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Ethnobotany and Sustainable Use of Medicinal Plants in Toraja: Phytochemistry, Pharmacology, and Conservation

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Abstract: The Toraja people have long utilized various species of medicinal plants as part of their local wisdom for maintaining health, with this knowledge being passed down through generations. The effectiveness of these plants in treating various diseases is believed to be linked to their pharmacological potential, supported by bioactive compounds. This study aims to identify the phytochemical contents of medicinal plant species used by the Toraja people, explore the relationship between active compounds and their therapeutic properties in traditional medicine, and discuss the importance of conservation and sustainable practices in the use of these plants. Data were collected through semi-structured interviews with informants selected using Snowball and Purposive Sampling methods. Field exploration documented plant species based on these interviews, and samples were collected for identification and herbarium specimen preparation. Phytochemical data were obtained through a literature review of research databases such as Science Direct, Scopus, PubMed, and Google Scholar, focusing on the phytochemical components of species identified in previous ethnobotanical studies. The study identified 94 medicinal plant species from 46 families, which contain phytochemical compounds supporting their traditional therapeutic uses. Phytochemical analysis revealed dominant compounds such as flavonoids (e.g., quercetin, kaempferol, myricetin, luteolin, rutin, catechin, apigenin, vitexin, isovitexin) and terpenoids (e.g., phytol, squalene, limonoids, β-carotene, carvacrol, momordicin, xanthorrhizol), known for their pharmacological activities, including wound healing, antibacterial, anti-inflammatory, antioxidant, immunomodulatory, antidiabetic, anti-ulcer, antihypertensive, antihyperlipidemic, antimalarial, and anticancer effects. Among these species, 28 species (30%) are wild plants, and 66 species (70%) are cultivated. The majority of species have a status of Least Concern (LC), while some are more threatened, including *Santalum album* (VU) and *Swietenia macrophylla* (EN). This study emphasizes the importance of sustainable harvesting and conservation efforts to protect valuable medicinal plant resources for future generations. Conservation strategies can be implemented through various approaches, including in-situ and ex-situ conservation, sustainable harvesting, customary protection, and cultivation practices following Good Agricultural Practices (GAP). The research provides scientific insights into the pharmacological basis of traditional medicinal plant use, highlights their potential for modern drug development, and underscores the urgent need for integrated conservation strategies to ensure their long-term availability.

Keywords: Bioactive compounds, Ethnobotany, Medicinal plants, Phytochemistry, Conservation.

1) Introduction

The use of plants in traditional medicine has been an integral part of supporting public health systems across various cultures for centuries, including among the Toraja people in South Sulawesi. Plants are widely utilized by the community due to their phytochemical content, particularly secondary metabolites, which have significant potential as medicinal substances and offer various other benefits to human life [1]. These secondary metabolites consist of specific compounds that play important roles in bodily physiology and are a primary source for the development of modern medicines [2, 3]. The effectiveness of medicinal plants in treating various diseases is generally associated with the pharmacological potential of the bioactive compounds they contain. Therefore, the sustainable use and conservation of these plant resources are crucial to ensure their availability for future generations, in line with conservation principles that emphasize the balance between resource utilization and environmental preservation.

Phytochemical studies of medicinal plants are essential for scientifically validating traditional healing practices. Local knowledge, supported by scientific research, has played a key role in utilizing biodiversity to promote public health [4]. The therapeutic use of plants depends largely on the phytochemical compounds or secondary metabolites they contain, which have diverse physiological effects on the human body [5]. Identifying these compounds is critical for uncovering the medicinal potential of plants. This not only enhances our understanding of plant bioactive compounds but also highlights their pharmacological potential. Such knowledge strengthens the role of plants in traditional medicine, bridges the gap between traditional and modern medicine, and creates opportunities for developing bioactive compounds into modern drugs.

The Toraja people are highly dependent on medicinal plants for traditional healing. However, scientific research on the phytochemical content and pharmacological potential of these plants is still limited and has not been comprehensively conducted. Documenting the diversity of medicinal plant species is crucial for preserving ethnomedicine knowledge, supporting the sustainable use of these plants, and playing a key role in the discovery and development of modern medicines [6]. Therefore, this study aims to document the medicinal plants used by the Toraja community, analyze their phytochemical profiles in detail, and assess their sustainable use and conservation practices. Additionally, the research connects the bioactive compounds in these plants to their traditional uses. It is hoped that this study will make a significant scientific contribution to the understanding of medicinal plants used by the Toraja people of South Sulawesi, promote sustainable harvesting practices, and open opportunities for the development of modern medicines in the future. This study is part of a broader ethnobotanical research on medicinal plants used by the Toraja people, focusing on phytochemical data, its relevance to traditional medicine, as well as the sustainable use and conservation of these plant species.

2) Methods and Methodology

(a) Study Area

This research was conducted in the highlands of Toraja, South Sulawesi, Indonesia, from October to November 2024. The study area includes the Tana Toraja and North Toraja regencies, located 280–355 km from Makassar, the capital of South Sulawesi Province, with geographic coordinates ranging from 2° 40' S to 3° 25' S and 119° 30' E to 120° 25' E. The region is characterized by its mountainous terrain, with elevations ranging from 600 to 2.800 meters above sea level, and a humid tropical climate. The annual rainfall in the area varies between 1.500 and 3.500 mm, creating an ideal environment for a diverse range of plant species.

The study focuses on four traditional villages: Sillanan (Gandangbatu Sillanan) and Tongkonan Karuaya (Sangalla Utara) in Tana Toraja, and Ke'te' Kesu' (Kesu') and Pallawa (Sesean) in North Toraja, as shown in Figure 1. These areas are surrounded by a variety of ecosystems, including agroforestry systems, agricultural fields, plantations, rivers, and different types of forests, contributing to the high plant species diversity observed in the region. This research site is the same as that used in the first article, which focused on the species diversity and utilization patterns of medicinal plants. However, this article shifts its focus to the phytochemical composition and potential pharmacological properties of the medicinal plants used by the Toraja community. By exploring the same area, we aim to bridge the gap between traditional plant usage and the bioactive compounds they contain, providing deeper insights into their therapeutic potential, while also highlighting the importance of sustainable use and conservation practices to ensure the continued availability of these plant.

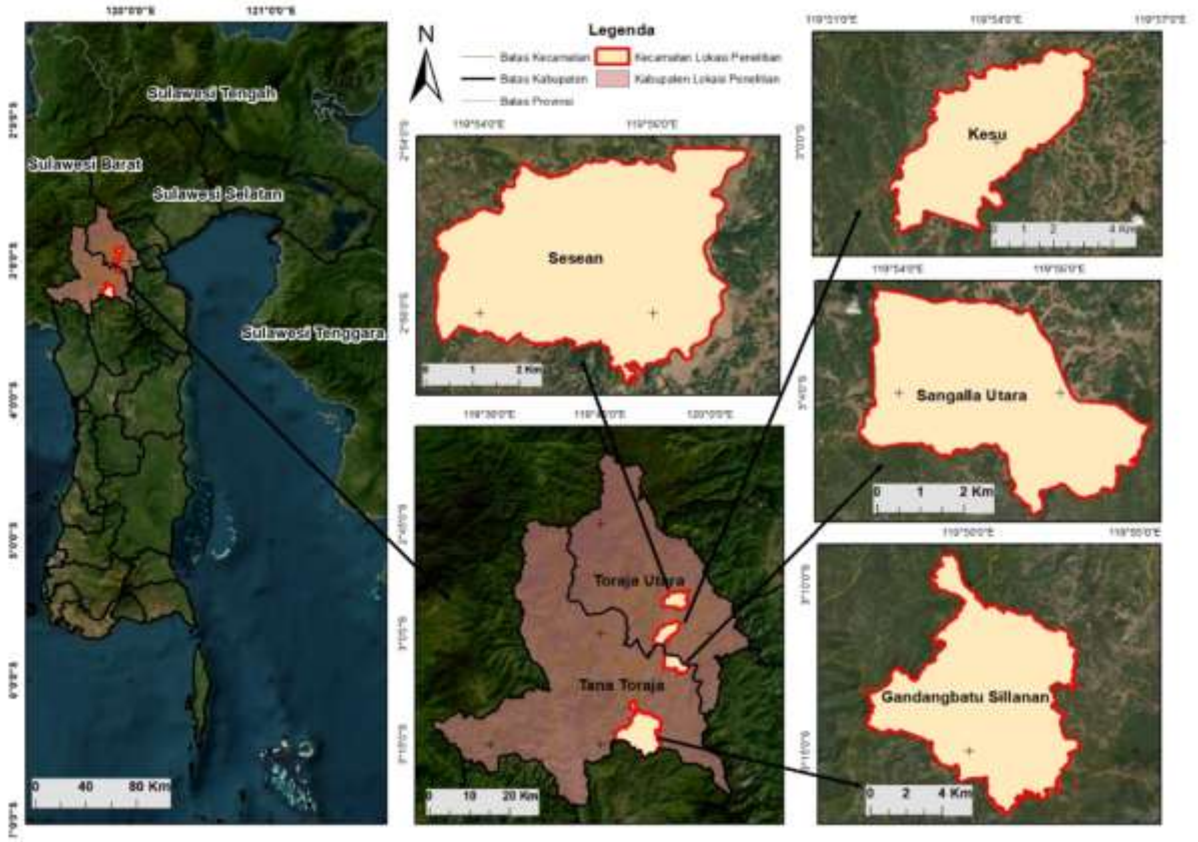

Figure 1 Research Framework

(b) Ethnobotanical Survey and Plant Identification

This study employed an ethnobotanical survey to document medicinal plants used by the Toraja community and subsequently identified the collected plant specimens. Ethnobotanical data collection was carried out through semi-structured interviews with local communities, particularly traditional healers, herbalists, and individuals with traditional knowledge of medicinal plants. The interviews aimed to identify the local names of plants, the parts used, processing methods, and the types of diseases treated, which will later be analyzed further concerning their phytochemical profiles, as well as the sources of these plants and conservation practices to ensure their sustainable use. Informants were selected using Snowball Sampling and Purposive Sampling methods, with the main criteria being traditional healers, community leaders, cultural figures, and general community members with experience in traditional medicine. The data obtained was systematically recorded and categorized based on the local names of plants, plant parts used, processing methods, and the diseases treated.

The collection of medicinal plant samples was carried out to ensure the accuracy of data obtained from interviews with informants. The plant samples were gathered from the research locations based on information provided by the informants such natural habitats, home gardens, and markets. Each specimen collected was documented through photography for identification purposes and the preparation of herbarium specimens. Identification was conducted at the Plant Systematics Laboratory, Faculty of Biology, Gadjah Mada University, by comparing the morphological characteristics of the plants with botanical literature and available identification keys, guided by reference books such as *Tumbuhan Berguna Indonesia* [7], *Illustrated Guide to Tropical Plants* [8], and *Flora of Malesiana* [9]. The plant classification followed the *Angiosperm Phylogeny Group* IV (APG IV) system to ensure the accuracy of scientific nomenclature. The process of verifying species names and authors was carried out using the Plants of the World Online (*www.powo.science.kew.org*) and the International Plant Name Index (*www.ipni.org*) websites. The conservation status of medicinal plants used is determined from sources

beyond the IUCN Red List (*iucnredlist.org*).
A total of 42 informants were interviewed from four traditional villages in the study area. The informants were categorized based on gender, knowledge level, age, and occupation. Among them, 23 were male (55%) and 19 were female (45%). The majority of informants were traditional healers (40 %). Regarding age, the largest group fell within the 61-70 age range (29%), with an average age of 63 years. The youngest informant was 41 years
old, and the oldest was 86 years old. In terms of occupation, most informants were farmers (69%). The demographic profile of the informants is presented in Table 1.

Table 1. Demographic profile of the informants

Category	Number of informants	Total (n=42)	Respondent frequency (%)
Gender			
Male	23	42	55
Female	19	42	45
Level of knowledge			
Traditional healers	17	42	40
Community leader	10	42	24
Traditional medicine users	15	42	36
Age of group			
40-50	8	42	19
51-60	10	42	24
61-70	12	42	29
71-80	9	42	21
>80	3	42	7
Occupation			
Farmer	29	42	69
Traditional leader	7	42	16
Government official	4	42	9
Housewife	2	42	5

Demographic profile of the informants, including the number of informants and the frequency and percentage distribution for each category: gender, knowledge level, age, and occupation summarize in Table 1.

(c) Phytochemical Data Collection
Phytochemical data collection was carried out to identify the active compounds found in medicinal plants used by the Toraja community. The data collection was conducted through a literature review to link the active compounds and their pharmacological benefits with traditional uses. Literature searches were performed using scientific databases such as *Google Scholar, PubMed, Science Direct,* and *Scopus*, with keywords that include the scientific names of plants, active compounds, and their pharmacological activities. The phytochemical compounds identified in each species were then classified based on major groups, namely alkaloids, glycosides, flavonoids, phenolic acids, terpenoids, saponins, lignans, aminosugars, carotenoids, and steroids.

Each species was associated with specific compounds reported in the literature along with pharmacological activities relevant to their traditional medicinal uses. The results of this phytochemical study were then compared with ethnobotanical data to assess the alignment between the active compound content and the reported medicinal benefits, focusing on compounds with antibacterial, antimicrobial, immunodulatory anti-inflammatory, antioxidant, anti-ulcer, antidiabetic, antihypertensive, antihyperlipidemic, anticancer, and other beneficial activities. The findings of this study are used to understand the mechanisms of action of active compounds in supporting the traditional use of plants by the community.

(d) Data Analysis

The data collected from the ethnobotanical survey on the use of medicinal plants in the Toraja community, the phytochemical data obtained from literature studies, and the conservation status of medicinal plants used were analyzed using a descriptive qualitative approach. This analysis aimed to identify patterns of medicinal plant use based on the diseases treated, included identifying the bioactive compounds found in the plants and linking these compounds to their pharmacological activities. This step involved a detailed comparison of the phytochemical properties of the identified species with known medicinal effects. This approach allows for a deeper understanding of how traditional medicinal practices align with modern pharmacological findings, highlighting the potential of these plants to contribute to maintaining community health, the development of future drugs, and the importance of sustainable use and conservation practices to ensure the long-term availability of these valuable plant resources.

3) Results and Discussion

(a) Medicinal Plant Species and Phytochemical Profiles

This study documented 94 species of medicinal plants used by the Toraja community, belonging to 46 plant families. These species were obtained through interviews with informants selected using Snowball and Purposive Sampling methods, as well as field exploration. Among the 94 species of medicinal plants used by the community, 28 species (30%) are wild plants found in their natural habitats, such as forests, mountains, riverbanks, rice fields, and thicket. Meanwhile, 66 species (70%) are cultivated plants that can be found in home gardens, fields, and agricultural land. The Toraja community accesses medicinal plants from three main sources: home gardens, the wild, and markets. All 42 informants interviewed (100%) reported collecting medicinal plants from their home gardens and the wild, while 7 informants (17%) also mentioned obtaining them from the market. Common medicinal plants found in the Toraja people's home gardens and easily accessible for daily use include *Jatropha curcas, Swietenia macrophylla,* and *Zingiber cassumunar*. On the other hand, medicinal plants obtained from the wild include *Ageratum conyzoides, Lantana camara,* and *Dendrophthoe pentandra*. Additionally, the market serves as an important source for the community to obtain medicinal plants, with some plants sold in dried or processed forms, such as *Centella asiatica, Piper betle,* and *Cymbopogon citratus*. The market becomes a vital alternative for those who do not have direct access to gardens or the wild, as well as for obtaining rarer medicinal plants. A diagram shows the percentage of wild and cultivated plants used for medicine, as well as the primary sources from which these plants are obtained, as shown in Figure 2 and 3.

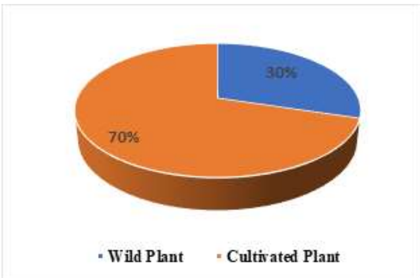

Figure 2 Percentage of wild plants and cultivated plants

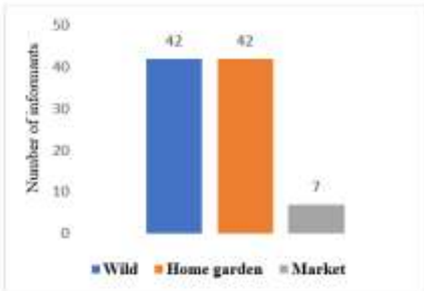

Figure 3 Souces of medicinal plants

The data shown in Figures 2 and 3 highlight the important role of both wild and cultivated plants in the lives of the Toraja people, as well as emphasizing the need for sustainable management of both. Given that 30% of the species used come from wild plants collected from natural habitats such as

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forests, mountains, and riverbanks, it is essential to adopt environmentally friendly harvesting practices to prevent over-exploitation that could threaten the survival of these species. Meanwhile, the majority of medicinal plants (70%) are cultivated, indicating a significant potential for conservation and reducing dependence on wild plants through cultivation in home gardens and farms. This practice supports conservation principles by reducing pressure on the wild and ensuring the sustainable availability of medicinal plants. Therefore, integrating environmentally friendly cultivation techniques and wise management of wild plants will play a key role in maintaining ecosystem balance and the sustainability of medicinal plant use in the future.

Phytochemical analysis of these plants revealed the presence of various bioactive compounds that support their traditional medicinal uses. Dominant compounds identified include flavonoids and terpenoids. Some flavonoid compounds, such as quercetin, kaempferol, myricetin, luteolin, rutin, catechin, apigenin, vitexin, and isovitexin, as well as terpenoids such as phytol, squalene, limonoids, β-carotene, carvacrol, momordicin, and xanthorrhizol, were found to have pharmacological activities such wound healing, antibacterial, anti-inflammatory, antioxidant, immunomodulatory, antidiabetic, anti-ulcer, antihypertensive, antihyperlipidemic, antimalarial, and anticancer properties. A comprehensive list of plant species, parts used, ethnomedicinal uses, phytochemical compounds, conservation status, and plant type (cultivated or wild) is provided in Table 2.

Table 2. Phytochemical constituents identified in the studied plant species and conservation status

Family	Scientific Name	Local Name	Part Used	Ethnomedicinal Uses	Phytochemical Constituents and Pharmacological Activities	PT	CS	Refs
Acanthaceae	*Strobilanthes crispa* (L.) Blume	Pecah beling	Leaves	Kidney	Rosmarinic acid (P), sinensetin (F) → anti-urolithiatic	WP	NE	[10]
Acanthaceae	*Andrographis paniculata* (Burm.f.) Wall. ex Nees	Sambiloto	Leaves	Malaria	Andrographolide (T) → antimalarial	CP	NE	[11]
Acanthaceae	*Graptophyllum pictum* (L.) Griff.	Katilamm	Leaves	Kidney, hematuria	Quercetin (F) → nephroprotective	CP	NE	[12, 13]
Achariaceae	*Pangium edule* Reinw.	Pangi	Leaves	Cholesterol	Pregnane (R), carotene (K) → antioxidant, hypolipidemic	CP	LC	[14]
Acoraceae	*Acorus calamus* L.	Kariango	Rizhome	Abdominal pain	α-asarone, β-asarone (T) → antidiarrheal, carminative	WP	LC	[15, 16]
Amaranthaceae	*Alternanthera sessilis* (L.) DC.	Parapa	Leaves	Acid reflux	Apigenin (F), Phytol (T) → antiulcer, antisecretory	WP	LC	[17, 18]
Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.	Bekke rada	Stem	Dysuria	Kaempferol (F), quercetin (P), ferulic acid (P) → anti-urolithiatic	WP	NE	[19]
Amaryllidaceae	*Allium sativum* L.	Lassuna busa	Tuber	Hypertension	S-allyl cysteine (U), allicin (T) → antihypertensive	CP	NE	[20, 21]
Amaryllidaceae	*Allium cepa* var. *aggregatum* G.Don	Lassuna rarang	Tuber	Fever, chickenpox	Quercetin (F), kaempferol (F), alfrutamide (A) → immunomodulatory, anti-inflammatory	CP	NE	[22, 23]
Amaryllidaceae	*Allium fistulosum* L.	Lassuna	Leaves	Headache, fever	Allicin (T), kaempferol (F) → anti-inflammatory, analgesic	CP	NE	[24, 25]
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	Kayu jawa	Bark	Wounds	Coumarin (P), flavonoid → antibacterial, wound healing	WP	LC	[26, 27]
Annonaceae	*Annona muricata* Linn.	Sarekaya'	Leaves	Diabetes	Acetogenins, rutin (F) → antidiabetic, antihyperglycemic	CP	LC	[28]
Apiaceae	*Centella asiatica* (L.) Urb.	Leme'	Leaves	Hypertension	Quercetin, apigenin (F) → antihypertensive, vasodilator	CP	LC	[29]
Apiaceae	*Apium graveolens* L.	Daun so'	Leaves	Acid reflux	Furanocoumarins, caffeic acid (P) → hepatoprotective	CP	LC	[30]
Apiaceae	*Daucus carota* L.	Wortel	Tuber	Hypertension	Daucuside (G), daucusol (T) → antihypertensive	CP	LC	[31]
Araceae	*Colocasia esculenta* (L.) Schott	Salonggo	Leaves	Wounds	Orientin, vitexin (F) → antibacterial, wound healing	CP	LC	[32]
Arecaceae	*Areca catechu* L.	Kalosi	Fruit	Malaria	Arecoline (A), catechins (F), quercetin (F) → antimalarial	CP	LC	[33, 34]
Arecaceae	*Arenga pinnata* (Wurmb) Merr.	Induk	Fruit	Diabetes	Galactomannan (G) → antidiabetic	CP	LC	[35]
Asphodelaceae	*Aloe vera* (L.) Burm.f.	Lidah buaya	Mucilage	Wounds	Aloe-emodin (P) → antibacterial, anti-inflammatory	CP	NE	[36]
Asteraceae	*Ageratum conyzoides* L.	Tassi' - tassi'	Leaves	Wound, gastritis	Kaempferol, quercetin (F) → wound healing, antiulcer	WP	LC	[37, 38, 39]
Asteraceae	*Elephantopus scaber* L.	Tapak liman	Leaves	Cancer, wounds	Deoxyelephantopin (T) → anticancer, wound healing	WP	NE	[40, 41]
Asteraceae	*Gynura bicolor* (Roxb. ex Willd.) DC.	Don dewa	Leaves	Wounds	Apigenin (F), lutein (K) → anti-inflammatory, antibacterial	WP	NE	[42]
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Sarambuallo	Leaves	Wounds, cancer	Hesperetin, persicogenin → antibacterial, wound healing Odoratin, acacetin (F) → anticancer, antiproliferative	CP	NE	[43]
Asteraceae	*Cosmos caudatus* Kunth	Kenikir	Leaves	Diabetes	Catechin, quercetin (F)→ antidiabetic, antihyperglycemic	CP	NE	[44]
Asteraceae	*Gynura procumbens* (Lour.) Merr.	Sambung nyawa	Leaves	Cholesterol	Caffeic acid (P), chlorogenic acid (P) → hypolipidemic	CP	NE	[45]
Basellaceae	*Anredera cordifolia* (Ten.) Steenis	Minahong	Leaves	Hypertension	Apigenin, apigetrin (F), vitexin (F) → antihypertensive	CP	NE	[46]
Bignoniaceae	*Crescentia cujete* L.	Bila	Leaves	Diabetes	Luteolin (F), protocatechuic acid (P) → antidiabetic	CP	NE	[47]

Bromeliaceae	*Ananas comosus* (L.) Merr.	Pondan	Fruit	Digestive disorder	Polyphenol, volatile, carotenoids → antidiarrhoeal	CP	NE	[48]
Campanulaceae	*Hippobroma longiflora* (L.) G.Don	Daun katarak	Leaves	Ocular disease	Quercetin (F), phenolic, flavonoids → anticataract	WP	NE	[49]
Caricaceae	*Carica papaya* L.	Taliki	Leaves	Malaria	Carpaine (A), kaempferol → antimalarial, antiplasmodial	CP	DD	[50, 51]
Convolvulaceae	*Ipomoea aquatica* Forssk.	Kangkung	Leaves	Insomnia	Quercetin (F) → anxiolytic	CP	LC	[52]
Crassulaceae	*Kalanchoe pinnata* (Lam.) Pers.	Cocor bebek	Leaves	Chicken pox	Bufadienolides (G), flavonoid→antiviral, immunodulator	CP	NE	[53, 54]
Cucurbitaceae	*Sechium edule* (Jacq.) Sw.	Ra'bisa	Fruit	Hypertension	Quercetin (F) → antihypertensive, vasodilator	CP	NE	[55, 56]
Cucurbitaceae	*Momordica charantia* L.	Paria	Fruit	Malaria	Momordicin (T) → antimalarial	CP	NE	[57, 58]
Euphorbiaceae	*Acalypha indica* L.	Akar kucing	Leaves	Cancer	Quercetin (F), catechin (F), indoline (A) → anticancer	WP	NE	[59, 60]
Euphorbiaceae	*Jatropha curcas* L.	Pallan	Leaves	Fever, sore throat	Isovitexin, vitexin (F) → antibacterial, antipyretic	CP	LC	[61, 62]
Euphorbiaceae	*Euphorbia tirucalli* (L.)	Patah tulang	Sap	Toothache, wound	Euphol, tirucallol (T) → analgesic, anti-inflammatory	CP	LC	[63, 64]
Euphorbiaceae	*Euphorbia hirta* L.	Pa'tik-pa'tik	Whole	Appendicitis	β-Sitosterol (R) → anti-inflammatory, antibacterial	WP	NE	[65]
Euphorbiaceae	*Manihot esculenta* Crantz	Dua' kayu	Leaves	Wounds	Kaempferol, myricetin→ anti-inflammatory, antibacterial	CP	DD	[66]
Euphorbiaceae	*Sauropus androgynous* (L.) Merr.	Katuk	Leaves	Lactation disorder	Quercetin (F), squalene E (T) → galactogogue	CP	NE	[67]
Fabaceae	*Pueraria montana* (Lour.) Merr.	Kadon-kadon	Whole	Glaucoma	C-glucoside/isoflavone daidzein (F) → antiglaucoma	WP	NE	[68]
Fabaceae	*Cassia alata* L.	Galinggang	Leaves	Malaria	Sennosides (G), anthraquinones (G) → antiplasmodial	WP	LC	[69]
Iridaceae	*Eleutherine palmifolia* (L.) Merr.	Lassuna deata	Tuber	Cancer	Isoliquirigenin (F), oxyresveratrol (F) → anticancer	CP	NE	[70]
Lamiaceae	*Plectranthus Scutellarioides* Blume	Bulunangko	Leaf tip	Cough, sore throat	Quercetin (F), tannins → anti-inflammatory, antibacterial	CP	NE	[71, 72]
Lamiaceae	*Orthosiphon aristatus* (Blume) Miq.	Danggo serre'	Whole	Kidney, dysuria	Eupatorine (F), sinensetin (F) → diuretic, anti-urolithiatic	CP	NE	[73]
Lamiaceae	*Mesosphaerum pectinatum* (L.) Kuntze	Pedampi sebu	Leaves	Wounds	β-caryophyllene (T), essential oil (T) →antibacterial, anti-inflammatory	WP	NE	[74, 75]
Lauraceae	*Persea americana* Mill.	Alpoka'	Leaves	Hypertension	Trihydroxy, pentahydroxy flavanone → antihypertensive	CP	LC	[76]
Loranthaceae	*Dendrophthoe pentandra* (L.) Miq.	Bettoto	Leaves	Cancer	Quercetin (F), quercitrine → anticancer, antiproliferative	WP	NE	[77, 78]
Malvaceae	*Abelmoschus manihot* (L.) Medik.	Daun gedi	Leaves	Diabetes	Hyperoside, myricetin, rutin, quercetin (F) → antidiabetic	CP	DD	[79]
Malvaceae	*Corchorus capsularis* L.	Songkadulang	Seed	Heart disease	Corchortoxin (A) → cardioprotective	CP	NE	[80]
Malvaceae	*Theobroma cacao* L.	Cokla'	Seed	Diabetes	Quercetin (F), gallic acid (P) → antidiabetic	CP	NE	[81]
Melastomataceae	*Melastoma malabathricum* L.	Botto'	Leaves	Wounds	Quercetin (F), kaempferol→ antibacterial, wound healing	WP	NE	[82]
Meliaceae	*Swietenia macrophylla* King	Mahoni	Seed	Malaria	Limonoids (T) → antimalarial	CP	EN	[83]
Meliaceae	*Sandoricum koetjape* (Burm.f.) Merr.	Katapi	Bark	Cancer	Koetjapic acid/KA (T) → antiangiogenic	CP	LC	[84]
Meliaceae	*Lansium domesticum* Corrêa	Langsa'	Bark	Malaria	Lansiolic acid, methyl lansiolate (T) → antimalarial	CP	NE	[85]
Moraceae	*Artocarpus altilis* (Park.) Fosberg	Baka'	Bark	Cancer	Artonin (A), artobiloxanthone → anticancer	CP	NE	[86]
Moraceae	*Ficus septica* Burm. f.	Lebannu	Leaves	Jaundice	Ficuseptamines (A), β-sitosterol (R) → hepatoprotective	WP	LC	[87, 88]
Moraceae	*Artocarpus heterophyllus* Lam.	Nangka'	Leaves	Cancer	Artocarpin (F) → anticancer	CP	NE	[89]
Moringaceae	*Moringa oleifera* Lam.	Roro'	Seed	Diabetes	Moringa isothiocyanate-1 → antidiabetic	CP	LC	[90]
Muntingiaceae	*Muntingia calabura* L.	Gersen	Leaves	Diabetes	Quercetine (F) → antidiabetic	WP	LC	[91]
Myrtaceae	*Psidium guajava* L.	Dambu	Leaf tip	Diare, diabetes	Quercetin → antidiare, Pedunculagin (F) → antidiabetic	CP	LC	[92]
Myrtaceae	*Syzygium polyanthum* (Wight) Walp.	Daun salam	Leaves	Hypertension	Gallic acid (P), glucogallin (G) → antihypertensive	CP	NE	[93, 94]
Oxalidaceae	*Oxalis corniculata* L.	Pisik	Whole	Cough	β-carotene (T) → anticough	WP	NE	[95]
Pandanaceae	*Pandanus amaryllifolius* Roxb. ex Lindl.	Don pandan	Root	Diabetes	Quercetin (F), hydroxybenzoic acid (P) → antidiabetic	CP	DD	[96, 97]
Phyllanthaceae	*Phyllanthus urinaria* L.	Meniran	Whole	Kidney	Phyllanthin (L), lignan, triterpenoid → anti-urolithiatic	WP	NE	[98, 99]
Piperaceae	*Peperomia pellucida* (L.) Kunth	Kaca-kaca	Whole	Hypertension	Quercetin (F), pellucidin (L) → antihypertensive	WP	NE	[100]
Piperaceae	*Piper betle* L.	Daun bolu	Leaves	Fever, gastritis	Hydroxychavicol → Immunomodulatory, antiulcer	CP	NE	[101, 102]
Plantaginaceae	*Plantago major* L.	Sawi-sawi	Leaves	Kidney	Iridoid (T), terpenoid, caffeic acid (P) → anti-urolithiatic	WP	LC	[103]
Poaceae	*Imperata cylindrica* (L.) Raeusch.	Ria	Whole	Kidney	Chryptochlorogenic acid (P)→ nephroprotection, diuretic	WP	LC	[104]
Poaceae	*Cymbopogon citratus* (DC.) Stapf	Sarre	Whole	Cough	Citral (T), Citronellal → antibacterial, antinociceptive	CP	NE	[105]
Poaceae	*Digitaria sanguinalis* (L.) Scop.	Billa'-billa'	Leaves	Wounds	Eucalyptol (T) → anti-inflammatory, antibacterial	WP	LC	[106]
Poaceae	*Coix lacryma-jobi* L.	Dalle-dalle	Seed	Urinary infection	Phytosterols, phenols → diuretic, nephroprotective	CP	NE	[107, 108]
Poaceae	*Saccharum officinarum* L.	Ta'bu rarang	Leaves	Diabetes	Genistin (F), quercetin → antihyperglycemic, anti-diabetic	CP	NE	[109]
Poaceae	*Zea mays* L.	Dalle	Seed	Chickenpox, scar	Chlorogenic acid → antiviral, Allantoin → healing agent	CP	LC	[110, 111]
Rutaceae	*Citrus aurantiifolia* (Christm.) Swingle	Lemo tadi	Leaves, fruit	Fever, cough	Eugenol → antipyretic; naringin (F), naringenin → antitussive	CP	NE	[112, 113]
Rutaceae	*Citrus hystrix* DC.	Lemo asa	Fruit	Cough	α-terpineol (T), terpinene-4-ol (T) → antibacterial	CP	LC	[114]
Santalaceae	*Santalum album* L.	Sendana	Wood	Cancer	α-santalol, β-santalol (T) → anticancer	CP	VU	[115]
Solanaceae	*Solanum americanum* Mill.	Tanatti	Fruit	Sore throat	Solanine (A), catechins (F) → antibacterial, antipyretic	WP	NE	[116, 117]
Solanaceae	*Solanum torvum* Sw.	Tarrung pipit	Fruit	Diabetes	Methyl caffeate → antidiabetic	CP	NE	[118]
Solanaceae	*Solanum lycopersicum* var. *cerasiforme* (Alef.) Fosberg	Tammate dondo'	Leaves, fruit	Ocular hypertension	Lycopene (K), flavonoids → neuroprotective	CP	NE	[119]
Thymelaeaceae	*Phaleria macrocarpa* (Scheff) Boerl.	Makota dewa	Fruit	Breast cancer	Gallic acid (P) → anti-breast cancer	CP	LC	[120]
Urticaceae	*Boehmeria nivea* (L.) Gaudich.	Karra'-karra'	Leaves	Appendicitis	Tetracontane (H) → antibacterial, anti-inflammatory	WP	NE	[121, 122]
Urticaceae	*Boehmeria cylindrica* (L.)	Sissing tuak	Leaves	Appendicitis	Cryptopleurine, stigmasterol → anti-inflammatory	WP	LC	[123, 124]
Verbenaceae	*Lantana camara* L.	Kassi'-kassi'	Leaves	Cough, gastritis	Lantadenes- A, B, C, D → antibacterial, antiulcerogenic	WP	NE	[125]
Zingiberaceae	*Zingiber cassumunar* Roxb.	Bangle	Rizhome	Fever	Eugenol, sabinene → antipyretic, immunodulatory	CP	DD	[126, 127]
Zingiberaceae	*Zingiber montanum* (J.Koenig) Link ex A.Dietr.	Bangle lotong	Rizhome	Abdominal pain	Zerumbone (T) → antiulcer	CP	NE	[128]
Zingiberaceae	*Zingiber officinale* Roscoe	Pana'	Rizhome	Cough	Zingiberene (T), zingiberol (T) → mucolytic, expectorant	CP	DD	[129]
Zingiberaceae	*Zingiber officinale* var. *rubrum*	Pana' rarang	Rizhome	Abdominal pain	6-gingerol → analgesic dan anti-inflammatory	CP	DD	[130]
Zingiberaceae	*Curcuma zedoaria* Roxb.	Kunyi' busa	Rizhome	Cancer, tumor	Isocurcumenol (T) → anticancer, antitumor	CP	DD	[131, 132]
Zingiberaceae	*Curcuma longa* L.	Kunyi'	Rizhome	Gastritis, wounds	Curcumin → gastroprotective, wound healing	CP	DD	[133, 134]
Zingiberaceae	*Curcuma zanthorrhiza* Roxb.	Tammula'	Rizhome	Gastritis	Xanthorrhizol (T), curcumin (P) → gastroprotective	CP	DD	[135]
Zingiberaceae	*Etlingera elatior* (Jack) R.M.Sm.	Patikala	Stem	Sore throat	Stigmastan (R), p-hydroxybenzoic acid (P)→antibacterial	CP	DD	[136, 137]
Zingiberaceae	*Alpinia galanga* (L.) Willd.	Likkua	Rizhome	Arthralgia	p-hydroxycinnamaldehyde (P)→ analgesic, inflammatory	CP	NE	[138]
Zingiberaceae	*Alpinia purpurata* (Vieill.) K.Schum.	Likkua rarang	Rizhome	Gastritis	Rutin (F), kaempferol → anti-inflammatory disease	CP	NE	[139]

PT: Plant type; WP: Wild plant; CP (Cultivated Plant), CS: Conservation Status; EN: Endanger (Very high risk of extinction in the wild); VU: Vurnerable (At risk of becoming endangered); LC: Least Concern (Low risk, population is stable and not currently threatened); DD: Data Deficient (Insufficient information to asses conservation status); NE: Not Evaluated (Has not yet been assessed); (A) Alkaloid; (F) Flavonoid; (P) Asam fenolik; (T) Terpenoid; (S) Saponin; (G) Glikosida; (L) Lignan; (R) Steroid; (K) Karotenoid; (U) Organosulfur

(b) Active Compounds and Therapeutic Properties

The correlation between phytochemical constituents and ethnomedicinal uses was analyzed to determine whether the presence of bioactive compounds supports the traditional medicinal applications. Many medicinal plants contain active compounds that are aligned with their traditional uses. These active compounds come from various major classes of phytochemicals, such as flavonoids, terpenoids, alkaloids, phenolic acids, saponins, and steroids, all of which are known to exhibit a range of pharmacological activities, including wound healing, antibacterial, anti-inflammatory, antioxidant, immunomodulatory, antidiabetic, anti-ulcer, antihypertensive, antihyperlipidemic, antimalarial, and anticancer effects. This correlation aligns with the reverse pharmacology approach, which suggests that traditional knowledge can guide the discovery of pharmacologically active substances. Reverse pharmacology, in particular, emphasizes the validation of traditional medicine through modern scientific methods, beginning with clinical observations and progressing toward laboratory and molecular studies [140]. For instance, flavonoids commonly found in ethnomedicinal plants have been documented to exhibit potent antioxidant and anti-inflammatory properties, thereby validating their traditional use in treating inflammatory conditions [141]. Thus, the presence of these bioactive compounds scientifically supports and rationalizes their traditional applications.

Wound-Healing Properties

Some species contain specific compounds with pharmacological activities strongly correlated with their traditional use in wound healing. For instance, *Ageratum conyzoides* (kaempferol and quercetin), *Chromolaena odorata* (hesperetin and persicogenin), *Anredera cordifolia* (vitexin), and *Aloe vera* (acemannan, aloe-emodin, and aloin) are commonly used for wound-healing purposes. These compounds, primarily belonging to the flavonoid class, exhibit wound-healing, antibacterial, and anti-inflammatory effects, which may explain their traditional applications in treating cuts, infections, and inflammation. This suggests that traditional healers may have selected plants based on their inherent medicinal properties.

Antimalarial Properties

Several plant species are traditionally used for their antimalarial effects, supported by the pharmacological activities of their bioactive compounds. For example, *Andrographis paniculata* (andrographolide), *Carica papaya* (carpaine), *Areca catechu* (arecoline), *Momordica charantia* (momordicin), *Swietenia macrophylla* (limonoids) and *Lansium domesticum* (Lansiolic acid) are well-known for their antimalarial properties. These compounds, primarily derived from alkaloid and terpenoid classes, have been shown to help combat the malaria parasite, which aligns with their long-standing use in traditional medicine for treating malaria. This suggests that traditional healers may have selected these plants based on their medicinal properties.

Antidiabetic and Antihyperglycemic Properties

Various plants have been recognized for their ability to support blood sugar regulation, with bioactive compounds contributing to their antidiabetic and antihyperglycemic effects. For instance, *Annona muricata* (acetogenin), *Cosmos caudatus* (catechin), *Crescentia cujete* (luteolin), *Abelmoschus manihot* (myricetin), *Muntingia calabura*, *Theobroma cacao* (quercetin), *Moringa oleifera* (Moringa isothiocyanate-1), and *Peperomia pellucida* (ellagic acid) have been shown to improve insulin sensitivity, reduce blood glucose levels, and provide antioxidant benefits. These findings support their use in traditional medicine for managing diabetes and related conditions.

Antihypertensive Properties

Numerous plant species are used in traditional medicine to manage hypertension and support cardiovascular health, owing to their antihypertensive and vasodilatory effects. These include *Allium sativum* (allicin), *Centella asiatica* (quercetin and apigenin), *Daucus carota* (daucusol), *Sechium edule* (quercetin), *Syzygium polyanthum* (gallic acid; glucogallin), and *Peperomia pellucida* (pellucidin A). The compounds in these plants have been shown to relax blood vessels and lower blood pressure, providing a scientific basis for their traditional use in treating hypertension.

Anticancer and Antiproliferative Properties

Certain plants have long been used for their anticancer, antiproliferative, and antiangiogenic effects, which are linked to the bioactive compounds they contain. For example, *Elephantopus scaber* (deoxyelephantopin), *Chromolaena odorata* (odoratin and acacetin), Acalypha indica (catechin; indoline), *Eleutherine palmifolia* (isoliquirigenin; oxyresveratrol), and *Dendrophthoe pentandra* (quercetin, quercitrine, and β-sitosterol) exhibit strong anticancer properties. Similarly, *Artocarpus altilis* (artonin E and artobiloxanthone), *Artocarpus heterophyllus* (artocarpin), *Santalum album* (α-santalol), *Curcuma zedoaria* (isocurcumenol), and *Sandoricum koetjape* (koetjapic acid) contain compounds with similar anticancer activities. These findings reinforce their traditional use in cancer treatment and related therapeutic purposes.

Figure 5 Medicinal plants species used traditionally for treating various disease, (A) *A. cordifolia*; (B) *C. odorata*; (C) *S. macrophylla*; (D) *A. catechu*; (E) *A. manihot*; (F); *P. pellucida*; (G) *D. pentandra*; (h) *E. palmifolia*

The findings of this study have significant implications for the development of modern pharmaceuticals, as many contemporary drugs have their origins in ethnopharmacology and traditional medicine [140]. The medicinal plants used by the Toraja community contain bioactive compounds that could potentially serve as the foundation for new drug development. For example, flavonoids such as quercetin and pellucidin, identified in Peperomia pellucida, are known to possess pharmacological effects, including antihypertensive properties, which make them strong candidates for further investigation as therapeutic agents. These compounds could provide novel treatments for diseases such as hypertension, heart failure, and stroke, potentially complementing or enhancing current therapies.

Moreover, the study emphasizes the importance of sustainable harvesting and conservation practices to ensure these plants remain available for future research and drug development. By ensuring the conservation of these valuable plant resources, we not only preserve traditional knowledge but also open up new possibilities for the future of medicine. Incorporating sustainable practices into the collection and use of these plants will be critical in balancing the needs of modern pharmaceutical development and the conservation of biodiversity. Future research should focus on both the bioactive potential of these plants and the preservation strategies necessary to maintain their availability.

(c) Conservation Status of Medicinal Plants Used

The Toraja community utilizes various species of medicinal plants with diverse conservation statuses. The majority of the species used have a status of *Least Concern* (LC), meaning they are not threatened, with 29 species (31%). On the other hand, some species fall into more threatened categories, such as one species listed as *Vulnerable* (VU) due to over-exploitation and habitat destruction, namely *Santalum album* (Sendana). Additionally, another species is classified as *Endangered* (EN), namely *Swietenia macrophylla* (Mahoni), which indicates a greater threat to its survival. Around 11 species (12%) are in the *Data Deficient* (DD) category, meaning there is insufficient conservation data for further assessment. The majority of species, about 52 species (55%), have not yet had their conservation status evaluated (NE). The diagram showing the conservation status percentage of medicinal plant species used by the Toraja community is shown in Figure 4.

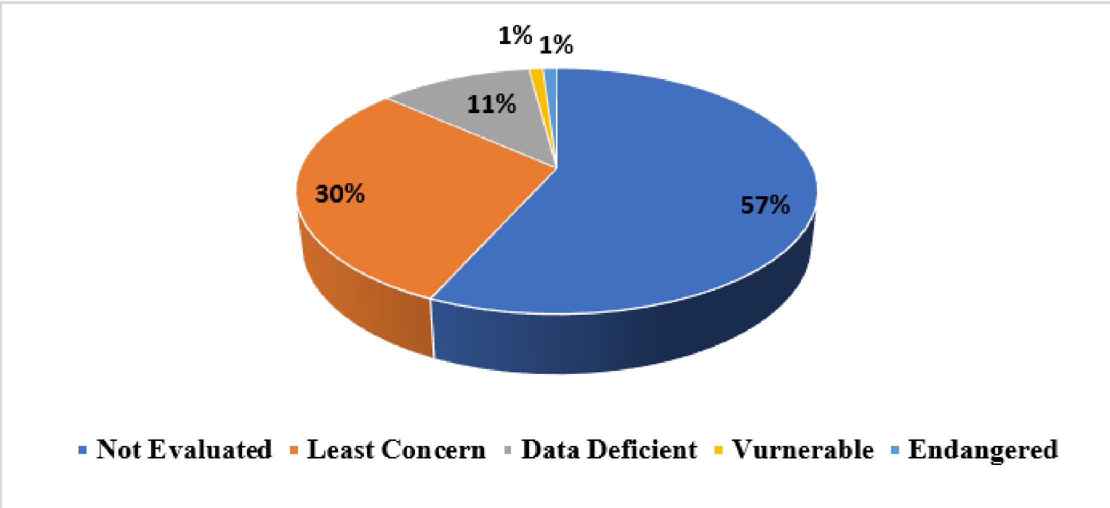

Figure 4 Conservation status of medicinal plants based on IUCN Red List.

The data shown in Figure 4 highlights the importance of implementing sustainable conservation practices in the utilization of medicinal plants by the Toraja community. The majority of the species used have a Least Concern (LC) status, indicating that they do not face immediate threats to their survival. This reflects that the Toraja community has wisely managed their natural resources, maintaining a balance in utilizing medicinal plants without increasing pressure on non-threatened species populations. However, the fact that around 12% of species are in the Data Deficient (DD) category and 55% have not yet had their conservation status evaluated emphasizes the need for further research to understand potential threats to these species. Species with more threatened statuses, such as *Santalum album* (Sendana), listed as Vulnerable (VU), and *Swietenia macrophylla* (Mahoni), listed as Endangered (EN), remind us of the importance of managing natural resources wisely and sustainably. Therefore, effective conservation must involve efforts to protect threatened species and monitor exploitation, to ensure the preservation of medicinal plants for future generations. In this regard, it is crucial for the community to participate in conservation practices that support the sustainable use of their natural wealth.

The results of this study show that the Toraja community utilizes a variety of plant species, both wild and cultivated, sourced from home gardens, natural forests, and markets. Despite their high dependence on medicinal plants, the species used in traditional medicine remain relatively safe, as indicated by the high diversity of plants and their generally well-preserved conservation status. The Toraja people practice sustainable management of medicinal plants through several methods. These include selective harvesting taking only parts such as leaves or stems to allow regeneration and rotational harvesting across different locations to support plant recovery. Additionally, they cultivate medicinal plants in home gardens, which reduces pressure on wild populations, protects natural habitats, and ensures access to economically and medicinally important species, such as those from the Zingiber family. Forest areas and gardens are also protected by strict local regulations that limit resource extraction, supporting biodiversity conservation and ensuring the long-term availability of these resources. These conservation practices align with findings from other regions, such as the Eastern Himalayas, where traditional belief systems have been shown to play a vital role in conservation. In that region, 28 out of 35 threatened mammal species were protected through local taboos and cultural [142]. Similarly, a study in Thathe Vondo, South Africa, found that customs, rituals, and myths associated with sacred forests foster strong conservation ethics among local communities, who enforce strict bans on human activities in those areas [143]. These cases highlight how Traditional Ecological Knowledge (TEK) and cultural norms can significantly contribute to biodiversity conservation, as also demonstrated by the Toraja community.

(d) Conservation Efforts and Sustainable Practices

The conservation of medicinal plant species is crucial for ensuring their availability for future generations. The unsustainable harvesting of wild medicinal plants poses a significant threat to biodiversity, making it essential to integrate traditional knowledge with cultivation practices for long-term sustainability [144]. Strategies for conserving medicinal plants can be implemented through various methods, such as in-situ conservation (natural reserves, wild nurseries), ex-situ conservation (botanic gardens, seed banks), and cultivation practices (Good Agricultural Practices/GAP) [145]. This section discusses the sustainable harvesting practices and conservation efforts employed by the Toraja community to preserve their medicinal plants. Interviews with local informants revealed that many medicinal plants are sourced from forests, mountains, riverbanks, rice fields, home gardens, and thickets, where traditional conservation practices are observed. These practices include in-situ and ex-situ conservation, sustainable harvesting, customary protection, and eco-friendly farming. Such practices help ensure that plant populations are not overharvested and that their habitats remain intact.

In-Situ Conservation (Inside Natural Habitats)

The people of Toraja practice in-situ conservation by preserving their natural environment through traditions and beliefs passed down through generations. One such practice is the protection of sacred forests (hutan pemali), which cannot be cut down as they are considered sacred places or hold deep spiritual significance. Additionally, selective logging is carried out for timber, particularly for building traditional Tongkonan houses, where only mature trees are chosen and harvested through specific rituals to maintain ecological balance. Protection of trees like the Tarra (*Artocarpus* sp.) is also an important aspect, as these trees are valued both spiritually and ecologically in ceremonial practices. Through these practices, the people of Toraja not only preserve their cultural heritage but also play a crucial role in sustainable environmental conservation.

Ex-Situ Conservation (Outside Natural Habitats)

The people of Toraja also engage in ex-situ conservation through practices like home gardens (ratte) and seed bank, where they cultivate a variety of medicinal and food plants. In their home gardens, they grow plants such as ginger (*Zingiber officinale*), Minahong (*Anredera cordifolia*), Sambiloto (*Andrographis paniculata*), and betel leaf (*Piper betle*), which not only serve medicinal purposes but also preserve plant diversity. Furthermore, wild medicinal plants like Ria (*Imperata cylindrica*) and Lebannu (*Ficus septica*) are being domesticated and cultivated near homes, ensuring that these valuable species are protected and can be sustainably harvested. Toraja people also relies on subsistence farming by saving seeds of local varieties, such as local rice, local corn, and medicinal plants, for the next planting season. These seeds are stored in special places, such as alang (a traditional Toraja seed storage structure), bamboo, or coconut shells, and in areas that are dry and shaded. The seed selection process is based on visual observation and experience, taking into account desirable traits such as resistance and taste. This is a form of traditional genetic conservation that is important for the sustainability of their farming practices. These practices help conserve important plant species outside of their natural habitats, contributing to biodiversity preservation while supporting the health and well-being of the community.

Sustainable Harvesting Practices

The people of Toraja practice sustainable harvesting to ensure that their natural resources are used responsibly and remain available for future generations. One key method is crop rotation for medicinal and food plants, such as bamboo and rattan, which are harvested in a rotational manner to prevent the depletion of any one area. Additionally, they practice harvesting regenerative plant parts, such as collecting leaves, bark and rizhome from medicinal plants like leme' (*Centella asiatica*), kunyi' (*Curcuma longa*), pana' *(Zingiber officinale),* kariango *(Acorus calamus)* and salonggo *(Colocasia esculenta)* without cutting down the entire plant, allowing it to regenerate. These sustainable practices reflect the community's deep understanding of the environment and their commitment to maintaining ecological balance.

Protection Based on Customary Laws and Beliefs

The people of Toraja have long relied on customary laws and beliefs to protect their natural resources and ensure their sustainable use. These laws specifically prohibit the excessive extraction of natural resources, particularly from sacred forests, which are considered spiritually significant and are passed down through generations. In addition to the protection of forests, the use of certain plants, such as betel leaves (*Piper betle*) and areca nuts (*Areca catechu*), is also regulated. These plants hold deep cultural significance and are integral to wedding and ritual ceremonies. By carefully managing the use of these plants, the Toraja people prevent overharvesting, ensuring that these resources remain available for future generations and continue to play a vital role in their cultural practices.

Sustainable Agriculture and Cultivation

The Toraja people practice sustainable agriculture and cultivation through methods that maintain soil fertility and preserve ecological balance. One such practice is shifting cultivation, where fields are cultivated for a period and then left fallow to allow the soil to regenerate naturally. This rotation helps prevent soil depletion and supports long-term agricultural productivity. Additionally, the Toraja people engage in polyculture, planting a variety of crops such as ubi (*Manihot esculenta*), Paria (*Momordica charantia*), taliki (*Carica papaya*), Nangka (*Artocarpus heterophyllus*) and Pana' *(Zingiber officinale)* together in the same fields. This diverse planting approach not only ensures a steady supply of food but also promotes ecosystem balance by reducing the risk of pests and diseases, maintaining soil health, and fostering biodiversity within their agricultural landscapes. Through these methods, the Toraja people sustainably manage their land and resources.

While traditional practices play an important role, modern challenges increasingly threaten the sustainability of medicinal plant species. Climate change and overharvesting are particularly concerning for high-demand species with proven medicinal properties, many of which are being collected at unsustainable rates, leading to population declines. The growing demand from both modern medicine and commercial markets further intensifies pressure on these plants. In addition, these environmental changes affect not only the geographic distribution of medicinal plants but also the production of their bioactive compounds. A study in Indonesia predicts that over half of medicinal plant species could lose up to 80% of their distribution range by 2050–2080. Heat and drought stress can reduce levels of key compounds such as flavonoids and essential oils, diminishing both their therapeutic effectiveness and market availability [146]. Therefore, implementing sustainable harvesting practices and collaborating with local communities remain essential for developing conservation strategies that integrate traditional knowledge with modern principles.

In conclusion, while the Toraja community has a strong tradition of sustainable plant use, modern conservation efforts and sustainable harvesting practices must be integrated to ensure the long-term preservation of these plant species. Both conservation strategies, such as in-situ and ex-situ conservation as well as cultivation practices, and resource management approaches, including good agricultural practices and sustainable use solutions, should be carefully considered to promote the sustainable use of medicinal plant resources. It is also recommended that biotechnical approaches, such as tissue culture, micropropagation, synthetic seed technology, and molecular marker-based methods, be applied to improve yields and enhance the potency of medicinal plants [145]. Future initiatives could include collaborating with government and academic institutions to research the status and population trends of medicinal plant species, developing certification programs or eco-labels for plant products to promote conservation, and integrating conservation education into local school curricula to equip younger generations with the knowledge and skills needed to protect plant biodiversity. These initiatives may also involve educating the younger generation about the importance of sustainable harvesting, promoting eco-tourism, or collaborating with local authorities and conservationists to protect plant habitats. Ultimately, sustainable practices should aim to strike a balance between utilizing medicinal plants for health and ensuring their long-term survival in the wild.

4) Conclusion

This study provides compelling evidence of the medicinal value of plants used by the Toraja people, linking traditional ethnobotanical knowledge with modern pharmacological understanding. The identification of key bioactive compounds, such as flavonoids and terpenoids, supports the therapeutic applications of these plants, showing potential in areas like wound healing, antibacterial, anti-inflammatory, antidiabetic, antihypertensive, antimalarial, and anticancer effects. While the findings validate the effectiveness of traditional practices, they also open avenues for further research to explore the mechanisms behind these compounds' effects. Future studies should focus on the clinical and pharmacological evaluation of these plants to fully realize their potential in modern medicine. Additionally, the preservation of both plant biodiversity and the indigenous knowledge associated with it is crucial to ensure sustainable healthcare solutions and the continued cultural relevance of Toraja's medicinal practices.

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7) Data Availability

The data that support the findings of this study are available from the corresponding author.

8) Conflict of Interest

The authors declare that there is **no conflict of interest.**

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