



Phytochemical Study of Andaliman (*Zanthoxylum acanthopodium*) for Contextual Chemotaxonomy Learning in Biology Education

Aswita Mardohar Hasibuan^{1*}, Suyitno Aloysius², Paidi²

¹ Master Study of Biology Education, FMIPA, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia.

² Biology Departement, FMIPA, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia.

Received: July 06, 2025

Revised: December 27, 2025

Accepted: January 25, 2026

Published: January 31, 2026

Corresponding Author:

Aswita Mardohar Hasibuan

aswitamardohar.2024@student.uny.ac.id

DOI: [10.29303/jppipa.v12i1.12037](https://doi.org/10.29303/jppipa.v12i1.12037)

 Open Access

© 2026 The Authors. This open access article is distributed under a (CC-BY License)



Abstract: The andaliman (*Zanthoxylum acanthopodium*), also known locally as toba-toba, is a species endemic to North Sumatra, Indonesia, possessing a significant diversity of phytochemical compounds. This study aims to conduct a systematic review of the phytochemical content of andaliman and evaluate its potential for developing contextual biology education, specifically the topic of chemotaxonomy at the secondary education level. The research employed a systematic literature review protocol based on a search of national and international journals published between 2015 and early 2025. The results indicate significant phytochemical variation in andaliman (especially essential oils, alkaloids, flavonoids, saponins, and terpenoids) in highland populations, supporting the concept of chemotaxonomy. Although chemotaxonomy is globally established, its integration into science education in Indonesia, particularly in teaching plant classification using local phytochemical data, remains limited. This gap highlights the potential for developing biology teaching materials that integrate taxonomic concepts with local wisdom, which can substantially enhance scientific literacy and foster an appreciation for Indonesia's biodiversity.

Keywords: Alkaloids; Andaliman; Biology learning; Chemotaxonomy; Phytochemistry; *Zanthoxylum acanthopodium*

Introduction

Indonesia is known for its extraordinary biodiversity, boasting over 40,000 plant species, including endemic flora with unique phytochemical characteristics (Nurlaeni et al., 2024). One prominent endemic plant is the andaliman or toba-toba (*Zanthoxylum acanthopodium*), a member of the Rutaceae family, which thrives in the highlands of North Sumatra, particularly around Lake Toba (Ompusunggu & Irawati, 2021).

Andaliman (*Zanthoxylum acanthopodium*) is a vital species endemic to North Sumatra and has long been used by the Batak people as a traditional cooking spice and herbal medicine (Lumbanbatu, 2025). This spice is

commonly used in the Toba Samosir and North Tapanuli regions at an altitude of approximately 1,500 meters above sea level (Harahap, 2019). In addition to its traditional culinary value, andaliman also holds high potential for bioactive compounds (Hutapea et al., 2024).

In plant taxonomy, the secondary metabolites produced by this plant are crucial as chemotaxonomic characters, a classification based on chemical compound profiles (Amin & Park, 2025). Modern phytochemical research has revealed a diverse range of secondary metabolites in andaliman, including alkaloids, flavonoids, saponins, terpenoids, and essential oils (Lewerissa et al., 2025). However, this rich potential has not been widely adopted in secondary biology

How to Cite:

Hasibuan, A. M., Aloysius, S., & Paidi, P. (2026). Phytochemical Study of Andaliman (*Zanthoxylum acanthopodium*) for Contextual Chemotaxonomy Learning in Biology Education. *Jurnal Penelitian Pendidikan IPA*, 12(1), 94–101. <https://doi.org/10.29303/jppipa.v12i1.12037>

education, which generally focuses solely on morphological approaches.

Chemotaxonomy is an approach to classifying organisms based on their chemical composition, particularly the secondary metabolites they produce (Suryani & Ramona, 2020). The essence of this approach is to classify plants based on specific types of secondary metabolites and their biosynthetic pathways (Mali et al., 2023). Chemotaxonomy has proven effective in solving complex taxonomic problems and providing additional insights into plant classification systems (Olabamiji, 2025).

Although extensive research on andaliman phytochemicals has been conducted, the use of these findings in educational contexts remains limited (Rosmiati et al., 2025). Chemotaxonomy, a branch of taxonomy that utilizes chemical characteristics, has great potential for integration into biology instruction in secondary schools (Khan et al., 2023). However, its implementation in the Indonesian education curriculum is rare. This research aims to bridge this gap by linking local phytochemical data with educational innovations.

The novelty of this research lies in the systematic integration of rich phytochemical data from an endemic Indonesian plant (*Zanthoxylum acanthopodium*) with the underutilized concept of chemotaxonomy, particularly to propose a contextual learning module for Indonesian secondary education. This research is important because: it provides a logical framework for integrating local wisdom (ethnobotany/utilization of andaliman) with scientific concepts (chemotaxonomy), making learning more meaningful; it addresses the gap in Indonesian science education related to the lack of chemical-based classification methods; and it offers concrete steps towards improving scientific literacy by connecting biology and chemistry through relevant local examples.

This study aims to analyze the diversity of phytochemical content of andaliman based on scientific literature, evaluate the development of chemotaxonomy concepts in plant systematics, and identify opportunities for integrating andaliman phytochemical findings into contextual biology learning.

Method

This study employed a Systematic Literature Review protocol. This procedure involved a comprehensive search of national and international journal databases, such as Google Scholar, Garuda, ResearchGate, ScienceDirect, and PubMed. The search focused on literature published between 2015 and early 2025, using key keywords such as "andaliman,"

"*Zanthoxylum acanthopodium*," "phytochemistry," "chemotaxonomy," and "biological learning."

The literature inclusion criteria were: research articles or reviews from scientific journals; focused on phytochemistry, taxonomy, ethnobotany, or biology education; in Indonesian or English; and fully accessible (full text). Data analysis was conducted using thematic analysis, categorizing the findings into four main topics: morphological diversity and distribution of andaliman; secondary metabolite content; development of the chemotaxonomy concept; and potential integration in biology learning.

Result and Discussion

Morphological, Botanical, and Distribution Diversity of Andaliman

Andaliman (*Zanthoxylum acanthopodium*), also known as toba-toba or Batak pepper, is a shrub or small tree that can reach 3–8 meters in height (Adrian et al., 2023). This plant is characterized by its strongly thorny stems and compound leaves arranged in a pinnate pattern. Andaliman fruit is small, round, with a diameter of 3–5 mm, and changes color from red to dark red when ripe (Syahputra et al., 2023). Its natural distribution is strictly limited to the highlands of North Sumatra, particularly around the Lake Toba region, at an altitude of 1,200–1,500 m above sea level (Lumbanbatu, 2025). The botanical characteristics and conservation status of andaliman are summarized in Table 1.

Table 1. Morphological characteristics and distribution of andaliman

| Parameters | Description |
|---------------------|--|
| Scientific Name | <i>Zanthoxylum acanthopodium</i> |
| Family | Rutaceae |
| Local Name | Andaliman; Toba-toba; Merica Batak |
| Habitus | Shrubs to small trees (3–8 m) |
| Distribution | North Sumatra Highlands |
| Altitude | 1,200–1,500 m above sea level |
| Used Parts | Fruit (round, 3–5 mm diameter, dark red); Seeds (shiny black, 2–3 mm diameter); Leaves (compound, 7–15 leaflets); Bark (thorny, 10–20 cm diameter) |
| Conservation Status | Vulnerable |

Andaliman morphological diversity shows significant variation between populations, particularly in fruit size, leaf shape, and aroma intensity (Kintamani et al., 2023). This variation is not only phenotypic but is also suspected to be closely related to differences in microclimate conditions and growing altitude, which directly affect the rate of biosynthesis and accumulation of secondary metabolites (Asbur & Khairunnisyah, 2018).

Research by Saragih & Raihandhany (2023) specifically documented variations in morphological characteristics of andaliman in five districts surrounding Lake Toba. These variations include differences in leaf shape, the presence and shape of thorns, and the size and color of the fruit (Ramadhani et al., 2022). Local communities even classify these varieties as “bitter andaliman” and “sweet andaliman,” which are empirically associated with strong differences in aroma and taste—an indication of a strong correlation between external morphology and internal chemical composition. This phenomenon of morphological variation triggered by environmental factors provides an ideal entry point for introducing the concepts of phenotypic plasticity and chemotaxonomy in biology learning.

Globally, the genus *Zanthoxylum* has over 200 identified species, with approximately 5–7 species recorded in Indonesia (Nurlaeni et al., 2024). The most prominent species endemic to North Sumatra is

Zanthoxylum acanthopodium, with a distribution restricted to the highlands around Lake Toba (Lumbanbatu, 2025). This endemic status and variability make andaliman an important study object not only for conservation but also for deeper exploration of taxonomic characters beyond traditional morphological characteristics.

Phytochemical Content of Andaliman

Andaliman fruit is a storehouse of secondary metabolites that play an important role in biological activity (Maulidza et al., 2025). A literature review shows that the main phytochemical components of andaliman include alkaloids, flavonoids, saponins, terpenoids, and essential oils (Hutapea et al., 2024). This analysis confirms that andaliman is a source of bioactive compounds, providing a strong basis for chemotaxonomic applications. The diversity of secondary metabolite content in various parts of the andaliman plant is presented in Table 2.

Table 2. Content of andaliman secondary metabolites in various parts of the plant

| Plant Parts | Alkaloids | Flavonoids | Saponins | Terpenoids | Tannins | Essential Oils |
|-------------|-----------|------------|----------|------------|---------|----------------|
| Fruit | +++ | ++ | + | +++ | + | +++ |
| Leaves | ++ | +++ | ++ | ++ | ++ | ++ |
| Stem Bark | ++ | + | +++ | + | +++ | + |
| Roots | + | ++ | ++ | ++ | ++ | + |

Description: +++ = very high, ++ = high, + = low

Alkaloids

Alkaloids are nitrogen-containing organic compounds known to possess various pharmacological activities. Harahap (2019) identified several specific alkaloid compounds in andaliman fruit, including berberine, palmatine, and magnoflorine. The total alkaloid content in andaliman fruit ranges from 0.80–1.50% of dry weight. This significant variation in concentration is based on geographic location and ecological conditions, reinforcing the role of alkaloids as chemotaxonomic markers. Berberine, in particular, is a distinctive compound frequently used in chemical classification.

Flavonoids

Flavonoids are polyphenolic compounds with high antioxidant activity. Lewerissa et al. (2025) reported that Andaliman fruit contains various types of flavonoids, including quercetin, kaempferol, and rutin. The total flavonoid content reached 15.00–25.00 mg QE/g extract. Interestingly, the highest concentrations were found in samples from the Samosir highlands, suggesting the presence of biochemical protective mechanisms in more stressful environments (e.g., higher UV light intensity). Because flavonoid profiles are often stable and easily

detected, these compounds make excellent markers for chemotaxonomic studies.

Saponins

Saponins are triterpenoid or steroid glycosides that play a role in antimicrobial and anti-inflammatory activities. Nurlaeni et al. (2024) showed that the saponin content in andaliman fruit ranges from 2.50–4.20% of dry weight, with a chemical structure dominated by triterpenoid saponins. This complex and specific chemical structure of saponins provides a strong basis for differentiating between species within the same genus (Fordos et al., 2025).

Terpenoids

Terpenoids are a group of compounds formed from isoprene units. GC-MS analysis by Syahputra et al. (2023) successfully identified more than 20 terpenoid compounds in andaliman fruit, including limonene, α -pinene, and β -caryophyllene. Terpenoids, particularly the volatile ones, contribute to the distinctive aroma of andaliman and are crucial for the classification of *Zanthoxylum*, which is often based on the essential oil profile.

Essential Oil

Essential oil is the main component that creates the distinctive aroma and tingling sensation of andaliman. Asbur & Khairunnisyah (2018) found that the essential oil content in andaliman fruit ranges from 3.00–8.00% of the dry weight. The main component is hydroxy- α -sanshool (up to 40–60%), the compound directly responsible for the anesthetic or tingling sensation on the tongue. The presence and high concentration of hydroxy- α -sanshool is a nearly definitive chemotaxonomic characteristic of *Zanthoxylum acanthopodium*.

Table 3. Main phytochemical content of andaliman fruit

| Compound groups | Content (% dry weight) | Main compounds | Biological activities |
|-----------------|------------------------|-----------------------------|----------------------------------|
| Alkaloids | 0.80–1.50 | Berberine; Palmatine | Antimicrobial; Anti-inflammatory |
| Flavonoids | 1.50–2.50 | Quercetin; Kaempferol | Antioxidant; Neuroprotective |
| Saponins | 2.50–4.20 | Saponins; Triterpenoids | Antimicrobial; Anti-inflammatory |
| Terpenoids | 1.00–2.00 | Limonene; α -Pinene | Antiseptic; Analgesic |
| Essential oils | 3.00–8.00 | Hydroxy- α -sanshool | Analgesic; Antimicrobial |

Ethnopharmacology and Phytochemical Variation of Andaliman

The Contextual Strength of Ethnopharmacology

In addition to the scientifically proven benefits of its chemical compounds, andaliman has significant ethnopharmacological value in Batak culture. Traditionally, the Batak people use andaliman fruit as a remedy for digestive disorders, a pain reliever, and as a natural antiseptic. This traditional use is scientifically confirmed by the presence of compounds such as berberine and quercetin, which have anti-inflammatory and antioxidant activity (Ginting & Simanjuntak, 2023).

Linking phytochemical data with local knowledge (ethnopharmacology) has tremendous pedagogical potential. In biology learning, it allows students to view science not as an isolated discipline, but as a tool for validating and understanding local wisdom. This approach makes learning more contextual and culturally meaningful, which is key to enhancing students' scientific literacy and relevance to their environment.

Phytochemical Variation as an Ecological Marker

Significant variation in phytochemical content between andaliman populations in various locations around Lake Toba (Nurzannah et al., 2024) provides important evidence of biochemical adaptation. This

variation is influenced by environmental factors such as altitude, rainfall, and soil composition.

Data collected by Asbur & Khairunnisyah (2018) explicitly show that essential oil content tends to increase with increasing altitude. The increased production of secondary metabolites (such as essential oils) at high altitudes can be interpreted as an adaptive response of plants to harsher environmental stresses, such as higher UV radiation or fluctuating temperatures. This phenomenon provides a concrete example of how biochemistry supports evolution and adaptation, which is essential material in the high school biology curriculum (Grade XI, Metabolism). This variation is not only ecologically interesting but also provides an empirical basis for intraspecific chemotaxonomic classification.

Development of the Chemotaxonomy Concept History and Evolution of the Concept

Chemotaxonomy, as a branch of taxonomy that applies chemical characters, has become an integral tool in modern plant systematics (Suryani & Ramona, 2020). This concept began to develop rapidly in the 1960s, driven by Erdtman's pioneering research in 1952, which highlighted the importance of pollen chemistry as a reliable taxonomic marker (Suryani & Ramona, 2020).

The development of chemical analysis technologies, including High-Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC-MS), and Liquid Chromatography-Mass Spectrometry (LC-MS), has driven rapid progress. Siboro et al. (2022) highlighted that these techniques enable the identification of specific chemical profiles of a species or genus. These profiles often correlate strongly with evolutionary relationships, helping to resolve classification problems that cannot be solved solely by morphology. Modern approaches even integrate secondary metabolite data with molecular data (metabolomics and DNA barcoding) to produce more precise classifications (Chen et al., 2021). This integration results in a more accurate and detailed mapping of evolutionary relationships.

Applications in the Genus *Zanthoxylum*

The genus *Zanthoxylum* is an ideal subject for chemotaxonomic research due to its diverse compounds. Hutapea et al. (2024) demonstrated that specific alkaloid profiles are effective in distinguishing species within this genus. Similarly, Nurzannah et al. (2024) used essential oil composition as a key chemotaxonomic character to clarify phylogenetic relationships.

Specifically, for *Zanthoxylum acanthopodium*, the most prominent chemotaxonomic characters—which distinguish it from other *Zanthoxylum* species—are the high content of hydroxy- α -sanshool, the dominance of

berberine in the alkaloid profile, the distinctive composition of flavonoids (such as quercetin), and the specific terpenoid pattern (Siboro et al., 2022). Analysis of these distinctive compounds can help students understand that classification is not only visual but also involves unique chemical fingerprints.

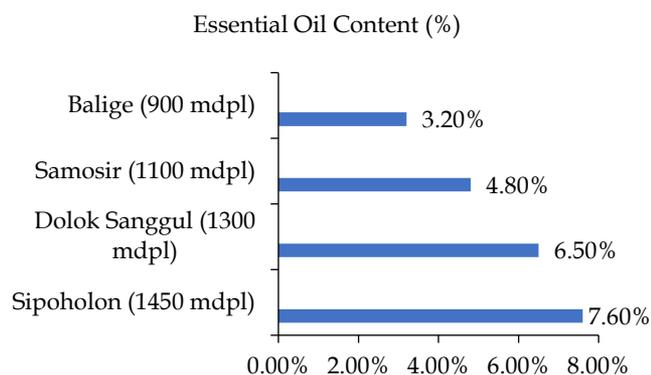


Figure 1. Distribution pattern of andaliman essential oil content

Table 4. Comparison of morphological taxonomy and chemotaxonomy in plant classification

| Aspects | Morphological Taxonomy | Chemotaxonomy |
|-----------------------------|--|--|
| Key parameters | Physical/morphological characteristics | Secondary metabolite compounds |
| Classification and accuracy | Limited to similar species | More accurate and specific |
| Tool requirements | Microscope/magnifying glass | Reagents, solvents, chromatography equipment |
| Practical relevance | High for basic observation | High for experiments and PBL |

Integrating Chemotaxonomy in Biology Learning Implementation Gaps and Learning Challenges

Although the concept of chemotaxonomy has developed rapidly globally, its application in biology education in Indonesia remains very limited. Taxonomy learning in secondary schools tends to be stagnant, focusing solely on morphological and anatomical characteristics (Afnan, 2024) (Grade 10, Biodiversity).

A survey conducted by Harahap et al. (2024) of 50 high school biology teachers in North Sumatra revealed alarming data: 85.00% of respondents were unfamiliar with the concept of chemotaxonomy, and 92.00% had never integrated phytochemical data into plant classification lessons. These data highlight a critical gap between the richness of local scientific data (andaliman) and its implementation in the curriculum. The inability to integrate local phytochemical data eliminates opportunities to enrich learning, make it relevant, and

connect science to local biodiversity (Chibuye & Singh, 2024).

The potential of andaliman is highly relevant for integration at various school levels, providing a coherent curriculum pathway. According to Hariati & Purwarno (2025), andaliman material can be included in: Junior High School Grade VIII: Chapter on Structure and Function of Plants (structure of leaves, fruit, and stems of Andaliman); Senior High School Grade X: Chapter on Biodiversity and Classification of Living Things (comparison of morphological taxonomy vs. chemotaxonomy); and Senior High School Grade XI: Chapter on Metabolism and Chemical Compounds in Living Things (biosynthesis and function of secondary metabolites of andaliman).

Integration Strategy and Pedagogical Potential

Andaliman-based chemotaxonomy integration offers significant pedagogical advantages (Harahap et al., 2025): Contextual and Relevant: The use of endemic local plants such as andaliman makes learning more meaningful and authentic for students, turning the abstract into the concrete; Interdisciplinary: This concept inherently connects biology with chemistry, thereby enhancing students' holistic understanding of science and meeting the demands of the STEM/STEAM approach; and Based on Local Wisdom: By utilizing traditional Batak knowledge (ethnopharmacology), learning instills an appreciation for local wisdom while encouraging biodiversity conservation (Lumbanbatu, 2025).

The phytochemical profile of andaliman (Table 3) provides an excellent case study. Students can be taught that morphologically similar species (such as the "bitter" and "sweet" varieties of andaliman, or other species in the genus *Zanthoxylum*) can differ chemically, thus justifying the need for a chemotaxonomic approach. By comparing the two taxonomic approaches (Table 4), students' fundamental understanding of plant classification is strengthened.

To address the implementation challenges mentioned by Harahap et al. (2024), this integration must be translated into simple yet robust lab activities. For example, teachers can use a simple Thin Layer Chromatography (TLC) method using andaliman fruit extracts from two different locations to visualize the differences in their "chemical fingerprints (Frederick et al., 2021)." This lab not only teaches classification but also basic chemical separation techniques.

Overall, these findings demonstrate that significant phytochemical variation in andaliman in highland populations provides a strong scientific basis for teaching chemotaxonomy concepts. The limited integration of these concepts in Indonesia presents an opportunity. Therefore, developing biology teaching

materials that integrate taxonomic concepts with local wisdom has great potential to substantially improve scientific literacy and foster a deeper appreciation for Indonesia's rich biodiversity. This implementation requires curriculum support, adequate teacher training, and collaboration between phytochemistry academics and education practitioners.

Conclusion

This study concludes that andaliman (*Zanthoxylum acanthopodium*) possesses a significant wealth of secondary metabolites, making it an ideal model for chemotaxonomy. The diversity of these compounds—including alkaloids, flavonoids, and essential components of essential oils (e.g., hydroxy- α -sanshool)—demonstrates strong potential for chemical-based classification analysis, a finding consistent with the abstract summary. The relevance of andaliman in biology learning at the junior and senior high school levels is very high, especially for topics such as plant structure, classification, and chemical compounds, as it provides an ideal example for contextual learning that directly connects science and local culture. The integration of Andaliman phytochemical data into chemotaxonomy concepts is a strategic step in strengthening 21st-century competencies through applied and culture-based science. This aligns with the global view that strong scientific literacy must be built through the integration of scientific knowledge and real-life contexts (HARIS) (OECD, 2019; Kereluik et al., 2019). With this approach, students not only learn to understand classification but also develop critical thinking skills, problem-solving skills, and an appreciation for local biodiversity. To realize this potential, practical action is needed in the form of developing specific and structured teaching materials based on andaliman chemotaxonomy. This action opens up opportunities for cross-sector collaboration between schools, research institutions, and local communities in designing biodiversity-based teaching modules. Recommendations for further research include the development of interactive teaching media and the implementation of learning trials using andaliman modules in various schools, as well as holding teacher training workshops to support the integration of this learning innovation in the classroom. The combination of phytochemistry, chemotaxonomy, and local wisdom is a strategic bridge in shaping a generation that thinks critically and is rooted in the nation's cultural values.

Acknowledgments

Dr. Drs. Suyitno Aloysius M.S. which I respect the supervisor who has provided guidance and support during the writing process of this paper.

Author Contributions

Conceptualization, methodology, validation, formal analysis, investigation, resources, A.M.H.; data curation, preparation of the initial draft of the manuscript, review and editing of the manuscript, visualization, S.A. and P. All authors have read and approved the published version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

- Afnan, M. A. (2024). Taxonomy of Educational Objectives: Teaching, Learning, and Assessing. *Journal of Curriculum and Teaching*, 13(4), 173-191. <https://doi.org/10.5430/jct.v13n4p173>
- Adrian, A., Syahputra, R. A., Juwita, N. A., Astyka, R., & Lubis, M. F. (2023). Andaliman (*Zanthoxylum acanthopodium* DC.) An Herbal Medicine from North Sumatera, Indonesia: Phytochemical and Pharmacological Review. *Heliyon*, 1-12. <https://doi.org/10.1016/j.heliyon.2023.e16159>
- Amin, A., & Park, S. (2025). Chemotaxonomy, an Efficient Tool for Medicinal Plant Identification: Current Trends and Limitations. *Plants*, 14(2234), 1-24. <https://doi.org/10.3390/plants14142234>
- Asbur, Y., & Khairunnisyah, K. (2018). The Effect of Altitude on the Chemical Composition of Andaliman (*Zanthoxylum acanthopodium* DC.) Essential Oil. *Kultivasi*, 17(1), 537-543. <https://doi.org/10.24198/kultivasi.v17i1.13501>
- Chen, S., Zhao, Q., & Sun, W. (2021). Metabolomics in Plant Taxonomy: Progress and Prospects. *Frontiers in Plant Science*, 12, 723. <https://doi.org/10.3389/fpls.2021.644723>
- Chibuye, B., & Singh, I. (2024). Integration of Local Knowledge in the Secondary School Chemistry Curriculum - A Few Examples of Ethno-Chemistry from Zambia. *Heliyon*, 1-15. <https://doi.org/10.1016/j.heliyon.2024.e29174>
- Fordos, S., Amin, S., Abid, N., Pasha, I., Khan, M. K. I., Amin, A., Gulzar, M., Subtain, M., & Abdi, G. (2025). Saponins: Advances in Extraction Techniques, Functional Properties, and Industrial Applications. *Applied Food Research*, 5(2). <https://doi.org/10.1016/j.afres.2025.101146>
- Frederick, E. H., Sibero, M. T., Wijaya, A. P., Syafitri, E., Siswanto, A. P., Murwani, R., Wijayanti, D. P., Sabdono, A., Pringgienis, D., & Radjasa, O. K. (2021). Preliminary Evaluation of Anti Fish Pathogenic Bacteria and Metabolite Profile of Andaliman Fruit (*Zanthoxylum acanthopodium*

- DC.) Ethanol Extract.
<https://doi.org/10.1088/1755-1315/750/1/012026>
- Ginting, S. P., & Simanjuntak, H. (2023). Ethnopharmacological Uses of *Zanthoxylum acanthopodium* in North Sumatra. *Journal of Ethnopharmacology*, 299, 115643. <https://doi.org/10.1016/j.jep.2022.115643>
- Harahap, A. U. (2019). *Mengenal Potensi Merica Batak: Andaliman (Zanthoxylum acanthopodium)*. Medan: Puspantara.
- Harahap, A. A., Rusip, G., Mutia, M. S., & Sartika, D. (2025). A Literature Review of Andaliman Phytochemical Composition and Pharmacological Properties. *Intisari Sains Medis*, 6(2), 662-665. <http://dx.doi.org/10.15562/ism.v16i2.2419>
- Harahap, D. L., Tanjung, I. F., & Reffina, R. (2024). Development of an Integrated Biodiversity Biology Module with Local Potential of Andaliman Plants (*Zanthoxylum acanthopodium*) at Senior High School. *Biosfer: Jurnal Tadris Biologi*, 15(1), 75-85. <https://doi.org/10.24042/biosfer.v15i1.21494>
- Hariati, P., & Purwarno, P. (2025). Andaliman: Harmonization of Spices with Batak Culture. *Indonesian EFL Journal*, 11(2), 233-242. <https://doi.org/10.25134/ieflj.v11i2.11673>
- Hutapea, D. B., Susilawati, Y., Muhaimin, M., & Chaerunisaa, A. Y. (2024). Potent Bioactivity of Andaliman (*Zanthoxylum acanthopodium* DC.). *Pharmacia*, 71(1), 17-25. <https://doi.org/10.3897/pharmacia.71.e107567>
- Khan, M., Khan, M., Alshareef, E., Alaqeel, S. I., & Alkhatlan, H. Z. (2023). Chemical Characterization and Chemotaxonomic Significance of Essential Oil Constituents of *Matricaria aurea* Grown in Two Different Agro-Climatic Conditions. *Plants*, 12(20), 3553. <https://doi.org/10.3390/plants12203553>
- Kintamani, E., Batubara, I., Kusmana, C., Tiryana, T., Mirmanto, E., & Asoka, S. F. (2023). Essential Oil Compounds of Andaliman (*Zanthoxylum acanthopodium* DC.) Fruit Varieties and Their Utilization as Skin Anti-Aging Using Molecular Docking. *Life*, 13(3), 754. <https://doi.org/10.3390/life13030754>
- Lewerissa, K. B., Lestario, L. N., & Sihombing, C. N. (2025). Antioxidant Activity of Herbal Drink Using Andaliman (*Zanthoxylum acanthopodium* DC). *Journal of Functional Food and Nutraceutical*, 6(2), 59-66. <https://doi.org/10.33555/jffn.v6i2.2>
- Lumbanbatu, H. A. (2025). The Toba Batak Tribe's Cultural Capital in the Context of Protecting Lake Toba from Environmental Threats. *Journal of Socio-Cultural Sustainability and Resilience*, 2(2), 130-150. <https://doi.org/10.61511/jscsr.v2i2.2025.1493>
- Mali, S., Yadav, R., Gauttam, V., & Sawale, J. (2023). An Updated Review on Taxonomy and Chemotaxonomy. An Updated Review on Taxonomy and Chemotaxonomy. *Toxicology International*, 30(1), 121-129. <https://doi.org/10.18311/ti/2023/v30i1/32123>
- Maulidza, C. P., Halim, B., Chiuman, L., Nasution, A. R., & Theresia, Y. (2025). The Effect of Andaliman Fruit Extract (*Zanthoxylum acanthopodium* DC) on α -Synuclein Levels in Rotenon-Induced Wistar Rats. *Jurnal Penelitian Pendidikan IPA*, 11(2), 516-524. <https://doi.org/10.29303/jppipa.v11i2.10362>
- Nurlaeni, Y., Junaedi, D. I., & Iskandar, J. (2024). Botany, Morphology, Ecology, Cultivation, Traditional Utilization and Conservation of Andaliman (*Zanthoxylum acanthopodium*) in North Sumatra, Indonesia. *Nusantara Bioscience*, 16(1), 1-10. <https://doi.org/10.13057/nusbiosci/n160109>
- Nurzannah, S. E., Ramija, K. E., Handayani, T., & Listiawati, L. (2024). Potensi Tanaman Andaliman sebagai Penghasil Minyak Atsiri. *Warta BSIP Perkebunan*, 2(3), 1-6. Retrieved from <https://epublikasi.pertanian.go.id/berkala/index.php/wartabun/article/view/3998>.
- Olabamiji, T. S. (2025). Advances in Plant Taxonomy: Integrating Morphological, Chemotaxonomic, Molecular, and Phylogenetic Approach. *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, 11(2), 75-90. <https://dx.doi.org/10.4314/dujopas.v1>
- Ompusunggu, N. P., & Irawati, W. (2021). Andaliman (*Zanthoxylum acanthopodium* DC.), A Rare Endemic Plant from North Sumatra that Rich in Essential Oils and Potentially as Antioxidant and Antibacterial. *Jurnal Biologi Tropis*, 21(3), 1063-1072. <http://dx.doi.org/10.29303/jbt.v21i3.2961>.
- Ramadhani, R. T., Djuita, N. R., & Dorly, D. (2022). Comparison of Leaf Anatomy Characteristics on Four Cultivars of Jackfruit (*Artocarpus heterophyllus* Lam.) Mekarsari Fruit Garden Collection, Bogor. *Buletin Kebun Raya*, 25(2), 84-95. <https://doi.org/10.55981/bkr.2022.8930>
- Rosmiati, R., Emilia, E., Firmansyah, H., Rahman, P. A., & Azhar, W. C. U. (2025). Physicochemical Properties and Antioxidant Activity of Powdered Beverage Based on Andaliman (*Zanthoxylum acanthopodium*) and Kuweni (*Mangifera odorata*). *Prev. Nutr. Food Sci.*, 30(6), 630-641. <https://doi.org/10.3746/pnf.2025.30.6.630>

- Saragih, B. R., & Raihandhany, R. (2023). Ulasan Aspek Etnobotani dan Fitokimia pada Tumbuhan Andaliman (*Zanthoxylum acanthopodium* DC.) oleh Suku Batak di Sumatera Utara. *Jurnal Pro-Life*, 10(1), 665-681. Retrieved from <https://www.researchgate.net/publication/369819564>
- Siboro, B., Manik, Y., Pardede, S., Panjaitan, O., Siahaan, M., Simamora, E., & Sihombing, E. I. (2022). *Peningkatan Nilai Andaliman: Rantai Pasok, Produk Turunan, dan Teknologi Tepat Guna*. Jakarta: PT Kanisius.
- Suryani, L., & Ramona, F. (2020). Ultrastructure Morphology of *Melastoma* L. (Melastomataceae) Pollen. *Jurnal Biologi UNAND*, 8(1), 9-13. <https://doi.org/10.25077/jbioua.8.1.9-13.2020>
- Syahputra, R. A., Juwita, N. A., Astyka, R., & Lubis, M. F. (2023). Andaliman (*Zanthoxylum acanthopodium* DC.) an Herbal Medicine from North Sumatera, Indonesia: Phytochemical and Pharmacological Review. *Heliyon*, 9(5), e15967. <https://doi.org/10.1016/j.heliyon.2023.e15967>