, flavonoids, tannins, terpenoids, phenolics, steroids, and saponins. These various compounds possess very promising pharmacological potential. Based on a number of research findings, these metabolites exhibit significant activity as antioxidants, antibacterials, and anticancer agents. Such bioactivities make *Solanum ferox* one of the strong candidates for further development in the field of modern herbal medicine. Its potential as a natural therapeutic agent highlights the need for more comprehensive and in-depth phytochemical and pharmacological investigations to ensure its optimal utilization. Furthermore, the use of *Solanum ferox* as a source of herbal medicine raw materials also supports the conservation of local biodiversity while encouraging the production of more sustainable and eco-friendly health products. Therefore, *Solanum ferox* is not only valuable from an ethnobotanical perspective but also holds considerable promise in the advancement of scientifically based, safe, and effective herbal medicines that align with modern health and environmental standards.

RECOMMENDATIONS

Based on the study results, it is recommended to conduct further research in vivo and in vitro to test the pharmacological activity of *Solanum ferox* compounds, such as alkaloids, flavonoids, tannins, and steroids. The methods for isolating and identifying compounds also need to be improved with more specific analytical techniques. In addition, it is important to research toxicity, explore other parts of the plant such as roots and stems, and develop stable and safe herbal formulations. Collaboration between researchers, industry, and the government is needed to support the development of *Solanum ferox* as a potential and environmentally friendly herbal medicine.

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