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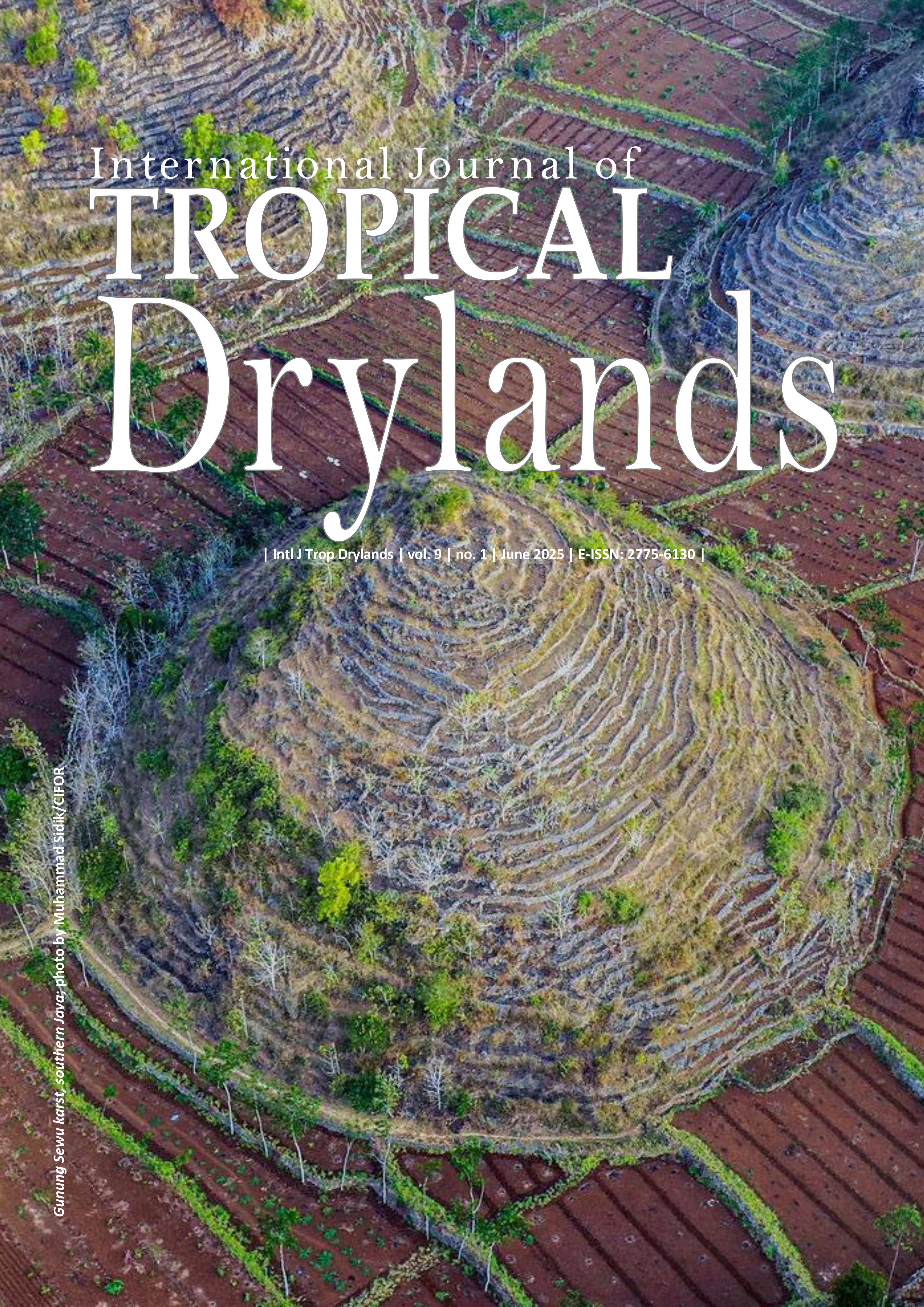

Gunung Sewu karst, southern Java, photo by Muhammad Sidik/CIFOR

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Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

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Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Traditional knowledge of karst land management in Gunung Sewu, Java, Indonesia

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[3]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

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Abstract. *Farikha KN, Arlysia V, Raharjo YAA, Santika YE, Deristani A, Setyawan AD. 2025. Traditional knowledge of karst land management in Gunung Sewu, Java, Indonesia. Intl J Trop Drylands 9: 1-9.* Karst is a landscape formed from the dissolution of rocks, particularly limestone, that are easily soluble in water. With the development of appropriate land management strategies, the karst area can be utilized as a productive and sustainable agricultural region. This research aims to understand how the community manages karst land by utilizing traditional knowledge in the villages of Songbledeg, Ketos, and Paranggupito of Wonogiri District, Central Java, Indonesia. The research employed qualitative method with data collection used interviews and field observations. Interviews was conducted using accidental sampling techniques, with questionnaires distributed to 100 respondents from the three research areas. The data was then analyzed using descriptively. The results show that most of the land is used to meet food and economic needs in the form of dry field (*tegalan*), rain-fed rice field (*sawah tadah hujan*), forest garden (*kebon*), homegarden (*pekarangan*), and vacant land. On rain-fed rice field that relies on rainwater, organic fertilizer is applied approximately two months before planting, continued with direct planting using rice seeds and the application of limestone to suppress insect pests. Since land productivity is highly dependent on rainfall, planting is typically done once a year or when the rainy season begins. To sustain their need, the farmers also plant drought-resistant crops such as peanuts (*Arachis hypogaea*), chili (*Capsicum frutescens*), and turmeric (*Curcuma longa*), as well as woody plants such as petai (*Parkia speciosa),* teak (*Tectona grandis*), etc. The local wisdom of *Gesik Deso* was conducted for clearing agricultural land at the end of dry season before rice planting. Additionally, any unused land is also utilized by the community for livestock, including cattle, goats, chickens, and ducks.

Keywords: Agriculture, community, karst, land management

INTRODUCTION

Karst is one of the most unique ecosystems in the world, characterized by its distinct topography, primarily shaped by the process of water dissolution on carbonate bedrock (Avrilan et al. 2022). The unique surface and subsurface relief characteristics of karst morphology allow it to store a large amount of water, making it strategically important (Nugroho et al. 2020). Karst serves as a water reserve because it contains aquifers that store and regulate groundwater, which is accessed through springs, caves, and wells. Karst morphology can be identified by the presence of springs in rock crevices, cone-shaped limestone hills, and underground rivers flowing through cave passages are key identifiers of karst morphology, adding to its unique charm (Nugroho and Paripurno 2019). As an ecologically important area, karst provides natural resources for various sectors, such as mining activities and utilization of karst aquifers (Pratiwi 2021). Additionally, the karst ecosystem plays an important role as a carbon sink, with its ability to capture carbon being twice as effective as that of forests (Chen et al. 2023). The larger carbon reserves in karst ecosystems are in the form of inorganic carbon stored in carbonate rocks, rather than in biomass or soil. Although the aboveground biomass of lowland rainforests such as those in Kalimantan, Sulawesi, and Sumatra is higher, however, if the carbon stored in carbonate rocks is also considered, karst ecosystems have far greater carbon reserves than any type of forest, including rainforests, peatlands, or mangroves.

Karst is a fragile terrestrial ecosystem with low resilience to environmental changes or disturbances. Its unique topography and distinctive ecology grant it high conservation value, but it remains highly vulnerable to both natural and human pressures (He et al. 2021). Natural threats to karst ecosystems include natural disasters and climate change (He et al. 2021). On the other hand, human activities such as population growth, mass tourism, water pollution, and declining water quality pose significant risks to the sustainability of its ecological functions (Duli and Mulyadi 2019; Siegel et al. 2023). These challenges highlight the critical need for immediate conservation efforts.

One of the ecological functions of karst is to regulate the hydrological system, as most springs in karst areas have significant rainfall variation (Lv et al. 2020). Karst area management must open up opportunities to utilize all existing potentials and regulate development efforts to align with the capabilities and challenges of a region. Karst areas are complex, and therefore, management must consider the specific values related to geology, geomorphology, and hydrology, as well as flora and fauna (Soedwiwahjono and Utomo 2020). Sustainable utilization of natural resources in karst area management requires careful consideration of what is used to measure maximum capacity, as exceeding this capacity can lead to damage that is difficult to recover. This potential damage underscores the urgency of responsible resource use in karst areas (Peng et al. 2021).

The villages of Songbledeg, Ketos, and Paranggupito are part of a karst geomorphology of Gunung Sewu, Wonogiri District, Central Java Province, Indonesia. The agricultural land in these areas faces various challenges related to water availability and soil fertility. The karst environment is fragile, and the rapid water flow presents many challenges for environmental protection and management (Li et al. 2021). Karst areas often experience drought, especially during the dry season, due to the soil's inability to retain water. This affects agricultural production, as crops require sufficient soil moisture to grow well (Khotimah et al. 2019). Agricultural land management should be approached not only to increase productivity but also to conserve the environment to prevent further damage.

Traditional techniques are often more suitable for application in certain areas because they are adapted to local natural conditions and cultures. Traditional agriculture is part of cultural heritage and ancestral legacy, often encompassing unique practices and community values. Preserving traditional agriculture based on local knowledge is part of the effort to safeguard valuable identity and traditions. Local knowledge also often includes ways to adapt to climate and reduce pest risks naturally without excessive chemicals. Furthermore, developing traditional agriculture based on local knowledge is an essential strategy to achieve economic independence that aligns with the culture and way of life of local communities. The development of appropriate land management strategies is expected to make the area a productive and sustainable agricultural region, ensuring food security (Satria et al. 2018).

There are several studies focusing on traditional ecological knowledge of land management in karst area. Karst areas face challenges that require restoration to restore ecological balance (Zhang et al. 2024). The potential of applying a landscape approach to karst systems lies in developing models that provide relevant ecological information to understand karst systems and their implications for natural resource management (Canedoli et al. 2022). Communities and governments must work together to carefully consider land use change and management to minimize the risk of environmental damage to karst areas (Li et al. 2021). This research aims to understand how the community manages land by utilizing traditional knowledge in Gunung Sewu karst area, i.e., the villages of Songbledeg, Ketos, and Paranggupito of Wonogiri District, Indonesia. This study is important by integrating traditional ecological knowledge and community-based land management, it offers insights into balancing resource use with ecological conservation while safeguarding cultural heritage and ensuring food security.

MATERIALS AND METHODS

Study area and period

This research was conducted in the villages of Songbledeg, Ketos, and Paranggupito in the Gunung Sewu karst area. Administratively, these villages are located in Paranggupito Subdistrict, Wonogiri District, Central Java, Indonesia (Figure 1).

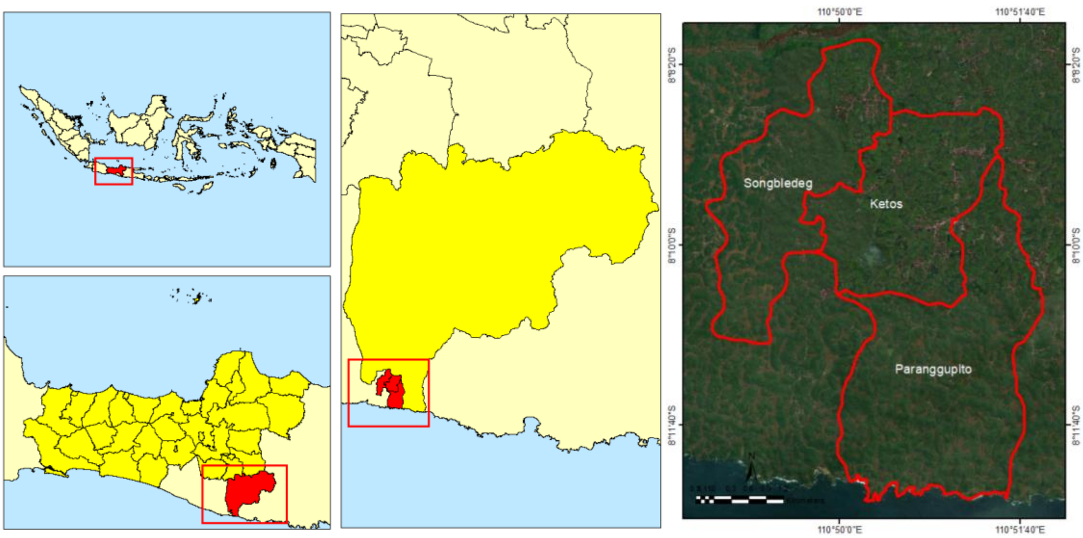

Figure 1. Map of the research location in Gunung Sewu karst area, including Villages of Songbledeg, Ketos, and Paranggupito, Paranggupito Subdistrict, Wonogiri District, Central Java, Indonesia

The reason for choosing these villages is that the agricultural activities are still considered to be traditional, which helps to reduce environmental degradation. The research was carried out in October 2024 through field observations and interviews with residents. The environmental conditions of the study area are karst, with unique topographical and hydrological characteristics, leading to limited utilization and availability of water (Jumadi et al. 2022). The southern part of Wonogiri District is known as a karst region that often faces issues of drought and a shortage of clean water due to the lack of usable clean water sources (Nurbaiti et al. 2023).

Procedures

Data were collected by field observation and semi-structured interviews using Indonesian and local language (Javanese). Data collection utilized an accidental sampling method (convenience sampling, grab sampling, or opportunity sampling) with interview questionnaires' instrument distributed to 100 respondents aged 17 years or more, representing resident of the three villages, i.e. Songbledeg, Ketos, and Paranggupito. The accidental sampling method involves selecting respondents met randomly by the researcher and are used as samples if they are suitable as data sources (Jainali et al. 2023). The selected respondents provide permission to be interviewed before the interviews proceed (Fahlevi and Fitrah 2022). Following this, interviews were conducted to determine the respondents' characteristics and gather socio-economic data such as education, occupation, gender, and age. Interviews can reveal issues more openly, allowing respondents to express their opinions in a more personal manner, which enables deeper information exploration (in-depth interview) (Ambarwati et al. 2021). This research also investigates information regarding the agricultural system, resource utilization, and policies implemented in the region. Additionally, documentation was used to capture data through images or audio recordings directly related to the research objects (Ardianti et al. 2022). A direct field survey gathered plant and animal inventory that were identified using an online sources (https://www.identify.plantnet.org/id and https://www.inaturalist.org/)

Data analysis

Interviews were conducted by filling in data or information obtained from informants into a pre-prepared questionnaire. The data was then analyzed using descriptive analysis, presenting the percentage (%) of social conditions with the total number of informants as follows.

$$Pi = \frac{ni}{N} \times 100\%$$

Where: Pi represents the proportion of socio-demographic characteristics (gender, education, occupation, and age group) in percentage (%), ni indicates the number of socio-demographic characteristics, and N denotes the total number of informants (Sagrim 2022). By using this formula, researchers can calculate and present data in the form of percentages for each socio-demographic characteristic, thus providing an overview of the overall social condition of the informants.

RESULTS AND DISCUSSION

Respondents' characteristics

This study conducted interviews to 100 respondents (Table 1), consisting of 50 males (50%) and 50 females (50%). Based on education level, the respondents can be described as follows: five respondents had no formal education (5%), 37 respondents completed elementary school (37%), 10 respondents completed junior high school (10%), and 45 respondents completed high school (45%). The majority of respondents (61%) work as farmers, eight respondents (8%) are civil servants, 13 respondents (13%) work in the private sector, and 18 respondents are entrepreneurs. Based on age, respondents were distributed as follows: over 51 years old 47 respondents (47%), 41-50 years old 16 respondents (16%), 31-40 years old 20 respondents (20%), 21-30 years old 10 respondents (10%), and under 21 years old 7 respondents (7%).

The population age in the three villages is divided into two categories: productive and non-productive age. The productive age includes individuals aged 15 to 64 who are considered capable of contributing to the production of goods and services (Prananta et al. 2023). Meanwhile, the non-productive age includes those over 64 years old, who are generally no longer active in productive activities. Figure 2 shows that 82% of respondents are in the productive age category, while the remaining 18% are in the non-productive category. The majority of the residents in the villages of Songbledeg, Ketos, and Paranggupito work as farmers (61%). People of productive age in these areas choose to work as farmers due to the limited availability of jobs outside the agricultural sector. Another influencing factor is the location of these villages, which are far from the city center; and the land uses are predominantly agricultural lands that have been managed for generations. Additionally, many respondents in the non-productive age category still work as farmers. This is due to the low rate of farmer profession regeneration among the younger generation (Oktafiani et al. 2021). The children of farmers who have completed formal education tend to migrate to other regions rather than continue working in the agricultural sector. Based on education, respondents with lower educational levels tend to choose farming because it does not require special skills or higher education (Sophan et al. 2022). On the other hand, respondents with higher education are less likely to choose farming as a profession, as most of them prefer to migrate to seek job opportunities with better income (Ibrahim 2023). This is in line with research conducted by Aprilia et al. (2019) stated that higher education leads to a preference for non-agricultural work.

Social conditions

The villages of Songbledeg, Ketos, and Paranggupito share the same natural conditions, being predominantly characterized by karst formations. Due to specific geological and hydrological backgrounds, karst areas are generally marked by high infiltration rates of water (Wu et al. 2017), thin soil layers (Ouyang et al. 2011), high soil erosion (Zeng et al. 2017), and low fertilization efficiency (Xiong and Chi 2015). These conditions shape the characteristics of karst regions, which have low environmental capacity, high sensitivity, poor stability, weak anti-interference ability, and ecological vulnerability (Hu et al. 2020). These factors contribute to the dryness or aridity of the karst surface areas, as water is stored deep underground. As a result, the local community relies on rainwater to meet their daily water needs. According to BBWS (Begawan Solo River Basin Authority 2024) data, the average monthly rainfall is 229.8 mm/month, classified as moderate based on the Meteorology, Climatology, and Geophysics Agency (BMKG).

The social conditions in the villages of Songbledeg, Ketos, and Paranggupito are influenced by the natural environment, as the difficulty in accessing groundwater forces the community to rely on rainwater for their needs. The majority of the residents in these villages work as farmers, and their work is affected by the availability of water. Some houses have rainwater storage tanks to meet the needs of several households (Figures 3.A and 3.B). The local government provided these storage tanks. Almost every house has a rainwater storage tank, with some reaching a capacity of approximately 25,000 liters. Figure 3.C shows the technique of channeling rainwater from the rooftops into the storage tanks. Harvesting rainwater in these tanks can supplement the water supply, replacing the need for springs, and is used for daily needs, including cooking (Kurniawan et al. 2023). The community perceives that the quality of rainwater is better. The three villages are also served by the regional water utility (PDAM), so water needs are fairly well met. However, residents believe that rainwater has higher quality than PDAM water. This perception may be influenced by the rural nature of the area, which means there are fewer pollutants mixed into the rainwater (Fahrudin et al. 2023). However, during the dry season, many residents seek alternative employment in the city, tend to their livestock, or rely on other crops that can still grow. Farmers often have to work outside the agricultural sector to make ends meet (Khotimah et al. 2019).

Table 1. Respondents' characteristics based on gender, education, occupation and age

Characteristics	Number of respondents	Percentage (%)
Gender		
Male	50	50
Female	50	50
Education		
No education	5	5
Elementary school	37	37
Junior high school	10	10
High school	45	45
College/University	3	3
Occupation		
Farmer	61	61
Government employees	8	8
Private - employee	13	13
Businessman	18	18
Age		
>51	47	47
41-50	16	16
31-40	20	20
21-30	10	10
< 21	7	7

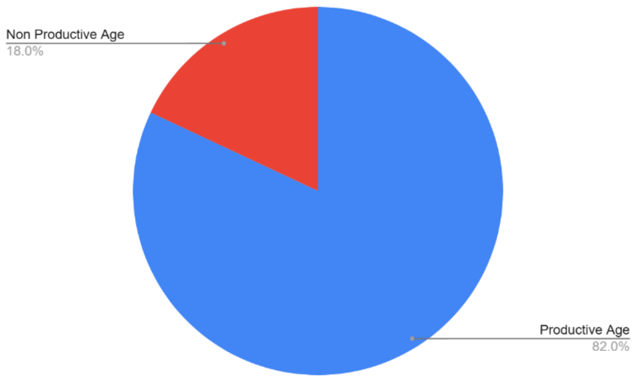

Figure 2. Respondents' characteristics based on productive and non-productive age

Figure 3. Water management at household level in Paranggupito Sub-district: A. Large-scale water storage tank; B. Small-scale water storage tank; C. Pipes for channeling rainwater into the storage tank

Biophysical conditions

Karst is utilized to support the livelihoods of the community, such as farming and cultivation, housing, plantations, clean water sources, and even tourist destinations (Bakri et al. 2023). This is exemplified by the residents of the karst area in Paranggupito Sub-district, who use karst for building houses. In addition to be used for residential, the karst in Paranggupito Sub-district is also used for agriculture by terracing fields with edges covered by karst stones. The landscape is predominantly characterized by solutional landforms resulting from the dissolution of easily soluble rocks, which typically develop on carbonate rocks (White 2020). Ecologically, karst areas function as habitats for various endemic flora and fauna (Villanueva et al. 2021). The villages of Songbledeg, Ketos, and Paranggupito host fauna such as monkeys (*Macaca fascicularis*) and porcupines (*Hystrix javanica*).

The soil in karst areas is usually formed from Mediterranean soil or soil developed from limestone (Noywuli 2023). This soil is located in hilly terrain and is characterized by a reddish to yellowish-red color, clayey texture, granular to clumpy structure, very sticky consistency when wet, slow permeability, and is classified as having low to moderate fertility (Prihatanto et al. 2022). The utilization of land resources by the communities in the villages of Songbledeg, Ketos, and Paranggupito still needs to be improved despite the large extent. The land in this area is dominated by dry fields, agroforestry land, and settlements (Wijayanti et al. 2020). These lands consist of fields located adjacent to residential areas (Figure 4.A). The land is planted with annual crops such as corn (*Zea mays*), soybean (*Glycine max*), and casava (*Manihot esculenta*). This is due to the fact that the soil in the karst tends to be very dry during the dry season (Pratama et al. 2021). The conditions of the land in karst areas lead farmers to adopt different farming practices compared to farmers in other areas, as the region is characterized by barren land and water scarcity due to the presence of limestone hills (Pranata et al. 2023).

The vacant land is also utilized by the community for livestock farming, such as cattle, goats, chickens, and ducks, as shown in Figure 4.B. The karst area also has mining activities that can alter the land's shape, which affects the hydrogeological system because the karst has a low-storage aquifer type. Fractures control water flow within the karst. Therefore, if fractures occur due to mining activities, water may not flow, altering the karst's function as an aquifer (Pratiwi 2021). In the villages of Songbledeg, Ketos, and Paranggupito, there are few new developments, whether in housing or industry. This is because the raw water sources that flow on the surface are difficult to find due to the dry soil type (Nugroho et al. 2020). Groundwater sources, such as deep wells, can reach depths of 20 meters from the surface.

Figure 4. Land management practices in Paranggupito Subdistrict: A. Field adjacent to residential areas; B. Utilization of vacant land for livestock farming; C. Land awaiting cultivation; D. Land that has been fertilized

Table 2. Plant diversity in agricultural land of Paranggupito karst area, Wonogiri, Indonesia

Local name	Scientific name
Crash crops	
Groundnut	*Arachis hypogaea* L.
Chili	*Capsicum frutescens* L.
Turmeric	*Curcuma longa* L.
Red Rice	*Oryza rufipogon* Grif.
Rice	*Oryza sativa* L.
Corn	*Zea mays* L.
Cassava	*Manihot esculenta* Crantz
Sweet Potato	*Ipomoea batatas* (L.) Lam.
Woody plants	
Petai	*Parkia speciosa* Hassk
Coconut	*Cocos nucifera* L.
Teak	*Tectona grandis* L.f
Acacia Trees	*Acacia auriculiformis* A.Cunn. ex Benth

Agricultural practices

The farmers in the karst area in Songbledeg, Ketos, and Paranggupito apply several agricultural practices to meet their economic needs, mainly based on dry land agriculture, including dry field (*tegalan*), upland rice field (*sawan tadah hujan*), forest gardens (*kebon*), home gardens (*pekarangan*), vacant lots and others. The land in the studied area has dry soil characteristics. They are dominated by easily soluble limestone, resulting from dissolution, which produces soil that is less fertile for agriculture. In their agricultural system, the farmers in Songbledeg, Ketos, and Paranggupito rely solely on rainwater without irrigation due to limited water sources, leading to a high risk of crop failure. This planting system is usually done once a year or according to the arrival of the rainy season. During the dry season, the farmers utilize drought-resistant crops such as ground nut (*Arachis hypogaea*), chili (*Capsicum frutescens*), petai (*Parkia speciosa*), and turmeric (*Curcuma longa*) to support their daily needs. Farmers also planting timber tree species such as coconut (*Cocos nucifera*), teak (*Tectona grandis*), and acacia (*Acacia auriculiformis*) to enhance economic diversification. Sometimes woody plants such as lamtoro (*Leucaena leucocephala* (Lam.) de Wit) and gamal (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) are planted on agricultural land for fences and source of animal feed (Table 2). Figure 4.C shows the condition of the land that is still left vacant and waiting for processing as the rainy season begins.

Local communities rely on dryland agriculture as their main source of livelihood. The agricultural system implemented is intercropping. Intercropping is a traditional agricultural technique that involves planting two or more types of crops simultaneously on one piece of land (Mulu et al. 2020). Intercropping allows farmers to harvest various products in a single growing season. For example, farmers can plant corn and legumes together, generating income from multiple commodities. This practice helps farmers avoid dependence on a single crop and reduces the risk of crop failure due to pests, water scarcity, etc. Intercropping also allows for more efficient land use, as plants can grow side by side without competing for resources (Habibah and Astika 2020). As a result, land productivity increases, leading to greater profits from the same area. Crops cultivated during the rainy season include rice (*Oryza sativa*) (albeit in limited areas), red rice (*Oryza rufipogon*), Corn (*Z. mays*), cassava (*M. esculenta*), and sweet potato (*Ipomoea batatas*).

Unlike the common planting system, where rice paddies are directly sown with seeds, dryland planting begins with the use of seeds and planting holes that have been fertilized before the rainy season arrives (Figure 4.D). Farmers use organic fertilizers such as chicken, cow, and goat manure. Organic fertilizers are considered more environmentally friendly, enhance productivity, and are cost-effective (Kugbe 2019). They contain nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), microorganisms, and high fiber that enrich the soil (Maula 2023). Farmers prepare the land about two months before the rainy season starts. The longer the fertilization process, the better it is for maintaining the availability of microorganisms in the soil (Verma et al. 2023). Holes are made in the soil to a depth of approximately 25-30 centimeters, and then the organic fertilizer is inserted into them. The depth of 25-30 cm is where the root growth process occurs. As in the study conducted by Anshori et al. (2022), rice cultivation is carried out on the topsoil at a depth of 20-30 centimeters.

Crops are not free from threats posed by pests that interfere with growth and productivity. Farmers utilize the availability of limestone resources as a pest deterrent (*Organisme Pengganggu Tanaman*, OPT). There are several ways in which compounds related to limestone, such as quicklime (*calcium oxide*) or slaked lime (*calcium hydroxide*), can play a role in pest control or as additives in organic farming practices. Limestone is used to raise the pH of acidic soils, creating an environment that is less ideal for the development of certain soil pathogens and pests (Oktafiansyah et al. 2020). Soils with a more balanced pH tend to support healthier plant growth and are more resistant to pest attacks (Sucofindo 2023). Some farmers also use lime to reduce moisture in crops or soil, which can help decrease the populations of certain insects that prefer humid conditions. Crushed limestone or processed limestone into agricultural lime can also improve soil structure, thereby reducing soil-dwelling insects like nematodes. Some farmers always bring their pet dogs to the fields to guard against attacks from porcupines or groups of monkeys, especially during the harvest season.

During the pre-planning phase, there is a traditional community activity called *Gesik Deso* a land clearing in preparation for planting. The entire community participates in this activity, including farmers, stakeholders, and the general public. Clearing the land of weeds and wild plants helps prevent competition with the main crops that will be planted (Grecia et al. 2022). Weeds can absorb nutrients, water, and light that should be used by cultivated plants, thereby reducing harvest yields (Satriyo and Husni 2019). By cleaning the land, it can be rearranged so that farmers can maximize the space for planting. Clean, flat soil facilitates orderly row arrangements of plants, making it easier to manage. For the community, the *Gesik Deso* activity also fosters a sense of cooperation. The community still uses traditional tools such as hoes to loosen the soil. Also, it uses machetes to clean grass, like research conducted by Sagrim (2022), which used traditional agricultural tools, machetes, sickles, and axes to clear bushes.

The designation of karst areas must refer to legislation in a holistic manner. Regulations are implemented with the aim of optimizing the sustainable utilization of karst for the continuity of human life (Osronita et al. 2023). Based on the Regional Regulation of Wonogiri District Number 2 of 2020 regarding the Regional Spatial Planning of Wonogiri District, the karst area in Paranggupito Sub-district is classified as a Geological Nature Reserve, where forestry, agriculture, fisheries, tourism, settlement, defense and security, research, and the construction of public facilities are permitted, provided that they do not change the function of the area and an environmental impact document is prepared for the Karst Landscape Area (*Kawasan Bentang Alam Karst,* KBAK). However, medium and large-scale industrial activities and mining are not permitted in this area. There are also policies regarding the raw water network for clean water optimization of groundwater resources in the form of Groundwater Basins (CAT) and groundwater within the karst. In addition, there is the development of Rainwater Harvesting (PAH) systems and Artificial Aquifer and Rainwater Storage Systems (ABSAH) in drought-prone areas. The community's high level of awareness and active participation in avoiding building structures in agricultural areas to preserve the environment is crucial. Although regulations regarding water networks are in place, the communities in Songbledeg, Ketos, and Paranggupito still need help accessing clean water during dry seasons. The residents of Songbledeg, Ketos, and Paranggupito continue to survive and manage their land using their traditional knowledge. Collaboration is key to addressing these challenges and ensuring the sustainable management of karst areas.

Discussion

The limited water conditions experienced in the villages of Songbledeg, Ketos, and Paranggupito pose risks of crop failure and hinder the economic development of the community. Unpredictable rainfall has resulted in crop failures in these villages. Groundwater in the karst areas is generally deep, leading to high exploitation costs. The water scarcity in karst areas can be addressed by expanding artificial rainwater harvesting areas to increase surface runoff coefficients and rainwater collection. In a study on karst areas in South and Southwest China, the use of water tanks for rainwater harvesting was proposed with a new design, namely by making the karst slope as a rainwater collection source and better supply service objectives to serve the local community better, increase crop production, and improve the ecology in the karst area (Jiang et al. 2019). The community could also develop concave water storage or small reservoirs to capture rainwater using geomembrane techniques (Qin et al. 2015). Further research is needed to identify potential sources of groundwater or underground rivers that can be channeled as irrigation water sources. Additionally, given the limited water conditions, farmers could switch from high-water-demand crops, such as rice (*O. sativa*), to low-water-demand crops, such as corn (*Z. mays*) or Fabaceae. It is also necessary to study the quality of rainwater the community uses for daily needs.

Farmers can also shift to cultivating crops that are less vulnerable to unpredictable rainfall, such as *Zingiber officinale* and *C. longa*, which can generate income (Putri et al. 2024). Another effective way to improve agricultural productivity is by covering rock outcrops with mulch film. This method can effectively increase groundwater content in karst agricultural land and enhance corn productivity by using film layers that cover the rocks, subsequently improving groundwater availability in the root zone (Zhao et al. 2024). Further research is still needed to focus on developing drought-resistant agricultural varieties. Another adaptation strategy is to provide financial assistance to communities for agricultural adaptation. This support is crucial for farmers to implement necessary changes and feel secure in the face of climate change. Finding alternative income sources (non-agricultural) is also important. There is a need for diversification in both agricultural and non-agricultural businesses so that the community has flexibility and economic resilience in the event of drought.

The settlement patterns in Songbledeg, Ketos, and Paranggupito villages are clustered. The clustered settlement pattern in the Wonogiri karst area results from community adaptation to challenging environmental conditions, such as limited air, difficult topography, and the need for infrastructure access and security. This pattern is supported by social traditions that encourage cooperation in everyday life. Land use in Songbledeg, Ketos, and Paranggupito villages is dominated by agriculture. Table 2 shows the plants found in the research area. The combination characteristics of Wonogiri's rocky karst soil and low rainfall are very suitable for plants with high adaptability and minimal maintenance requirements. With good management, these plants are not only suitable for planting but can also provide good economic results for local communities. Karst areas are suitable for livestock because the topography, vegetation, and environmental conditions support grazing and raising livestock. Utilizing this area for livestock also helps people optimize land resources other than for agriculture. Many people in karst areas with dry land choose to raise livestock because of limited environmental conditions for agricultural activities. Karst areas generally have thin, rocky, and less fertile soil, making it difficult to support intensive agriculture. Apart from that, low rainfall and limited water availability are the main obstacles to managing crops. Therefore, livestock farming is the main alternative as a source of livelihood because livestock such as goats, cows, or sheep are more adaptive to dry environments. These animals can take advantage of natural food available in nearby grasslands or bushes, which grow even in less fertile soil. Breeding livestock also has high economic value for society, both for daily needs and as an asset that is easy to buy and sell when needed.

In conclusion, the land utilization in the karst areas of Songbledeg, Ketos, and Paranggupito is divided into residential, agricultural, livestock, and plantation uses. The agricultural system implemented in these three villages is intercropping, where various types of crops are planted simultaneously to reduce the risk of crop failure and maximize land use. The crops cultivated during the rainy season include *O. sativa, O. rufipogon, Z. mays, M. esculenta,* and *I. batatas*. Planting begins with the use of seeds and planting holes that have been fertilized before the rainy season arrives. During the dry season, farmers utilize drought-resistant crops such as *A. hypogaea, C. frutescens, P. speciosa,* and *C. longa* to meet their daily needs. The community uses livestock manure for organic fertilizer and limestone to help suppress pests and participates in the *Gesik Deso* activity. Traditional agriculture practiced by communities can help preserve the environment and reduce land degradation.

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REFERENCES

Ambarwati A, Kusuma RA, Pratama YA, Astuti WP, Susilowati N. 2021. Maro system for sustainable agricultural land management in Tlawong Village. Solidarity 10 (2): 117-126. DOI: 10.15294/solidarity.v10i2.51905.

Anshori A, Pramono A, Mujiyo M. 2020. The stratification of organic carbon and nitrogen in top soils as affected by the management of organic and conventional rice cultivation. Caraka Tani J Sustain Agric 35: 126. DOI: 10.20961/carakatani.v35i1.34488.

Aprilia A, Nugroho CP, Mutisari R. 2019. Preference of rural youth livelihood in indonesia rural areas and its factors. Habitat 30 (3): 88-95. DOI: 10.21776/ub.habitat.2019.030.3.11.

Ardianti Y, Eprilianto DF. 2022. Partisipasi masyarakat dalam pengembangan Desa Wisata melalui pendekatan community based tourism (Studi pada Desa Tanjungan Kecamatan Kemlagi Kabupaten Mojokerto). Publika 1: 1269-1282. DOI: 10.26740/publika.v10n4.p1269-1282. [Indonesian]

Avrilan D, Siregar K, Suhendrayatna S. 2022. Level of desertification of karst ecosystems in Darul Imarah District, Aceh Besar Regency. J IPA Pembelajaran IPA 6: 70-85. DOI: 10.24815/jipi.v6i1.24044. [Indonesian]

Bakri W, Laupe S, Salam AMI. 2023. Mining karts area and social conditions of the community. Sociologia: J Relig Soc 3 (1): 139-150. DOI: 10.35905/sosiologia.

Balai Besar Wilayah Sungai Bengawan Solo. 20243. Data Hujan BulananHarian. Kementerian Pekerjaan Umum dan Perumahan Rakyat, Direktorat Jenderal Sumber Daya Air. https://hidrologi.bbws-bsolo.net/curahhujan/65 Access: January, 15 2025. [Indonesian]

Canedoli C, Ficetola GF, Corengia D, Tognini P, Ferrario A, Padoa-Schioppa E. 2022. Integrating landscape ecology and the assessment of ecosystem services in the study of karst areas. Landsc Ecol 37: 347-365. DOI: 10.1007/s10980-021-01351-2.

Carsologica A. 2005. Karst Science Reviews. Intl J 34: 85-89.

Chen L, Tan L, Zhao M. Sinha A, Wang T, Gao Y. 2023. Karst carbon sink processes and effects: A review. Quat Intl 652: 63-73. DOI: 10.1016/j.quaint.2023.02.009.

Fahlevi MR, Fitrah M. 2022. Management of natural resources or potential by creating a website and village profile video. Dinamisia: J Community Serv 6 (5): 1148-1154. DOI: 10.31849/dinamisia.v6i5.10380.

Fahrudin F, Kusnarta IGM, Iemaaniah ZM. 2023. Assistance in the implementation of semi-automatic drip irrigation in water use efficiency for chili farmers on rainfed land, Sukadana Village, Southern Central Lombok. J Siar Sci Farmers 4 (2): 250-257.

Grecia AM, Saraswati AD, Safitri B, Diza AN, Billah M. 2022. Socialization and training on organic coconut water herbicides in Mundusewu Village Farmer Groups. WORKS J Community Serv 2: 149-155.

Habibah N, Astika IW. 2020. Analisis sistem budi daya tanaman talas (*Colocasia esculenta* L.) di Kelurahan Bubulak, Bogor Barat, Jawa Barat. Jurnal Pusat Inovasi Masyarakat 2 (5): 771-781. [Indonesian]

He G, Zhao X, Yu M. 2021. Exploring the multiple disturbances of karst landscape in Guilin World Heritage Site, China. Catena 203: 105349. DOI: 10.1016/j.catena.2021.105349.

Hu Z, Wang S, Bai X, Luo G, Li Q, Wu L, Yang Y, Tian S, Li C, Deng Y. 2020. Changes in ecosystem service values in karst areas of China. Agric Ecosyst Environ 301: 1-16. DOI: 10.1016/j.agee.2020.107026.

Ibrahim MS, Amir NO, Suprapti PSD. 2023. Minat anak petani terhadap pekerjaan di sektor pertanian. Paradigma Agribisnis 6 (1): 10-20. DOI: 10.33603/jpa.v6i1.8762.

Jailani A, Prayuginingsih H, Fauzi NF. 2023. The influence of motivation and job satisfaction on: Performance of rice farmers in Jember regency. Agri Anal J 1 (2): 29-36. DOI: 10.47134/agri.v1i2.2020.

Jiang G, Guo F, Lo KFA, Liu F, Guo Y, Wu W, Polk JS. 2019. Utilization status of rainwater harvesting and its improvement techniques in bare karst areas for domestic use and ecological restoration. Carbonates Evaporites 34: 1381-1390. DOI: 10.1007/s13146-018-0459-5.

Jumadi J, Danardono D, Fikriyah VN, TS MITMI, Sari DN. 2022. Pemetaan potensi air tanah di Kecamatan Paranggupito, Kabupaten Wonogiri. In Prosiding Seminar Nasional Hasil Penelitian dan Pengabdian kepada Masyarakat 1 (1): 68-81. [Indonesian]

Khotimah YK, Supardi S, Antriyandarti E. 2019. Utilization of dry land agricultural resources in the karst mountains of Gunungkidul. In Proc Natl Seminar Faculty Agric UNS 3 (1): 50-57.

Kugbe JX, Wuni M, Alhassan MH, Maganoba C. 2019. Increase in the use of organic fertilizers as complements to inorganic fertilizers in maintenance of soil fertility and environmental sustainability. World J Agric Soil Sci 4 (1): 1-4. DOI: 10.33552/WJASS.2019.04.000577.

Kurniawan EA, Ramadani RN, Wijaksana IK. 2023. Study of alternative clean water provision through rainwater harvesting in the Citatah Industrial Area. J Mining Environ Innov 3 (1): 34-42.

Li A, Liu C, Chen J, Wang S. 2021. Karst ecosystem and environment: Characteristics, evolution processes, and sustainable development. Agric Ecosyst Environ 306 (1): 107173. DOI: 10.1016/j.agee.2020.107173.

Li SL, Liu CQ, Chen JA, Wang SJ. 2021. Karst ecosystem and environment: Characteristics, evolution processes, and sustainable development. Agric Ecosyst Environ 306: 1-4. DOI: 10.1016/j.agee.2020.107173.

Lv Y, Jiang Y, Hu W, Cao M, Mao Y. 2020. A review of the effects of tunnel excavation on the hydrology, ecology, and environment in karst areas: Current status, challenges, and perspectives. J Hydrol 586: 1-15. DOI: 10.1016/j.jhydrol.2020.124891.

Maula IM. 2023. Agricultural waste management: Utilization of goat manure as organic fertilizer. Action Res Lit 7: 70-76. DOI: 10.46799/arl.v7i1.183. [Indonesian]

Mulu M, Ngalu R, Lazar LF. 2020. Pola tanam tumpang sari di Desa Satar Punda Barat, Kabupaten Manggarai Timur, Provinsi Nusa Tenggara Timur. Agrokreatif: Jurnal Ilmiah Pengabdian Kepada Masyarakat 6 (1): 72-78. [Indonesian]

Noywuli N. 2023. Conservation approach in management of hill land for agricultural businesses. J Superior Agric 2 (1): 16-27.

Nugroho J, Zid M, Miarsyah M. 2020. Potential water sources and community wisdom in facing the risk of drought in karst areas (Gunung Kidul Regency, Yogyakarta Province). J Environ Sustain Manag 1: 438-447. DOI: 10.36813/jplb.4.1.438-447.

Nugroho NE, Paripurno ET. 2019. Karakter dan potensi risiko kerusakan ekosistem karst cekungan air tanah Watuputih Kabupaten Rembang, Provinsi Jawa Tengah. Jurnal Ilmiah Lingkungan Kebumian 2 (1): 34-45. DOI: 10.31315/jilk.v2i1.3288. [Indonesian]

Nurbaiti I, Nugraha S, Tjahjono GA. 2023. Pemanfaatan penampungan air hujan untuk pemenuhan kebutuhan air domestik di Desa Songbledeg Kecamatan Paranggupito Kabupaten Wonogiri Tahun 2021. Indones J Environ Disaster 2 (1): 48-56. DOI: 10.20961/ijed.v2i1.654. [Indonesian]

Oktafiani I, Sitohang MY, Saleh R. 2021. Sulitnya regenerasi petani pada kelompok generasi muda. Jurnal Studi Pemuda 10 (1): 1-17. DOI: 10.22146/studipemudaugm.62533. [Indonesian]

Oktafiansyah MAA, Lagowa MI, Tampubolon G. 2020. Kajian teknis dan ekonomis pengaruh jenis kapur dalam upaya pengelolaan Air Asam Tambang (AAT). JTK (Jurnal Teknik Kebumian) 5 (2): 29-36. DOI: 10.22437/jtk.v5i2.8158. [Indonesian]

Osronita O, Suryani N, Febrianto H, Fajri F. 2023. Geopark management planning analysis (Earth Park) Goa Batu Kapal, Sangir District, South Solok Regency. Jurnal Azimut 5 (2): 85-89.

Ouyang ZW, Song TQ, Peng WX, Du H, Zeng FP. 2011. Spatial heterogeneity of soil main mineral composition in manmade forest in karst peak-cluster depression region. J Hunan Agric Univ 37 (3): 325-328. DOI: 10.3724/SP.J.1238. 2011.00325.

Pamardhi-Utomo R. 2020. A strategy for the sustainable development of the karst area in Wonogiri. In IOP Conf Ser: Earth Environ Sci 447 (1): 1-9. DOI: 10.1088/1755-1315/447/1/012057.

Peng T, Deng H, Lin Y, Jin Z. 2021. Assessment on water resources carrying capacity in karst areas by using an innovative DPESBRM concept model and cloud model. Sci Total Environ 767: 1-15. DOI: 10.1016/j.scitotenv.2020.144353.

Peraturan Daerah Kabupaten Wonogiri Nomor 2 Tahun 2020 mengenai Rencana Tata Ruang Wilayah Kabupaten Wonogiri. [Indonesian]

Pranata MFY, Antriyandarti E, Barokah U. 2023. Analisis pola tanam beras merah di pegunungan karst Kabupaten Gunungkidul. In Prosiding Seminar Nasional Fakultas Pertanian UNS 7 (1): 390-400. [Indonesian]

Pratama AD, Dwiputra DS, Nurkholis A, Haryono E, Cahyadi A, Agniy RF, Adji TN. 2021. Factors affecting hydrochemistry of karst springs and their relationship to aquifer development. Environ Process 8: 1379-1413. DOI: 10.1007/s40710-021-00547-7.

Pratiwi IM. 2021. Geokonservasi dalam fungsi perlindungan dan pemanfaatan ekosistem Karst Gunung Sewu. J Rekayasa Lingkungan 21: 33-40. DOI: 10.37412/jrl.v21i1.90. [Indonesian]

Prihatanto ZHNM, Rabbani TZ, Heriyanti AP, Fariz TR. 2022. Perbedaan karakteristik ekosistem karst Kecamatan Ponjong, Gunungkidul Dengan Ekosistem Karst Pracimontoro, Wonogiri. In Proceeding Seminar Nasional IPA 142-149.

Putri WEC, Zamroni A, Asih AS, Prasetya HNE, Sagala ST, Almadrones-Reyes KJ. 2024. Drought disaster causes and their proposed adaptation strategies around karst areas in Gunungkidul Regency, Indonesia: A review. Geosfera Indonesia 9 (2): 248-264. DOI: 10.19184/geosi.v9i2.46536.

Qin L, Bai X, Wang S, Zhou D, Li Y, Peng T, Tian Y, Luo G. 2015. Major problems and solutions on surface water resource utilisation in karst mountainous areas. Agric Water Manag 159: 55-65. DOI: 10.1016/j.agwat.2015.05.024.

Sagrim M. 2022. Traditional knowledge of land management in Maybrat District, West Papua Province, Indonesia: Implication for agriculture development. Biodiversitas 23 (8): 4144-4151. DOI: 10.13057/biodiv/d230836.

Satria J, Falatehan AF, Beik IS. 2018. Strategy for protecting sustainable food agricultural land in Bogor Regency. J Reg Dev Manag 10 (2): 48-59. DOI: 10.29244/jurnal_mpd.v10i2.27786.

Satriyo WD, Husni TS. 2019. Pengaruh jarak tanam dan waktu penyiangan terhadap pertumbuhan gulma pada tanaman kedelai (*Glycine max* (L.) Merril). J Produksi Tanam 7: 1538-1546. [Indonesian]

Siegel L, Goldscheider N, Petitta M, Xanke J, Andreo B, Bakalowicz M, Barberá JA, Bouhlila R, Burg A, Doummar J, Ezzine I, Stevanović Z. 2023. Distribution, threats and protection of selected karst groundwater-dependent ecosystems in the Mediterranean region. Hydrogeol J 31 (8): 2231-2249. DOI: 10.1007/s10040-023-02711-9.

Soedwiwahjono, Utomo RP. 2020. A strategy for the sustainable development of the karst area in Wonogiri. IOP Conf Ser: Earth Environ Sci 447: 1-9. DOI: 10.1088/1755-1315/447/1/012057.

Sophan M, Agustar A, Erwin E. 2022. Faktor-faktor yang mempengaruhi minat generasi muda terhadap sektor pertanian sebagai lapangan pekerjaan di wilayah pedesaan Kabupaten Solok. Jurnal Riset Tindakan Indonesia 7 (3): 326. DOI: 10.29210/30031858000. [Indonesian]

Sucofindo. 2023. Types and Indicators of Soil pH Indicating Fertility. Sucofindo. https://www.sucofindo.co.id/artikel-1/jenis-indikator-ph-tanah-menunjukkan-kesuburan/. [Indonesian]

Verma RC, Singh NK, Gangavati AR, Ashoka P, Kesarwani A, Ali I, Pandey SK. 2023. A review of long-term effects of mineral fertilizers on soil microorganisms. Intl J Plant Soil Sci 35 (20): 1145-55. DOI: 10.9734/ijpss/2023/v35i203912.

White WB. 2020. Rate processes: Chemical kinetics and karst landform development. In Groundwater as a geomorphic agent (pp. 227-248). Routledge.

Wijayanti P, Noviani R. 2020. Disaster threats in the Gunungsewu Karst area and mitigation efforts in the framework of disaster risk reduction review of the hydrological and geomorphological aspects. In Social, Humanities, and Educational Studies (SHEs): Conference Series 3 (1): 285-291. DOI: 10.20961/shes.v3i1.45067.

Wijayanto HW, Anantayu, S, Wibowo A. 2021. Behavior in managing agricultural land in the upstream watershed conservation area (DAS) of Karanganyar Regency. Agri Humanis: J Agric Human Resour Dev Stud 2 (1): 25-34. DOI: 10.46575/agrihumanis.v2i1.96.

Wu LH, Wang SJ, Bai XY, Tian YC, Zeng C, Luo GJ, He SY. 2017. Quantitative assessment of the impacts of climate change and human activities on runoff changes in a typical Karst watershed, SW China. Sci Total Environ 601-202 (1): 1449-1465. DOI: 10.1016/j.scitotenv.2017.05.288.

Xiong KN, Chi YK. 2015. The problems in Southern China karst ecosystem in Southern of China and its countermeasures. Ecol Econ 31 (1): 23-30.

Zeng C, Wang S, Bai X, Li Y, Tian CY, Li Y, Wu L, Luo JG. 2017. Soil erosion evolution and spatial correlation analysis in a typical karst geomorphology, using RUSLE with GIS. Solid Earth 8 (4): 721-736. DOI: 10.5194/se-8-721- 2017.

Zhang S, Luo Y, Xiong K, Yu Y, He C, Zhang S, Wang Z. 2024. Research progress on ecological carrying capacity and ecological security, and its inspiration on the forest ecosystem in the karst desertification control. Forests 15 (9): 1632. DOI: 10.3390/f15091632.

Zhao Z, Deng J, Zhang J, Shen Y. 2024. Effects of film-mulched rock outcrops on rainwater redistribution and maize growth in the cropland of a rocky karst area. Water 16 (2): 254. DOI: 10.3390/w16020254.

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Local knowledge of environmental management of karst area in Ketro Village, Pacitan District, East Java, Indonesia

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Abstract. *Ramadhani DD, Setyaputri AF, Almadani AR, Sholichah DM, Dianti, Hanum U, Setyawan AD. 2025. Local knowledge of environmental management of karst area in Ketro Village, Pacitan District, East Java, Indonesia. Intl J Trop Drylands 9: 10-19.* Karst areas are unique and complex landscapes formed by the natural dissolution of limestone, creating unique environmental conditions, and are home to the karst area in Ketro Village, Pacitan District, East Java, Indonesia. This area, with its high ecological and aesthetic values, including biodiversity and ecotourism potential. However, behind the beauty is a close relationship between the local community and the karst environment that has developed over many years. This study aims to determine the knowledge of the karst area community of Ketro Village, Kebonagung Sub-district, Pacitan District, East Java Province, Indonesia, on environmental management in accordance with the traditions prevailing in the community for generations. This research was conducted using survey and interview methods in Ketro Village community related to karst area management in Ketro Village using purposive sampling techniques in determining respondents. Based on the results of the data analysis obtained, this research shows that the management of karst areas in Ketro Village still uses hereditary habits, and the community has the principle that every house has empty land for planting crops.

Keywords: Community, environment, karst, local knowledge, tradition

INTRODUCTION

Indonesia is a nation that is rich in natural resources, islands, population, customs, languages, tribes, cultures, and traditions (Hidayah 2020). The national motto of *Bhinneka Tunggal Ika*, which translates to Unity in Diversity, has been the driving force behind Indonesia's ongoing expansion of diversity for centuries. The archipelago in which the people of Indonesia currently reside was primarily inherited by their forebears (Sulistiyono and Amaruli 2023). The legacy can take the form of rules and management that are passed down through generations, often accompanied by religious beliefs and belief systems. For instance, land can be cleared by cutting or burning without causing harm to the surrounding environment (Murhaini and Achmadi 2021). Diversity also influences the numerous natural products that God has bestowed upon humanity. Therefore, it is a human responsibility to safeguard and prevent their destruction, as this is a form of preservation that ensures the persistence of nature in human civilization (Noviana et al. 2023). It is our collective responsibility to preserve this diversity, ensuring its continuation for future generations.

The vast territory of Indonesia supports a large population of communities, which can provide an adequate supply of natural resources to sustain life. The continuity of indigenous knowledge with extant knowledge systems can further contribute to environmental management practices (Jarvis et al. 2021). Communities' significance in the preservation of sustainable natural resources has been acknowledged globally (Garnett et al. 2018). Natural resources that are currently in existence are gifts from God that should be preserved and maintained to ensure that their benefits can be experienced sustainably (Alfiani 2022). One such resource is in the karst area. The karst area is a geologically formed rock area that is the result of the dissolution of limestone or carbonate minerals by rainwater or groundwater (Zerga 2024). Karst regions offer numerous advantages, such as the capacity to retain pure water in their holes (Kaiser et al. 2023), the potential for mining due to the presence of minerals that can be extracted to produce gypsum, lime, and marble, and the presence of a high level of biodiversity (Fatinaware et al. 2019). The community's pressing requirements frequently supplant efforts to preserve karst areas, resulting in the exploitation of these areas without regard for the conservation and protection functions they contain (Siegel et al. 2023).

In this era of accelerated globalization, numerous challenges arise, particularly in the management of the environment (Jie et al. 2023). These changes are precipitated by population growth, accelerated development, and heightened community requirements (Khan et al. 2021). The changes that occur should be utilized to enhance the prosperity and accessibility of the community; however, a significant number of individuals intentionally exploit and cause environmental damage. Mining is a common form of exploitation in karst areas, where the limestone content is extracted in large quantities as a basic material for cement production. The disintegration of karst boulders is a consequence of the vibrations that mining produces (Wei et al. 2023). The rate of degradation of natural resources will be influenced by the decline in environmental quality, which will disrupt the equilibrium that has been established by society to coexist with nature. The water system within karst areas can be impacted by the exploitation of these areas, such as a decrease in water quantity and groundwater pollution (Fang and Fu 2011). Local knowledge is, of course, based on a long history ranging from land tenure to natural resource management (Yanou et al. 2023). Local knowledge in each region is different, including in preserving the environment, this is because each region has a different topography. Ketro Village is one of the villages in Pacitan that has a karst area, and this village also has its own natural resources that integrated management is needed to protect it. This research was conducted to find out the local knowledge of the Ketro Village community in preserving the environment. This research aims to find out how the community manages the environment in accordance with local traditions or knowledge.

MATERIALS AND METHODS

Study area

Research on community knowledge in managing the karst area environment according to prevailing customs was conducted at the end of 2023 in Ketro Village, Kebonagung Sub-district, Pacitan District, East Java, Indonesia, with coordinates 8°10′3.432″S, 111°11′54.42″E which is pictured in Figure 1. Ketro Village is limestone mountains stretching to the north and is directly adjacent to clay hilly land with a landslide character because it has a fairly steep slope. Ketro Village has an abiotic environment consisting of fertile soil and sufficient water sources, supporting agriculture and daily life. The biotic environment includes diverse local flora and fauna, including agricultural crops such as rice and corn, as well as livestock such as cows and goats. The culture of the people in this village is very thick with Javanese traditions and customs, with social and religious activities routinely carried out, reflecting the values of beneficial cooperation and togetherness. This village consists of 7 hamlets, namely Krajan, Wonojoyo, Njeruk, Nongko, Gawang, Klepu and Brengosan Hamlets. Ketro Village is a rural area that has an area that includes a plateau, around 800 meters above sea level. The administrative boundaries to the north are Kalikuning Village, the south Sanggrahan Village, the east Jatigunung Village, and the west Ketepung Village.

Data collection

The data collection methods used were observation, interview, and documentation. The three methods are used because they can produce data that can be explained in detail, clearly, and comprehensively related to a phenomenon (Hazzan and Nutov 2014), in this case, community knowledge in managing the karst area environment in accordance with the prevailing traditions in Ketro Village, Kebonagung, Pacitan.

Field observation

Observation is carried out directly in the field by the author, an experienced researcher in the field of environmental studies, so that the author can directly observe the conditions and activities of the research area, which can help the author in comparing the data found with other methods. The conditions observed were related to the state of the biotic environment, and abiotic and community habits. This community habit will be deepened in the observation to find out how the Ketro Village community manages the environment. Documentation is needed in this observation activity because it can provide actual evidence in accordance with the conditions that occur in the field from the observations that have been made (Irawati et al. 2022).

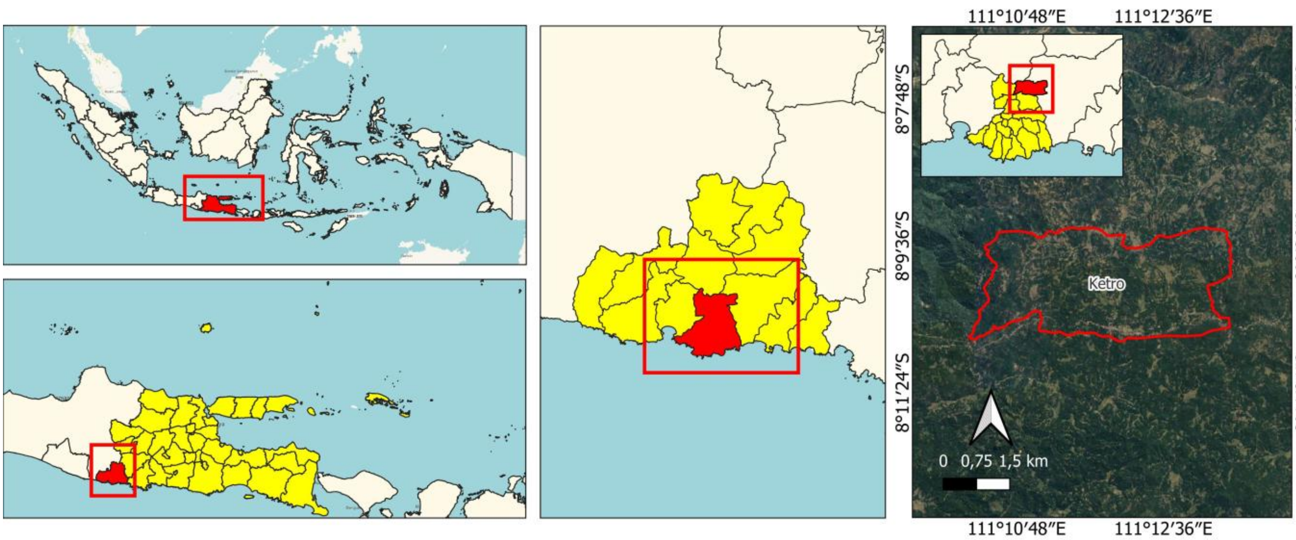

Figure 1. Location of Ketro Village, Kebonagung Sub-district, Pacitan District, East Java, Indonesia

Interview

Interview and questionnaire data collection methods are carried out personally to several respondents who are randomly selected (purposive sampling) according to certain considerations (Hossan et al. 2023). This interview was aimed at the Ketro Village community to find out the community's knowledge related to karst environmental management. The category of respondents is based on the age group where they have participated in the process of managing the karst environment. Some of the questions that will be asked during interviews and questionnaires include agricultural cultivation and irrigation, construction and maintenance of water systems, nature conservation actions, views on nature and the universe, transmission of local customs, responsibility for environmental protection, collective moral obligations, community self-organization, and leadership roles.

Data analysis

This research is descriptive qualitative research, which is research whose process will be studied in detail and presented descriptively based on primary data that has been collected previously. Primary data in this study are data obtained from observations, interviews, questionnaires, and documentation. According to Sugiyono (2016), the credibility test that primary data can verify is the triangulation method, where information testing is carried out continuously until the data is saturated. The data that has been collected is processed and presented in a table which includes respondent data and respondents' assessment of their knowledge of the environmental tradition of karst areas in Ketro Village, Kebonagung, Pacitan.

Respondent data in Table 1 shows that the assessment data from respondents were processed using valid and reliable instruments to obtain reliable research results. Valid in the sense that the instrument can be used to measure what should be measured and reliable in the sense that if the instrument is used several times to measure the same object, it will produce the same data (Yusup 2018). Validity and reliability tests are instruments for processing assessment data using the help of the SPSS computer program. The list of questions asked for the interview has been tested through SPSS. The answers to each question are accumulated to determine the average answer means "Good category," "Excellent category," or "Moderate category."

RESULTS AND DISCUSSION

Based on observations, karst environmental management in Ketro Village, Kebonagung, Pacitan, is still strongly influenced by local customs that emphasize nature conservation and ecosystem balance. The people of this village practice various traditions aimed at preserving natural resources, such as river clean-up events that honor springs and karst caves. In addition, they also implement environmentally friendly and sustainable farming systems, and protect forests and karst lands from overexploitation. This approach not only preserves the environment but also maintains cultural values and local wisdom that have been passed down for generations. The following Table 1 shows the results of respondents' interview answers in Ketro village.

Agricultural cultivation and irrigation

The majority of responses show that 40 residents chose the good category regarding special rules or procedures for cultivating agricultural commodities. This is because the current agricultural cultivation has been able to adapt to current conditions. Starting from the planting process, irrigation, maintenance, to harvesting. This is because the sediment in this area is different from other areas. The soil in this area is not fertile for certain agricultural commodities due to its karst soil structure, so it requires special treatment (Khusna et al. 2020). The crops they grow are not subject to specific rules, as indicated by the interview results. However, they demonstrate a keen understanding of local conditions by modifying the types of crops planted based on the season, with different crops for the rainy and dry seasons. The crops observed during the observations are depicted in Figure 3, particularly rice, as data collection was conducted during the rainy season. Meanwhile, the producers planted maize and beans during the dry season. Observations also showed that not all of their usual crops were grown during this period, as observations were made during the rainy season.

Table 1. Frequency of gender, age, education level and work

Parameters	Specifications	Frequency
Gender	Male	22
	Female	38
Age	16-25	1
	26-35	9
	36-45	18
	56-65	26
	>66	6
Education level	Not attending school	9
	Elementary School	34
	Junior High School	10
	Senior High School	7
Work	Farmer	33
	Housewife	19
	Trader	8

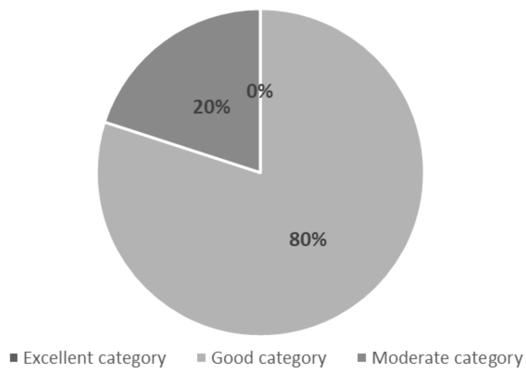

Figure 2. Category of irrigation system condition

Figure 3. Agricultural cultivation

Figure 4. Irrigation system

Based on the results of the questionnaire distribution regarding the irrigation system that irrigates farms in Ketro Village as shown in Figure 2, the good category has the highest number of 48 responses. Existing agricultural cultivation in Ketro Village is represented in Figure 3. The irrigation system used in the research location is illustrated in Figure 4. The community stated that the irrigation system that irrigates their rice fields has never experienced problems. In addition, the village has never experienced drought. The equitable water distribution system means that there are no disputes between residents over irrigation water. This finding was obtained from interviews conducted with the community. The water used to irrigate crops is sourced from a very deep spring, and residents report that the depth of the water is even unlimited. This information is based on observation. Water is delivered through additional pipes.

According to the results of the community dominance questionnaire, 30 residents considered the decrease in crop yields to be adequate compared to the previous year. The community did not experience a decrease in yields, as they believed that their yields remained consistent. This is because the land area used has not increased or decreased, resulting in the same yield. Interview results support this statement. Observations showed that none of the crops in the farming areas or fields were affected by disease, drought, or rot as a result of excessive water. As a result, there was no indication of potential causes of crop failure that could result in lower yields. This underscores the crucial role of stable water, normal rainfall, and appropriate soil content in maintaining healthy crop yields. In agriculture, these factors are of paramount importance (Harbowo and Muliawati 2023).

Construction and maintenance of dams and canal systems

As shown in Figure 5, 49 residents answered good category to the questionnaire regarding the existence of dams, waterways, and maintenance systems. Based on interviews conducted, Ketro Village has an irrigation system that comes from springs but not in the form of a dam. Water from these springs is distributed through a maintenance and distribution system to ensure farmland and fields have access to water. The socio-economic life of the community is heavily influenced by the extant dam (Milanovic 2021). Residents reported that the irrigation process from the dam to the community is not hampered by any problems, as indicated by the interviews. The community guards the spring area with an iron fence to ensure its safety, and the area around the water source is vegetated. There are no buildings or sources of pollution. This is evident from the observations. It should be noted that dams must follow specific standards for maintenance as karst areas have different geological structures, groundwater, intensity, and depth compared to non-karst areas (Milanovic 2021).

As shown in Figure 6, 38 residents answered good category on the questionnaire regarding the relationship between dams or water canals and the preservation of existing karst ecosystems, which was the dominant answer. The people of Ketro Village believe that the current water system provides benefits to the community and does not interfere too much with nature, as shown by the interview results. According to observations, the Karst environment that dominates the land of Ketro Village is also partly utilized as agricultural land or fields. Therefore, the sustainability of the karst ecosystem is indirectly influenced by the presence of dams or waterways that serve as a source of water for these crops. The availability of water sources in Ketro Village can be seen in Figures 7 and 8.

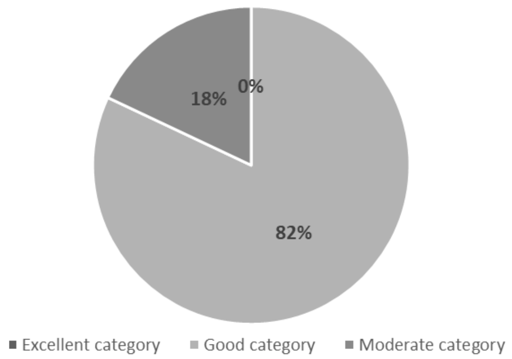

Figure 5. Category of dam, waterways, and maintenance system conditions

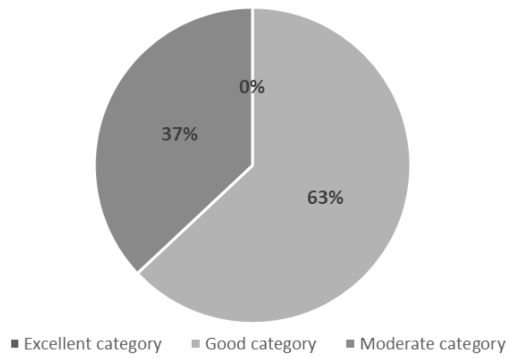

Figure 6. Category of relationship between dam's preservation of existing karst ecosystems

Figure 7. Spring water flow in Ketro Village, Kebonagung, Pacitan, East Java, Indonesia

Figure 8. Spring water source Ketro Village, Kebonagung, Pacitan, East Java, Indonesia

Local knowledge of karst environment and conservation actions as responsibility for environmental protection, collective moral obligation

The dominance of responses from Ketro villagers regarding nature conservation actions is evident from the interviews conducted, the results of the questionnaire regarding nature conservation actions and views on nature and the universe, and the fact that 53 people strongly agreed with the need for nature conservation activities (Figure 9.A). The study revealed that 56 people strongly agreed with the question of interdependence between humans and nature. In comparison, 50 people responded positively to the concept of spirituality or local beliefs, indicating that people's views on the elderly are interconnected (Figure 9.B). The moderate category relates to community activities that disturb the karst ecosystem, and 28 individuals have dominated the responsibility to protect the environment, as shown by the questionnaire results (Figure 9.C). In addition, 52 residents chose the excellent category for questions regarding environmental protection efforts that are the collective responsibility of residents (Figure 9.D).

Based on the results of the collective moral obligation questionnaire, 46 residents (Figure 9.D) dominated the good category for the question regarding the collective role of ensuring that individuals who utilize shared natural resources, such as karst or forest products, operate responsibly, especially in terms of environmental sustainability. The good category in relation to questions about collective activities undertaken by communities or organizations that can prevent environmental damage caused by human activities dominated the answers of 50 residents (Figure 9.D). We combined these three principles because of the significant link between community answers and observations. Communities often conduct village clean-up activities to maintain sanitation in order to protect the environment, as shown by the interview results. In addition, the government and community conduct reforestation initiatives to maintain the existing environment. The resources and services of an ecosystem are not separate entities but are intricately interconnected (Goldscheider 2019). The community believes that nature has fulfilled the needs of the community, so the community is obliged to maintain its sustainability. The actions of the Ketro Village community are structured and not tied to a specific period. In particular, they were established at the request of the local neighborhood chairman. Although some minerals in this area are extracted and utilized as building materials by individuals from outside the area, the sustainability of the extant karst ecosystem is not greatly affected by these activities, as they do not occur on an ongoing basis.

Based on the results of interviews and field observations, Ketro Village has no pattern of natural resource utilization that can lead to exploitation or utilization activities that can damage the environment. Therefore, until now there has been no collective community activity in the form of preventing environmental damage caused by human activities that utilize natural resources such as karst and forest products. The Ketro Village community only utilizes natural resources as necessary to meet their needs and does not overexploit them. As a result of this pattern of behavior, the karst area and its natural resources are preserved, and no efforts are made to prevent environmental damage caused by human activities (Taheri and Groves 2023). This pattern of behavior has been inherited since ancient times, and Ketro Village community continues to instill the principle of utilizing nature only to the extent necessary to support their daily needs. The environment of Ketro Village is still well maintained, as evidenced by our observations. The streets are free of garbage, and the surrounding area is dotted with verdant green vegetation. This research was conducted when community service activities were not taking place, but the results of these activities can be seen in the clean and trash-free appearance of Ketro Village (Figures 10 and 11).

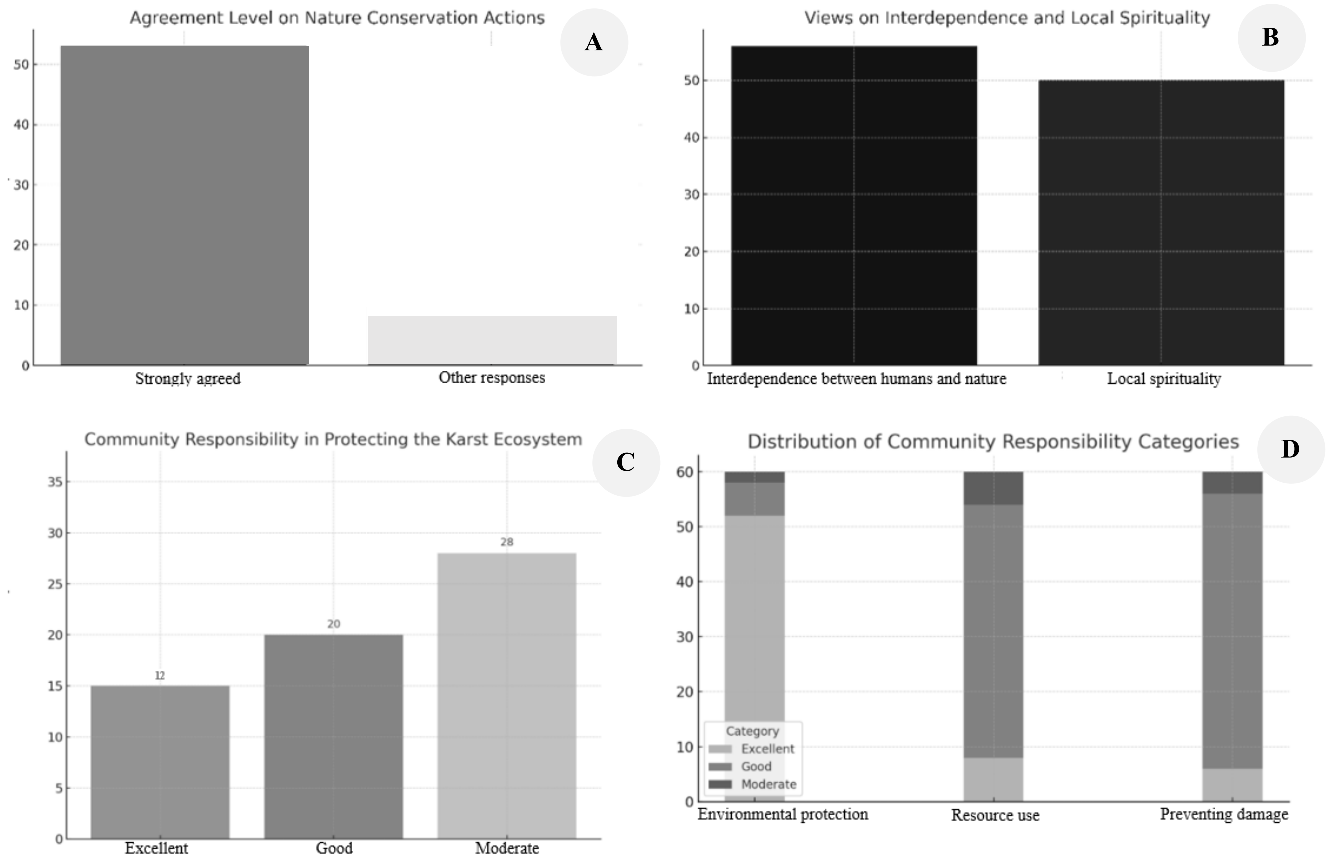

Figure 9. Local knowledge of karst environment and conservation actions as responsibility for environmental protection, collective moral obligation. A. Nature conservation activities; B. Interdependence between humans and nature and spirituality or local beliefs; C. Responsibility to protect the karst ecosystem; D. Community responsibility in environmental protection, resource use, preventing damage

Figure 10. Karst land is converted into rice field

Figure 11. The conversion of karst area into agricultural land

Transmission of local customs

The results of the questionnaire as shown in Figure 12, that 48 residents strongly support the preservation of local customs, 43 residents support the integration of other customs, and 34 residents support the existence of customs that have an impact on karst or forest ecosystems. Most individuals are unaware of the importance of local customs, as evidenced by interviews. However, several individuals stated that they had consistently utilized nature to meet their needs for a long time, ensuring that nature was not damaged or manipulated arbitrarily. These actions are sufficient to show that hereditary customs were established by previous societies, especially moderation and avoidance of excessive use of natural products. The community continues to carry out various social activities that have been considered mandatory, including "*arisan*" in Indonesian, which means activities carried out together in groups to raise funds and socialize with neighbors, village cleaning, and other activities designed to commemorate certain days, such as Independence Day. According to the community, the customs in Ketro Village are not affected by the customs that were introduced, thus ensuring that the existing customs continue to function effectively. Because the prevailing customs provide benefits to the community and the current ecosystem, these customs continue to run well (Riyanto et al. 2020). The condition of the area in Ketro Village can be seen from the results of the interview; not a single area was monitored to be exploited. As a result, it is clear that the community is moderate in utilizing it.

Community self-organization

The existence of youth organizations and similar entities in Ketro Village was answered favorably by 51 residents, as indicated by the questionnaires that were disseminate as shown in Figure 13. The organizations that are present in the Ketro Village community are largely comparable to those that are present in other areas of Indonesia. The village is home to successful organizations, including *Karang Taruna* and *Rukun Warga*. *Karang Taruna* is a self-organization formed to build community harmony managed by young people, while *Rukun Warga* was formed to mobilize self-help and community participation in the area. Self-organization is a critical factor in encouraging villagers to protect the environment for the benefit of all (Li and Han 2022). As shown in Figure 14 the questionnaire results about conditions of effectiveness of the existence of self-organization indicated that 49 residents were awarded the youth association's work program in the field of environmental management, including community service and high marks. The organization's current labor program is also functioning effectively. *Karang Taruna* participates in village clean-up initiatives, serves as a committee member for Independence Day celebrations, and participates in other activities in Ketro Village. The community is more socially active and independent in daily life as a result of the presence of a youth organization. This is directly correlated with the observations that were made, which indicate that the current youth organization is still functioning effectively.

Leadership role

As shown in Figure 15 the questionnaire results regarding the labor program supplied by the hamlet head consistently demonstrated that 42 residents deemed it satisfactory. The role of leadership influences the extant communal activities. The existing community will also implement various existing provisions as appropriate if the leadership is executed correctly. Then, 36 residents indicated that the lack of communication between residents and hamlet heads regarding community activities was sufficiently addressed as shown in Figure 16. This indicates that the community and the existing leadership are effectively communicating. The work program that has been developed is also classified as good, which indicates that the current leadership in the community is good and acceptable to the community (Li and Han 2022). The findings of the observations indicate that the leadership in Ketro Village is functioning effectively. This is evidenced by the successful completion of various activities, such as the clean-up of the villages, a testament to the community's collective efforts and effective leadership, which is evident in the absence of litter near the village.

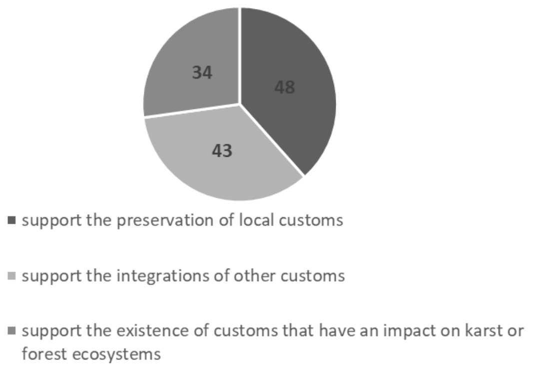

Figure 12. Graph of transmission of local customs

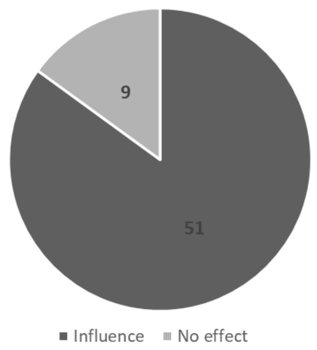

Figure 13. Residents perspectives on the existence of self-organization

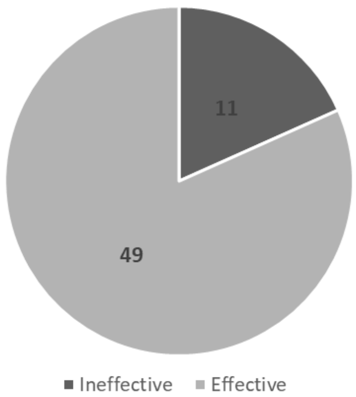

Figure 14. The conditions of effectiveness of the existence of self-organization

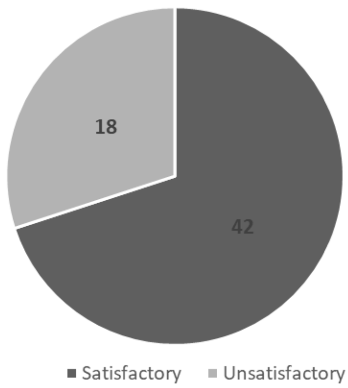

Figure 15. Assessment of work programs by residents

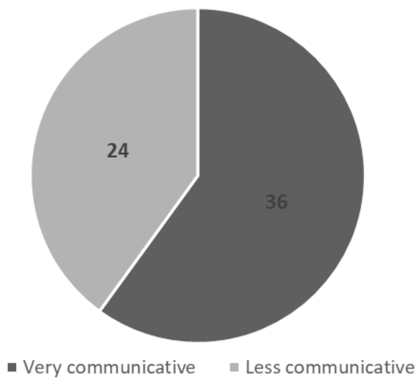

Figure 16. Residents views on communication in self-organization

Discussion

The karst area is characterized by limestone, which is readily soluble and has both surface and underground components. Consequently, numerous underground caverns are formed as a result of cracks and fissures. The soil in karst areas is less fertile as a result of the dissolution of minerals, as per Sudarmadji et al. (2013). Karst is characterized by land that is less fertile for agriculture, susceptible to erosion and landslides, and susceptible and has limited aeration pores, which are small openings in the soil that allow air to penetrate and reach plant roots. Limestone mining is one of the ways in which karst land can be utilized, as limestone is a basic material for cement (Indriyani et al. 2023). Karst land use that unintentionally alters the karst environment can diminish the quality of the environment, which will impact the rate of damage to natural resources. This disruption will disrupt the harmony of the environment that the previous community has established in order to coexist with nature (Wibowo et al. 2022). The natural conditions in Ketro Village, which is primarily a karst area, have resulted in the majority of the population becoming cultivators. They plant crops based on the season, ensuring that the varieties of plants planted during the rainy and dry seasons are distinct. *Cocos nucifera* is typically planted during the dry season; however, it is crucial to appropriately fertilize and irrigate karst soils due to their low nutrient content and reduced fertility (Djaenudin et al. 2002). As a result of the fact that a portion of the population in Ketro Village is employed as farmers, they are exceedingly reliant on the irrigation system. This is due to the fact that the karst area is notoriously challenging to access, necessitating the irrigation of plants from extremely deep springs. According to residents, the water's depth is not even that deep (Pramudita et al. 2023). In order to irrigate agricultural land and fields, the water is circulated through additional pipelines.

The residents of Ketro maintain an environmental tradition that includes refraining from the heedless cutting of trees, the burning of agricultural land, and the regular execution of village cleansing activities. The manner in which land users cleanse land is a factor in the level of soil fertility, as per Panda et al. (2018). The reforestation activities of the government and the residents of Ketro Village are also contributing to environmental conservation efforts. Using shrubs as nurse plants is one method of greening agricultural land (Castro et al. 2004). They are of the opinion that the essentials of existence are provided by nature, and as such, society is obligated to ensure its preservation. The local citizen leadership directed the organization of these actions, which were not associated with a specific period. While some of the stones in this area are extracted and utilized as building materials both within and outside the region, the impact on the karst ecosystem is not particularly substantial due to the fact that the extraction is not conducted sustainably. Currently, communities are working together to prevent environmental harm that is a result of the excessive use of natural resources, including karst and forest products. This is due to the fact that Ketro Village has not encountered a pattern of exploitation or utilization of natural resources that could potentially harm the environment. Individuals utilize natural resources exclusively in accordance with their requirements, avoiding exploitation or excess. This stance has ensured the preservation of natural resources and karst areas, necessitating no preventive measures to mitigate environmental damage caused by human activities. This practice has been handed down through generations as a means of utilizing nature for the necessities of daily life, and the inhabitants of Ketro Village continue to adhere to these principles. Martini and Tisngati (2017) also researched the conservation of local culture in Pacitan District. The community's confidence in its cultural values and their consistent application to ensure its safety and prosperity is a source of security about the sustainability of Ketro's practices.

The inhabitants of Ketro Village continue to observe numerous customs and traditions, including the implementation of policies that prioritize the prudent use of natural resources, the preservation of equilibrium, and the prevention of arbitrary treatment of the environment. These actions are indicative of a hereditary cultural heritage, in which the values promote the efficient utilization of natural resources without generating pollution. These events are often held to commemorate important events, such as Independence Day. Even though there are external customs that have infiltrated Ketro Village, they do not alter the existing customs of the community. Consequently, traditional customs persist without being influenced by external customs.

In conclusion, the people of Ketro Village who work as farmers have a straight view regarding the use of karst land for agricultural land where land conversion does not have a negative impact on the karst environment. Environmental management based on customs passed down from generation to generation is still maintained, such as river cleaning activities or cleaning water sources in the form of springs with the help of the management of the Regional Drinking Water Company, or known as PDAM, for distribution to residents around Ketro Village. In addition, in Ketro Village, development has not been massive. The community has the principle of leaving empty land to be planted with agricultural crops, such as secondary crops, in each house. This activity has become a tradition passed down from generation to generation for the people of Ketro Kebonagung Village, Pacitan, so it can be interpreted that the people have knowledge regarding environmental management in karst areas in accordance with applicable customs.

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REFERENCES

Alfiani LO. 2022. Upaya pelestarian kekayaan alam Indonesia berlandaskan nilai-nilai Pancasila. Jurnal Pancasila dan Bela Negara 2 (2): 41-50. DOI: 10.31315/jpbn.v2i2.6417. [Indonesian]

Castro J, Zamora R, Hódar JA, Gómez JM, Gómez-Aparicio L. 2004. Benefit of using shrubs as nurse plants for reforestation in Mediterranean Mountains: A 4-year study. Restor Ecol 12 (3): 352-352. DOI: 10.1111/j.1061-2971.2004.0316.x.

Djaenudin D, Sulaeman Y, Abdurachman A. 2002. Pendekatan pewilayahan komoditas pertanian menurut pedo-agroklimat di kawasan timur Indonesia. Jurnal Litbang Pertanian 21 (1): 1-10. [Indonesian]

Fang X, Fu Y. 2011. Impact of coal mining on karst water system in North China. Procedia Earth Planet Sci 3: 293-302. DOI: 10.1016/j.proeps.2011.09.097.

Fatinaware A, Fauzi A, Hadi S. 2019. Kebijakan pengelolaan ruang dan keberlanjutan kawasan karst Maros Pangkep Provinsi Sulawesi Selatan. J Agric Resour Environ Econ 2 (1): 26-37. DOI: 10.29244/jaree.v2i1.25934. [Indonesian]

Garnett ST, Burgess ND, Fa JE, Fernández-Llamazares Á, Molnár Z, Robinson CJ, Watson JEM, Zander KK, Austin B, Brondizio ES, Collier NF, Duncan T, Ellis E, Geyle H, Jackson MV, Jonas H, Malmer P, McGowan B, Sivongxay A, Leiper I. 2018. A spatial overview of the global importance of indigenous lands for conservation. Nat Sustain 1: 369-374. DOI: 10.1038/s41893-018-0100-6.

Goldscheider N. 2019. A holistic approach to groundwater protection and ecosystem services in karst terrains. Carbonates Evaporites 34: 1241-1249. DOI: 10.1007/s13146-019-00492-5.

Harbowo DG, Muliawati T. 2023. A decade drought monitoring through enhanced and standardized vegetation index in isolated karst environment: Nusa Penida Island, Bali, Indonesia. IOP Conf Ser: Earth Environ Sci 1287 (1): 012033. DOI: 10.1088/1755-1315/1287/1/012033.

Hazzan O, Nutov L. 2014. Teaching and learning qualitative research≈ Conducting qualitative research. Qual Rep 19 (24): 1-29. DOI: 10.46743/2160-3715/2014.1218.

Hidayah Z. 2020. A Guide to Tribes in Indonesia: Anthropological Insights from the Archipelago. Springer, Singapore. DOI: 10.1007/978-981-15-1835-5.

Hossan D, Mansor ZD, Jaharuddin NS. 2023. Research population and sampling in quantitative study. Intl J Bus Technopreneurship 13 (3): 209-222. DOI: 10.58915/ijbt.v13i3.263.

Indriyani S, Aurina DM, Ramadhan MF, Rachmalia F, Fauziyyah MD, Faturrahman AD, Nazar IA, Septiasari A, Naim DMD, Setyawan AD. 2023. The potential utilization of non-timber vascular plants in the karst area of Ayah Village, Kebumen District, Central Java, Indonesia. Intl J Trop Drylands 7 (2): 51-61. DOI: 10.13057/tropdrylands/t070201.

Irawati N, Lestari HD, Kesuma WP. 2022. Upaya penguatan nilai kearifan lokal Desa Wisata Nglanggeran Gunung Kidul secara berkelanjutan. Kepariwisataan: Jurnal Ilmiah 16 (2): 81-91. DOI: 10.47256/kji.v16i2.158. [Indonesian]

Jarvis D, Stoeckl N, Larson S, Grainger D, Addison J, Larson A. 2021. the learning generated through indigenous natural resources management programs increases quality of life for indigenous people – Improving numerous contributors to wellbeing. Ecol Econ 180: 106899. DOI: 10.1016/j.ecolecon.2020.106899.

Jie H, Zaman S, Zaman Qu, Shah AH, Lou J. 2023. A pathway to a sustainable future: Investigating the contribution of technological innovations, clean energy, and women's empowerment in mitigating global environmental challenges. J Clean Prod 421: 138499. DOI: 10.1016/j.jclepro.2023.138499.

Kaiser RA, Polk JS, Taing L, Datta T. 2023. Antimicrobial resistance and karst groundwater systems: A policy gap analysis for addressing water quality and contaminants of emerging concern. Environ Sci Policy 148: 103544. DOI: 10.1016/j.envsci.2023.07.004.

Khan I, Hou F, Le HP. 2021. The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. Sci Total Environ 754: 142222. DOI: 10.1016/j.scitotenv.2020.142222.

Khusna NI, Amin S, Efrianinrum FY, Bashith A. 2020. The effect of using biopore on soil fertility in karst area, District of Besuki, Tulungagung Regency. IOP Conf Ser: Earth Environ Sci 485: 012066. DOI: 10.1088/1755-1315/485/1/012066.

Li J, Han F. 2022. Strong ethics and flexible actions, the properties of Traditional Ecological Knowledge (TEK), as key resources for socioecological resilience to the impacts of climate change: A case study of Baojiatun, Yunnan-Guizhou Plateau karst area, Southwest China. Ecol Soc 27 (4): 31. DOI: 10.5751/ES-13400-270431.

Martini SDR, Tisngati U. 2017. Kebudayaan Lokal Pacitan: Analisis Historis, Nilai-Nilai Dan Sikap Konservasi Masyarakat. In Seminar Nasional Hasil Penelitian Universitas Kanjuruhan Malang 5 (1). [Indonesian]

Milanovic P. 2021. Dams and reservoirs in karst? Keep away or accept the challenges. Hydrogeol J 29: 89-100. DOI: 10.1007/s10040-020-02273-0.

Murhaini S, Achmadi. 2021. The farming management of Dayak People's community based on local wisdom ecosystem In Kalimantan Indonesia. Heliyon 7 (12): e08578. DOI: 10.1016/j.heliyon.2021.e08578.

Noviana E, Faizah H, Mustafa MN, Elmustian, Hermandra, Kurniaman O, Rusandi MA, Situmorang DDB. 2023. Understanding' *Tunjuk Ajar Melayu Riau*': Integrating local knowledge into environmental conservation and disaster education. Heliyon 9 (9): e19989. DOI: 10.1016/j.heliyon.2023.e19989.

Panda D, Panda D, Padhan B, Biswas M. 2018. Growth and physiological response of lemongrass (*Cymbopogon citratus* (D.C.) Stapf.) under different levels of fly ash-amended soil. Intl J Phytoremediation 20 (6): 538-544. DOI: 10.1080/15226514.2017.1393394.

Pramudita DA, Armando MF, Rahmayani D, Afifah FN, Putri NRA, Hartanti AN, Safira RN, Mahajoeno E, Indrawan M, Nazar IA, Buot Jr IE, Setyawan AD. 2023. Species diversity, richness, and conservation status of Pteridophyta in the karst ecosystem of Donorejo Forest, Kaligesing, Purworejo, Indonesia. Intl J Trop Drylands 7 (1): 16-25. DOI: 10.13057/tropdrylands/t070103.

Riyanto IA, Pratama AR, Bachtiar H, Fauzi NA, Widyastuti M, Widyastuti AN, Rahmawati N. 2020. Local wisdom and karst spring management in Playen District, Gunungkidul Regency, Indonesia. Geographica: Sci Educ J 1 (2): 62-67. DOI: 10.31327/gsej.v1i2.1186.

Siegel L, Goldscheider N, Petitta M, Xanke J, Andreo B, Bakalowicz M, Barberá JA, Bouhlila R, Burg A, Doummar J, Ezzine I, Fernández-Ortega J, Ghanmi M, Jourde H, Marín AI, Mhimdi A, Pipan T, Ravbar N, Stevanović AM, Stevanović Z. 2023. Distribution, threats and protection of selected karst groundwaterdependent ecosystems in the Mediterranean region. Hydrogeology J 31 (8): 2231-2249. DOI: 10.1007/s10040-023-02711-9.

Sudarmadji, Haryono E, Adji TN, Widyastuti M, Harini R, Nurjani E, Cahyadi A, Nugraha H. 2013. Ekologi Lingkungan Kawasan Karst Indonesia: Menjaga Asa Kelestarian Kawasan Karst Indonesia. Deepublish, Yogyakarta. [Indonesian]

Sugiyono. 2016. Metode Penelitian Pendidikan Pendekatan Kuantitatif, Kualitatif dan R&D. Alfabeta, Bandung. [Indonesian]

Sulistiyono ST, Amaruli RJ. 2023. Learning Indonesian history based on multiculturalism to strengthen national integration. J Mar Stud Natl Integr 6 (2): 88-98. DOI: 10.14710/jmsni.v6i2.16666.

Taheri K, Groves C. 2023. Human-Karst Landscape Interactions and the Anthropo-Karstosphere: Toward a Nexus of Geoethics, Groundwater, and A Sustainable Society. In: Çiner A, Khan MF, Kallel A, Rodrigo-Comino J, Parise M, Barzegar R, Ergüler ZA, Khelifi N, Ali I (eds.). Recent Research on Environmental Earth Sciences, Geomorphology, Soil Science, Paleoclimate, and Karst. MedGU 2021. Advances in Science, Technology & Innovation. Springer, Cham. DOI: 10.1007/978-3-031-42917-0_52.

Wei Y, Li Z, Chen B, Yin H, Xiao J, Kong J. 2023. A numerical simulation study on the evolutionary characteristics of the damage process of karst soil cavity under positive pressure effec. Geohazard Mech 1 (4): 288-296. DOI: 10.1016/j.ghm.2023.10.002.

Wibowo AA, Basukriadi A, Nurdin E, Benhard G. 2022. Ecology and microhabitat model of long-tongued fruit bat *Macroglossus minimus* (Chiroptera: Pteropididae) in karst ecosystem of Klapanunggal, Bogor, West Java, Indonesia. Intl J Trop Drylands 6 (1): 11-15. DOI: 10.13057/tropdrylands/t060102.

Yanou MP, Ros-Tonen MAF, Reed J, Moombe K, Sunderland T. 2023. Integrating local and scientific knowledge: The need for decolonising knowledge for conservation and natural resource management. Heliyon 9 (11): e21785. DOI: 10.1016/j.heliyon.2023.e21785.

Yusup F. 2018. Uji validitas dan reliabilitas instrumen penelitian kuantitatif. Jurnal Ilmiah Kependidikan 1 (7): 17-23. DOI: 10.18592/tarbiyah.v7i1.2100. [Indonesian]

Zerga B. 2024. Karst topography: Formation, processes, characteristics, landforms, degradation and restoration: A systematic review. Watershed Ecol Environ 6: 252-269. DOI: 10.1016/j.wsee.2024.10.003.

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Traditional knowledge and utilization of non-medicinal plants in homegardens of a tropical karst landscape in Central Java, Indonesia

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[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Graduate Program of Bioscience, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia
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Abstract. *Reza AD, Firdausi E, Kusuma LA, Sabrina MA, Fadhillah EN, Md Naim D, Setyawan AD. 2025. Traditional knowledge and utilization of non-medicinal plants in homegardens of a tropical karst landscape in Central Java, Indonesia. Intl J Trop Drylands 9: 20-35.* Homegardens in tropical karst landscapes of Central Java, Indonesia represent vital biocultural systems that conserve plant biodiversity and traditional ecological knowledge while supporting rural livelihoods. This study documents the diversity, uses, and cultural significance of 143 non-medicinal plants across homegardens in Johunut, Paranggupito, and Gudangharjo Villages of Paranggupito Sub-district, Wonogiri District, Central Java. Through interviews with 100 respondents and field observations, plants were categorized into five functional groups: food (45.6%), ornamental (34.7%), spice (12.2%), fodder (8.8%), and other uses (6.8%). Use Value (UV) analysis identified *Mangifera indica*, *Carica papaya*, and *Zingiber officinale* as culturally keystone species. The predominance of trees (39.5%) and utilization of fruits (37.4%) and leaves (15.6%) demonstrate adaptive strategies to karst-specific constraints like shallow soils and seasonal droughts. Inter-village comparisons revealed localized variations, with Paranggupito emphasizing spice plants (e.g., *Capsicum annuum* UV=0.4) and Gudangharjo prioritizing fodder species, reflecting ecological and cultural adaptations. Notably, 26.5% of species served multiple purposes, exemplified by *Cocos nucifera* (food, construction, rituals) and *Musa acuminata* (food, fodder, ceremonial use). The study highlights homegardens as dynamic, multifunctional landscapes where biodiversity conservation intersects with cultural preservation. However, knowledge concentration among elders (51-60 years age group) signals erosion risks. We emphasize the urgency of intergenerational knowledge transfer and community-based conservation to sustain these resilient agroecosystems amidst socioeconomic and environmental changes in fragile karst regions.

Keywords: Ethnobotany, homegardens, karst landscape, non-medicinal plants, traditional knowledge, use value

INTRODUCTION

Homegardens represent one of the oldest and most resilient agroforestry systems practiced globally, particularly in tropical regions, and are not just about plants. These small-scale, multispecies, and multifunctional land-use systems serve as an important reservoir of plant biodiversity and traditional ecological knowledge (Kefale 2020; Ivanova et al. 2021). In rural communities, homegardens not only supply households with food, spices, fodder, and materials but also play essential roles in cultural expression, ecological sustainability, and local economies. Their significance in cultural expression is a testament to the deep connection between people and their environment. Studies across Southeast Asia have shown that the composition of homegarden flora reflects both ecological conditions and cultural practices of the inhabitants (Ashari et al. 2012; Mekonen et al. 2015).

Most ethnobotanical studies in Indonesia have emphasized the medicinal uses of plants due to the rich tradition of herbal medicine and its economic relevance (Arsyad 2018; Hanun et al. 2023). However, a significant proportion of plants cultivated or protected by local communities fall outside the medicinal domain. These non-medicinal plants—including edible fruits, vegetables, ornamental species, fodder plants, spices, and construction materials play a crucial role in the local economy. They are often undervalued in scientific discourse despite their daily importance to rural livelihoods (Borelli et al. 2020). The nuanced understanding of their roles, especially in biodiversity-rich but economically marginalized settings such as karst landscapes, remains limited.

Karst ecosystems are recognized as globally important biodiversity hotspots, shaped by highly porous limestone geology, shallow soils, seasonal droughts, and uneven nutrient availability (Widyaningsih 2017; Mane et al. 2019). In Indonesia, tropical karst areas are characterized by unique ecological constraints and a strong dependence of local communities on surrounding biological resources. Limited arable land and distant access to markets have encouraged subsistence practices centered around homegardens and forest margins. As a result, plant selection in homegardens of karst areas is often adapted to micro-environmental conditions and long-established cultural preferences (Tolentino et al. 2020; Farikha et al. 2025).

Paranggupito Sub-district in Wonogiri, Central Java, represents a typical karst region where communities heavily depend on local plant resources for daily subsistence. While previous studies in Java have extensively documented medicinal plants (Nofrianti et al. 2021; Rahman et al. 2022; Nurcahyo et al. 2024), research on non-medicinal species remains limited, despite their greater species richness and more frequent daily use. These plants fulfill essential roles in nutrition, cultural practices, spiritual symbolism, and environmental adaptation.

Traditional knowledge about these plants is orally transmitted across generations and embedded in agricultural systems, ceremonies, and social norms (Tynsong et al. 2020; Malapane et al. 2024). However, this knowledge system faces threats from rapid socioeconomic changes, land conversion, and eroding intergenerational transfer. Younger generations in Paranggupito's karst villages show declining familiarity with traditional plant uses, while commercial agricultural inputs and market foods increasingly replace local varieties, reducing both plant diversity and agroecological resilience (Borelli et al. 2020; Hanun et al. 2023).

Documenting traditional knowledge of non-medicinal plants is critical for four key reasons: (i) it provides a comprehensive understanding of ethnobotanical diversity beyond medicinal applications; (ii) it identifies culturally significant and ecologically adaptive species for conservation priorities; (iii) it reveals sustainable land management practices tailored to karst environments; and (iv) it helps preserve Indonesia's rural biocultural heritage.

Despite their ecological and cultural importance, non-medicinal homegarden plants are frequently overlooked in scientific inventories and national biodiversity assessments. There is an urgent need for inclusive ethnobotanical surveys that systematically record all plant use categories - including food, construction, aesthetics, ritual, and livelihood support. Quantitative approaches like Use Value (UV) analysis (Zenderland et al. 2019; Wulandari et al. 2024), while well-established in medicinal plant research, remain underutilized for non-medicinal species. Implementing such methods could significantly enhance our understanding of these plants' relative importance to local communities.

This study aims to address these gaps by documenting the diversity, use categories, and local knowledge associated with non-medicinal plants in the homegardens of Paranggupito Sub-district, a karst region in Central Java, Indonesia. The specific objectives are: (i) to identify non-medicinal plant species cultivated or protected in rural homegardens, (ii) to categorize their primary and secondary uses, (iii) to analyze their relative importance using the UV index, and (iv) to explore the cultural and ecological implications of their continued use. By focusing on an ecologically constrained and culturally rich karst landscape, this study contributes to a deeper understanding of human-plant relationships beyond medicinal use. It supports efforts to integrate traditional knowledge into conservation and rural development planning.

MATERIALS AND METHODS

Study area

The research was conducted in three rural villages—Johunut, Paranggupito, and Gudangharjo—within the administrative boundaries of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (Figure 1). These villages are located in the southernmost part of Central Java and form part of the tropical karst landscape of southern Java Island. The karst terrain is typified by rugged limestone hills, steep slopes, and shallow, discontinuous, fertile soils interspersed with porous bedrock. The area experiences a dry tropical climate, with distinct wet and dry seasons and limited water retention capacity due to its geological features.

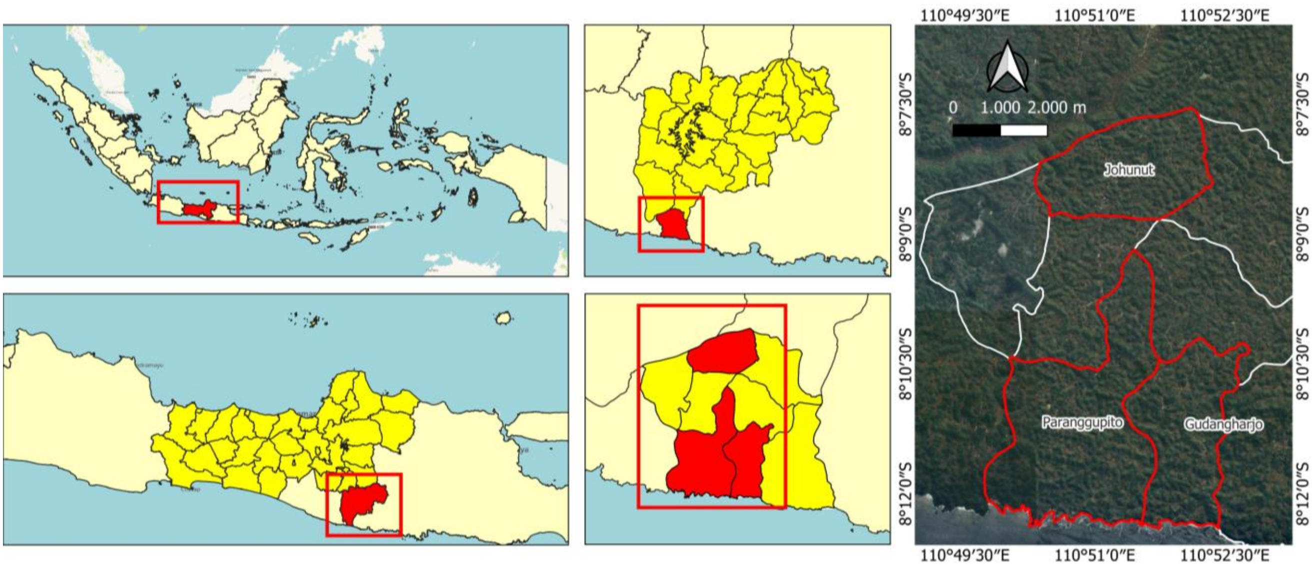

Figure 1. Map of the study area in Paranggupito Sub-district, Wonogiri, Central Java, Indonesia

Geographically, the study sites lie at an elevation of approximately 195 meters above sea level and are situated close to the Indian Ocean, with a combined coastal length of about 15 kilometers. Such proximity to the sea, coupled with karst topography, contributes to diverse microhabitats and challenges for conventional agriculture. According to official statistics (BPS 2023), the population densities in Johunut, Paranggupito, and Gudangharjo Villages are 307.85, 241.53, and 201.54 persons per square kilometer, respectively (Table 1). Due to limited market access, irregular road infrastructure, and seasonal water scarcity, many households in this area maintain large and functionally diverse homegardens as part of their subsistence strategy. These homegardens serve not only as a source of food, fodder, and fuel but also as a space for preserving culturally important plant species adapted to the karst environment.

Data collection

Data collection was conducted during October 2024 using two complementary methods: semi-structured interviews and direct field observations. These methods were employed to document local knowledge, species diversity, and utilization patterns of non-medicinal plants cultivated or maintained in homegardens.

Respondent selection

The study applied a purposive sampling technique to identify knowledgeable informants in each village. A total of 100 respondents were selected based on the following criteria: (i) minimum age of 17 years, (ii) ownership or active involvement in managing a homegarden, and (iii) recognized by neighbors or village leaders as knowledgeable about plant uses. The sample size was determined using Slovin's formula with a 10% margin of error based on an estimated adult population across the three villages. Table 3 presents the demographic profile of respondents, including gender, age, education level, and occupation. Interviews were conducted in Indonesian and Javanese, depending on respondents' preferences. All interviews were audio recorded with informed consent, and responses were immediately transcribed to structured tally sheets.

Interview themes

Each interview covered multiple dimensions of plant use and cultural knowledge transmission. (i) Respondents were first asked to identify both the local and scientific names of plants cultivated or managed in their homegardens. (ii) This was followed by documentation of the plant parts utilized, such as fruits, leaves, stems, roots, or wood. (iii) Informants then described the mode of use, whether the plants were consumed raw, cooked, dried, or used ornamentally. (iv) The interviews also explored the primary and secondary functions of each species, including roles as food, animal feed, spice, or material source. (v) Additional information was collected on cultivation methods, as well as the exchange or sharing of plant materials among community members. (vi) Finally, the process of knowledge transmission—how plant-related information and practices were passed across generations—was discussed to understand the continuity of ethnobotanical knowledge within households.

Field observation

Simultaneously, field observations were conducted in respondents' homegardens to verify the physical presence and condition of plants mentioned during interviews. Observations included photographing the plants, identifying growth forms (herb, shrub, tree, or climber), and recording site conditions (e.g., shade, slope, distance from the house). Some informants also demonstrated usage practices directly in the field.

Plant identification

All plant species mentioned by respondents during interviews and observed directly in the homegardens were recorded and preliminarily identified using their local (vernacular) names, with field notes and photographs supporting the identification process. Scientific identification of each species was carried out through a multi-step procedure involving: (i) cross-referencing vernacular names with standard references such as Heyne (1987) and relevant regional floras (Backer and Bakhuizen van den Brink 1963; Whitten et al. 1996), as well as morphological comparison using field images matched against botanical databases; (ii) morphological comparison using field images matched against online herbarium databases and botanical identification keys; and (iii) verification through international taxonomic databases, primarily the Global Biodiversity Information Facility (GBIF) (https://www.gbif.org) and Plants of the World Online (POWO) (https://powo.science.kew.org).

Table 1. Geographic and demographic characteristics of study villages in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Village	Coordinates	Elevation (m asl)	Population density (people/km²)	Coastal proximity
Johunut	8°08′10.5″ S, 110°51′40.5″ E	~195	307.85	Yes
Paranggupito	8°11′18.5″ S, 110°50′57.6″ E	~195	241.53	Yes
Gudangharjo	8°10′58.0″ S, 110°51′50.0″ E	~195	201.54	Yes

For taxa that could not be identified at the species level due to morphological ambiguity, the identification was limited to the genus or family level. Only species with valid scientific names matched to accepted taxonomic entries in GBIF or POWO were included in the final dataset and used for subsequent UV calculations. Plant life forms (e.g., trees, shrubs, herbs, climbers) were recorded based on field observations and confirmed through secondary literature, with growth forms contributing to the interpretation of ecological functions and domestication status. Voucher specimens were collected for taxa with uncertain identities, while digital photographs were archived to ensure proper documentation and enable future verification.

Data analysis

Data collected from interviews and field observations were analyzed using both descriptive statistics and quantitative ethnobotanical methods, with a focus on evaluating the diversity and importance of non-medicinal plant species in homegardens.

Categorization of plant use

All recorded species were categorized based on their primary function in daily household use, with classification into five mutually exclusive categories: (i) food plants, including fruits, vegetables, and tubers; (ii) ornamental plants, cultivated for aesthetic or landscaping purposes; (iii) cooking spices, used as seasoning or flavoring in household dishes; (iv) animal feed, particularly for goats, cattle, or poultry; and (v) other uses, encompassing construction materials, firewood, and insect repellents. Each species was assigned to a single category based on informant consensus and its dominant mode of use.

Use Value (UV) calculation

To quantify the relative importance of each species across informants, the Use Value (UV) index was calculated for all identified plants following the standard formula (Phillips and Gentry 1993)

$$UV = \frac{\sum U_i}{N}$$

Where:

U_i: Total number of use reports cited for species *i* by all informants

N: Total number of informants (n=100)

UV values range from 0.01 (mentioned by only one respondent with a single use) to a maximum of 1.00 (mentioned by all 100 respondents). Higher UV scores indicate greater cultural salience and frequency of use within the community.

Only species that were directly observed and correctly identified were included in the UV analysis. Species mentioned inconsistently or with uncertain identification were excluded to maintain data integrity.

Data tabulation and visualization

All data were tabulated using Microsoft Excel, and basic statistical summaries (e.g., number of species per use category, most-used plant parts, dominant growth forms) were generated. Visualizations such as bar charts and pie charts were developed to illustrate distribution patterns (e.g., most-used plant parts, UV-ranked species).

RESULTS AND DISCUSSION

Socio-demographic profile of respondents

A total of 100 respondents participated in the study, representing households from Johunut, Paranggupito, and Gudangharjo Villages. The gender distribution consisted of 56% female and 44% male, indicating that women play a dominant role in the management and utilization of homegardens. This aligns with findings from other rural ethnobotanical studies, where women are often the custodians of household-level plant knowledge and practice.

The respondents' age distribution revealed that the majority were in the older age groups, with 28% aged 51-60 years and 25% above 60 years. This demographic pattern suggests that knowledge of non-medicinal plant uses is concentrated among middle-aged and elderly residents. Meanwhile, younger individuals (<30 years) made up less than 10% of participants, reflecting potential gaps in intergenerational knowledge transmission.

Regarding educational background, 39% of respondents had completed only elementary school, followed by 36% with senior high school education and 5% with university degrees. This range illustrates the varied literacy levels within the community, which may influence how plant knowledge is acquired and shared, either orally or through more formal learning channels.

In terms of occupation, the majority of respondents identified as farmers (45%), followed by housewives (29%), and the rest engaged in informal or mixed livelihoods such as small traders or construction workers. The strong representation of farming households underscores the reliance on homegardens not only for food but also as a multifunctional component of subsistence agriculture and household resource management. These socio-demographic characteristics support the validity of the ethnobotanical data, as respondents were actively involved in plant cultivation and use. The demographic composition is summarized in Table 3.

Diversity and utilization of non-medicinal homegarden plants

A total of 143 plant species belonging to 111 genera and 55 families were documented from the homegardens of respondents across the 3 study villages (Table 2). These species are cultivated, protected, or maintained primarily for non-medicinal purposes, reflecting the multifunctionality of homegardens in rural karst environments. Plant diversity was consistently high across all locations despite the ecological constraints of shallow soils and irregular rainfall common to karst landscapes. A summary of plant distribution by use category is presented in Table 2, with food plants being the most represented group

Table 2. Categorized utilization of homegarden plants in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (N=143)

Scientific name	Local name	Family	Life-form	Used part	Mode of preparation	UV	Category				
							F	O	C	A	Other uses
Allium fistulosum L.	*Bawang daun*	Amaryllidaceae	Herb	Leaf	Cooked	0.4	+	-	+	-	-
Allium tuberosum Rottler ex Spreng.	*Kucai*	Liliaceae	Herb	Leaf	Cooked	0.2	+	-	-	-	-
Amaranthus caudatus L.	*Bayam*	Amaranthaceae	Shrub	Leaf	Cooked, boiled	0.2	+	-	-	-	-
Anacardium occidentale L.	*Jambu mete*	Anacardiaceae	Tree	Seed	Fried	0.4	+	-	-	+	-
Annona squamosa L.	*Srikaya*	Annonaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Apium graveolens L.	*Seledri*	Apiaceae	Shrub	Leaf	Boiled	0.2	+	-	-	-	-
Artocarpus altilis (Parkinson) Fosberg	*Sukun*	Moraceae	Tree	Fruit	Steamed, fried	0.2	+	-	-	-	-
Artocarpus camansi Blanco	*Kluwih*	Moraceae	Tree	Fruit	Cooked	0.2	+	-	-	-	-
Artocarpus heterophyllus Lam. [1)]	*Nangka*	Moraceae	Tree	Fruit, wood	Raw	0.2	+	-	-	-	+
Averrhoa bilimbi L.	*Belimbing wuluh*	Oxalidaceae	Tree	Fruit	Raw, cooked	0.4	+	-	+	-	-
Averrhoa carambola L.	*Belimbing*	Oxalidaceae	Tree	Fruit	Raw, boiled	0.2	+	-	-	-	-
Carica papaya L.	*Pepaya*	Caricaceae	Herb	Fruit, leaf	Raw	0.4	+	-	-	+	-
Citrus aurantifolia (Christm.) Swingle	*Jeruk nipis* "Jawa"	Rutaceae	Tree	Fruit, leaf	Raw, cooked, squeezed	0.2	+	-	-	-	-
Citrus hystrix DC.	*Jeruk purut*	Rutaceae	Tree	Fruit	Raw, squeezed	0.2	+	-	-	-	-
Citrus limon (L.) Osbeck	*Lemon*	Rutaceae	Tree	Fruit	Raw, squeezed	0.2	+	-	-	-	-
Citrus maxima (Burm.) Merr.	*Jeruk bali*	Rutaceae	Shrub	Fruit	Raw	0.2	+	-	-	-	-
Citrus paradisi Macfad.	*Jeruk manis*	Rutaceae	Shrub	Fruit	Raw	0.2	+	-	-	-	-
Citrus reticulata Blanco	*Jeruk keprok*	Rutaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Citrus *sinensis* (L.) Osbeck	*Jeruk sunkist*	Rutaceae	Tree	Fruit	Raw, squeezed	0.2	+	-	-	-	-
Cnidoscolus aconitifolius (Mill.) I.M. Johnst.	*Pepaya jepang*	Euphorbiaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Cocos nucifera L.	*Kelapa*	Arecaceae	Tree	Fruit	Raw, shredded	0.2	+	-	-	-	-
Coffea arabica L.	*Kopi*	Rubiaceae	Shrub	Seed	Dried, mashed, brewed, fried	0.2	+	-	-	-	-
Cosmos sulphureus Cav.	*Kenikir*	Asteraceae	Shrub	Leaf	Raw, boiled	0.2	+	-	-	-	-
Cucurbita sp.	*Labu*	Cucurbitaceae	Climber	Fruit	Raw, steamed	0.2	+	-	-	-	-
Dimocarpus longan Lour.	*Kelengkeng*	Sapindaceae	Tree	Fruit	Raw	0.4	+	-	-	-	+
Durio zibethinus L.	*Durian*	Malvaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Ficus septica Burm. f.	*Awar-awar*	Moraceae	Shrub	Leaf	Raw	0.2	+	-	-	-	-
Garcinia mangostana L.	*Manggis*	Clusiaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Gnetum gnemon L.	*Melinjo*	Gnetaceae	Tree	Fruit, leaf, seed	Boiled, cooked	0.4	+	-	+	-	-
Hylocereus undatus (Haw.) Britton & Rose	*Buah naga*	Cactaceae	Climber	Fruit	Raw	0.2	+	-	-	-	-
Ipomoea aquatica Forssk.	*Kangkung*	Convolvulaceae	Herb	Leaf	Boiled, cooked	0.2	+	-	-	-	-
Ipomoea batatas (L.) Lam.	*Ketela rambat*	Convolvulaceae	Climber	Tuber	Steamed, baked	0.2	+	-	-	-	-
Leucaena leucocephala (Lam.) de Wit	*Petai cina*	Fabaceae	Tree	Seed	Raw	0.4	+	-	-	+	-
Mangifera indica L.	*Mangga*	Anacardiaceae	Tree	Fruit	Raw	0.4	+	-	-	+	-
Manihot esculenta Crantz	*Singkong*	Euphorbiaceae	Shrub	Tuber, leaf	Steamed, fried, boiled, fed directly	0.2	+	-	-	+	-
Manilkara kauki (L.) Dubard	*Sawo kecik*	Sapotaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Manilkara zapota (L.) P. Royen	*Sawo manila*	Sapotaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Momordica charantia L.	*Pare*	Cucurbitaceae	Shrub	Fruit	Cooked	0.2	+	-	-	-	-

Morinda citrifolia L.	*Mengkudu*	Rubiaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Moringa oleifera Lam.	*Kelor*	Moringaceae	Shrub	Leaf	Cooked	0.2	+	-	-	-	-
Morus alba L.	*Murbei*	Moraceae	Shrub	Fruit	Raw	0.2	+	-	-	-	-
Muntingia calabura L.	*Kersen*	Muntingiaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Musa acuminata Colla var. pisang susu	*Pisang susu*	Musaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Musa acuminata balbisiana Colla	*Pisang kepok*	Musaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Musa paradisiaca L.	*Pisang raja*	Musaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Musa × paradisiaca L.	*Pisang ambon*	Musaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Nephelium lappaceum L.	*Rambutan*	Sapindaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Ocimum basilicum L.	*Kemangi*	Lamiaceae	Herb	Leaf	Raw	0.2	+	-	-	-	-
Parkia speciosa Hassk.	*Petai*	Fabaceae	Tree	Seed	Raw, cooked	0.2	+	-	-	-	-
Persea americana Mill.	*Alpukat*	Lauraceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Phoenix dactylifera L.	*Kurma*	Arecaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Psidium guajava L.	*Jambu biji*	Myrtaceae	Tree	Fruit	Raw	0.4	+	-	-	+	-
Psophocarpus tetragonolobus (L.) DC	*Kecipir*	Fabaceae	Herb	Fruit	Cooked	0.2	+	-	-	-	-
Punica granatum L.	*Delima*	Punicaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Sauropus androgynus (L.) Merr.	*Katuk*	Phyllanthaceae	Shrub	Leaf	Cooked	0.2	+	-	-	-	-
Sesbania grandiflora (L.) Pers.	*Turi*	Fabaceae	Tree	Flower	Cooked	0.2	+	-	-	+	-
Solanum indicum L.	*Terong kuning*	Solanaceae	Shrub	Fruit	Cooked	0.2	+	-	-	-	-
Solanum lycopersicum L.	*Tomat*	Solanaceae	Herb	Fruit	Raw, cooked	0.2	+	-	-	-	-
Solanum melongena L.	*Terong*	Solanaceae	Shrub	Fruit	Cooked	0.2	+	-	-	-	-
Solanum nigrum L.	*Leunca*	Solanaceae	Shrub	Fruit	Raw	0.2	+	-	-	-	-
Solanum torvum Sw.	*Takokak*	Solanaceae	Shrub	Fruit	Raw	0.2	+	-	-	-	-
Syzygium aqueum (Burm. f.) Alston	*Jambu air*	Myrtaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Syzygium malaccense (L.) Merr. & L.M. Perry	*Jambu jamaika*	Myrtaceae	Tree	Fruit	Raw	0.2	+	-	-	-	-
Vigna unguiculata (L.) Walp.	*Kacang panjang*	Fabaceae	Climber	Fruit	Cooked	0.2	+	-	-	-	-
Vigna unguiculata subsp. *unguiculata* (L.) Walp.	*Kacang tunggak*	Fabaceae	Climber	Fruit	Cooked	0.2	+	-	-	-	-
Vitis lincecumii Buckley	*Anggur*	Vitaceae	Climber	Fruit	Raw	0.2	+	-	-	-	-
Zea mays L.	*Jagung*	Poaceae	Herb	Fruit	Cooked, boiled	0.4	+	-	-	+	-
Aglaonema commutatum Schott	*Sri rezeki*	Araceae	Herb	Herb	-	0.2	-	+	-	-	-
Allamanda cathartica L.	*Bunga alamanda*	Apocynaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Aloe vera (L.) Burm.f.	*Lidah buaya*	Asphodelaceae	Herb	Herb	-	0.2	-	+	-	-	-
Andrographis paniculata (Burm.f.) Nees	*Sambiloto*	Acanthaceae	Climber	Climber	-	0.2	-	+	-	-	-
Anredera cordifolia (Ten.) Steenis	*Binahong*	Basellaceae	Climber	Climber	-	0.2	-	+	-	-	-
Anthurium andraeanum Linden ex André	*Kuping gajah*	Araceae	Herb	Herb	-	0.2	-	+	-	-	-
Anthurium plowmanii Croat	*Gelombang cinta*	Araceae	Herb	Herb	-	0.2	-	+	-	-	-
Bambusa vulgaris var. *striata* (Lodd. ex Lindl.) Gamble	*Bambu kuning*	Poaceae	Herb	Herb	-	0.2	-	+	-	-	-
Bougainvillea spectabilis Willd.	*Bunga kertas*	Nyctaginaceae	Climber	Climber	-	0.2	-	+	-	-	-
Opuntia cochenillifera (L.) Mill.	*Kaktus*	Cactaceae	Tree	Tree	-	0.2	-	+	-	-	-
Calathea sp.	*Calathea kuning*	Marantaceae	Herb	Herb	-	0.2	-	+	-	-	-
Cananga odorata (Lam.) Hook.f. & Thomson	*Kenanga*	Annonaceae	Tree	Tree	-	0.2	-	+	-	-	-
Casuarina equisetifolia L.	*Cemara*	Casuarinaceae	Tree	Tree	-	0.2	-	+	-	-	-
Catharanthus roseus (L.) G.Don	*Tapak dara*	Apocynaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Clerodendrum paniculatum L.	*Bunga pagoda*	Lamiaceae	Tree	Tree	-	0.2	-	+	-	-	-
Codiaeum variegatum (L.) Rumph. ex A.Juss.	*Puring*	Euphorbiaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Coleus scutellarioides (L.) R.Br.	*Miana*	Lamiaceae	Shrub	Shrub	-	0.2	-	+	-	-	-

Cordyline fruticosa (L.) A.Chev.	*Andong*	Asparagaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Epiphyllum anguliger (Lem.) G.Don	*Bunga wijayakusuma*	Cactaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Euphorbia tirucalli L.	*Patah tulang*	Euphorbiaceae	Tree	Tree	-	0.2	-	+	-	-	-
Euphorbia trigona Mill.	*Kaktus katedral*	Euphorbiaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Gliricidia sepium (Jacq.) Walp.	*Gamal*	Fabaceae	Shrub	Shrub	-	0.2	-	+	-	+	-
Hibiscus rosa-sinensis L.	*Bunga sepatu*	Malvaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Indigofera tinctoria L.	*Bunga tarum*	Fabaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Ixora coccinea L.	*Bunga soka*	Rubiaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Jasminum sambac (L.) Aiton	*Melati putih*	Oleaceae	Climber	Climber	-	0.2	-	+	-	-	-
Kalanchoe pinnata (Lam.) Pers.	*Cocor bebek*	Crassulaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Lavandula angustifolia Mill.	*Lavender ungu*	Lamiaceae	Herb	Herb	-	0.2	-	+	-	-	-
Monstera adansonii Schott	*Janda bolong*	Araceae	Herb	Herb	-	0.2	-	+	-	-	-
Murraya paniculata (L.) Jack	*Kemuning*	Rutaceae	Tree	Tree	-	0.2	-	+	-	-	-
Orthosiphon aristatus (Blume) Miq.	*Kumis kucing*	Lamiaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Pandanus odorifer (Forssk.) Kuntze	*Pandan laut*	Pandanaceae	Tree	Tree	-	0.2	-	+	-	-	-
Pennisetum purpureum Schumach.	*Rumput gajah*	Poaceae	Shrub	Shrub	-	0.4	-	+	-	+	-
Phalaenopsis amabilis (L.) Blume	*Anggrek bulan ungu*	Orchidaceae	Climber	Climber	-	0.2	-	+	-	-	-
Pilea cadierei Gagnep. & Guillaumin	*Tanaman perak*	Urticaceae	Herb	Herb	-	0.2	-	+	-	-	-
Piper betle L.	*Sirih*	Piperaceae	Climber	Climber	-	0.4	-	+	+	-	-
Platycerium bifurcatum (Cav.) C.Chr.	*Paku tanduk rusa*	Polypodiaceae	Climber	Climber	-	0.2	-	+	-	-	-
Pluchea indica (L.) Less.	*Beluntas*	Asteraceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Plumeria alba L.	*Kamboja putih*	Apocynaceae	Tree	Tree	-	0.2	-	+	-	-	-
Polyscias scutellaria (Burm.f.) Fosberg	*Mangkokan*	Araliaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Rosa chinensis Jacq.	*Mawar tiongkok*	Rosaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Rubia cordifolia L.	*Pohon langitan*	Rubiaceae	Tree	Tree	-	0.2	-	+	-	-	-
Ruellia tuberosa L.	*Kencana ungu*	Acanthaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Saccharum officinarum L.	*Tebu hitam*	Poaceae	Herb	Herb	-	0.2	-	+	-	-	-
Sansevieria trifasciata Prain	*Lidah mertua*	Asparagaceae	Herb	Herb	-	0.2	-	+	-	-	-
Senna alata (L.) Roxb.	*Ketepeng cina*	Fabaceae	Tree	Tree	-	0.2	-	+	-	-	-
Spathiphyllum wallisii Regel	*Lili perdamaian putih*	Araceae	Herb	Herb	-	0.2	-	+	-	-	-
Stauntonia hexaphylla (Thunb.) Decne.	*Stauntonia*	Lardizabalaceae	Shrub	Shrub	-	0.2	-	+	-	-	-
Streblus asper Lour.	*Serut*	Moraceae	Tree	Tree	-	0.2	-	+	-	-	-
Syzygium myrtifolium (Roxb.) Walp.	*Pucuk merah*	Myrtaceae	Tree	Tree	-	0.2	-	+	-	-	-
Wrightia religiosa (Teijsm. & Binn.) Hook.f.	*Anting putri*	Apocynaceae	Tree	Tree	-	0.2	-	+	-	-	-
Alpinia galanga (L.) Sw.	*Laos*	Zingiberaceae	Herb	Rhizome	Crushed, cut	0.2	-	-	+	-	-
Capsicum annuum L.	*Cabai*	Solanaceae	Herb	Fruit	Cooked, cut, mashed	0.2	-	-	+	-	-
Capsicum frutescens L.	*Cabai Rawit*	Solanaceae	Herb	Fruit	Cooked, cut, mashed	0.2	-	-	+	-	-
Citrus latifolia (Yu.Tanaka) Yu.Tanaka	*Jeruk Nipis* "Persia"	Rutaceae	Tree	Fruit, leaf	Cut, squeezed	0.2	-	-	+	-	-
Curcuma longa L.	*Kunyit*	Zingiberaceae	Herb	Rhizome	Mashed, crushed	0.2	-	-	+	-	-
Curcuma xanthorrhiza Roxb.	*Temulawak*	Zingiberaceae	Herb	Rhizome	Crushed	0.2	-	-	+	-	-
Cymbopogon citratus (DC.) Stapf	*Serai*	Poaceae	Herb	Stem	Crushed, cut	0.2	-	-	+	-	-
Kaempferia galanga L.	*Kencur*	Zingiberaceae	Herb	Rhizome	Mashed	0.2	-	-	+	-	-
Pandanus amaryllifolius Roxb.	*Pandan*	Pandanaceae	Herb	Leaf	Boiled	0.2	-	-	+	-	-
Piper retrofractum Vahl.	*Cabai Jawa*	Solanaceae	Herb	Fruit	Cooked, cut	0.2	-	-	+	-	-
Syzygium aromaticum (L.) Merr. & L. M. Perry	*Cengkih*	Myrtaceae	Tree	Flower	Dried	0.2	-	-	+	-	-
Syzygium polyanthum (Wight) Walp.	*Salam*	Myrtaceae	Tree	Leaf	Boiled	0.2	-	-	+	-	-

Tamarindus indica L.	*Asem*	Fabaceae	Tree	Fruit	Crushed	0.2	-	-	+	-	-
Zingiber officinale Rosc.	*Jahe*	Zingiberaceae	Herb	Rhizome	Crushed, cut	0.2	-	-	+	-	-
Indigofera zollingeriana Miq.	*Indigofera*	Fabaceae	Herb	Leaf	Fed directly	0.2	-	-	-	+	-
Musa acuminata Colla. var. pisang mas	*Pisang Mas*	Musaceae	Herb	Leaf, stem	Fed directly, dried	0.2	-	-	-	+	-
Musa sapientum L.	*Pisang Raja*	Musaceae	Herb	Leaf, stem	Fed directly, dried	0.2	-	-	-	+	-
Acacia mangium Willd. [2)]	*Akasia*	Fabaceae	Tree	Wood	-	0.2	-	-	-	-	+
Ficus benjamina L.	*Beringin*	Moraceae	Tree	Wood	-	0.2	-	-	-	-	+
Gigantochloa atter (Hassk.) Kurz [1,2,3)]	*Bambu Ater*	Poaceae	Tree	Wood	-	0.2	-	-	-	-	+
Hevea brasiliensis (Willd. ex A. Juss.) Mull. Arg. [1)]	*Karet*	Euphorbiaceae	Tree	Wood	-	0.2	-	-	-	-	+
Murraya paniculata var. *paniculata* [4)]	*Kemuning*	Rutaceae	Tree	Leaf	-	0.2	-	-	-	-	+
Paraserianthes falcataria (L.) I.C. Nielsen	*Sengon*	Fabaceae	Tree	Wood	-	0.2	-	-	-	-	+
Swietenia macrophylla King. [2)]	*Mahoni*	Meliaceae	Tree	Wood	-	0.2	-	-	-	-	+
Tectona grandis L.f. [1,2)]	*Jati*	Lamiaceae	Tree	Wood	-	0.2	-	-	-	-	+

Note: F: Food plants, O: Ornamental plants, C: Cooking spices, A: Animal feed, Others uses: 1: House building, 2: Firewood, 3: House cleaner, 4: Insect repellent

Each recorded species was categorized into one of five primary utilization categories based on the dominant use reported by informants: food plants, ornamental plants, cooking spices, animal feed, and other uses (e.g., firewood, building material, repellents). The largest group was food plants, comprising 67 species (45.6%), followed by ornamental plants with 51 species (34.7%). Cooking spices accounted for 18 species (12.2%), animal feed included 13 species (8.8%), and the remaining 10 species (6.8%) were used for construction, tools, or household utilities. The number of species in each use category is shown in Figure 2, with food plants being the most represented group.

Several species were multifunctional, with different parts utilized in more than one context. For instance, *Gnetum gnemon* was used for its fruit (as a vegetable or snack), leaves (as edible greens), and seeds (as a cooking ingredient), demonstrating the breadth of use within a single species. Similarly, *Carica papaya* provided edible fruits and young leaves; *Musa acuminata* was valued for its fruit, leaves (used as wrappers), and pseudostem (used as fodder); while *Tectona grandis* served for both firewood and construction. However, for analytical consistency, each species was categorized under its primary function based on the most frequently cited use and perceived importance as reported by informants during interviews.

This diversity of plant functions highlights the adaptive strategies of rural households in managing plant resources for everyday needs. The reliance on diverse species types also supports household resilience in the face of limited market access, making homegardens not only a space of subsistence but also of cultural continuity and environmental adaptation. A summary of plant distribution by use category is presented in Table 4.

Use value of key food plants

Among the five primary utilization categories, food plants exhibited the highest species richness and use frequency. A total of 67 food plant species were recorded, including fruits, vegetables, tubers, and edible leaves commonly found in household gardens. Informants identified a wide range of preparation methods, such as raw consumption, boiling, steaming, frying, or use as complementary ingredients in traditional dishes. Cooking and boiling were the most prevalent methods, indicating their dominant role in daily food processing (Figure 3).

Table 3. Demographic profile of respondents in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (n=100)

Parameter	Category	Frequency	Percentage (%)
Gender	Male	44	44.0
	Female	56	56.0
Age group (years)	< 20	2	2.0
	21-30	7	7.0
	31-40	14	14.0
	41-50	24	24.0
	51-60	28	28.0
	> 60	25	25.0
Education level	No formal education	2	2.0
	Elementary school	39	39.0
	Junior high school	18	18.0
	Senior high school	36	36.0
	University	5	5.0
Main occupation	Farmer	45	45.0
	Housewife	29	29.0
	Trader	11	11.0
	Others (e.g., laborers)	15	15.0

Table 4. Number of species, genera, and families used for non-medicinal purposes by communities of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Utilization category	Number of species	Number of genera	Number of families	Percentage of total species (%)
Food plants	67	47	34	42.1
Ornamental plants	51	49	32	32.1
Cooking spices	18	14	11	11.3
Animal feed	13	13	7	8.2
Other uses	10	10	10	6.3
Total	143	111	55	100.0

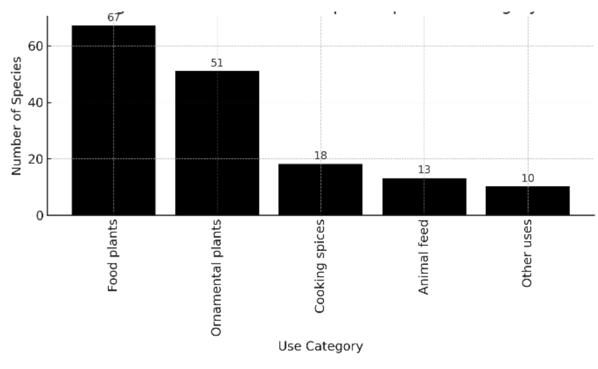

Figure 2. Number of plant species per use category

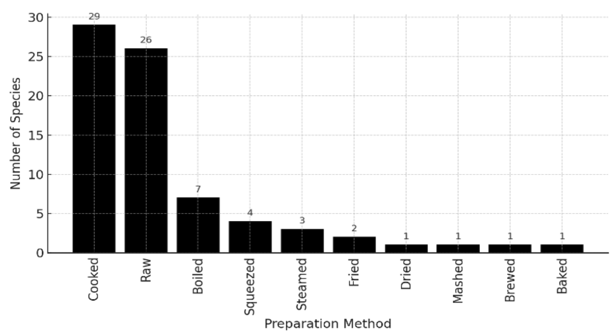

Figure 3. Distribution of preparation methods for useful plants of the food plants category

The Use Value (UV) index was calculated to assess each species' relative cultural and practical importance across all non-medicinal use categories. UV scores reflected how frequently a species was cited by respondents, regardless of whether it was used as food, spice, ornamental, fodder, or for other household purposes. Species with higher UV values typically possessed multiple functional roles, had year-round availability, or were considered essential to daily household practices. For instance, plants such as *Mangifera indica*, *C. papaya*, and *Zingiber officinale* achieved high UV scores due to their frequent citation across diverse usage contexts.

The top-ranked species, all with a UV score of 0.4, included *M. indica* (mango), *C. papaya* (papaya), *G. gnemon*, and *Z. officinale* (ginger), among others. These species were highly cited by respondents due to their frequent use in daily life, multiple edible parts, and year-round availability. For instance, *M. indica* was valued for its sweet fruit consumed fresh, while *C. papaya* was used for both its fruit and young leaves. *Z. officinale* and *Capsicum annuum* (chili) were widely used as essential kitchen spices. The 12 highest-ranked species with UV 0.4 are presented in Figure 4. Figure 4 presents the species with the highest UV scores, reflecting their multifunctional roles and prominence in household practices.

Utilization by plant part used

Across all non-medicinal plant categories, respondents identified a total of 8 different plant parts that were regularly utilized in their daily activities. These included fruits, leaves, rhizomes, seeds, stems, tubers, wood, and flowers. The variation in part use reflects the multifunctionality of species in homegardens and the practical adaptation of households to karst environmental conditions.

Among these, fruits were the most commonly used plant part, cited in 55 species (37.4% of the total), particularly among food and spice plants. Most fruits, such as *M. indica*, *Syzygium aqueum*, and *Psidium guajava*, were consumed fresh or raw. Fruits were also processed into drinks, jams, or used as seasoning ingredients—for instance, *Citrus aurantifolia* and *Tamarindus indica* were frequently used for sour flavoring in traditional recipes.

Leaves were the second most commonly used plant part, found in 23 species (15.6%). These included edible leafy vegetables (*Sauropus androgynus*, *Ipomoea aquatica*), animal fodder plants (*Leucaena leucocephala*, *Manihot esculenta*), and aromatic species (*Ocimum basilicum*, *Syzygium polyanthum*). Leaf use was especially prominent in species adapted to continuous growth and year-round availability, making them a reliable source for both food and household applications.

Other parts with notable utilization included: (i) rhizomes (9 species), mostly from the Zingiberaceae family such as *Z. officinale*, *Curcuma longa*, and *Kaempferia galanga*, used as cooking spices and traditional condiments; (ii) tubers (e.g., *M. esculenta*, *Ipomoea batatas*) serving as carbohydrate staples; (iii) stems and wood, utilized as firewood, tools, and materials for house construction (*T. grandis*, *Gigantochloa atter*); and (iv) flowers (e.g., *Sesbania grandiflora*, *Bougainvillea spectabilis*) valued for aesthetics or as culinary garnishes. Figure 5 illustrates the distribution of plant parts used across all species reported in the study.

Multipurpose and culturally important species

Among the 143 non-medicinal plant species recorded, a substantial number were found to serve multiple functions, highlighting their significance in both the subsistence economy and the cultural life of the community. A total of 39 species (26.5%) were categorized as multipurpose, being cited by respondents for at least two different primary uses. This functional overlap reinforces the value of homegardens as integrated agroecosystems that combine utility, tradition, and biodiversity.

Several food plants, for example, were also used for animal feed, shade, fencing, or ceremonial purposes. *Musa acuminata balbisiana* (banana) was used not only for its fruit but also for its leaves (as food wrappers), pseudostems (as animal fodder), and as decorative or ritual materials during community ceremonies. *Cocos nucifera* (coconut) has at least five distinct uses—including its fruit, shell, leaves, and trunk—making it one of the most versatile species reported.

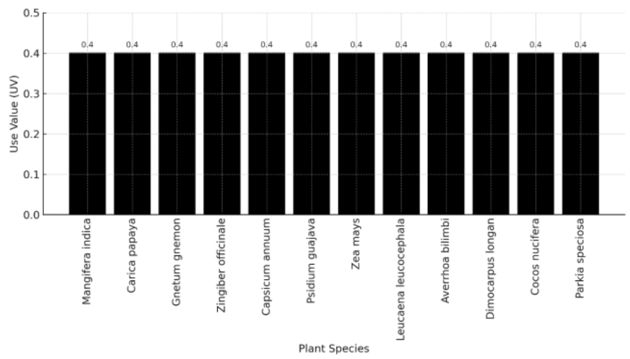

Figure 4. Top 12 plant species with the highest Use Value (UV)

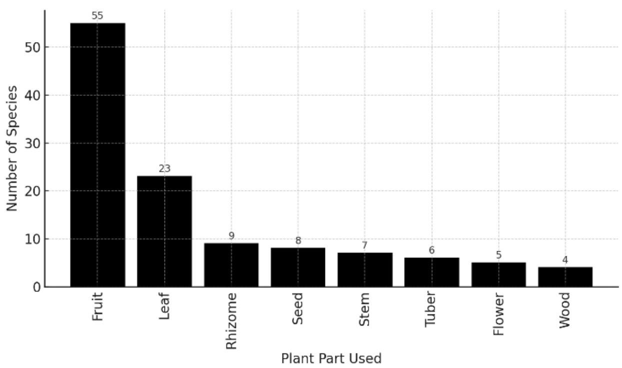

Figure 5. Frequency distribution of plant parts used by local communities in their homegardens in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Other culturally embedded species included *B. spectabilis*, used both as an ornamental and as a boundary marker; *T. grandis*, planted for its timber but also valued symbolically as a sign of prosperity; and *O. basilicum* and *S. polyanthum*, which are used in traditional cooking but also placed in ritual offerings and graveyard plantings.

These culturally important plants were often preserved even when no longer actively used, indicating their symbolic rather than utilitarian function. Older respondents, in particular, emphasized the role of such species in local identity and customary practices. Many of these species were inherited or propagated through familial exchange, reinforcing their social value across generations.

The combination of utility and cultural meaning contributes to the long-term resilience and continuity of homegarden management in the karst villages. It also suggests that conservation strategies must go beyond ecological parameters to include the preservation of biocultural relationships between people and plants. A list of key multipurpose and culturally significant species with their combined functions can be presented in Table 5. Several homegarden species were reported to serve multiple roles within the household, particularly as food, spices, and materials for other uses such as construction or ritual practices. The overlap of these uses is visualized in Figure 6.

Plant growth forms and adaptation to karst conditions

The analysis of growth forms among the 143 documented non-medicinal plant species revealed distinct patterns of vertical and functional stratification within homegardens. Species were classified into four major growth forms: trees, shrubs, herbs, and climbers. The distribution of plant life forms is illustrated in Figure 7, showing the dominance of trees and shrubs among homegarden species in Paranggupito Sub-district.

Trees represented the largest growth form category, accounting for 58 species (39.5%), including *M. indica*, *Artocarpus heterophyllus*, *C. nucifera*, and *T. grandis*. These species were favored not only for their fruit or timber but also for their shade-providing function, which regulates microclimate and supports the layered structure of the garden. Their deep-rooting systems also enhance resilience to drought and poor soil fertility—key characteristics of karst landscapes.

Shrubs comprised 34 species (23.1%), many of which were fruit-bearing or spice-producing taxa such as *C. annuum*, *Muntingia calabura*, and *B. spectabilis*. Shrubs were typically located at the mid-canopy level or used as living fences and hedgerows.

Herbs accounted for 37 species (25.2%), including vegetables and culinary spices such as *C. longa*, *O. basilicum*, *I. aquatica*, and *Z. officinale*. These species were mainly cultivated in the understory or near kitchen areas, benefiting from partial sunlight and routine watering.

Climbers were the least represented group, with 18 species (12.2%), including *Momordica charantia*. These plants are often grown on trellises or fences and valued for their edible fruits or shoots.

The coexistence of vertically layered species—trees, shrubs, herbs, and climbers—demonstrates the structural complexity and ecological adaptability of homegardens in karst environments. Respondents emphasized that species selection was influenced by tolerance to water scarcity, shallow soils, and heat stress. Species like *M. esculenta*, *L. leucocephala*, and *I. batatas* were noted for thriving in marginal spaces such as rock crevices or sloped plots.

These patterns reflect not only environmental filtering but also accumulated traditional ecological knowledge that informs plant selection and spatial arrangement. The dominance of hardy perennials and multi-strata vegetation in karst homegardens is a functional adaptation to environmental constraints, showcasing the resilience and ingenuity embedded in local agroecosystems.

Table 5. Multipurpose non-medicinal plant species and their combined functional roles

Scientific name	Functional roles
Musa acuminata balbisiana Colla	Fruit, wrapper, fodder, ritual
Cocos nucifera L.	Fruit, oil, wood, ritual, roof material
Tectona grandis L.f.	Timber, symbolic planting, boundary
Bougainvillea spectabilis Willd.	Ornamental, boundary marker
Ocimum basilicum L.	Spice, ritual, ornamental
Syzygium polyanthum (Wight) Walp	Culinary, ritual, grave planting
Zea mays L.	Food, fodder, ornamental
Leucaena leucocephala (Lam.) de Wit	Fodder, shade, soil enrichment
Cassia siamea Lam.	Firewood, shade, ritual
Cananga odorata (Lam.) Hook.f. & Thomson	Ornamental, ritual, fragrance

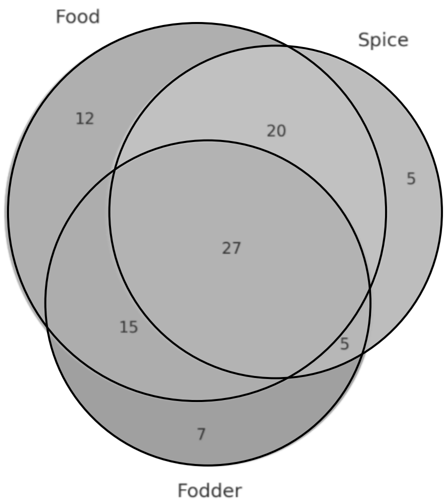

Figure 6. Venn diagram illustrating the overlapping uses of homegarden plants in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

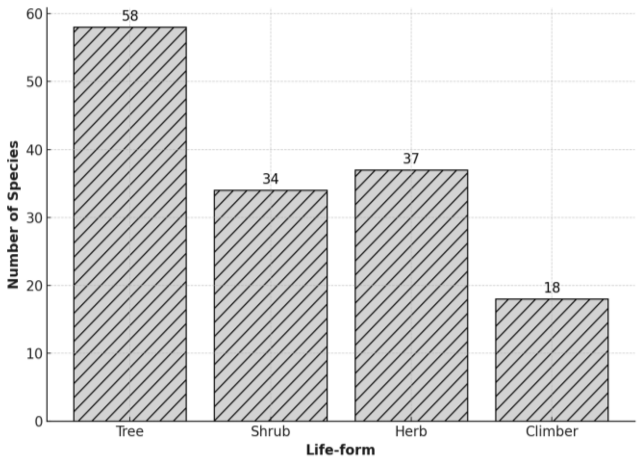

Figure 7. Distribution of life forms among useful homegarden plant species

Inter-village comparison of species composition and UV patterns

Comparative analysis among the three study villages—Johunut, Paranggupito, and Gudangharjo—revealed both shared and unique aspects in non-medicinal plant composition and use values. While many core species were present across all locations, notable differences emerged in species richness and UV distribution, shaped by ecological micro-conditions, household preferences, and sociocultural practices.

In terms of species richness, Johunut recorded the highest number of species (121), followed by Paranggupito (116) and Gudangharjo (108). The higher diversity in Johunut may be attributed to its relatively larger homegarden plots and higher population density, which enhances plant exchange and propagation networks among neighbors. Johunut also had the most varied ornamental species, while Gudangharjo showed greater dependence on food-producing perennials.

The Use Value (UV) analysis revealed several species with consistently higher UV scores (0.4) across villages, such as *M. indica*, *C. papaya*, and *Z. officinale*, indicating their widespread and frequent use. However, the distribution of UV values also reflected localized differences in species importance. For example, *C. annuum* had a UV of 0.4 in Paranggupito, where spicy foods are an everyday staple, while *S. polyanthum* also scored 0.4 in Gudangharjo, highlighting its significance in local rituals and culinary practices. Meanwhile, species with a UV of 0.2 were generally cited less frequently and often limited to specific households or uses.

Some plants were culturally or ecologically restricted to specific villages. For instance, *Hibiscus rosa-sinensis* was a prominent feature in Johunut due to its ornamental and boundary functions. At the same time, *L. leucocephala* was more common in Gudangharjo as a fodder plant on steep marginal land. These distinctions highlight the significant role of local traditions and household priorities in shaping species distribution alongside environmental conditions.

Despite such variations, the overall structure of homegarden plant use showed remarkable consistency in supporting household needs, underscoring the impressive adaptability and resilience and adaptability of this traditional land-use system across multiple karst settings.

Species with highest cultural use and symbolism

Beyond their practical functions, several non-medicinal plant species held distinct symbolic or ritual value within the communities of Paranggupito. Respondents frequently cited these species not only for their utility but also for their role in social events, ceremonies, and markers of local identity. In many cases, their continued cultivation was motivated more by cultural attachment than direct material use (Table 6).

One of the most consistently mentioned species was *M. a. balbisiana* (banana), whose leaves and pseudostems are essential components in local rituals such as *selamatan*, funerals, and wedding offerings. The banana plant was also valued as a boundary marker and a symbol of fertility.

Cocos nucifera (coconut) was another culturally significant species. In addition to its multi-use nature, it was associated with ancestral traditions, house-building rituals, and culinary symbolism. Its water and oil were believed to have purifying properties, and the plant was often present in ceremonial offerings.

Tectona grandis (teak) was respected not only for its high economic value but also as a status symbol. Planting teak near the house was often linked to aspirations of prosperity and intergenerational wealth. Its presence was particularly emphasized in Johunut and Paranggupito.

Other culturally loaded species included *O. basilicum* and *S. polyanthum*, which are used in food flavoring, religious offerings, and grave maintenance; *B. spectabilis*, which is valued not only as an ornamental but also as a privacy screen and informal property demarcator; and Cananga odorata, which older respondents cite for its role in traditional Javanese rituals and wedding decorations.

These species exemplify the biocultural interface of homegardens, where ecological choices are deeply interwoven with spiritual, symbolic, and social meanings. Their conservation, therefore, is not merely a matter of species survival but of cultural continuity and heritage preservation.

Discussion

Diversity and multifunctionality of non-medicinal plants

The extensive diversity of non-medicinal plants recorded in the homegardens of Paranggupito—comprising 143 species across 55 families—demonstrates the critical role these systems play in rural livelihoods within karst landscapes. Such biodiversity surpasses that documented in similar tropical agroecosystems and reflects a dynamic interplay between ecological constraints and human management strategies (Wiersum 2004; Kefale 2020; Sholekha et al. 2023).

Table 6. Species richness and key culturally significant species (UV=0.4) across the three study villages

Village	Species richness	Culturally significant species (UV = 0.4)
Johunut	95	*Pennisetum purpureum*, *Anacardium occidentale*, *Piper betle*, *Manihot esculenta*, *Citrus aurantifolia*, *Psidium guajava*, *Capsicum annuum*
Paranggupito	102	*Piper betle*, *Anacardium occidentale*, *Psidium guajava*, *Leucaena leucocephala*, *Mangifera indica*, *Cocos nucifera*, *Zea mays*, *Capsicum annuum*, *Syzygium polyanthum*
Gudangharjo	83	*Carica papaya*, *Psidium guajava*, *Zea mays*, *Mangifera indica*, *Gnetum gnemon*, *Capsicum annuum*

This richness can be attributed to the multifunctional nature of homegardens, which integrate food production, aesthetic values, cultural practices, and ecological services within a limited spatial framework (Nair 2001; Yinebeb et al. 2022; Suwartapradja et al. 2023). In karst regions, where soil fertility and water availability are limited, the deliberate selection of drought-tolerant, multipurpose species ensures resilience and continuity of resource availability (Mane et al. 2019; Jiang et al. 2023).

The dominance of food and ornamental plants highlights the intertwined goals of sustenance and cultural identity preservation. Food plants provide essential nutrition and supplement household diets, while ornamental species fulfill aesthetic, symbolic, and social functions, enhancing community well-being (Cahyaningsih et al. 2022; Hanun et al. 2023). This multifunctionality confirms homegardens as socio-ecological hotspots where biodiversity conservation and cultural heritage coalesce (Garibaldi and Turner 2004; Sharma et al. 2024).

Furthermore, the presence of spices, fodder, and construction materials within the non-medicinal category underscores the diverse livelihood needs met by homegardens. This diversity buffers households against external shocks, such as market fluctuations or climatic variability, by providing readily accessible resources (Adhikari 2021; Korpelainen 2023).

Overall, the findings emphasize the value of non-medicinal plant diversity not merely as a reflection of species richness but as a manifestation of complex human-environment interactions, where traditional knowledge guides sustainable resource use and ecosystem stewardship in fragile karst environments.

Cultural salience and Use Value (UV) patterns

Use Value (UV) analysis serves as an effective quantitative tool to elucidate the relative cultural importance of plant species within local communities (Phillips and Gentry 1993). In this study, species such as *M. indica*, *C. papaya*, and *Z. officinale* emerged with the highest UV scores, reflecting their pervasive use and cultural embeddedness in Paranggupito's karst homegardens. These results align with previous ethnobotanical research in Indonesian rural settings, which consistently identifies fruit trees and spices as keystone species due to their versatile and multifunctional roles, showcasing the adaptability of local communities (Hanun et al. 2023; Wulandari et al. 2024; Afrianto et al. 2025).

The prominence of culinary spices with UVs comparable to staple food plants indicates the cultural centrality of flavor and traditional cuisine in local foodways. For example, *C. annuum*'s high UV underscores the importance of chili as both a dietary staple and an element in ritual preparations, a pattern also reported in Javanese ethnobotany (Wijaya et al. 2020). This reflects a broader understanding that plant importance is not solely driven by caloric contribution but also by symbols and the rich sensory values they bring to local foodways.

Variations in UV values further illuminate household preferences and adaptation strategies. Species with year-round availability, ease of propagation, and multipurpose functions tend to achieve higher UV scores, illustrating practical and cultural criteria in species selection. These findings underscore the integration of ecological suitability and cultural relevance in sustaining homegarden diversity.

Ultimately, UV patterns provide insights not only into which species are most valued but also into the resilience of traditional knowledge systems. Species with consistently high UVs across villages suggest stable cultural transmission, while those with variable UVs may point to shifts influenced by changing socio-economic or environmental factors.

Plant part use and household adaptation

The predominance of fruits and leaves as the most utilized plant parts within the homegardens reflects a pragmatic adaptation to both nutritional and ecological factors. Fruits, being rich in essential vitamins and sugars, serve as important direct food sources for households, while leaves offer micronutrients and are often used as vegetables or fodder, contributing to dietary diversity and livestock sustenance (Adhikari 2021).

This preference aligns with the seasonally limited growing conditions characteristic of karst landscapes, where shallow soils and irregular water availability restrict plant growth. Perennial fruit trees and leafy vegetables tend to be more resilient and provide more reliable yields than annual crops, making them valuable in buffering food security risks (Vico and Brunsell 2018; Mane et al. 2019).

The substantial use of rhizomes and tubers, particularly among Zingiberaceae and Euphorbiaceae families, further illustrates households' strategies to optimize energy storage and ensure availability during periods of scarcity. These below-ground storage organs also contribute to soil stabilization and carbon sequestration, supporting the ecological function of homegardens beyond direct consumption (Nair 2001; Wiersum 2004; Ottaviani et al. 2021).

Moreover, the use of multiple plant parts within a single species—such as fruit, leaf, and stem—indicates a high degree of plant resource efficiency and multifunctionality, a hallmark of traditional agroecosystems (Garibaldi and Turner 2004). This multifunctionality not only maximizes resource use but also enhances resilience to environmental stresses and socio-economic fluctuations. In sum, the patterns of plant part utilization documented in this study demonstrate intimate knowledge of species' ecological traits and a deliberate alignment of household needs with the constraints imposed by the karst environment.

Growth forms and spatial structuring in karst systems

The predominance of tree species (39.5%) in homegardens across the karst landscape of Paranggupito reflects a strategic ecological and cultural adaptation to the constraints of limestone geology. Trees provide essential resources such as fruits, timber, and shade, while also contributing to microclimate regulation, soil stability, and limited water retention capacity—functions that are vital in karst environments with shallow, porous soils and seasonal drought (Ellison et al. 2017)

Shrubs and herbs together account for nearly half of the recorded species, at 23.1% and 25.2% respectively, reinforcing the concept of vertical stratification in homegarden design. This stratification enhances productivity by optimizing light use and spatial efficiency (Nair 2001). Moreover, it buffers households from seasonal scarcity, as different growth forms yield resources at different times and microhabitats (Wiersum 2004).

Climbing plants, though comprising only 12.2% of total species, occupy vertical niches that would otherwise remain unused. Their integration exemplifies local ecological intelligence in intensifying land use on marginal terrain typical of karst regions.

The overall architectural complexity of these homegardens demonstrates a deep-rooted traditional knowledge system that integrates ecological function with household subsistence. Such spatial configurations embody sustainable land-use practices that support both biodiversity maintenance and ecological services in fragile karst ecosystems.

Inter-village variations and cultural specificity

The comparative analysis of plant species composition and Use Value (UV) across the villages of Johunut, Paranggupito, and Gudangharjo reveals both shared usage trends and distinctive local preferences. While several species appeared across multiple sites, their perceived importance varied. For instance, *M. indica* was identified as a culturally significant species only in Paranggupito based on its high UV, while *C. papaya* held similar status only in Gudangharjo. These differences reflect how microclimatic conditions, socio-economic contexts, and cultural practices shape plant selection and valuation at the village level (Arsyad 2018; Suwardi et al. 2024).

For instance, *C. annuum* displayed notably higher UV scores in Paranggupito, aligning with the village's culinary traditions that favor spicier flavors. Conversely, *S. polyanthum* was more culturally significant in Gudangharjo, often linked to specific ritual practices and culinary customs unique to that community. Johunut's greater species richness, particularly in ornamental plants, may be associated with its higher population density and more extensive social exchange networks fostering plant diversity.

These findings underscore the importance of recognizing local context and cultural specificity in ethnobotanical studies. Conservation and development initiatives should, therefore, be tailored to respect and incorporate community-level knowledge systems and plant preferences rather than applying uniform strategies across heterogeneous landscapes.

Biocultural conservation and knowledge transmission

The strong cultural significance attached to multipurpose species such as *M. a. balbisiana*, *C. nucifera*, and *T. grandis* highlights the intertwined nature of biological and cultural conservation within the homegarden systems of Paranggupito. These species serve not only practical functions but also embody social identities, spiritual values, and historical continuity, fitting the concept of cultural keystone species (Garibaldi and Turner 2004).

However, the demographic profile of respondents, skewed toward older adults, signals a potential erosion of traditional knowledge as younger generations become less engaged with local agroecological practices. This knowledge loss threatens the maintenance of species diversity and the sustainable management of homegardens, as the cultural transmission is essential for preserving both plant use and associated practices (Hanun et al. 2023; Suwardi et al. 2024).

To address these challenges, conservation strategies must integrate biocultural approaches. This approach supports community-led documentation, education, and revitalization of ethnobotanical knowledge, which are not just beneficial but necessary. Strengthening intergenerational learning, promoting cultural pride, and linking traditional plant management with contemporary sustainable development goals are critical to safeguarding both biodiversity and cultural heritage in karst landscapes.

The results from this study affirm the urgency of recognizing homegardens as living repositories of biocultural diversity. They also underline the crucial role of traditional knowledge in fostering resilient socio-ecological systems, emphasizing the importance of preserving and utilizing this knowledge.

In conclusion, this study provides a comprehensive insight into the diversity, use, and cultural significance of non-medicinal plants in homegardens of a tropical karst landscape in Central Java, Indonesia. The documented 143 species demonstrate the high biodiversity and multifunctionality of these agroecosystems, which fulfill diverse household needs ranging from food and ornamentation to fodder and ritual use. Use Value (UV) analysis highlighted key species such as *M. indica*, *C. papaya*, and *Z. officinale* as culturally and practically important. The structural predominance of trees and the utilization of fruits and leaves reflect adaptive strategies to the challenges of the karst environment, such as shallow soils and water scarcity. Comparisons across villages reveal both shared and distinct patterns of plant use shaped by local cultural practices and ecological conditions. Moreover, the presence of culturally significant multipurpose plants underscores the importance of integrating biocultural conservation with traditional knowledge transmission. Given high levels of concentration of plant knowledge among older community members, urgent efforts are needed to sustain intergenerational knowledge exchange and incorporate traditional practices into broader conservation and development frameworks. Ultimately, this research contributes valuable understanding of biodiversity conservation, cultural heritage preservation, and sustainable livelihoods in fragile karst ecosystems.

REFERENCES

Adhikari J. 2021. Home garden, along with its functional category and key species reported in Nepal: A review. Revi Food Agric 2 (1): 16-19. DOI: 10.26480/rfna.01.2021.16.19.

Afrianto WF. 2025. Ethnobotanical documentation of home gardens in relation to Javanese basic life needs in Kediri District, East Java, Indonesia. Asian J Ethnobiol 8 (1): 79-91. DOI: 10.13057/asianjethnobiol/y080107.

Arsyad M. 2018. Studi etnobotani tumbuhan obat oleh masyarakat Tamban Kabupaten Barito Kuala. Insan Farmasi Indonesia 1 (1): 85-95. [Indonesian]

Ashari FN, Saptana FN, Purwantini TB. 2012. Potensi dan prospek pemanfaatan lahan pekarangan untuk mendukung ketahanan pangan. Forum Penelitian Agro Ekonomi 30 (1): 13-30. DOI: 10.21082/fae.v30n1.2012.13-30. [Indonesian]

Backer CA, Bakhuizen van den Brink JR. 1963. Flora of Java Vol. I. P Noordhoff, Groningen, Netherlands.

Badan Pusat Statistik (BPS). 2023. Kecamatan Paranggupito Dalam Angka 2023. BPS, Wonogiri. [Indonesian]

Borelli T, Hunter D, Powell B, Ulian T, Mattana E, Termote C, Pawea L, Beltrame D, Penafiel D, Tan A, Taylor M, Engels J. 2020. Born to eat wild: An integrated conservation approach to secure wild food plants for food security and nutrition. Plants 9 (10): 1299. DOI: 10.3390/plants9101299.

Cahyaningsih AP, Arifiani KN, Aprilia D, Nugroho ME, Setyawan AD. 2022. Ethnobotanical study of the non-medicinal plant by village communities in the karst area of Pacitan, East Java, Indonesia. Intl J Trop Drylands 6 (1): 1-10. DOI: 10.13057/tropdrylands/t060101.

Ellison D, Morris CE, Locatelli B et al. 2017. Trees, forests and water: Cool insights for a hot world. Glob Environ Chang 43: 51-61. DOI: 10.1016/j.gloenvcha.2017.01.002.

Farikha KN, Arlysia V, Raharjo YAA, Santika YE, Deristani A, Setyawan AD. 2025. Traditional knowledge of karst land management in Gunung Sewu, Java, Indonesia. Intl J Trop Drylands 9 (1): 1-9. DOI: 10.13057/tropdrylands/t090101.

Garibaldi A, Turner N 2004. Cultural keystone species: Implications for ecological conservation and restoration. Ecol Soc 9 (3): 1. DOI: 10.5751/ES-00669-090301.

Hanun Z, Athaya DN, Sholekha AM, Damayanti CE, Nazar IA, Cahyaningsih AP, Junaedi E, Buot JR IE Setyawan AD. 2023. The use of non-medicinal plants by the community of Ayah Village in South Gombong Karst Area, Kebumen, Central Java, Indonesia. Nusantara Biosci 15 (1): 68-78. DOI: 10.13057/nusbiosci/n150108.

Heyne K. 1987. Tumbuhan Berguna Indonesia, Volume II. Yayasan Sarana Wana. Jaya, Jakarta. [Indonesian]

Ivanova S, Delattre C, Karcheva-Bahchevanska D, Benbasat N, Nalbantova V, Ivanov K. 2021. Plant-based diet as a strategy for weight control. Foods 10 (12): 3052. DOI: 10.3390/foods10123052.

Jiang S, Xiong K, Xiao J, Yang Y, Huang Y, Wu Z. 2023. Agroforestry ecosystem structure and the stability improvement strategy in control of karst desertification. Forests 14 (4): 845. DOI: 10.3390/f14040845.

Kefale B. 2020. Homegarden agroforestry in Ethiopia-A review. Intl J Bio-resour Stress Manag 11 (4): 345-352. DOI: 10.23910/1.2020.2118d.

Korpelainen H. 2023. The role of home gardens in promoting biodiversity and food security. Plants 12 (13): 2473. DOI: 10.3390/plants12132473.

Malapane OL, Musakwa W, Chanza N. 2024. Indigenous agricultural practices employed by the Vhavenda community in the Musina local municipality to promote sustainable environmental management. Heliyon 10 (13): e33713. DOI: 10.1016/j.heliyon.2024.e33713.

Mane AM, Prabakaran N, Manchi SS. 2019. Floral diversity, composition, and recruitment on the karstland of Baratang Island, India. Ecol Complex 37: 47-54. DOI: 10.1016/j.ecocom.2018.11.002.

Mekonen T, Giday M, Kelbessa E. 2015. Ethnobotanical study of homegarden plants in Sebeta-Awas District of the Oromia Region of Ethiopia to assess use, species diversity and management practices. J Ethnobiol Ethnomed 11: 64. DOI: 10.1186/s13002-015-0049-8.

Nair PKR 2001. Do tropical homegardens elude science, or is it the other way around? Agrofor Syst 53 (3): 239-245. DOI: 10.1023/A:1013388806993.

Nofrianti N, Utaminingrum W, Hartanti D. 2021. Traditional use of medicinal plants in Baturraden, Central Java. Jurnal Jamu Indonesia 6 (2): 42-60. DOI: 10.29244/jji.v6i2.206.

Nurcahyo FD, Zen HM, Rahma HS, Triyanto A, Yasa A, Naim DM, Setyawan AD. 2024. Ethnobotanical study of medicinal plants used by local communities in the Upper Bengawan Solo River, Central Java, Indonesia. Intl J Bonorowo Wetlands 14 (1): 25-36. DOI: 10.13057/bonorowo/w140104.

Ottaviani G, Lubbe FC, Lepš J, Lisner A, Martínková J, Mudrák O, Klimešová J. 2021. Strong impact of management regimes on rhizome biomass across Central European temperate grasslands. Ecol Appl 31 (4): e02317. DOI: 10.1002/eap.2317.

Phillips OL, Gentry AH. 1993. The useful plants of Tambopata, Peru. II: Additional hypothesis testing in quantitative ethnobotany. Econ Bot 47: 33-43. DOI: 10.1007/BF02862204.

Rahman AA, Rubiyanti R, Kosasih ED. 2022. Increasing knowledge of medicinal plants usage for the prevention of digestive tract diseases in Tamansari Sub-district, Tasikmalaya City. Jurnal Pengabdian dan Pemberdayaan Masyarakat Indonesia 2 (2): 39-44. DOI: 10.59247/jppmi.v2i2.66.

Sharma R, Mina U, Devi A, Kumar BM. 2024. Do homegardens act as agent of agrobiodiversity conservation: a case study of homegardens of diverse socio-ecological zones in the Brahmaputra Valley, Assam. Front Sustain Food Syst 8: 1366499. DOI: 10.3389/fsufs.2024.1366499.

Sholekha AM, Yulia IT, Hanun Z, Perwitasari IG, Cahyaningsih AP, Sunarto, Sutarno, Sugiyarto, Buot Jr IE, Setyawan AD. 2023. Local knowledge and the utilization of non-medicinal plants in home garden by the people of Donorejo Village in the Menoreh Karst Area, Purworejo, Central Java, Indonesia. Biodiversitas 24 (1): 645-657. DOI: 10.13057/biodiv/d240173.

Suwardi AB, Navia ZI, Mubarak A, Rahmat R, Cristy P, Wibowo SG, Irawan H. 2024. The diversity and traditional use of home garden plants near Kerinci Seblat National Park, Indonesia. Biodiversitas 25 (7): 3284-3299. DOI: 10.13057/biodiv/d250750.

Suwartapradja OS, Iskandar J, Iskandar BS, Mulyanto D, Suroso, Nurjaman D, Nisyapuri FF. 2023. Plants diversity and socioecological functions of homegarden in Sundanese rural area: a case in Sumedang district, West Java, Indonesia. Biodiversitas 24 (1): 156-175.DOI: 10.13057/biodiv/d240120.

Tolentino PJS, Navidad JRL, Angeles MD, Fernandez AP, Villanueva ELC, Obena RDR, Buot Jr IE. 2020. Review: Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines. Biodiversitas 21 (4): 1597-1613. DOI: 10.13057/biodiv/d210441.

Tynsong H, Dkhar M, Tiwari BK. 2020. Review: Traditional ecological knowledge of tribal communities of North East India. Biodiversitas 21: 3209-3224. DOI: 10.13057/biodiv/d210743.

Vico G, Brunsell NA. 2018. Tradeoffs between water requirements and yield stability in annual vs. perennial crops. Adv Water Resour 112: 189-202. DOI: 10.1016/j.advwatres.2017.12.014.

Whitten T, Soeriaatmadja RE, Afiff SA. 1996. Ecology of Java & Bali. Periplus Editions, HK.

Widyaningsih GA. 2017. Permasalahan hukum dalam perlindungan ekosistem karst di Indonesia (Studi Kasus: Ekosistem Karst Sangkulirang–MangkaliHat, Provinsi Kalimantan Timur). Jurnal

Hukum Lingkungan Indonesia 3 (2): 73-95. DOI: 10.38011/jhli.v3i2.44. [Indonesian]
Wiersum KF 2004. Forest gardens as an intermediate land-use system in the nature-culture continuum: Characteristics and future potential. Agrofor Syst 61: 123-134. DOI: 10.1023/B:AGFO.0000028994.54710.44
Wijaya CH, Harda M, Rana B. 2020. Diversity and potency of *Capsicum* spp. grown in Indonesia. In: Dekebo A (eds). *Capsicum*. IntechOpen, London. DOI: 10.5772/intechopen.92991.
Wulandari RS, Muflihati M, Aden LL, Wahdina W. 2024. Utilization of plants as traditional food by the Dayak Iban community of Mensiau Village, Batang Lupar District, Kapuas Hulu Regency. Jurnal Biologi Tropis 24 (1): 489-500. DOI: 10.29303/jbt.v24i1.6512.
Yinebeb M, Lulekal E, Bekele T, Lemessa D. 2022. Homegardens plant species richness and their use types have positive associations across agricultural landscapes of Northwest Ethiopia. Glob Ecol Conserv 40: e02342. DOI: 10.1016/j.gecco.2022.e02342.
Zenderland J, Hart R, Bussmann RW, Paniagua Zambrana NY, Sikharulidze S, Kikvidze Z, Kikodze D, Tchelidze D, Khutsishvili M, Batsatsashvili K. 2019. The use of “Use Value”: Quantifying importance in ethnobotany. Econ Bot 73: 293-303. DOI: 10.1007/s12231-019-09480-1.

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Traditional foodways and conservation beliefs among Javanese communities in the Paranggupito Karst, Indonesia

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Abstract. *Candraningtyas CF, Charsyah C, Setyasih DMD, Mardianto MB, Chairunisa S, Md Naim D, Setyawan AD. 2025. Traditional foodways and conservation beliefs among Javanese communities in the Paranggupito Karst, Indonesia. Intl J Trop Drylands 9: 36-49.* This study explores the interconnections between food traditions, ritual practices, and biodiversity conservation among Javanese communities living in the karst landscape of Paranggupito, Central Java, Indonesia. Drawing on ethnographic fieldwork in three villages—Songbledeg, Gudangharjo, and Gunturharjo—the research documents the use of plant and animal species in both daily diets and ceremonial contexts. It highlights how traditional foods such as *tumpeng*, *urap*, *tiwul*, and *nagasari* require specific species that are cultivated, preserved, and protected across generations. Ritual events—including *mitoni*, *nembung*, *rasulan*, and commemorations of the deceased—emerge as cultural drivers of biodiversity conservation, reinforcing the need to maintain agroecological diversity. Moreover, the study reveals how sacred beliefs and taboos, such as the protection of white Java porcupines (*Hystrix javanica*) and *Danyangan* trees (*Ficus* spp.), shape informal yet potent conservation ethics. These beliefs, deeply rooted in spirituality and upheld by social norms, significantly contribute to the sustainability of species and landscapes without the need for external regulation. The findings underscore the invaluable role of integrating indigenous knowledge and cultural practices into modern conservation frameworks, particularly in ecologically fragile regions such as karst areas. By viewing food and ritual as conduits of ecological stewardship, the study presents a compelling model of biocultural resilience where cultural identity and environmental sustainability are mutually reinforcing.

Keywords: Biodiversity, culinary heritage, Javanese rituals, karst ecosystem, traditional knowledge

INTRODUCTION

Indonesia, as one of the world's mega-biodiverse countries, harbors not only rich biological resources but also an abundance of cultural heritage across its archipelagic landscape. The intersection between biological and cultural diversity is especially evident in rural communities, where natural resource use is intimately tied to long-standing traditions, rituals, and culinary practices. These communities, through their deep-rooted knowledge and practices, play a crucial role in managing resources, a fact that we, as environmental scientists, cultural anthropologists, and policymakers, should deeply respect and appreciate. This cultural richness is supported by ecological specificity in various regions, including the karst landscapes of Java, Indonesia. In such environments, human adaptation to environmental limitations has produced locally grounded wisdom in managing biodiversity. The cultural practices of these communities—reflected in food, rituals, and taboos—constitute valuable systems of knowledge that contribute to the sustainable use of biodiversity (Batoro and Siswanto 2017; Iskandar 2017).

Among these cultural expressions, food emerges as one of the most enduring domains. It serves not only as sustenance but also as a medium of identity, spirituality, and ecological interaction. Traditional cuisine is often shaped by the availability of native plant and animal species, which are selected and maintained for their taste, symbolism, ritual function, and adaptive value. In many parts of Indonesia, particularly in Java, food plays a central role in life-cycle rituals such as birth ceremonies, weddings, and funerals. These rituals reflect a deeply rooted worldview that links human well-being to environmental balance (Bessière 1998; Nasir 2019). As a result, unique crop varieties are preserved, and agrodiversity is promoted, since ritual and everyday foods are rarely substituted or abandoned (Sutrisno et al. 2020).

The Javanese community, which comprises over 40% of Indonesia's population, upholds a diverse culinary repertoire embedded in both spiritual and ecological values (Suharnomo and Syahruramdan 2018). In the karst regions of Central Java, such as Paranggupito, agricultural practices are shaped by the challenges of shallow soils and limited water access. Here, culturally selected crops like cassava (*Manihot esculenta*), maize (*Zea mays*), and coconut (*Cocos nucifera*) become vital. These food plants not only meet nutritional needs but also play symbolic roles in community rituals. Events such as *slametan* and *rasulan*, which are performed to honor ancestors or give thanks to nature, often feature these ingredients as offerings (Koentjaraningrat 2009; Henri et al. 2018). Food, in this context, becomes more than sustenance—it is a form of ecological stewardship.

Many of these rituals also incorporate sacred prohibitions and taboos that function as informal conservation tools. For example, the white porcupine (*Hystrix javanica*) is regarded as a spiritual guardian and is therefore protected from hunting. This belief indirectly supports government conservation efforts (Geng et al. 2017). Similarly, ritual protection is extended to spiritually charged trees such as the *banyan* (*Ficus benjamina*) or strangler fig (*Ficus annulata*), collectively known as *danyangan*. These beliefs are not written into law, yet they are practiced and internalized through cultural codes passed down across generations (Hongmao et al. 2002; Mensah et al. 2020).

Integrating such traditions into conservation frameworks has shown promise in enhancing community participation and achieving sustainable outcomes. While top-down conservation models often struggle to gain local compliance, cultural practices embedded in daily life provide a bottom-up alternative that aligns ecological health with community interests (Kealiikanakaoleohaililani et al. 2021; Ahmad et al. 2022). In Paranggupito's agricultural landscape—where forests, fields, and homes are interwoven—rituals grounded in food and spirituality serve as practical conservation mechanisms. These practices also preserve heirloom food species and foster agroecological diversity, which in turn buffers communities against climate risks and economic dependence (dos Santos et al. 2021).

Despite the pressures of modernization, Paranggupito's karst communities continue to uphold their cultural and ecological heritage through food. Traditional ingredients like tubers (*Dioscorea esculenta*), arrowroot (*Maranta arundinacea*), sticky rice, banana, and coconut remain central to both ritual and daily dishes. Their continued use reflects not nostalgia, but a conscious commitment to resilience. Culinary items such as *tiwul*, *gethuk*, *nagasari*, and *serundeng* encapsulate a system in which agriculture, spirituality, and ecological values are intertwined (Herminingrum 2019; Dewantara 2018). In this way, foodways become living expressions of memory, identity, and environmental care.

This study aims to document and analyze the role of cultural food traditions and ritual practices in biodiversity conservation among Javanese communities in the Paranggupito Karst of Central Java. It explores how local knowledge, foodways, and symbolic rituals contribute to the protection of plant and animal species, agricultural diversity, and overall ecosystem health. By examining these cultural-environmental interactions, the study offers insights into how indigenous knowledge systems can be integrated into modern conservation strategies. Ultimately, it advocates for culturally grounded, community-led approaches that strengthen both biodiversity and local livelihoods in the face of ecological change.

MATERIALS AND METHODS

Study area

This research was conducted in the karst region of Paranggupito Sub-district, located in Wonogiri District, Central Java, Indonesia (Figure 1). The area is part of the Gunung Sewu UNESCO Global Geopark, which is known for its unique karst topography and rich cultural heritage. Three villages were selected as study sites: Songbledeg Village, Gudangharjo Village, and Gunturharjo Village. These villages represent different population densities and land use characteristics within the karst system. Gunturharjo is the largest, covering an area of 10.58 km², followed by Gudangharjo (7.78 km²) and Songbledeg (7.46 km²). Based on 2023 data from the Central Statistics Agency, the populations of Gunturharjo, Gudangharjo, and Songbledeg were 3,034, 1,568, and 2,543 people, respectively (Central Statistics Agency 2023).

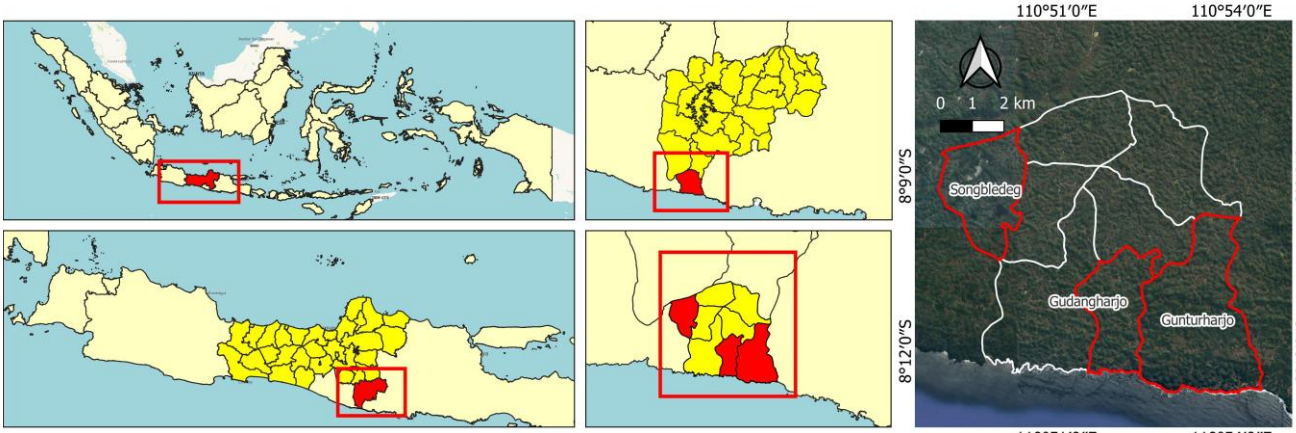

Figure 1. Map of the research location in Paranggupito, Wonogiri, Central Java, Indonesia

The karst ecosystem in this region consists of limestone hills, caves, underground rivers, and rock crevices that support distinctive biological assemblages. Vegetation is generally adapted to dry, shallow, and nutrient-poor soils, with species such as wild orchids, drought-tolerant shrubs, and small trees with deep root systems (Martosuwito et al. 2013). Fauna includes cave-dwelling bats, specialized insects, birds, and endemic aquatic organisms inhabiting subterranean streams (Sulistiyowati and Haryono 2021). The biodiversity of this karst landscape holds important ecological and economic value, supporting community livelihoods through small-scale agriculture, ecotourism, and environmental research (Tolentino et al. 2020).

Despite its ecological value, the karst landscape in Paranggupito faces ongoing threats from limestone mining, land conversion, and unsustainable natural resource extraction. These pressures highlight the urgent need for community-based conservation initiatives that integrate local cultural practices into biodiversity management. Cultural values held by local people—especially in relation to sacred trees and protected fauna—offer pathways for sustainable coexistence between humans and nature (Mensah et al. 2020).

Community and ecosystem characteristics

The communities residing in Songbledeg, Gudangharjo, and Gunturharjo Villages are predominantly farmers who rely heavily on the surrounding environment for their livelihoods. These rural populations maintain close relationships with their land, forests, and water sources, which are integral to agricultural practices, animal husbandry, and food processing. Shrubs and tree leaves are commonly collected from nearby forests to feed livestock. At the same time, local fields and gardens are cultivated with food crops such as cassava, maize, rice, and various vegetables. These practices demonstrate the community's dependence on natural cycles and reflect an agroecological system shaped by the karst environment.

The karst topography presents unique ecological challenges. Soil in these areas is often thin and rocky, limiting intensive farming and requiring adaptive strategies for food production. Terraced fields are used to maximize cultivation on sloped limestone terrain, and the cropping system is typically diversified to ensure food security throughout the dry and rainy seasons. In many cases, households maintain home gardens that serve not only as food sources but also as medicinal and ritual plant reserves, reflecting both practical and cultural functions of local biodiversity (Iskandar 2017; Sutrisno et al. 2020).

A deeply spiritual worldview underpins the environmental management practices in these villages. Sacred natural elements such as large old trees—locally known as *danyangan*—are preserved as dwelling places for spirits and ancestral guardians. These trees are ritually protected and never cut down, except for minimal trimming during ceremonial events. Similarly, certain animals, such as the white-colored Java porcupine (*H. javanica*), are protected due to taboos that associate them with mystical consequences if harmed. These cultural norms play a crucial role in local conservation ethics, indirectly protecting species and maintaining ecosystem stability (Hongmao et al. 2002; Geng et al. 2017).

The integration of ritual beliefs and environmental management is further demonstrated in annual community ceremonies such as *rasulan* and *slametan*. These ceremonies, where the entire village participates in environmental clean-up activities, offerings, and food sharing, serve as a testament to the community's commitment to preserving their cultural heritage. These events not only strengthen social cohesion but also reinforce environmentally responsible behaviors. In such ceremonies, specific trees and water sources are ritually purified, and the use of designated plant species for offerings serves as a cultural mechanism for preserving local biodiversity.

The interaction between the community and its karst ecosystem is a prime example of an ethnoecological system—one in which environmental constraints, spiritual beliefs, and cultural practices coevolve. These communities play a crucial role in managing the karst ecosystem, viewing nature not as separate from culture but as a continuum of mutual responsibility. Their way of life reflects a low-impact, high-resilience strategy for managing biodiversity in fragile ecosystems.

Data collection procedures

This study employed a qualitative ethnographic approach to document traditional practices, food systems, and conservation-related beliefs among Javanese communities in the Paranggupito Karst region. Fieldwork was conducted in three villages: Songbledeg, Gudangharjo, and Gunturharjo. The research team utilized structured and semi-structured interview guides, field notebooks, a digital camera for documentation, and a laptop for data processing and reporting.

A total of 102 respondents were interviewed, selected using a combination of purposive and random sampling techniques. Purposive sampling targeted key informants such as village elders, ritual leaders, and individuals with extensive knowledge of cultural practices and local biodiversity. These individuals were typically over 50 years old and had long-standing involvement in ritual and culinary traditions. To capture a broader range of perspectives, random sampling was also employed to include participants from diverse social, economic, and gender backgrounds within each village.

Interviews were conducted through home visits, with each session lasting approximately 30 minutes. Researchers engaged directly with participants to build rapport and ensure context-rich responses. The semi-structured interview format allowed for both guided and open-ended discussions, facilitating the collection of factual knowledge—such as species used in food or ritual—as well as insights into belief systems and taboos (Döringer 2021).

The questionnaire consisted of two sections. The first covered demographic information, including age, gender, education level, and occupation. The second explored respondents' familiarity with local flora and fauna, traditional food preparation, and participation in cultural events such as *slametan*, *rasulan*, and other ceremonies.

Specific focus was given to species used in offerings and food, the parts harvested, and the symbolic meanings attached. Information on local taboos—such as prohibitions on hunting certain animals during pregnancy—was also gathered to understand culturally embedded conservation behavior. Table 1 presents a summary of respondent demographics across the three study sites.

Interview focus and themes

The interview sessions were designed to explore various dimensions of local knowledge, with a focus on the community's relationship with biodiversity, ritual practices, and food traditions. The main themes covered during the interviews included: (i) traditional food preparation and plant use; (ii) cultural ceremonies and associated food species; (iii) spiritual beliefs and environmental taboos; and (iv) perceptions of conservation and ecological change.

Respondents were asked to describe traditional dishes and their main ingredients, with particular emphasis on local plant and animal species used in ceremonial and daily cooking. Each interview also aimed to capture the specific parts of the plants (e.g., leaves, tubers, seeds, fruits) that were harvested and their symbolic or ritual significance. These discussions provided insight into how biodiversity is maintained through the continuous use of culturally valued species, a concept aligned with previous ethnobotanical findings in other Indonesian contexts (Putri et al. 2014; Sutrisno et al. 2020).

In addition to documenting food-related knowledge, interviews investigated the structure and meaning of traditional ceremonies such as *mitoni*, *nembung*, *rasulan*, *slametan*, and death rituals. Informants were asked to explain the foods presented during these ceremonies and the cultural logic behind their selection. For example, the preparation of *tumpeng* (cone-shaped rice) during *slametan* was described as a symbol of spiritual ascent and environmental harmony. Respondents also discussed ritual taboos such as the prohibition against hunting *H. javanica* and the cultural significance of sacred trees like the *danyangan*, which reinforced local ecological ethics.

Further, respondents elaborated on their personal experiences and family traditions related to plant conservation, including the cultivation of ritual species in home gardens and the transmission of knowledge about traditional recipes. These themes helped frame biodiversity conservation not only as an ecological process but also as a cultural and spiritual one. Insights from these interviews formed the empirical basis for identifying species of cultural importance and the conservation behaviors embedded in local traditions.

Data analysis

The data obtained from interviews and field observations were analyzed using a qualitative thematic approach. This method involved identifying recurring patterns, meanings, and cultural expressions within the narratives related to biodiversity, ritual practices, and traditional food systems. Responses were first grouped into categories based on the main research themes, such as traditional food knowledge, species used in rituals, spiritual taboos, and perceived links between nature and culture. These categories were then interpreted to reveal the underlying cultural logic that informs community-based environmental stewardship (Döringer 2021).

Each plant and animal species mentioned during the interviews was documented along with its local name, scientific name, family, part used, and its role in either daily food preparation or ceremonial events. These data were used to construct a detailed inventory of culturally important species and their ethnobotanical uses. Descriptive summaries were created to explain the types of rituals, associated foods, and conservation-related beliefs, which are later presented in the next section, along with tables and figures.

Whenever possible, the analysis also linked specific practices to broader theoretical concepts in ethnobiology and conservation science. For instance, the concept of sacred species—such as the *danyangan* trees or white porcupines—was interpreted as a cultural mechanism for in situ conservation. Ritual requirements that involve precise plant species for offerings were analyzed as drivers of agrobiodiversity preservation in household gardens and terraced farms (Hongmao et al. 2002; Mensah et al. 2020). These cultural drivers are particularly significant in dryland karst regions, where ecological fragility demands sustainable land-use strategies rooted in tradition.

Moreover, the data analysis also considered external pressures—such as modernization, urbanization, and climate variability—that challenge the continuity of these cultural practices. In this context, the role of traditional foods and rituals in maintaining biodiversity was examined not only as a legacy system but also as a dynamic response to contemporary ecological and socio-economic realities. The goal of the analysis was to uncover how these culturally embedded practices function as living forms of conservation and how they may be leveraged in designing inclusive, community-based biodiversity strategies.

RESULTS AND DISCUSSION

Sociodemographic characteristics of respondents

The respondents involved in this study were residents of three karst villages in Paranggupito Sub-district: Songbledeg, Gudangharjo, and Gunturharjo. The selection of respondents focused on individuals with rich experiential knowledge related to traditional food practices, rituals, and environmental beliefs. Most participants were elderly and had strong cultural ties to ancestral traditions. The average age of respondents across the three villages ranged from 51 to 56 years, indicating that the older generation largely preserves the knowledge documented in this study.

In terms of gender distribution, female respondents constituted a slightly larger proportion of the sample in Songbledeg and Gunturharjo, while male respondents were more prevalent in Gudangharjo. This variation reflects the different roles men and women play in preserving and transmitting cultural knowledge—women often manage food-related practices. In comparison, men may be more involved in ritual leadership and land management.

Educational attainment among the respondents was generally low, with most having completed only primary or junior secondary school. A few had no formal education, particularly among the older population. Despite limited formal schooling, these individuals possessed deep local knowledge related to biodiversity, agriculture, and cultural ceremonies. Occupationally, the majority of respondents were farmers or engaged in agroforestry, reflecting their dependence on land-based livelihoods and natural resource management. The details of respondent characteristics are summarized in Table 1.

Traditional food practices in the Paranggupito Karst

In the Paranggupito Karst region, traditional food systems are shaped by the community's dependence on locally cultivated and foraged resources. The majority of residents are subsistence farmers who process their agricultural yields into everyday meals and ceremonial dishes. This practice reinforces local food sovereignty while preserving cultural knowledge surrounding the preparation, symbolism, and seasonality of ingredients. Key staple crops include cassava (*M. esculenta*), maize (*Z. mays*), rice (*Oryza sativa*), and coconut (*C. nucifera*), which are grown on terraced lands adapted to the karst topography and limited irrigation.

Cassava holds a prominent place in local food culture. Though not native to Java, its resilience and yield have made it a staple, especially in dryland areas. A variety of dishes have evolved around cassava, such as *nasi tiwul*, *gethuk*, *romeon*, and *utri*, each with distinct preparation techniques and cultural meanings. For instance, *tiwul*—a rice substitute made by steaming dried cassava flour—is often consumed daily, while *gethuk* and *romeon* serve as snacks during social or ritual gatherings. These food items not only highlight nutritional adaptation but also cultural resilience in the face of ecological limitations (Herminingrum 2019).

Rice-based dishes such as *tumpeng* and *nasi jagung* are typically reserved for ceremonial occasions, particularly those involving communal prayers or rites of passage. *Tumpeng*, in particular, is a symbolic dish shaped like a mountain, representing the harmony between humans and nature. It is usually served with side dishes made from vegetables (*urap*), chicken (*ingkung*), eggs, and tempeh, reflecting the agricultural abundance and spiritual unity of the community (Atikaalistiana 2006; Dewantara 2018).

Other traditional foods include *urap*, *pecel*, *nagasari*, *serundeng*, *jadah*, and *ketan*, each combining locally available ingredients with culinary techniques passed down through generations. The use of fresh vegetables such as *Ipomoea aquatica* (water spinach), *Vigna unguiculata* (long bean), and *Cucumis sativus* (cucumber) reflects the integration of biodiversity into daily dietary habits. Furthermore, these dishes are commonly linked with ritual use, creating an inseparable bond between food and spirituality.

Table 2 summarizes the diversity of food traditions recorded during fieldwork. It lists 16 local food types, the species used, and the parts utilized. These traditional foods are also illustrated in Figure 2, while key food crops cultivated in the karst landscape are depicted in Figure 3.

Table 1. Sociodemographic characteristics of respondents (N=102)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	47	46.1%
	Female	55	53.9%
Age Group	40-49 years	17	16.7%
	50-59 years	54	52.9%
	≥60 years	31	30.4%
Average Age	—	—	53.68 years
Education Level	No formal education	5	4.9%
	Elementary school	49	48.0%
	Junior high school	30	29.4%
	Senior high school	14	13.7%
	Higher education	4	3.9%
Occupation	Farmer	84	82.4%
	Small trader/craftsman	10	9.8%
	Housewife	5	4.9%
	Other	3	2.9%

Figure 2. Several traditional foods in Paranggupito, Wonogiri, Central Java, Indonesia: A. *Urap* (Triasandy 2024), B. *Tumpeng* (Atikaalistiana 2006), C. *Tiwul* (Dwiwahyudi 2019)

Table 2. Types of local food, local ingredients/species used

Food traditions	Description	Local name	Common name	Species as the main ingredient	Family	Part used
Tumpeng	Rice is shaped like a mountain, accompanied by side dishes that are typically sourced from the people's harvest.	*Beras*	Rice	*Oryza sativa* L.	Poaceae	Seed
		Ayam	Chicken	*Gallus gallus* f *domesticus*	Phasianidae	Meat and skin
		Telur	Chicken	*Gallus gallus* f. *domesticus*	Phasianidae	Egg
		Tempe	Tempeh	*Glycine max* L.	Fabaceae	Seeds
Pecel	Vegetables that are boiled and then served with peanut sauce.	*Kangkung*	Spinach	*Ipomoea aquatica* Forssk.	Convolculaceae	Young shoots and leaves
		Kacang Panjang	Long beans	*Vigna unguiculata* (L.) Walp.	Papilionaceae	Entire part
		Mentimun	Cucumber	*Cucumis sativus* L.	Cucurbitaceae	Fruit
		Kacang tanah	Peanuts	*Arachis hypogaea* L.	Fabaceae	Seeds
		Tauge	Bean sprouts	*Vigna radiata* (L.) R.Wilczek	Fabaceae	Seeds
Nasi Tiwul	Rice with a chewy texture made from cassava flour.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber
Nasi Jagung	Rice with a sweet flavor and coarse texture made from ground corn.	*Jagung*	Corn	*Zea mays* L.	Gramineae	Seeds
Urap	Traditional salad served with seasoned grated coconut.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber
		Kacang Panjang	Long beans	*Vigna unguiculata* (L.) Walp.	Fabaceae	Entire part
		Kelapa	Coconut	*Cocos nucifera* L.	Arecaceae	Coconut fruit meat
Garut	Food made from boiled or fried arrow-tuber, which has a chewy texture and a slightly sweet flavor.	*Umbi Garut*	Arrow tuber	*Maranta arundinacea* L.	Marantaceae	Tuber
Ganyong	Food made from ganyong tubers with a chewy texture and sweetness tasted similar to potatoes.	*Umbi ganyong*	Cassava tubers	*Canna edulis* Kerr.	Cannaceae	Tuber
Gembili	Food made from boiled or steamed gembili tubers is typically served as a snack.	*Umbi Gembili*	Gembili tubers/ yam bean	*Diosorea esculenta* L.	Diosoreaceae	Tuber
Serundeng	Food made from toasted grated coconut seasoned with spices.	*Kelapa*	Coconut	*Cocos nucifera* L.	Arecaceae	Fruit
Nagasari	Steamed cake made from rice flour, coconut milk, and bananas was wrapped in banana leaves.	*Beras*	Rice	*Oryza sativa* L.	Poaceae	Seeds
		Pisang	Banana	*Musa paradisiaca* L.	Musaceae	Fruit and leaves
		Kelapa	Coconut	*Cocos nucifera* L.	Arecaceae	Coconut fruit water
Utri	Snack made from grated cassava, mixed with palm sugar, wrapped in banana leaves, and steamed.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber
		Gula Jawa	red sugar	*Cocos nucifera* L.	Arecaceae	Coconut tree sap
Ketan	Sticky rice is a type of rice that has a high starch content, which makes it sticky when cooked.	*Beras Ketan*	Sticky rice	*Oryza sativa* var. *glutinosa*	Poaceae	Seed

Jadah	Traditional food made from steamed sticky rice	*Beras Ketan*	Sticky rice	*Oryza sativa* var. *glutinosa*	Poaceae	Seed
		Kelapa	coconut	*Cocos nucifera* L.	Arecaceae	Coconut meat
Gethuk	Preparations were made from crushed cassava and usually mixed with sugar and coloring.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber
		Kelapa	coconut	*Cocos nucifera* L.	Arecaceae	Coconut meat
Manggleng	Meals were made from steamed or boiled cassava (manioc) that is then mashed and mixed with grated coconut and sugar. This dish has a chewy texture and a sweet flavor.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber
		Kelapa	Coconut	*Cocos nucifera* L.	Arecaceae	Coconut fruit meat
		Gula Pasir	Sugarcane	*Saccharum officinarum* L.	Poaceae	Sugarcane stalks
Romeon	Cassava chips are food made from thinly sliced cassava and then fried using cooking oil.	*Singkong*	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Tuber

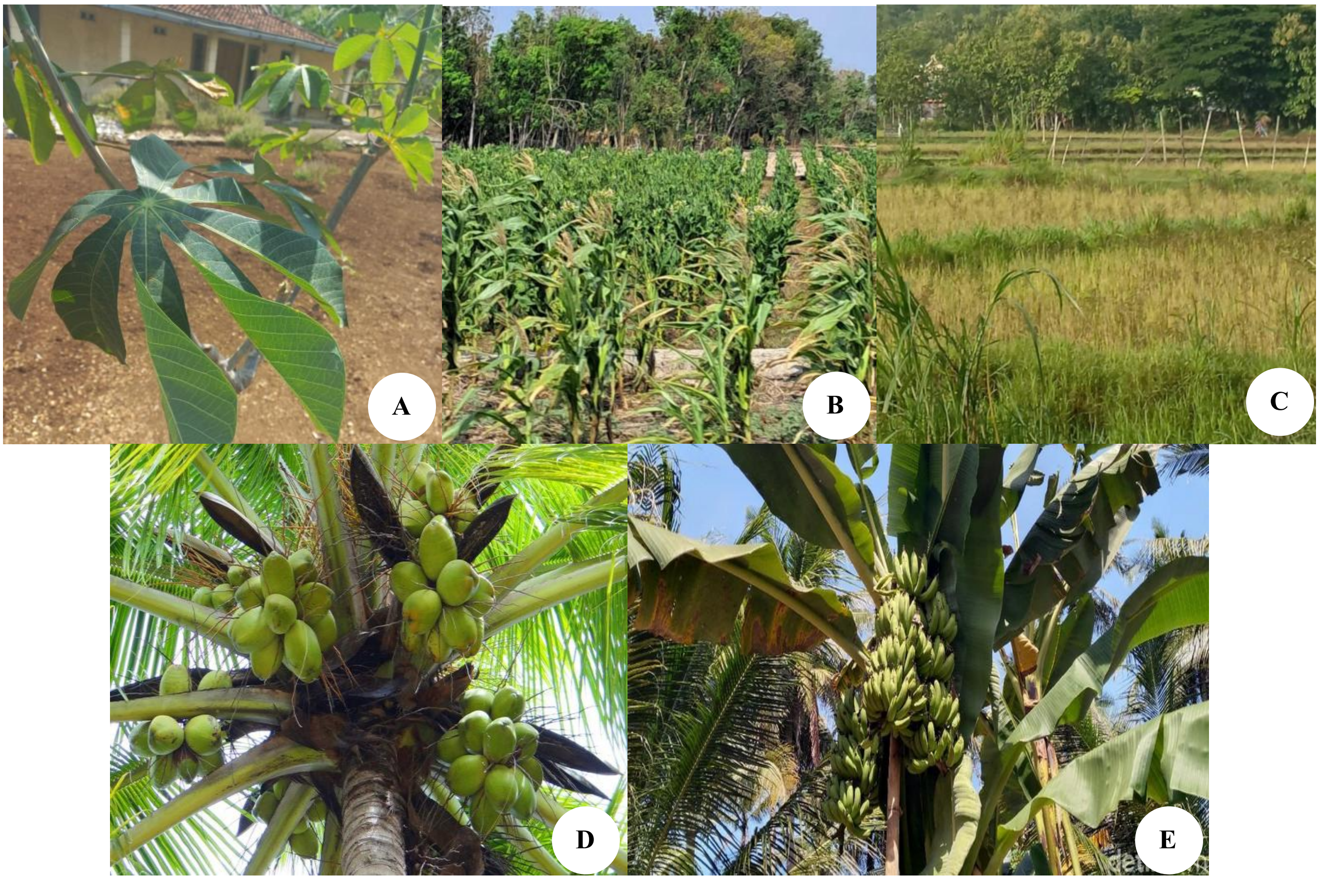

Figure 3. Several plants are used for making traditional foods in dryland Paranggupito Karst, Wonogiri, Indonesia. A. Cassava (*Manihot esculenta*), B. Corn (*Zea mays*), C. Rice (*Oryza sativa*), D. Coconut (*Cocos nucifera*), E. Banana (*Musa paradisiaca*)

Traditional food is not only a matter of sustenance but also functions as a regional identity marker and potential driver of community-based ecotourism. The diversity of flavors, ingredients, and preparation styles offers economic opportunities through culinary tourism while contributing to biodiversity conservation by maintaining the cultivation of heirloom crops. As reported in other contexts (Samtono et al. 2022), such community-centered culinary practices can enhance food security, cultural pride, and ecological resilience.

Ritual ceremonies and symbolic food

Rituals and ceremonies occupy a central role in the cultural life of Javanese communities in the Paranggupito Karst region. These events—spanning life-cycle transitions from pregnancy to death—are expressions of gratitude, spiritual protection, and communal identity. Food offerings are integral components of these ceremonies, functioning as both symbolic gestures and instruments for ecological continuity. The preparation, selection, and serving of particular foods reflect deeply held cosmological beliefs and ecological awareness.

One of the most prominent ritual traditions is the *slametan*, a communal prayer event performed at various points in life such as childbirth (*mitoni*), postnatal blessings (*sepasaran*), marriage arrangements (*nembung*), weddings, and death commemorations (*nyewu*). In each of these events, food plays a vital symbolic function. For instance, *tumpeng*—a cone-shaped rice dish—serves as a centerpiece of offerings, symbolizing mountains and the balance of the universe. The accompanying side dishes (e.g., *ingkung*, *urap*, *tempeh*, eggs) are carefully chosen not only for their availability but also for their symbolic resonance (Dewantara 2018).

In childbirth ceremonies such as *bancakan* and *mitoni*, *tumpeng* is served alongside other dishes to invoke blessings for the mother and unborn child. During *kething-kething*, a buffalo-head-shaped dish called *kebo gerang* is presented as a prayer for strength and endurance in toddlers. In marriage rituals like *nembung* and *sisetan*, *ketan* (sticky rice) and *jadah* (glutinous rice cake) represent commitment, unity, and harmony, as the sticky texture metaphorically bonds the couple.

Ritual foods are also presented in sequences during funerary ceremonies—from *geblag* (first day) to *nyewu* (1,000th day)—with *tumpeng* and goat meat being commonly served to symbolize sustenance for the soul's journey and appreciation for those conducting the burial. The layers of symbolic meaning attributed to food in these events are crucial to understanding how biodiversity is embedded within ritual frameworks.

Table 3 provides a comprehensive summary of these ritual events, the associated dishes, and their cultural meanings. Figure 4 shows visual documentation of selected ceremonies.

These ceremonial practices promote the continuity of plant and animal use within culturally regulated cycles. Because specific species are required for offerings—such as coconut (*C. nucifera*), glutinous rice (*O. sativa* var. *glutinosa*), banana (*Musa paradisiaca*), and cassava (*M. esculenta*)—their cultivation is preserved, and knowledge of their preparation is passed on through generations. In this way, ritual foods act not only as cultural expressions but also as tools for species conservation.

The strict ritual codes surrounding food use reinforce the value of biodiversity beyond mere subsistence. They represent a culturally embedded conservation strategy, where species are protected and nurtured due to their spiritual importance and irreplaceable roles in communal life.

Cultural beliefs and taboos supporting species conservation

In the Paranggupito Karst communities, deeply rooted cultural beliefs and taboos serve as informal mechanisms for wildlife and habitat conservation (Figure 5). These unwritten rules, transmitted orally and embedded in local cosmologies, play a crucial role in shaping community behavior toward the environment. Rather than relying on formal enforcement, conservation is achieved through fear of spiritual consequences, respect for ancestral teachings, and adherence to ritual norms. Such culturally grounded practices demonstrate how indigenous belief systems can align closely with ecological sustainability goals (Hongmao et al. 2002; Geng et al. 2017).

One notable belief held by local residents is the prohibition against hunting white-colored Java porcupines (*H. javanica*). These animals are considered spiritual beings or "queens" of their species. The presence of a white porcupine is thought to signify supernatural warning, and those who attempt to harm or kill them are believed to suffer misfortune, illness, or crop failure. Although the white morph is rarely, if ever, observed, the myth surrounding it ensures protection for the entire porcupine population, including the more commonly seen brown individuals. This culturally maintained taboo thus functions as a highly effective conservation tool, reducing hunting pressure on a protected species that is listed under Indonesia's Ministry of Environment and Forestry Regulation No. P.106/MENLHK/SETJEN/KUM.1/6/2018.

Another form of ecological stewardship is observed in the reverence for sacred trees, particularly large, old *banyan* trees (*F. benjamina*) and strangler figs (*F. annulata*), collectively known as *danyangan*. These trees are seen as the spiritual homes of ancestral spirits and are considered untouchable outside of ritual contexts. They are ritually cleaned during the annual *rasulan* ceremony, but cutting or damaging them outside this event is strongly discouraged. As a result, these trees are preserved for generations, serving as keystone habitats for birds, mammals, insects, and epiphytes. Their large biomass also contributes significantly to local carbon sequestration, soil stability, and microclimate regulation (Mensah et al. 2020).

In addition to animal and plant taboos, the community also practices behavioral restrictions during sensitive periods. For example, men with pregnant wives are forbidden from hunting or killing animals, based on the belief that doing so may cause physical or spiritual harm to the unborn child. This belief not only serves as a protective measure for the child but also helps reduce hunting during certain seasons, allowing animal populations to recover. These belief systems reflect a profound understanding of ecological interdependence. While they are not derived from scientific frameworks, their effects align closely with conservation principles. By imposing spiritual boundaries on resource exploitation, these practices contribute to the sustainability of species and ecosystems without requiring external intervention. Furthermore, they foster a collective sense of responsibility and continuity, ensuring that ecological ethics are embedded in everyday life and transmitted across generations.

Table 3. Rituals performed by villagers

Event	Name of ceremony	Major food arrangements involved in the ceremony	Description of the foods/species	The meaning of the ceremony
Birth	*Bancakan* (3 months pregnant) and *Mitoni* (7 months pregnant)	*Tumpeng*	*Tumpeng* is a cone-shaped rice. At the bottom of the cone are various dishes, such as *ingkung*, which is chicken cooked with coconut milk and bay leaves; *urap* or vegetables mixed with grated coconut; eggs, tofu, tempeh, and meat.	Form of gratitude and a means to ask for safety and a smooth delivery process.
	Sepasaran bayi	*Sego tumpeng janganan*	Yellow cone-shaped rice with various side dishes was served, such as fried chicken, omelet, salted fish, braised tofu, and tempeh.	The tradition of welcoming the birth of a baby is carried out on the fifth day after the baby is born as a form of prayer and hope that the baby will receive safety and protection in his life.
	Kething-kething	*Kebo gerang*	*Jadah* is food made from ketan or glutinous rice (made of *Oryza sativa* var. *glutinosa*), which is shaped like a buffalo's head and given horns from a coconut.	As a form of celebration and prayer for children aged 2-3 years. In this tradition, children will be asked to choose various foods or objects provided in front of them, each of which symbolizes a certain aspect of life, talent, or future. Kebo gerang itself can symbolize strength and physical endurance.
	Upacara Adat Anak	*Jajan pasar*	Snacks such as *nagasari* are made from a mixture of rice flour and bananas wrapped in banana leaves (*Musa* spp). *Kolong* snacks, on the other hand, can be made from sticky rice flour or cassava (*Manihot esculenta*), etc.	Symbolic meaning as a representation of prosperity, blessings, and abundance. The shape and variety of market snacks show hope for a colorful, diverse, and rich life.
Adult	*Nembung (menjelang pernikahan)*	*Ketan*	Ketan is a traditional sticky rice dish made from *Oryza sativa var. glutinosa* (glutinous rice), known for its natural stickiness when cooked.	Pre-marriage tradition to clarify the commitment between a man and a woman. It establishes whether both parties are seriously considering marriage. A symbolic gesture involves offering ketan (glutinous rice), which represents a bond or commitment, as it adheres tightly, signifying that the woman is "bound" if she accepts it.
	Sisetan	*Jadah*	Sticky rice cake was made of ketan or glutinous rice (*Oryza sativa* var. *glutinosa*) mixed with coconut (*Cocos nucifera*).	Sisetan symbolizes the binding between two people in a romantic relationship. The sticky texture of this jadah (traditional sticky rice cake) represents the wish for the engaged couple to remain inseparable and united until their marriage ceremony.
	Wedding	*Tumpeng*	A cone-shaped rice. At the bottom of the cone are various dishes, such as *ingkung* made from chicken cooked with coconut milk and bay leaves; *urap* or vegetables mixed with grated coconut; eggs, tofu, tempeh, and meat.	The tumpeng, a cone-shaped rice structure, represents the ecosystem and resembles a mountain, representing harmony within the environment. The array of accompanying dishes signifies abundance and prosperity.

Death	*Geblag* (the first day of a person's death), *Nelung dino* (the third day of a person's death), *Pitung dino* (the seventh day of a person's death), *Patangpuluh* (40 days of a person's death), *Pendak 1* (1 year), *Pendak 2* (2 years), and *Nyewu* (1000 days)	*Tumpeng*	The same as above, except on *geblag* (the first day of a person's death), the family typically slaughters a goat.	The succession of funeral ceremonies serves as stages of spiritual support and honor to the departed. The cone-shaped rice tumpeng symbolizes the balance of nature and interconnected life. Various dishes at the base of the tumpeng represent life's elements, representing the soul's journey and the family's prayers for peace and spiritual tranquility. The slaughtering of a goat is seen as a means of exchange that aids the spiritual journey of the deceased. The goat meat is subsequently given primarily to key individuals involved in the burial, like the gravediggers, as an expression of appreciation for their service. This distribution reinforces community ties and honors those assisting in the funeral rites.

Figure 4. Ceremonies performed by villagers A. Wedding (Oktavia et al. 2022), B. *Mitoni* (Intani and Damayanti 2018), C. Death ceremony (Dewantara 2018)

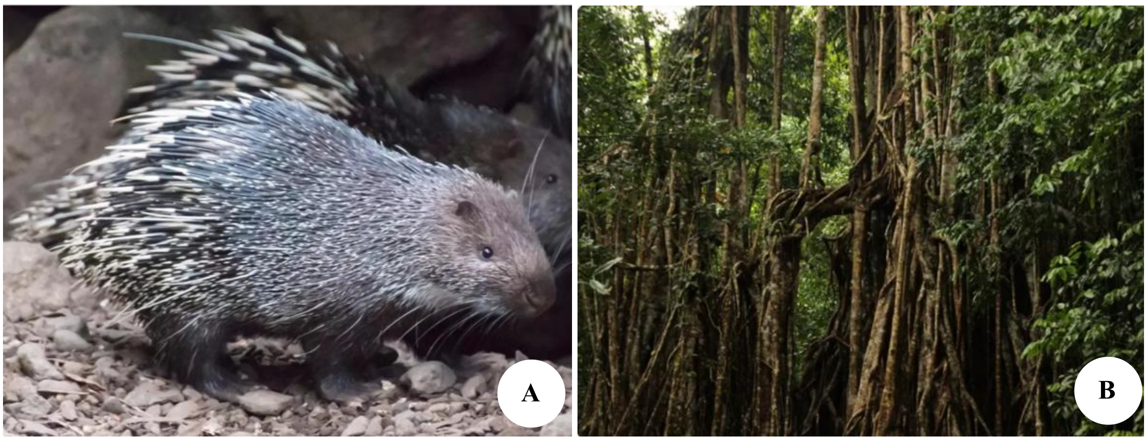

Figure 5. Culturally protected species and sacred trees in the Paranggupito Karst landscape. A. Javan porcupine (*Hystrix javanica*), considered a sacred animal and protected by taboo, B. *Banyan* tree (*Ficus benjamina*), locally known as *danyangan*, ritually preserved as a spiritual dwelling and biodiversity refuge

Contribution of food and ritual traditions to biodiversity conservation

Traditional food and ritual practices in the Paranggupito Karst landscape are more than cultural expressions—they serve as active mechanisms for biodiversity conservation. The sustained use of specific plant and animal species in both daily life and ceremonial contexts reinforces agrobiodiversity and ecological stewardship. Species such as *O. sativa* (rice), *C. nucifera* (coconut), *M. paradisiaca* (banana), and *M. esculenta* (cassava) are consistently cultivated because of their ritual significance in dishes like *tumpeng*, *urap*, *tiwul*, and *nagasari*. These dishes, essential in life-cycle ceremonies from birth to death, generate a cyclical demand that ensures the continuous propagation of these culturally important crops in home gardens and farms.

Food-related rituals not only preserve species but also promote environmental ethics. Taboos—such as prohibitions against hunting *H. javanica* or cutting sacred *Ficus* trees (*danyangan*)—act as informal governance systems. These beliefs, rooted in spiritual worldviews, discourage overexploitation and foster respect for local fauna and flora. Since such taboos are enforced through cultural norms rather than external regulations, they tend to be resilient to ecological and socio-economic pressures.

Agricultural practices in the region mirror this ethos. Local gardens are planted with a diverse array of species—including *M. arundinacea*, *Canna edulis*, *D. esculenta*, *Leucaena leucocephala*, and *Moringa oleifera*—which serve culinary, medicinal, and ritual purposes. These multifunctional gardens act as micro-reserves for plant genetic resources while supporting household nutrition and ritual needs. Collective ceremonies such as *rasulan* also demonstrate how ritual fosters conservation behavior. During these events, community members purify sacred trees and springs, prepare traditional foods, and reaffirm their ecological responsibilities. Such activities embed biodiversity care within communal routines and intergenerational knowledge.

Ultimately, the foodways and ritual practices of the Paranggupito Karst communities represent a locally grounded model of conservation. By linking ecological function with cultural meaning, these traditions support species continuity, cultural resilience, and sustainable land use. In ecologically fragile karst systems where top-down conservation often falters, these bottom-up, community-led practices offer enduring strategies for preserving biocultural diversity.

Several culturally important species—such as *L. leucocephala*, *M. arundinacea*, *C. edulis*, and *F. annulata*—were documented through narrative accounts and interviews. Although not included in Tables 2 or 3 due to insufficient frequency data, their roles in ritual practices, food systems, and homegarden diversity are explained in the main text.

Discussion

Ritual food practices as cultural drivers of biodiversity conservation

Ritual food practices in the Paranggupito Karst landscape embody a form of biocultural conservation, where culinary traditions actively contribute to maintaining species diversity and ecological balance. Far from being merely symbolic, these practices rely on the consistent use of specific plants, which must be cultivated, foraged, or protected to sustain ritual functions. Dishes such as *tumpeng*, *urap*, *tiwul*, *nagasari*, and *gethuk* depend on a variety of plant species, embedding them within seasonal agricultural cycles and household agroecosystems.

The ritual prominence of *tumpeng*, a cone-shaped rice dish symbolizing the cosmic mountain, illustrates how food reinforces ecological thinking within cultural contexts. This ceremonial dish is accompanied by *urap*, *ingkung*, and tempeh (from *Glycine max*), promoting a diverse, multi-species food system. Ingredients include *O. sativa*, *V. unguiculata*, *Arachis hypogaea*, *I. aquatica*, and *C. nucifera*, among others, as reflected in Table 2 and Figures 2-3. Such culinary diversity sustains both nutritional and ecological resilience through integrated farming practices.

Ritual events throughout the life cycle—such as *mitoni* (prenatal blessing), *sepasaran bayi* (infant ritual), and *rasulan* (village purification)—create strong incentives to grow and maintain culturally significant crops. These patterns mirror findings from other ethnobotanical contexts, where sacred plant use fosters long-term species conservation (Geng et al. 2017; Sutrisno et al. 2020). Thus, food sustains ritual, and ritual in turn sustains biodiversity.

Crops like *M. esculenta* (cassava), *M. arundinacea* (arrowroot), and *D. esculenta* (yam) are central to daily and ceremonial diets. Their consistent use supports their conservation within karst-based agriculture. These tubers are not selected merely for productivity but for cultural relevance and ecological adaptability—a contrast to market-driven monocultures (Bérard and Marchenay 2006).

Ritual needs influence agricultural planning, encouraging species diversification, seed saving, and knowledge transmission across generations. Home gardens and terraced plots are often managed with upcoming ceremonies in mind, ensuring continuity through both cultural and ecological stewardship. This reflects what Hongmao et al. (2002) term "traditional conservation through use," where survival of species is ensured through embedded cultural practice.

In the fragile karst environment, where soils are shallow and water scarce, this ritual-based food system builds resilience. It not only safeguards agrobiodiversity and food sovereignty but also functions as a living cultural archive, preserving ecological knowledge, crop diversity, and community autonomy in the face of modern agricultural change.

Sacred beliefs and informal conservation ethics

In Paranggupito, local belief systems function as a powerful ethical framework for biodiversity conservation. These systems are expressed through taboos, myths, and spiritual practices that govern human interactions with nature. Though unwritten and passed down orally, they are widely respected and often more strictly followed than formal legal regulations. This aligns with the concept of "sacred ecological knowledge," in which spiritual and moral values are intimately linked to environmental stewardship (Geng et al. 2017; Kealiikanakaoleohaililani et al. 2021).

One well-known example involves the taboo against hunting white-colored *H. javanica* (Java porcupine), which is believed to be a sacred creature or queen of its species. Even though sightings of white porcupines are rare or possibly mythical, the belief discourages hunting of all porcupines to avoid spiritual consequences. This taboo functions as a form of species-level protection and mirrors legal efforts, since *H. javanica* is listed as a protected species in Indonesia (under Indonesia's Ministry of

Environment and Forestry Regulation No. P.106/MENLHK/SETJEN/KUM.1/6/2018. The convergence of cultural beliefs and state policy illustrates how informal and formal conservation mechanisms can reinforce each other.

Sacred trees, particularly *F. benjamina* and *F. annulata*, known locally as *pohon Danyangan*, also play a vital role in this spiritual ecology. These trees are believed to be inhabited by ancestral spirits and are ritually cared for but never felled. As shown in Figure 5, they function ecologically as keystone structures, providing habitat, stabilizing slopes, and storing carbon. Their spiritual status grants them protection from land-use change, ensuring continuity in both ecological and cultural landscapes.

Belief-based prohibitions also guide behavior during sensitive life stages. For example, men with pregnant wives are traditionally forbidden from killing animals, out of fear that it may harm the unborn child. This taboo not only expresses intergenerational care but also reduces hunting pressure during critical periods. Such reproductive taboos have been documented in other indigenous communities and serve as culturally embedded mechanisms for wildlife conservation (Hongmao et al. 2002; Sharma and Pegu 2011).

Unlike externally imposed conservation rules, these sacred beliefs are upheld through collective memory, fear of supernatural repercussions, and respect for tradition. They create "invisible fences" that limit access and exploitation without physical barriers. In fragile karst ecosystems, where enforcement is often limited, these culturally grounded norms offer resilient and effective conservation models. By merging spirituality, morality, and ecological knowledge, Paranggupito's belief systems generate a conservation ethic that is holistic and deeply rooted in daily life. Together with ritual food practices and ecological customs, they illustrate how culture and nature are tightly interwoven and mutually reinforcing.

Culinary traditions, food sovereignty, and ecological resilience

The culinary traditions of the Paranggupito Karst communities are deeply rooted in their dryland environment, where limited water and poor soils necessitate adaptive strategies for food security and sustainable resource use. These traditions serve not only cultural functions but also support local food sovereignty and ecological resilience.

Staple crops such as *M. esculenta* (cassava), *Z. mays* (maize), and *O. sativa* (rice) form the backbone of local agriculture. Cultivated on terraced slopes that help conserve water and prevent erosion (Figure 3), these crops are rotated with legumes, vegetables, and tubers to improve soil fertility and break pest cycles. Beyond agronomic considerations, crop selection is closely tied to cultural practices—for example, cassava is essential for making *tiwul*, a traditional food consumed in both everyday and ritual contexts. Home gardens play a complementary role by hosting a wide variety of useful plants, including *M. oleifera*, *C. nucifera*, *Capsicum* spp., *V. unguiculata*, and *M. paradisiaca*. Managed primarily by women, these gardens serve as vital sources of food, medicine, and ritual materials. As noted by Bérard and Marchenay (2006), such gardens act as "cultural reservoirs," conserving plant diversity and traditional ecological knowledge across generations.

The preparation of traditional foods such as *urap*, *nagasari*, *jadah*, and *romeon* (Figure 2) emphasizes seasonal, plant-based ingredients and energy-efficient methods. Manual processing and communal preparation foster social cohesion and intergenerational knowledge transfer. These practices contrast with industrial food systems that often fragment communities and impose environmental costs (dos Santos et al. 2021).

Importantly, the community's control over seeds, cropping patterns, and food preparation methods reflects a strong commitment to food sovereignty. This form of autonomy is not only political but ecological, enabling decisions that sustain both cultural identity and agroecosystem resilience. The foodways of Paranggupito represent more than cultural heritage—they are adaptive, ecologically grounded systems of knowledge and practice. By linking biodiversity conservation with daily sustenance, they offer a compelling model of biocultural resilience in a changing environment.

Integration of indigenous knowledge into contemporary conservation discourse

The study underscores the crucial role of indigenous knowledge systems in biodiversity conservation, particularly in ecologically sensitive areas like the Paranggupito Karst in Java. Despite being marginalized in formal policy and scientific discourse, local traditions—rooted in ritual, taboo, and food culture—offer rich ecological insights and enduring sustainability practices. Integrating these systems into modern conservation frameworks is not only a matter of cultural respect but a strategic necessity for long-term ecological resilience. In Paranggupito, community-based conservation arises organically through culturally embedded practices. Activities such as planting ritual crops, protecting sacred trees, and observing wildlife taboos foster ecological stewardship without the need for external enforcement. These systems are sustained by spiritual beliefs, social norms, and everyday needs—dimensions often lacking in conventional, top-down conservation programs (Kealiikanakaoleohaililani et al. 2021).

Recognizing these cultural mechanisms within broader conservation strategies can enhance both equity and effectiveness. Local communities are often the most consistent guardians of their environment, but remain underrepresented in conservation planning. Bridging scientific and indigenous knowledge requires a paradigm shift that views culture not as an obstacle, but as a foundational element of conservation. Ethnobiological documentation, such as this study, plays a vital role in illuminating the ways cultural practices sustain biodiversity (Hongmao et al. 2002; Iskandar 2017). Moreover, indigenous knowledge fills critical gaps left by ecological science, which excels in modeling ecosystems but often overlooks the socio-cultural factors that drive land use and species resilience. Indigenous perspectives capture long-term environmental observations and relational values central to place-based conservation. This synergy has been demonstrated in sacred groves in India and agroforestry systems in Latin America, and is evident in the Paranggupito Karst.

Although global frameworks like the Convention on Biological Diversity (CBD) and Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) increasingly recognize local knowledge, on-the-ground implementation is still lacking. Future conservation must adopt inclusive, co-developed approaches that empower communities and legitimize food and ritual traditions as integral parts of environmental governance. The cultural systems of Paranggupito are not static relics, but dynamic and adaptive frameworks that offer relevant models for contemporary, just, and sustainable conservation.

In conclusion, this study demonstrates that the culinary and ritual traditions of the Javanese communities in the Paranggupito Karst region are closely linked to biodiversity conservation. Traditional food practices, including the preparation of *tumpeng*, *tiwul*, *urap*, and other culturally embedded dishes, require the continued cultivation and use of specific plant species, thereby promoting agrobiodiversity and the conservation of heirloom crops. Ritual events such as *mitoni*, *rasulan*, and *slametan* serve as culturally sanctioned spaces for environmental management, where symbolic foods and sacred practices reinforce ecological ethics. Informal conservation is further strengthened through local taboos, such as the prohibition against hunting white porcupines (*H. javanica*) and the protection of sacred *danyangan* trees (*Ficus* spp.), which function as spiritual, ecological, and social foundations in the community. These beliefs and customs, passed down through generations, form a sophisticated system of indigenous environmental management that continues to shape land use, species protection, and food systems in the karst landscape. By maintaining ritual obligations and culinary identity, these communities ensure the sustainability of their ecosystems in ways that are self-regulated, spiritually meaningful, and ecologically healthy. The findings of this study confirm that integrating indigenous knowledge into formal conservation discourse is not only feasible but essential for culturally relevant and community-based biodiversity strategies. In an era of accelerating environmental degradation and cultural homogenization, the Paranggupito case offers a compelling model of biocultural resilience, where food, belief, and ecology coexist in mutually reinforcing harmony.

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REFERENCES

Ahmad M, Ahmed Z, Yang X, Hussain N, Sinha A. 2022. Financial development and environmental degradation: do human capital and institutional quality make a difference? Gondwana Res 105: 299-310. DOI: 10.1016/j.gr.2021.09.012.

Atikaalistiana. 2006. Filosofi tumpeng. https://id.scribd.com/doc/275822388/Filosofi-tumpeng. [Indonesian]

Batoro J, Siswanto D. 2017. Ethnomedicinal survey of plants used by local society in Poncokusumo District, Malang, East Java Province, Indonesia. Asian J Med Biol Res 3 (2): 158-167. DOI: 10.3329/ajmbr.v3i2.33563.

Bérard L, Marchenay P. 2006. Local products and geographical indications: taking account of local knowledge and biodiversity. Intl Soc Sci J 58 (187): 109-116. DOI: 10.1111/j.1468-2451.2006.00592.x.

Bessière J. 1998. Local development and heritage: Traditional food and cuisine as tourist attractions in rural areas. Sociol Rural 38 (1): 21-34. DOI: 10.1111/1467-9523.00061.

Central Statistics Agency. 2023. Paranggupito Sub-district in Figures 2023. BPS Kabupaten Wonogiri, Wonogiri. https://wonogirikab.bps.go.id. [Indonesian]

Dewantara YF. 2018. Gastronomi tumpeng dalam budaya selamatan masyarakat Jawa. Jurnal Pesona Hospitality 11 (1): 9-19. [Indonesian]

Döringer S. 2021. The problem-centred expert interview: Combining qualitative interviewing approaches for investigating implicit expert knowledge. Intl J Soc Res Method 24 (3): 265-278. DOI: 10.1080/13645579.2020.1766777.

dos Santos JS, Dodonov P, Oshima JEF, Martello F, Jesus AS de, Ferreira ME, Silva-Neto CM, Ribeiro MC, Collevatti RG. 2021. Landscape ecology in the Anthropocene: an overview for integrating agroecosystems and biodiversity conservation. Perspect Ecol Conserv 19 (1): 21-32. DOI: 10.1016/j.pecon.2020.11.002.

Dwiwahyudi A. 2019. Nasi tiwul yang tak lekang oleh waktu. https://desakarangasem-ponjong.gunungkidulkab.go.id/first/artikel/431-Nasi-Tiwul-yang-Tak-Lekang-Oleh-Waktu. [Indonesian]

Geng Y, Hu G, Ranjitkar S, Shi Y, Zhang Y, Wang Y. 2017. The implications of ritual practices and ritual plant uses on nature conservation: a case study among the Naxi in Yunnan Province, Southwest China. J Ethnobiol Ethnomed 13 (1): 58. DOI: 10.1186/s13002-017-0186-3.

Henri, Hakim L, Batoro J. 2018. Kearifan lokal masyarakat sebagai upaya konservasi hutan Pelawan di Kabupaten Bangka Tengah, Bangka Belitung. Jurnal Ilmu Lingkungan 16 (1): 49-57. DOI: 10.14710/jil.16.1.49-57. [Indonesian]

Hermininrum S. 2019. The genealogy of traditional Javanese cassava-based foods. J Ethn Foods 6 (1): 15. DOI: 10.1186/s42779-019-0015-5.

Hongmao L, Zaifu X, Youkai X, Jinxiu W. 2002. Practice of conserving plant diversity through traditional beliefs: a case study in Xishuangbanna, southwest China. Biodivers Conserv 11 (4): 705-713. DOI: 10.1023/A:1015532230442.

Intani R, Damayanti N. 2018. Pemaknaan tradisi mitoni adat Jawa Tengah pada pasangan Jawa dan Padang. Jurnal Prosiding Konferensi Nasional Komunikasi 2 (1): 539-552. [Indonesian]

Iskandar J. 2017. Etnobiologi dan keragaman budaya di Indonesia. Umbara 1 (1): 27-42. DOI: 10.24198/umbara.v1i1.9602. [Indonesian]

Kealiikanakaoleohailani K, Sato AY, Giardina CP, Litton CM, Ramavarapu S, Hutchins L, Wight EH, Clark M, Cordell S, Francisco KS, McMiller H, Pascua P, Yogi D. 2021. Increasing conservation

capacity by embracing ritual: Kuahu as a portal to the sacred. Pac Conserv Biol 27 (4): 327-336. DOI: 10.1071/PC20010.
Koentjaraningrat. 2009. Pengantar Ilmu Antropologi. Rineka Cipta, Jakarta. [Indonesian]
Martosuwito S, Samodra H, Sidarto S. 2013. Hubungan Lembah Sadeng, Cekungan Baturetno dan Teras Bengawan Solo, Jawa Bagian Tengah. Jurnal Geologi dan Sumberdaya Mineral 23 (3): 155-165. DOI: 10.33332/jgsm.geologi.v23i3.88. [Indonesian]
Mensah S, Salako VK, Seifert T. 2020. Structural complexity and large-sized trees explain shifting species richness and carbon relationship across vegetation types. Funct Ecol 34 (8): 1731-1745. DOI: 10.1111/1365-2435.13585.
Nasir MA. 2019. Revisiting the Javanese Muslim slametan: Islam, local tradition, honor and symbolic communication. Al-Jami'ah: J Islam Stud 57 (2): 329-358. DOI: 10.14421/ajis.2019.572.329-358.
Oktavia O, Adinda A, Widianto AD. 2022. Pernikahan adat Jawa mengenai tradisi turun-temurun siraman dan sungkeman di Daerah Yogyakarta. Jurnal Review Pendidikan dan Pengajaran 5 (2): 100-110. DOI: 10.31004/jrpp.v5i2.10023. [Indonesian]
Putri RI, Supriatna J, Walujo EB. 2014. Ethnobotanical study of plant resources in Serangan Island, Bali. Asian J Conserv Biol 3 (2): 135-148.
Samtono S, Rahayu E, Risyanti YD. 2022. Upaya pengembangan ekonomi kreatif sektor wisata kuliner Kampung Singkong. RESONA: Jurnal Ilmiah Pengabdian Masyarakat 6 (2): 153-161. DOI: 10.35906/resona.v6i2.1223. [Indonesian]
Sharma UK, Pegu S. 2011. Ethnobotany of religious and supernatural beliefs of the Mising tribes of Assam with special reference to the 'Dobur Uie'. J Ethnobiol Ethnomed 7: 16. DOI: 10.1186/1746-4269-7-16.
Suharnomo, Syahruramdan FN. 2018. Cultural value differences among ethnic groups in Indonesia: Are Hofstede's Indonesian findings still relevant? J Glob Bus Adv 11 (1): 6-21. DOI: 10.1504/JGBA.2018.093168.
Sulistiyowati E, Haryono E. 2021. Karst and conservation research in Indonesia and its implication to education. J Phys: Conf Ser 1796 (1): 012071. DOI: 10.1088/1742-6596/1796/1/012071.
Sutrisno IH, Akob B, Navia ZI, Nuraini N, Suwardi AB. 2020. Documentation of ritual plants used among the Aceh tribe in Peureulak, East Aceh District, Indonesia. Biodiversitas 21 (11): 4990-4998. DOI: 10.13057/biodiv/d211102.
Tolentino PJS, Navidad JRL, Angeles MD, Fernandez AP, Villanueva ELC, Obena RDR, Buot Jr IE. 2020. Review: Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines. Biodiversitas 21 (4): 1597-1613. DOI: 10.13057/biodiv/d210441.
Triasandy A. 2024. Resep bumbu urap dan cara memasaknya yang enak. https://www.idntimes.com/food/recipe/andry-trisandy/resep-membuat-bumbu-urap. [Indonesian]

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Vegetation structure and carbon sequestration potential in the tropical karst forest of Gunung Sewu, Indonesia

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Abstract. *Putri NRA, Setyawan AD, Kusumaningrum L. 2025. Vegetation structure and carbon sequestration potential in the tropical karst forest of Gunung Sewu, Indonesia. Intl J Trop Drylands 9: 50-63.* Karst ecosystems are ecologically fragile yet provide critical services, including biodiversity support, water regulation, and carbon sequestration. However, restoration in these environments remains complex due to thin soils, seasonal drought, and limited rooting volume. This study assesses vegetation structure, aboveground biomass (AGB), and carbon sequestration potential in the reforested karst landscape of the Paliyan Wildlife Reserve, Yogyakarta, Indonesia. A systematic inventory was conducted across 100 plots stratified by tree and pole size classes, encompassing 1,180 woody individuals from 19 species. Biomass was estimated using both species-specific and general allometric equations. Results reveal a total AGB of 136.77 Mg ha^{-1}, corresponding to 64.28 Mg C ha^{-1} or 235.88 Mg CO_2 ha^{-1}. Biomass was disproportionately stored in the tree stratum (78.23%) and overwhelmingly dominated by non-native species—particularly *Tectona grandis*, *Delonix regia*, and *Senna siamea*—which together accounted for over 70% of total carbon stock. Although restoration has successfully increased canopy cover and carbon storage, vertical stratification and native species richness remain low. Native taxa such as *Dalbergia latifolia* and *Casuarina equisetifolia* made minor but ecologically important contributions. These findings emphasize the ecological trade-offs of relying on fast-growing exotics, which, while effective for rapid biomass gain, may compromise long-term ecosystem resilience. The study advocates for a shift toward structurally diverse, native-enriched restoration strategies in tropical karst forests, aligned with biodiversity goals and climate mitigation targets under the UN Decade on Ecosystem Restoration, REDD+, and national policy frameworks. This research provides a critical empirical foundation for balancing carbon-oriented and biodiversity-conscious reforestation in vulnerable karst systems.

Keywords: Aboveground biomass, carbon sequestration, Gunung Sewu, karst forest, *Tectona grandis*

INTRODUCTION

Forests play a pivotal role in mitigating climate change by sequestering atmospheric carbon dioxide (CO_2) through photosynthesis and storing it in their biomass. This process reduces greenhouse gas concentrations and contributes to global climate regulation (Wilkes et al. 2018; Pratama et al. 2025). Globally, forests store approximately 289 gigatons of carbon, with tropical forests accounting for more than half of this total (FAO 2010; Rawal and Subedi 2022). However, the accelerating pace of deforestation, land-use change, and forest degradation threatens these natural carbon sinks, releasing stored carbon and amplifying climate instability (Wahyuni and Suranto 2021; Gunawan et al. 2024a, b).

In response to these challenges, forest restoration has emerged as a critical strategy to recover carbon stocks while simultaneously supporting biodiversity and ecosystem services. A key metric for evaluating restoration success is Aboveground Biomass (AGB), which directly correlates with carbon storage. Since destructive sampling is often impractical in protected or recovering areas, non-destructive methods such as allometric equations—based on tree Diameter at Breast Height (DBH), total height, and wood density—are widely applied and continually refined (Chave et al. 2014; Jara et al. 2015).

Karst ecosystems represent a unique subset of tropical landscapes, characterized by rugged limestone topography, thin soils, water scarcity, and limited rooting depth (Clements et al. 2006; Zerga 2024; Bai et al. 2025). These harsh conditions often limit conventional forestry practices but provide critical ecological services, including carbon sequestration, water regulation, and habitat support. Increasing interest has emerged regarding the role of reforested karst landscapes as carbon sinks, particularly in the face of ongoing land degradation (Aprilia et al. 2021; Song et al. 2022). However, restoring karst systems requires tailored strategies that consider their unique edaphic and hydrological constraints to ensure long-term ecological resilience.

Indonesia's karst regions, such as the Gunung Sewu Karst in southern Yogyakarta, have experienced severe degradation due to logging, shifting agriculture, and human settlement. The Paliyan Wildlife Reserve (PWR), located within this area, was historically managed as a production forest dominated by *Tectona grandis*. Since 2005, and especially after 2014, PWR has been the focus of ecological rehabilitation involving both exotic and native tree species (Wahyudi and Aminatun 2018). While there have been visible improvements in canopy cover, the impact of mixed-species planting on biomass accumulation and carbon retention remains poorly understood.

Previous studies in the Gunung Sewu region have addressed general aspects of biodiversity and forest structure (Septiasari et al. 2021; Yuslinawari et al. 2021; Hikari et al. 2023), but few have explicitly examined the relationship between vegetation structure and carbon storage in restored karst systems. Yet, it is well-established that forest structural parameters—such as stem diameter, basal area, and vertical stratification—are key drivers of biomass accumulation and carbon dynamics (Dovrat et al. 2019; Macias et al. 2017). Forests dominated by fewer, large individuals often store more carbon than diverse forests composed of smaller trees (Brown 1997). Consequently, comprehensive evaluations that integrate structural attributes with functional outcomes are essential for assessing reforestation success in karst environments.

The extensive use of fast-growing exotic species such as *Delonix regia*, *Senna siamea*, and *Gliricidia sepium* in restoration efforts introduces important ecological trade-offs. These species are valued for their rapid biomass accumulation and drought tolerance but can suppress native species regeneration, alter successional pathways, and reduce habitat heterogeneity (Ekayanti et al. 2015; Hendrati and Nurrohmah 2018). In contrast, native species like *Dalbergia latifolia* and *Casuarina equisetifolia* are better suited to local edaphic conditions and contribute to ecological stability through their high wood density and specialized adaptations.

This study aims to evaluate vegetation structure and carbon sequestration potential in the Paliyan Wildlife Reserve, a restored karst forest landscape within the Gunung Sewu UNESCO Global Geopark. Specifically, the objectives are to: (i) quantify stand structure across tree and pole strata; (ii) estimate aboveground biomass and carbon stocks using species-appropriate allometric equations; (iii) compare the relative contributions of native and non-native species; and (iv) assess the implications of species dominance and structural simplification for restoration effectiveness. The results are expected to inform both local and national forest restoration policies under REDD+, Indonesia's National Biodiversity Strategy and Action Plan (NBSAP), and global climate frameworks, including the UN Decade on Ecosystem Restoration.

MATERIALS AND METHODS

Study area

This study was conducted in the Paliyan Wildlife Reserve (PWR), located in Gunungkidul District, Yogyakarta, Indonesia (Figure 1). The reserve situated in the eastern part of the Gunung Sewu Karst, a geologically unique landscape, is characterized by conical limestone hills, shallow rocky soils, underground rivers, and seasonal water scarcity (Aprilia et al. 2021). Covering approximately 434.83 hectares, PWR is part of the broader Gunung Sewu UNESCO Global Geopark, recognized for its geomorphological diversity and, more importantly, its crucial ecological role.

The elevation in PWR ranges from 100 to 300 meters above sea level, with an average altitude of around 260 meters. The terrain is undulating to steep, with slope gradients often exceeding 40%, presenting considerable challenges for vegetation establishment. The climate is classified as tropical monsoon, with an average annual rainfall of 2,071 mm concentrated in the wet season, while the dry season may last up to six months. Air temperatures typically fluctuate between 24.7°C and 31.8°C, and relative humidity ranges from 26% to 58.3%, indicating a semi-arid microclimate typical of karst environments (Wahyudi and Aminatun 2018). This semi-arid microclimate significantly impacts the flora and fauna of the reserve, influencing their distribution, diversity, and survival strategies.

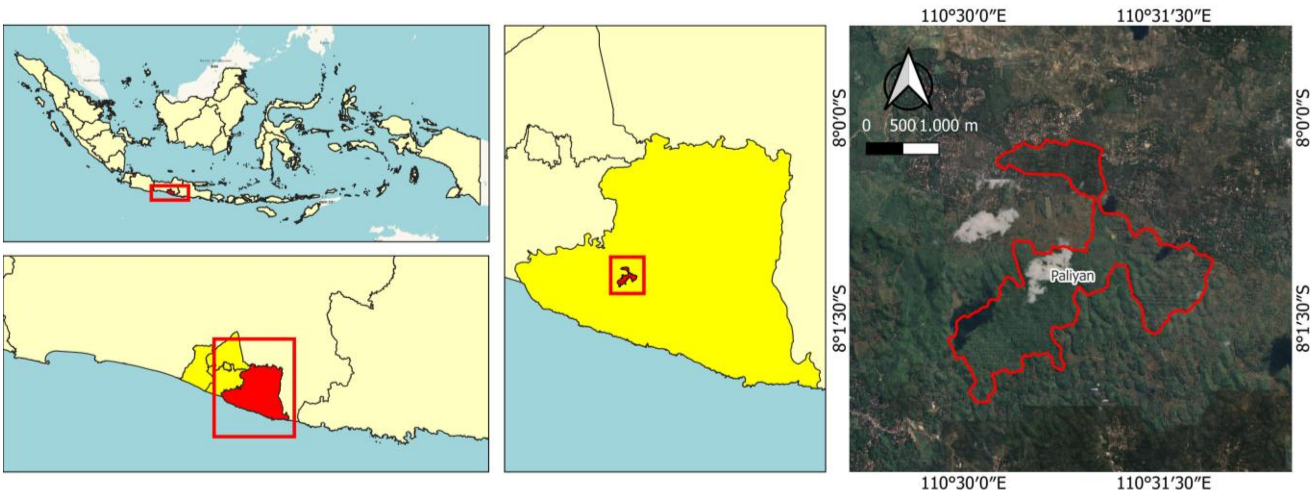

Figure 1. Map of the study area in Paliyan Wildlife Reserve, Gunung Sewu, Yogyakarta, Indonesia

Historically, the Paliyan site was exploited as a monocultural production forest dominated by *T. grandis*. Due to logging, land conversion, and soil degradation, the area experienced significant ecological decline. Since 2005, the site has undergone rehabilitation through reforestation and conservation programs, with intensified efforts starting in 2014 focusing on ecosystem restoration and native species reintroduction (Wahyudi and Aminatun 2018). These programs aimed to stabilize the fragile landscape, restore habitat functions, and enhance ecosystem services, including carbon sequestration and biodiversity conservation.

The PWR landscape now comprises a mosaic of vegetation patches, including reforested stands dominated by non-native species, regenerating native vegetation, and semi-natural karst scrubland. These different zones provided a representative sampling framework for examining stand structure and biomass accumulation across varying ecological conditions.

Sampling design and plot establishment

To evaluate vegetation structure and carbon sequestration potential, a systematic sampling design was meticulously applied across the Paliyan Wildlife Reserve (PWR). The sampling campaign was conducted in August 2024, encompassing both rehabilitated areas and semi-natural forest patches to capture variability in floristic composition and stand development stages. This approach ensures spatial representativeness and allows for meaningful comparisons between vegetation types within the restored karst landscape.

A total of 100 observation plots were established along pre-defined transects, with fixed intervals to minimize spatial bias. Each plot was classified into two strata based on vegetation size classes: tree plots for individuals with a Diameter at Breast Height (DBH)>20 cm, and pole plots for individuals with DBH between 10–20 cm. Tree plots were sized 20×20 meters (400 m²), while pole plots measured 10×10 meters (100 m²), following strict adherence to standard ecological protocols (Pearson et al. 2014; Preece et al. 2015).

Within each plot, all individuals meeting the respective DBH threshold were identified to species level, and their DBH and total height were measured using a diameter tape and digital hypsometer, respectively. Individuals with buttresses or irregular basal forms were measured slightly above the irregularity, as recommended in dendrometric standards (Chave et al. 2014). This stratified approach allowed for the separation of growth stages, which is important for understanding structural development and biomass accumulation across the landscape.

In total, data were collected from 1,180 individuals—659 at the pole level and 521 at the tree level. Regional floras, field guides, and consultation with herbarium references aided species identification. Basic environmental attributes such as GPS coordinates, elevation, slope gradient, and general soil condition were also recorded for each plot to support further ecological interpretation.

The selected plot number and distribution were calibrated to achieve a minimum 90% confidence level and a 10% margin of error, which is acceptable for biomass and carbon stock assessments in heterogeneous landscapes (IPCC 2003; Pearson et al. 2014). This robust sampling framework provides a reliable foundation for subsequent analysis of aboveground biomass, carbon storage, and species-level contributions in the PWR karst forest.

Vegetation data collection

Vegetation data were obtained through direct field observation using non-destructive measurement techniques. All trees and poles within the designated plots were identified to species level, relying on regional floras, local field guides, and consultation with botanical experts familiar with karst vegetation. In cases where field identification was uncertain, voucher specimens were photographed and cross-referenced with herbarium records and online taxonomic databases to ensure accuracy.

For each individual, two key biometric parameters were measured: Diameter at Breast Height (DBH) and total height. DBH was measured at 1.3 meters above ground level using a diameter tape. When buttresses or deformities were present, measurements were taken just above the irregularity to maintain consistency with allometric requirements (Chave et al. 2005, 2014). Tree height was recorded using a digital hypsometer, which provided reliable vertical estimates across variable canopy layers. These measurements are essential inputs for estimating aboveground biomass using allometric models.

Species were further categorized into two structural classes based on DBH thresholds: poles (10-20 cm) and trees (>20 cm). This classification reflects ontogenetic stages and allows the analysis of forest structural heterogeneity, particularly important in restored or secondary karst forests where stand maturity varies significantly. Structural stratification also enables comparative analysis of carbon accumulation across growth stages.

For each recorded species, wood density values (g cm^{-3}) were compiled from published sources, including the Global Wood Density Database (Zanne et al. 2009), national forestry reports, and species-specific studies relevant to tropical Southeast Asia (Rosmerita and Purwanto 2008; Siregar 2012). These values were later used in allometric calculations to estimate biomass and carbon stock.

In addition to biometric data, the Importance Value Index (IVI) was calculated for each species as a composite measure of its ecological role within the forest community. IVI incorporates three metrics—relative density, relative frequency, and relative dominance—providing a comprehensive picture of species significance in terms of abundance, distribution, and basal area (Odum 1971; Mueller-Dombois and Ellenberg 1974). Relative dominance was computed from basal area values derived from DBH, while frequency captured the proportion of plots in which a species was found.

All field data, including raw measurements and plot characteristics, were compiled into structured spreadsheets and cross-checked for consistency. This comprehensive dataset served as the analytical foundation for estimating biomass, calculating carbon storage, and interpreting the structural role of both native and non-native species in the Paliyan Wildlife Reserve.

Biomass estimation using allometric equations

To estimate Aboveground Biomass (AGB) without destructive harvesting, both species-specific and generalized allometric equations were applied. These models relate tree biometric parameters—particularly DBH, height, and wood density—to total biomass using empirically derived mathematical formulas (Chave et al. 2005, 2014). The use of allometric models is widely recommended for biomass estimation in tropical forests, particularly where field conditions or conservation status prohibit destructive methods.

For major species in the study area, species-specific equations were prioritized whenever available, as they offer greater accuracy for particular taxa and local growing conditions. Such models were sourced from peer-reviewed studies and forestry research relevant to Southeast Asia, particularly for species such as *T. grandis*, *S. siamea*, and *D. latifolia* (Rosmerita and Purwanto 2008; Siregar 2012; Ilyas 2013). When no specific model was available for a species, the general moist tropical forest equation developed by Chave et al. (2014) was used:

AGB = 0.0673×(ρ×D2×H)0.976

Carbon stock = AGB×0.47

Where AGB is the aboveground biomass (kg), ρ is wood density (g cm^{-3}), D is DBH (cm), and H is tree height (m). This three-variable equation has been validated across numerous tropical forest types and provides robust estimates for structurally diverse stands.

Table 1 summarizes the allometric equations applied for major species found in the Paliyan Wildlife Reserve. These equations were used to calculate individual biomass, which was then scaled to a per-hectare basis based on plot size and sampling intensity.

The selection of models was based on equation availability, species relevance, and data completeness. When species-specific equations were not available, the general model (Equation 12, Table 1) was applied to ensure consistency in biomass estimation.

Carbon storage and sequestration calculation

Carbon storage was estimated by converting the Aboveground Biomass (AGB) values using a standard carbon fraction. According to the Indonesian National Standard (SNI 7724:2011), it is assumed that carbon constitutes approximately 47% of the dry biomass of woody plants. Thus, total carbon storage (Mg C ha^{-1}) was calculated by multiplying biomass by a factor of 0.47:

Carbon stock=AGB×0.47

This coefficient is widely used in national and international forest carbon assessments and provides a reliable proxy for the amount of carbon retained in aboveground vegetation (SNI 2011; Duncanson et al. 2021). While actual carbon content may vary by species and site conditions, the use of a standardized fraction allows for comparability across studies and regions.

To express the climate mitigation potential of restored vegetation in terms of greenhouse gas offsets, carbon stock values were further converted into carbon dioxide equivalents (CO_2-eq). This was achieved using the molecular weight ratio of CO_2 to C, which is 44/12, or approximately 3.67 (IPCC 2003).

This transformation enables comparison of forest carbon sequestration capacity with anthropogenic CO_2 emissions and supports reporting in carbon markets and climate policy frameworks, including REDD+ and the Paris Agreement. Carbon calculations were conducted separately for each structural class—trees and poles—to evaluate growth stage contributions. Likewise, species-level carbon contributions were calculated to assess the relative importance of dominant taxa in overall carbon dynamics. These calculations were based on species-specific biomass estimates derived from the allometric equations presented in Table 1.

Table 1. Allometric equations used to estimate Aboveground Biomass (AGB) for major tree species in Paliyan Wildlife Reserve, Gunungkidul District, Yogyakarta Province, Indonesia

Species	**Allometric equation**	**Reference**
Tectona grandis L.f.	AGB = 0.0548 × DBH^2.5792	Siregar (2012)
Senna siamea (Lam.) H.S.Irwin & Barneby	AGB = 0.3699 × DBH^1.9374	Ilyas (2013)
Gliricidia sepium (Jacq.) Kunth	AGB = 0.019 × DBH^2.7192	Mulyana et al. (2020)
Acacia auriculiformis	AGB = 0.070 × DBH^2.58	Wicaksono (2004)
Dalbergia latifolia Roxb.	AGB = 0.7458 × (DBH^2 × H)^0.6394	Rosmerita and Purwanto (2008)
Anacardium occidentale	AGB = exp(−2.6516 + 1.9741 ln(DBH) + 0.7169 ln(H))	Biah et al. (2019)
Swietenia macrophylla G.King	AGB = 0.048 × DBH^2.68	Adinugroho and Sidiyasa (2006)
Artocarpus heterophyllus Lam.	AGB = 0.065 × DBH^2.28	Martin et al. (2010)
Calophyllum inophyllum	AGB = exp(−0.972 + 2.078 × ln(DBH))	Basuki et al. (2022)
Melia azedarach L.	AGB = 0.71 × DBH^2.451	Lukito and Rohmatiah (2022)
Gmelina arborea Roxb. ex Sm.	AGB = exp(−3.028 + 0.925 × ln(DBH^2 × H))	Khushi et al. (2019)
General (tropical forests)	AGB = 0.0673 × (ρ × D^2 × H)^0.976	Chave et al. (2014)

Note: AGB: Aboveground Biomass (kg), DBH: Diameter at Breast Height (cm), H: Total height (m), ρ: Wood density (g cm^{-3})

CO_2-eq=Carbon Stock×3.67

Finally, plot-level estimates were scaled up to a per-hectare basis and extrapolated to the entire area of the Paliyan Wildlife Reserve (434.83 ha), assuming that the sampled plots represent the average condition of the forest. This extrapolation provides landscape-level estimates of carbon storage and CO_2 sequestration, which are essential for evaluating the ecological and climate value of restoration interventions.

Data analysis and interpretation

All field data—including species identity, DBH, height, and wood density—were compiled into structured databases and cross-validated to ensure consistency prior to analysis. Biomass and carbon values were computed for each individual using the relevant allometric equations (Table 1), and then aggregated by plot, growth stratum (pole vs. tree), and species origin (native vs. non-native). These values were scaled to per-hectare estimates using plot area and sampling intensity as the basis for extrapolation.

Species dominance was assessed using the Importance Value Index (IVI), which integrates three components: relative density, relative frequency, and relative dominance. Relative density was calculated as the proportion of individuals of a species relative to the total number of individuals. Relative frequency was based on the number of plots in which a species occurred, while relative dominance was derived from the total basal area contributed by each species (Curtis and McIntosh 1950; Odum 1971). IVI scores were interpreted separately for poles and trees to account for structural differentiation.

To assess the role of species origin in biomass and carbon dynamics, each species was categorized as either native or non-native based on floristic records specific to Java and Southeast Asia. This classification enabled comparisons of structural and functional metrics—including individual abundance, basal area, IVI, biomass, and carbon storage—between origin groups. Such comparisons help evaluate the ecological trade-offs of using exotic species in forest restoration efforts, such as potential impacts on local biodiversity and ecosystem stability.

The relationship between structural parameters (e.g., DBH, height, basal area) and carbon accumulation was also examined descriptively to highlight which attributes most strongly influence carbon storage. Species-level contributions to total biomass and carbon stocks were ranked to identify key functional taxa driving sequestration patterns. These analyses were complemented by graphical visualizations presented in the Results section. These visualizations, designed for clarity and ease of understanding, clarify differences among species, strata, and origin types, making the results accessible to our audience.

All computations were performed using Microsoft Excel and supported by standard statistical functions for logarithmic, exponential, and ratio-based operations. The resulting dataset provides a comprehensive profile of vegetation structure and carbon dynamics in the Paliyan Wildlife Reserve, which is a testament to the thoroughness of our research process. It serves as the analytical foundation for interpretation in subsequent sections, ensuring the confidence of our audience in the validity of our results.

RESULTS AND DISCUSSION

Species richness and floristic composition

A total of 1,180 individual woody plants were recorded across all sampling plots in the Paliyan Wildlife Reserve, comprising 659 individuals in the pole stratum (DBH 10-20 cm) and 521 individuals in the tree stratum (DBH>20 cm). These individuals represented 19 unique species from 14 plant families, indicating moderate floristic diversity in this restored karst landscape. The two strata exhibited distinct patterns in terms of species richness, stem size, and vertical structure. Of the 19 total species, 4 occurred exclusively in the tree stratum, one species was unique to the pole stratum, and 14 species were shared between both layers (Tables 2 and 3). This pattern highlights a degree of vertical continuity in forest composition while also reflecting regeneration-stage specificity for certain taxa.

In the pole stratum, 16 species were identified, with an average DBH of 14.95 cm and a mean height of 10.57 m. The highest density was observed in Fabaceae (48% of pole individuals), followed by Lamiaceae (41%). Non-native species such as *T. grandis*, *G. sepium*, and *S. siamea* dominated the pole layer in terms of both abundance and basal area, reflecting either active replanting or successful vegetative regeneration following disturbance.

In the tree stratum, 18 species were recorded. These individuals exhibited a higher average DBH of 26.09 cm and a taller mean height of 13.86 m, with stem density reaching 130.25 individuals ha^{-1}. As in the pole layer, the tree stratum was also dominated by introduced species, most notably *T. grandis*, *D. regia*, and *S. siamea*, which together contributed substantially to total basal area and canopy formation.

The Importance Value Index (IVI) further confirmed the dominance of a few fast-growing, structurally important taxa across both strata. Tables 2 and 3 present the IVI components—relative density, frequency, and dominance—highlighting the pivotal ecological roles of both native and non-native species. Although several native species were present, structural composition was largely shaped by exotic trees introduced during the forest rehabilitation phase, pointing to a restoration trajectory that favors biomass recovery but may constrain long-term species heterogeneity.

These IVI values confirm the structural dominance of a few exotic species in both strata. *Tectona grandis* and *G. sepium* ranked highest in the tree and pole strata, respectively. At the same time, native species such as *D. latifolia* and *Ficus benjamina* were less structurally prominent despite their ecological value.

Dominance and ecological role of major species

The vegetation structure of the Paliyan Wildlife Reserve is characterized by the predominance of a limited number of fast-growing species, most of which are non-native. *Tectona grandis* emerged as the most dominant taxon in the tree stratum, exhibiting the highest Importance Value Index (IVI) at 129.1%. However, it was not prominent in the pole layer, where *G. sepium* and *Tamarindus indica* held the highest IVI scores (Tables 2 and 3). These patterns reflect differences in recruitment dynamics, growth strategies, and the legacy of past forest management interventions. The historical use of *T. grandis* as a timber species in production systems explains its persistence and structural dominance in the upper stratum. In contrast, the frequent occurrence of *G. sepium* and *T. indica* in the pole layer likely results from recent replanting or natural regeneration, supported by their rapid juvenile development and high ecological plasticity.

Delonix regia, another introduced species, ranked second in the tree stratum with an IVI of 74.4%. Despite having fewer individuals than *T. grandis*, its high basal area and widespread presence across regenerating plots indicate strong competitive ability. Its broad canopy and notable drought tolerance confer advantages in karst environments where soil depth and water availability are limiting.

Senna siamea was also among the dominant taxa in both strata, with IVI values of 43.5% in the tree layer and 39.4% in the pole layer. As a nitrogen-fixing legume and early successional species, it contributes not only to rapid biomass accumulation but also to soil improvement and microclimatic buffering. Its adaptability to degraded soils and ecological functions may enhance early-stage forest development, despite its non-native status.

In the pole stratum, *G. sepium* exhibited the highest IVI (82.5%), highlighting its role as a colonizer in rehabilitated areas. Commonly used in agroforestry and restoration programs, this species is favored for its rapid growth, ease of propagation, and compatibility with other crops. Its dominance in the lower canopy likely reflects high vegetative propagation success and tolerance of disturbance.

Other prominent species in the pole layer include *T. indica* and *Melia azedarach*. Although native, *T. indica* showed strong performance with an IVI of 60.4%, suggesting a capacity to ascend into the tree layer in later successional stages. In contrast, *M. azedarach*, though introduced, was relatively abundant and broadly distributed, indicating a degree of ecological compatibility with restored karst landscapes.

Among native taxa, *D. latifolia* and *C. equisetifolia* contributed moderate but ecologically meaningful values. *D. latifolia* was primarily present in the tree stratum with an IVI of 15.9%, appreciated for its dense wood and role in structural reinforcement. *C. equisetifolia*, with an IVI of 23.9%, is well-adapted to rocky soils and plays an important role in erosion control and soil stabilization.

Table 2. Importance Value Index (IVI) of tree species in Paliyan Wildlife Reserve, Yogyakarta. Indonesia

Species name	RD (%)	RF (%)	RDo (%)	IVI (%)
Tectona grandis L.f.	38.5	32.0	58.6	129.1
Delonix regia (Bojer ex Hook.) Raf.	24.0	28.0	22.4	74.4
Senna siamea (Lam.) H.S.Irwin & Barneby	14.7	16.0	12.8	43.5
Casuarina equisetifolia L.	7.3	12.0	4.6	23.9
Dalbergia latifolia Roxb.	6.7	8.0	1.2	15.9
Hibiscus tiliaceus L.	2.1	3.0	0.4	5.5
Ficus benjamina L.	1.5	3.0	0.3	4.8
Tamarindus indica L.	1.0	2.0	0.2	3.2
Melia azedarach L.	1.0	2.0	0.2	3.2
Swietenia macrophylla G.King	0.9	2.0	0.2	3.1
Pterocarpus indicus Willd.	0.8	1.0	0.2	2.0
Artocarpus heterophyllus Lam.	0.7	1.0	0.1	1.8
Ficus racemosa L.	0.5	1.0	0.1	1.6
Mangifera indica L.	0.5	1.0	0.1	1.6
Gmelina arborea Roxb. ex Sm.	0.4	1.0	0.1	1.5
Alstonia scholaris (L.) R.Br.	0.3	1.0	0.1	1.4
Schleichera oleosa (Lour.) Oken	0.2	0.5	0.05	0.75
Pterospermum javanicum Jungh.	0.2	0.5	0.05	0.75

Note: RD: Relative Density, RF: Relative Frequency, RDo: Relative Dominance, IVI: Importance Value Index

Table 3. Importance Value Index (IVI) of pole species in Paliyan Wildlife Reserve, Yogyakarta, Indonesia

Species name	RD (%)	RF (%)	RDo (%)	IVI (%)
Gliricidia sepium (Jacq.) Kunth	31.4	24.0	27.1	82.5
Tamarindus indica L.	21.8	20.0	18.6	60.4
Melia azedarach L.	16.0	18.0	14.0	48.0
Senna siamea (Lam.) H.S.Irwin & Barneby	12.3	16.0	11.1	39.4
Delonix regia (Bojer ex Hook.) Raf.	8.5	14.0	9.2	31.7
Ficus benjamina L	3.5	4.0	2.8	10.3
Ficus racemosa L.	2.5	3.0	2.0	7.5
Gmelina arborea Roxb. ex Sm.	1.8	2.5	1.5	5.8
Swietenia macrophylla G.King	1.6	2.0	1.2	4.8
Alstonia scholaris (L.) R.Br.	0.9	1.5	1.0	3.4
Schleichera oleosa (Lour.) Oken	0.8	1.0	0.8	2.6
Pterocarpus indicus Willd.	0.7	1.0	0.7	2.4
Mangifera indica L.	0.6	0.8	0.5	1.9
Artocarpus heterophyllus Lam.	0.5	0.7	0.4	1.6
Pterospermum javanicum Jungh.	0.4	0.5	0.3	1.2

Note: RD: Relative Density, RF: Relative Frequency, RDo: Relative Dominance, IVI: Importance Value Index

Conversely, many native species such as *Ficus* spp., *Alstonia scholaris*, and *Pterospermum javanicum* exhibited low structural representation. These taxa were recorded sporadically and in low numbers, suggesting suppressed regeneration or competition with more aggressive exotics. Nevertheless, their ecological functions—including providing habitat, enhancing nutrient cycling, and tolerating seasonal drought—may become increasingly important as forest succession proceeds.

Collectively, the results reveal a structurally simplified forest dominated by a narrow suite of exotic species that were either intentionally planted or facilitated through assisted regeneration. While these species contribute substantially to aboveground biomass and canopy formation, their dominance may constrain ecosystem heterogeneity and resilience in the long term. The observed pattern emphasizes the need for restoration strategies that encourage native species recruitment and promote structural complexity to ensure ecological sustainability.

Comparison between native and non-native species

The species composition in the Paliyan Wildlife Reserve is overwhelmingly dominated by non-native species, which contributed disproportionately to stand structure, individual abundance, and overall biomass. Of the 1,180 recorded individuals, 1,083 (91.78%) were non-native, while only 97 (8.22%) belonged to native species. This asymmetry reflects the historical reliance on exotic species in the restoration process, particularly during the initial reforestation phase.

In the pole stratum, non-native species accounted for 589 of 659 individuals (89.38%), while natives contributed only 70 individuals (10.62%). This imbalance was mirrored in ecological metrics, with non-natives attaining a cumulative IVI of 259.89%, compared to 40.11% for native species. Structurally, non-native poles also exhibited greater average DBH and height, indicating more rapid growth and establishment advantages.

The tree stratum showed an even more skewed distribution. Non-native trees made up 494 of 521 individuals (94.82%), and attained a combined IVI of 280.98%, compared to just 27 individuals (5.18%) and 19.02% IVI for native species. *Tectona grandis*, *D. regia*, and *S. siamea* were the dominant non-native contributors. At the same time, native species such as *C. equisetifolia* and *D. latifolia* were present in low numbers and with limited spatial occurrence.

In terms of biomass, non-native species contributed the majority of aboveground carbon across both strata. To provide clearer insight into species-level contributions, Table 4 presents dominant taxa along with total biomass values summarized by structural class. As shown in Table 4, non-native trees stored 102.36 Mg ha^{-1} of biomass, compared to 4.59 Mg ha^{-1} in native trees. In the pole stratum, non-natives contributed 27.71 Mg ha^{-1}, while natives stored only 2.11 Mg ha^{-1}.

These patterns are visualized in Figure 2, which presents a comparative analysis of native and non-native species across tree and pole strata, using three structural indicators: average DBH, total number of individuals, and Importance Value Index (IVI). Non-native species consistently outperformed native taxa across all metrics, underscoring their overwhelming structural dominance within the restored forest.

The results shown in Figure 2 confirm that non-native species, particularly in the tree stratum, dominate not only in terms of abundance but also in stem size and ecological importance. This pattern underscores the role of fast-growing exotic taxa such as *T. grandis* and *D. regia* in shaping the current forest structure. In contrast, native species—although ecologically valuable—remain underrepresented in both size and spatial distribution, especially within the tree layer. These structural imbalances reflect the legacy of past planting strategies and highlight the need for enrichment interventions that prioritize native species recruitment and promote vertical stratification.

The reliance on non-native species during rehabilitation efforts has successfully accelerated canopy development and biomass recovery. However, it has also resulted in a structurally homogeneous forest with low native species representation. This composition may pose long-term ecological risks, such as reduced habitat heterogeneity, which can lead to decreased species diversity and ecosystem stability, limited food resources for native fauna, and decreased resilience to pests, diseases, or climate fluctuations, such as increased susceptibility to invasive species or extreme weather events (Ekayanti et al. 2015).

Nevertheless, the presence of native taxa—though limited—suggests a promising potential for future recovery if active enrichment or natural regeneration is supported. Species like *D. latifolia* and *C. equisetifolia* demonstrate traits suitable for karst environments, including high wood density and drought resistance, can significantly contribute to improving ecological stability and emphasizing their role in future restoration planning, can provide a sense of reassurance, particularly in promoting functional redundancy and biodiversity conservation.

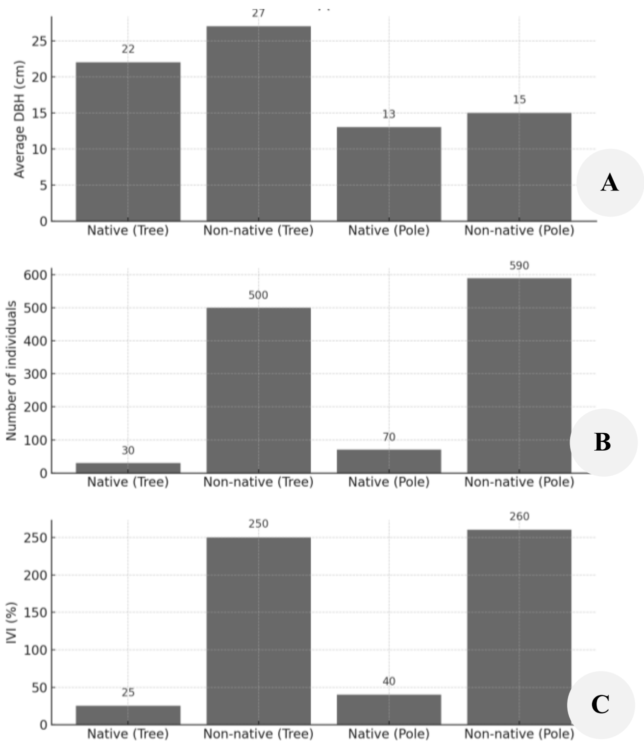

Figure 2. Comparison of native and non-native species across tree and pole strata in the Paliyan Wildlife Reserve, Yogyakarta, Indonesia, based on A. Average Diameter at Breast Height (DBH), B. Number of individuals, and C. Importance Value Index (IVI). Native species consistently exhibited lower structural dominance across all parameters compared to non-native species in both strata

Biomass estimation at tree and pole levels

The total Aboveground Biomass (AGB) in the Paliyan Wildlife Reserve was estimated at 136.77 Mg ha^{-1}, distributed across tree and pole strata. Biomass accumulation was highly skewed toward the tree stratum, which contributed 106.95 Mg ha^{-1} or 78.23% of total AGB, while the pole stratum contributed 29.82 Mg ha^{-1} or 21.77%. This pattern reflects the advanced development of tree-sized individuals in certain plots and their dominant structural role in the restored forest.

Non-native species accounted for the majority of biomass in both strata. In the tree layer, non-native species contributed 102.36 Mg ha^{-1}, while native species contributed only 4.59 Mg ha^{-1}. In the pole layer, non-natives contributed 27.71 Mg ha^{-1}, compared to 2.11 Mg ha^{-1} from native species. These differences reflect the disparity in species abundance, DBH distribution, and wood density between exotic and native taxa.

The total carbon stock, derived by applying a 0.47 conversion factor to AGB, amounted to 64.28 Mg C ha^{-1}. This translates to a total sequestration of 235.88 Mg CO_2 ha^{-1}, using the IPCC conversion ratio of 3.67. The contribution of each vegetation stratum and species origin to carbon storage and CO_2-equivalent sequestration is presented in Table 5.

These values are illustrated in Figure 3, which shows the distribution of aboveground biomass by vegetation stratum and species origin. Tree-level non-native species are the primary biomass contributors, followed by pole-level non-natives. Native species occupy a small proportion of the total biomass in both strata.

Figure 4 summarizes the conversion to CO_2-equivalent sequestration and visualizes the restored forest's total potential for mitigating atmospheric carbon. The tree stratum alone accounted for 183.39 Mg CO_2 ha^{-1}, while the pole stratum contributed 52.49 Mg CO_2 ha^{-1}. These values demonstrate the functional importance of structural development, particularly in the tree layer, for maximizing carbon sequestration services in karst ecosystems.

These results confirm that current restoration efforts—despite their strong reliance on non-native species—have successfully established a high-biomass forest with moderate-to-high carbon accumulation potential. However, long-term sustainability will depend on the forest's ability to maintain and diversify structural attributes, especially in response to environmental stressors typical of karst systems.

Table 4. Biomass contribution of dominant species by stratum and species origin

Species name	Stratum	Species origin	AGB (Mg ha^{-1})
Tectona grandis L.f.	Tree	Non-native	65.31
Delonix regia (Bojer ex Hook.) Raf.	Tree	Non-native	16.27
Senna siamea (Lam.) H.S.Irwin & Barneby	Tree	Non-native	12.85
Gliricidia sepium (Jacq.) Kunth	Pole	Non-native	9.18
Melia azedarach L.	Pole	Non-native	6.47
Tamarindus indica L.	Pole	Native	5.22
Casuarina equisetifolia L.	Tree	Native	3.62
Dalbergia latifolia Roxb.	Tree	Native	2.97
Ficus benjamina L.	Tree	Native	2.12
Others (combined)	Tree & pole	Mixed	12.76
Subtotal	Tree	Non-native	102.36
	Tree	Native	4.59
	Pole	Non-native	27.71
	Pole	Native	2.11
Total	—	—	136.77

Table 5. Carbon stock and CO_2-equivalent by vegetation stratum and species origin

Stratum	Species origin	AGB (Mg ha^{-1})	Carbon stock (Mg C ha^{-1})	CO_2-eq (Mg CO_2 ha^{-1})
Tree	Non-native	102.36	48.11	176.56
Tree	Native	4.59	2.16	7.93
Pole	Non-native	27.71	13.02	47.77
Pole	Native	2.11	0.99	3.63
Total	All	136.77	64.28	235.88

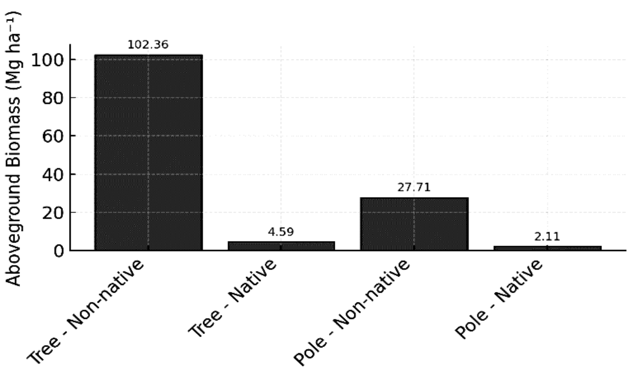

Figure 3. Distribution of aboveground biomass by stratum and species origin in Paliyan Wildlife Reserve. Yogyakarta, Indonesia

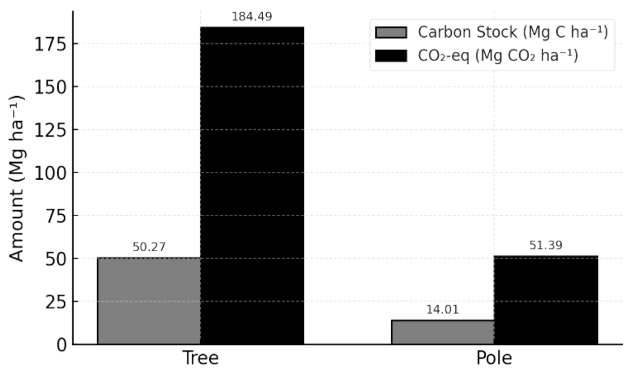

Figure 4. Total carbon stock and CO_2-equivalent by vegetation stratum in Paliyan Wildlife Reserve, Yogyakarta, Indonesia

Carbon storage and sequestration potential

The restored vegetation in the Paliyan Wildlife Reserve demonstrates moderate to high carbon storage capacity for a secondary forest in a karst ecosystem. Based on aboveground biomass estimates, the total carbon stock is 64.28 Mg C ha^{-1}, which translates to 235.88 Mg CO_2 ha^{-1}. These values are broadly comparable to other restored forests in tropical Southeast Asia and underscore the climate mitigation potential of karst reforestation efforts when supported by sustained silvicultural intervention (Indrajaya et al. 2022; Kiswanto et al. 2023).

The tree stratum accounts for the majority of this carbon reserve, with 50.27 Mg C ha^{-1}, equivalent to 183.39 Mg CO_2 ha^{-1}. The pole stratum contributes 14.01 Mg C ha^{-1}, or 52.49 Mg CO_2 ha^{-1}, highlighting the lesser but still notable role of younger or smaller trees in carbon accumulation. This stratified contribution reflects differences in DBH, height, and wood density between the two structural classes, as well as the dominance of fast-growing exotics in both strata.

Carbon storage is also highly skewed by species origin. As presented in Table 5, non-native species collectively store 61.13 Mg C ha^{-1} (223.33 Mg CO_2 ha^{-1})—constituting 95.1% of total carbon—whereas native species contribute only 3.15 Mg C ha^{-1} (11.55 Mg CO_2 ha^{-1}). This disparity mirrors the structural and numerical dominance of introduced species in the reserve. It indicates that the current sequestration potential is largely driven by a few highly productive exotic taxa, notably *T. grandis* and *D. regia*.

The stratified sequestration pattern is further illustrated in Figure 4, which visualizes the total CO_2-equivalent captured per vegetation stratum. The disproportionate contribution of the tree layer reinforces the importance of promoting vertical growth and stand maturity in restoration programs, especially in challenging karst terrain.

While the current restoration design has effectively enhanced biomass and carbon retention, it remains ecologically unbalanced due to limited native species participation. The urgency and significance of enhancing the role of native trees with high wood density—such as *D. latifolia*, *C. equisetifolia*, and *Schleichera oleosa*—cannot be overstated. This action may improve both biodiversity value and long-term carbon persistence. Native species are also more resilient to regional climatic cycles and may provide critical habitat functions not fulfilled by exotics.

The current carbon storage profile suggests strong climate mitigation potential, especially if restoration efforts are reoriented to incorporate native functional traits and improve structural heterogeneity. Such a shift would not only enhance resilience and ecosystem service delivery but also align with national and global forest restoration frameworks under the Paris Agreement and the UN Decade on Ecosystem Restoration, making our collective efforts part of a larger, impactful movement.

Species-level contributions to biomass and carbon stocks

A limited number of species, particularly fast-growing, non-native taxa, disproportionately contribute to the overall aboveground biomass and carbon storage in the Paliyan Wildlife Reserve. Species-level analysis reveals that only a few dominant species account for the majority of stored biomass and sequestered carbon, reflecting their structural prominence and functional roles within the restored karst forest.

Tectona grandis emerged as the single most important species, contributing 65.31 Mg ha^{-1} of AGB, which translates to 30.70 Mg C ha^{-1} and 112.66 Mg CO_2 ha^{-1}. This contribution alone represents nearly 47.7% of the total AGB across the landscape. Its dominance is attributed to large individual size, high wood density, and wide spatial distribution across plots.

Delonix regia and *S. siamea*, both non-native species, followed as major contributors. *D. regia* stored 16.27 Mg ha^{-1} of AGB (7.64 Mg C ha^{-1}; 28.06 Mg CO_2 ha^{-1}), while *S. siamea* accounted for 12.85 Mg ha^{-1} (6.04 Mg C ha^{-1}; 22.16 Mg CO_2 ha^{-1}). Together with *T. grandis*, these species accounted for more than 70% of the reserve's total carbon stock. While Table 4 emphasizes species dominance by stratum and origin, Table 6 further elaborates on the functional carbon contributions of each species, including their role in CO_2 sequestration.

Only *C. equisetifolia* and *D. latifolia* made appreciable contributions among native species. Although their shares were modest compared to exotics, they represent important ecological functions—such as drought resilience, soil stabilization, and habitat support—and are critical to long-term forest health.

These species-level contributions are also illustrated in Figure 5, which presents a comparative visualization of AGB, carbon stock, and CO_2 sequestration by dominant species. The figure highlights the steep drop-off in contribution beyond the top five species, emphasizing the monodominant nature of the current forest composition.

This finding reinforces the restored forest's structural dependency on a narrow set of non-native species. While effective in rapid biomass accumulation, such dependency could pose ecological risks related to resilience, biodiversity support, and susceptibility to pests or climate shifts. Increasing the presence of functional native species through targeted enrichment or protection of natural regeneration would be a necessary step toward ecological balance and long-term carbon stability.

Discussion

Structural dynamics of reforested karst vegetation

The structural profile of the Paliyan Wildlife Reserve, as revealed by the dominance of small- to medium-diameter stems and limited vertical stratification, reflects a forest in the early-to-intermediate stages of recovery following anthropogenic disturbance and reforestation intervention. Despite two decades of rehabilitation efforts, most individuals remain concentrated in the pole and lower tree strata, with a mean DBH of 14.95 cm for poles and 26.09 cm for trees. This structure is typical of secondary tropical forests in karst areas where soil depth, moisture availability, and rooting space are severely constrained (Eamus and Froend 2006; Kühnhammer et al. 2023).

The dominance of a few exotic species—particularly *T. grandis*, *D. regia*, and *S. siamea*—has resulted in a simplified canopy architecture. These species exhibit rapid vertical growth and competitive crown expansion, but their spatial dominance may inhibit the establishment of native species and limit vertical layering. The forest lacks the emergent stratum and complex understory layers typically found in mature tropical karst forests, such as those in southern China (Guo et al. 2017; Zeng et al. 2024) or northern Vietnam (Ngo and Hölscher 2014), where native hardwoods such as *Pistacia weinmannifolia* or *Parashorea chinensis* form intricate vertical profiles supporting diverse faunal assemblages.

Vertical structure in karst ecosystems is often shaped not only by tree age but also by microhabitat heterogeneity, soil pocket distribution, and karstic rock porosity (Clements et al. 2006). In Paliyan, limited stratification may also result from uniform planting patterns and insufficient recruitment of shade-tolerant or understory species. The observed vertical profile shows a dominance of mid-canopy trees with a sparse representation of higher and lower strata. This reduces niche availability for epiphytes, shrubs, and forest-dependent vertebrates, which are known to rely on vertical complexity for habitat and resource partitioning (Slik et al. 2013).

In terms of basal area and stem density, the values in Paliyan (ranging between 130-230 individuals ha^{-1} per stratum) are comparable to other reforested sites in tropical Southeast Asia (Chua et al. 2013; Chanlabut and Nahok 2022), but still fall short of natural old-growth karst forests, which typically exhibit stem densities >350 individuals ha^{-1} and a basal area exceeding 30 m^2 ha^{-1} (Chave et al. 2008). The relatively small mean DBH and height in both strata indicate that forest biomass accumulation is still in progress and that structural maturity has not yet been achieved.

Although pole-level contributions to stand structure remain high, these individuals represent a valuable recruitment layer for future canopy development. However, without effective thinning, enrichment, or natural mortality cycles, the current density of small stems may lead to stagnation or self-thinning without significant gains in vertical complexity or biomass.

These findings underscore the importance of monitoring forest structural attributes—not just species composition—as indicators of restoration success in karst regions. While the existing plantation has achieved moderate canopy closure and biomass recovery, it remains structurally simplified and compositionally imbalanced. Further interventions should prioritize structural enhancement through vertical stratification, recruitment of native mid-story species, and management of competitive dynamics among dominant exotic taxa.

Dominance of non-native species: Ecological trade-offs

The reliance on non-native species in the reforestation of the Paliyan Wildlife Reserve has produced rapid early-stage biomass accumulation and partial canopy closure, as evidenced by the dominance of *T. grandis*, *D. regia*, *S. siamea*, and *G. sepium*. These species contributed more than 90% of total stem count and accounted for over 95% of estimated carbon stock, underscoring their functional significance in shaping the current forest structure (Tables 4 and 6). Their use reflects a pragmatic restoration approach widely practiced in tropical regions: selecting fast-growing, drought-tolerant exotics to stabilize degraded lands and rapidly re-establish vegetation cover (Parrotta et al. 1997; Erskine et al. 2006; Cunningham et al. 2015; Pancel 2016).

However, this strategy comes with important ecological trade-offs. The overwhelming dominance of a few exotic taxa has resulted in a floristically impoverished and structurally homogeneous forest, potentially reducing habitat heterogeneity and narrowing the spectrum of ecological niches available to native flora and fauna. Such simplification may impair key ecosystem functions—including pollination, seed dispersal, and recruitment—that depend on complex native plant–animal networks (Holl and Aide 2011; Brancalion et al. 2017).

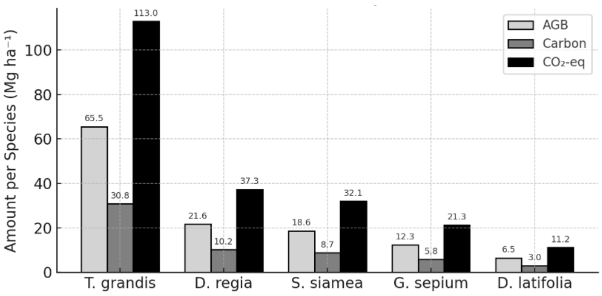

Figure 5. Species-level contribution to aboveground biomass, carbon stock, and CO_2 sequestration in Paliyan Wildlife Reserve, Yogyakarta, Indonesia

Table 6. Species-level contributions to aboveground biomass, carbon stock, and CO_2-equivalent

Species name	Origin	AGB ($Mg\ ha^{-1}$)	Carbon Stock ($Mg\ C\ ha^{-1}$)	CO_2-eq ($Mg\ CO_2\ ha^{-1}$)
Tectona grandis L.f.	Non-native	65.31	30.70	112.66
Delonix regia (Bojer ex Hook.) Raf.	Non-native	16.27	7.64	28.06
Senna siamea (Lam.) H.S.Irwin & Barneby	Non-native	12.85	6.04	22.16
Gliricidia sepium (Jacq.) Kunth	Non-native	9.18	4.31	15.82
Melia azedarach L.	Non-native	6.47	3.04	11.17
Tamarindus indica L.	Native	5.22	2.45	8.99
Casuarina equisetifolia L.	Native	3.62	1.70	6.24
Dalbergia latifolia Roxb.	Native	2.97	1.40	5.14
Ficus benjamina L	Native	2.12	1.00	3.67
Others (combined)	Mixed	12.76	6.00	22.97
Total	—	136.77	64.28	235.88

Several of the dominant exotic species in Paliyan, particularly *S. siamea* and *G. sepium*, are reported to exert allelopathic effects and possess aggressive root systems, which can suppress native species regeneration. Their vigorous vegetative propagation and prolific seeding capacity further contribute to the development of dense, monospecific stands that limit biodiversity recovery (Lugo 1997). These attributes, while useful for short-term soil protection, may hinder long-term ecosystem diversification and resilience.

From a carbon perspective, exotic species such as *T. grandis* function as efficient carbon sinks due to their favorable wood density and fast growth, especially under managed conditions. Yet, their long-term contribution to sequestration is contingent upon climatic stability, pest resistance, and continued stand vitality. Exotic-dominated stands—particularly in fragile substrates like karst—may be more vulnerable to abiotic stressors, including drought, fire, and pathogen outbreaks (Richardson et al. 2007; Castro et al. 2020).

Moreover, the broader goal of ecosystem multifunctionality—encompassing carbon storage, soil stabilization, hydrological regulation, and cultural services—is unlikely to be fully achieved through exotic-dominated plantings alone. Native species tend to support richer trophic webs and more complex ecological interactions, thereby enhancing the system's adaptive capacity and long-term sustainability (Benayas et al. 2009; Sayer et al. 2013).

Thus, while non-native species have functioned effectively as pioneer colonizers, their continued dominance may jeopardize the ecological integrity and multifunctional potential of the restored forest. Future restoration strategies should prioritize gradual transition toward diverse, native-enriched assemblages, integrating assisted enrichment, selective thinning, and facilitation of natural regeneration to steer ecosystem development toward structurally complex and ecologically resilient forest systems.

Vegetation structure as a driver of carbon sequestration

The distribution and magnitude of aboveground carbon stocks in the Paliyan Wildlife Reserve are closely linked to structural parameters of vegetation, DBH, total height, and basal area. These attributes not only reflect individual tree biomass but also determine stand-level carbon accumulation across successional stages. The analysis confirms that individuals with larger DBH and greater height disproportionately contribute to aboveground biomass and carbon reserves, a trend consistent with findings in other tropical forest systems (Slik et al. 2013; Chave et al. 2014).

Structurally dominant species—particularly *T. grandis*, *D. regia*, and *S. siamea*—play an outsized role in carbon storage despite limited species diversity. For instance, *T. grandis* alone contributed nearly 48% of total aboveground biomass, owing to its superior DBH range and high wood density. This pattern reflects a functional concentration of carbon storage capacity in a small subset of fast-growing, high-biomass species. Similar phenomena have been documented in reforested sites where a few high-performing taxa act as biomass anchors, driving carbon accumulation far beyond what would be predicted by species richness alone (Jensen et al. 2021).

This structural bias has important implications for carbon-oriented forest restoration. Forests with a higher proportion of large-diameter individuals store substantially more carbon, making the protection and promotion of such individuals essential for maximizing sequestration. Yet in karst environments, where soil depth, water availability, and rooting space are limited, the development of large trees is inherently restricted. Thus, species selection and spatial planning become critical determinants of biomass potential (Pérez-Cordero and Kanninen 2003).

The strong correlation between DBH and carbon stock underscores the importance of managing for stem growth and longevity. Strategies should emphasize long-lived species with favorable allometric traits, while minimizing disturbance and avoiding premature harvesting. In contrast, species with low wood density, short life cycles, or small maximum diameters—even if present in high densities—may contribute little to long-term carbon reserves.

Moreover, spatial heterogeneity in karst systems further complicates carbon accounting. Vegetation growth is often patchy due to shallow soil pockets and uneven microtopography, which constrain root development and tree stature. Accurate stand-level carbon estimates therefore require plot-based assessments that account for structural variability and species-specific biomass equations, reinforcing the need for spatially explicit, species-sensitive restoration design.

Ultimately, the vegetation structure observed in Paliyan offers a dual message: first, targeted planting of structurally dominant species can accelerate early-stage carbon accumulation in degraded karst forests; second, such accumulation may be ecologically precarious unless accompanied by species diversity and adaptive structural complexity. Forest managers must balance short-term carbon objectives with long-term goals of ecological functionality, biodiversity conservation, and resilience to environmental change.

Contribution of native species to ecosystem stability

Although native species contributed less than 10% of the total individual count and stored only 3.15 Mg C ha^{-1} (or 11.55 Mg CO_2 ha^{-1}) across strata (Table 5), their ecological role in supporting long-term ecosystem stability far exceeds their numerical and biomass representation. Native taxa such as *D. latifolia*, *C. equisetifolia*, *T. indica*, and *Ficus* spp. provide essential structural, hydrological, and trophic functions that are poorly replicated by exotic species.

Unlike many introduced trees, native species possess morphological and physiological adaptations finely tuned to the harsh edaphic conditions of karst ecosystems—including shallow, discontinuous soils, fractured limestone bedrock, and high evapotranspiration rates. *Casuarina equisetifolia*, for instance, thrives in nutrient-poor substrates and plays a significant role in stabilizing slopes and preventing erosion, while *D. latifolia*, with its dense and durable wood, contributes to long-term carbon retention and structural resilience (Eamus and Froend 2006).

These native species also enhance biodiversity conservation by providing critical resources such as fruit, nectar, and nesting substrates. For example, fruit-bearing *Ficus* trees act as keystone species that sustain frugivorous birds and mammals during periods of seasonal scarcity (Shanahan et al. 2001; Mulyani et al. 2021; Hendrayana et al. 2022). In contrast, exotic species such as *D. regia* and *S. siamea* often lack co-evolved relationships with native fauna, limiting their contribution to ecosystem complexity and trophic connectivity (Holl and Aide 2011).

Strategically incorporating native species into restoration trajectories is thus imperative for restoring functional integrity. This includes enrichment planting in canopy openings, protecting naturally regenerating seedlings, and prioritizing propagation of locally adapted genotypes. While native species may not match exotics in short-term biomass gain, their contribution to ecosystem resilience, nutrient cycling, and successional dynamics becomes increasingly valuable over time (Benayas et al. 2009; Brancalion et al. 2017).

Moreover, native species offer important safeguards against climate uncertainty. Their long evolutionary history in the region equips them with tolerance to local stressors such as periodic drought, fluctuating light regimes, and endemic pests and diseases. As climate variability intensifies, these inherent adaptive traits become central to ensuring restoration outcomes are robust and enduring (Suding et al. 2004; Thinkampheang et al. 2024).

Therefore, while exotic species may serve as initial facilitators of canopy closure and carbon input, native species must form the foundation of long-term ecosystem persistence. Achieving this requires a shift from purely biomass-centric metrics toward function-oriented indicators that reflect ecological stability, biotic interactions, and regenerative capacity. In karst ecosystems, where environmental constraints are acute, this balance is especially crucial to restoring not only carbon stocks but also the ecological identity embedded in native plant assemblages.

Implications for biodiversity and restoration policy in karst regions

The results of this study have direct relevance for restoration policy in karst landscapes, which are ecologically sensitive yet often marginalized in national land-use planning. Although reforestation in the Paliyan Wildlife Reserve has achieved considerable biomass recovery and carbon sequestration, the observed low structural complexity and dominance of non-native species suggest limited support for ecological processes and native biodiversity. These findings underscore the need for restoration strategies that prioritize not only biomass accumulation but also long-term ecological integrity, particularly in environmentally constrained karst systems where recovery trajectories are inherently variable and site-specific (Clements et al. 2006; Eamus and Froend 2006).

Restoration in karst regions should move beyond standardized plantation paradigms and adopt biodiversity-centered frameworks that emphasize native species inclusion, structural layering, and microhabitat diversification. Integrating functionally diverse native trees into enrichment schemes and maintaining heterogeneous landscape mosaics can enhance system resilience, ecological connectivity, and adaptive capacity. Such approaches are demonstrably more effective than exotic monocultures in sustaining ecosystem services like pollination, hydrological buffering, nutrient cycling, and resistance to biotic or climatic stressors (Holl and Aide 2011; Sayer et al. 2013; Brancalion et al. 2017).

These recommendations are in alignment with both global and national restoration mandates, including the UN Decade on Ecosystem Restoration (2021-2030), Indonesia's National Biodiversity Strategy and Action Plan (NBSAP), and REDD+ frameworks that promote synergies between carbon sequestration and biodiversity conservation. To meet these objectives, restoration policies must explicitly recognize karst landscapes as priority zones—not only for their carbon potential but also for their role as refugia of endemic biodiversity and ecosystem services.

By highlighting the functional outcomes and trade-offs of current reforestation practices, this study contributes empirical insights that can inform more adaptive, inclusive, and ecologically grounded restoration planning. Karst ecosystems demand context-sensitive management—balancing early carbon gains with the restoration of long-term ecosystem functionality, structural complexity, and biological heritage.

In conclusion, this study assessed the structure, biomass, and carbon stock of reforested vegetation in the Paliyan Wildlife Reserve, a karst landscape in southern Yogyakarta. The results show that while aboveground biomass and carbon sequestration have reached moderate levels—136.77 Mg ha^{-1} AGB and 235.88 Mg CO_2 ha^{-1}—the vegetation structure remains simplified and heavily dominated by non-native species. The tree stratum contributed nearly 80% of total carbon stock, with a few fast-growing exotics accounting for over 90% of ecosystem-level storage. Although these species accelerated early restoration success, their dominance has limited native species regeneration, reduced vertical complexity, and constrained long-term ecological resilience. The low representation of native trees—despite their vital ecological functions—underscores the need to shift restoration strategies toward structurally diverse, native-enriched, and functionally adaptive systems. These findings support restoration policies aligned with the UN Decade on Ecosystem Restoration, Indonesia's NBSAP, and REDD+ co-benefit frameworks, which recognize karst forests not only for climate mitigation but also for sustaining ecological and cultural resilience.

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REFERENCES

Adinugroho WC, Sidiyasa K. 2006. Model pendugaan biomassa pohon mahoni (*Swietenia macrophylla* King) di atas permukaan tanah. Jurnal Penelitian Sosial dan Ekonomi Kehutanan 3 (1): 103-117. DOI: 10.20886/jphka.2006.3.1.103-117. [Indonesian]

Aprilia D, Arifiani KN, Sani MF, Jumari, Wijayanti F, Setyawan AD. 2021. Review: A descriptive study of karst conditions and problems in Indonesia and the role of karst for flora, fauna, and humans. Intl J Trop Drylands 5 (2): 61-74. DOI: 10.13057/tropdrylands/t050203.

Bai X, Xiong K, Liu Z, Chen Y, Zhang Y, Liu Q. 2025. The scientometric analysis of Karst ecosystem structure and stability: Insights for sustainable protection of World Heritage Sites. npj Herit Sci 13 (1): 203. DOI: 10.1038/s40494-025-01743-6.

Basuki TM, Leksono B, Baral H, Andini S, Wahyuni NS, Artati Y, Choi E, Shin S, Kim R, Yang AR, Samsudin YB, Windyarini E. 2022. Allometric equations for the biomass estimation of *Calophyllum inophyllum* L. in Java, Indonesia. Forests 13 (7): 1057. DOI: 10.3390/f13071057.

Benayas JM, Newton AC, Diaz A, Bullock JM. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. Science 325 (5944): 1121-1124. DOI: 10.1126/science.1172460.

Biah I, Guendehou S, Goussanou C, Kaire M, Sinsin AB. 2019. Allometric models for estimating biomass stocks in cashew (*Anacardium occidentale* L.) plantation in Benin. Bull de la Recherche Agron du Bénin (BRAB) 84: 16-27.

Brancalion PHS, Lamb D, Ceccon E, Boucher D, Herbohn J, Strassburg B, Edwards DP. 2017. Using markets to leverage investment in forest and landscape restoration in the tropics. For Policy Econ 85: 103–113. DOI: 10.1016/j.forpol.2017.08.009.

Brown S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO Forest Paper 134, Rome.

Castro SP, Esch EH, Eviner VT, Cleland EE, Lipson DA. 2020. Exotic herbaceous species interact with severe drought to alter soil N cycling in a semi-arid shrubland. Geoderma 361: 114111. DOI: 10.1016/j.geoderma.2019.114111.

Chanlabut U, Nahok B. 2022. Forest structure and carbon stock of Suan Phueng Nature Education Park in Ratchaburi Province, Western Thailand. Biodiversitas 23 (8): 4314-4321. DOI: 10.13057/biodiv/d230856.

Chave J, Andalo C, Brown S et al. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145: 87-99. DOI: 10.1007/s00442-005-0100-x.

Chave J, Olivier J, Bongers F, Châtelet P, Forget PM, van Der Meer P, Norder N, Riéra B, Charles-Dominique P. 2008. Above-ground biomass and productivity in a rain forest of eastern South America. J Trop Ecol 24 (4): 355-366. DOI: 10.1017/S0266467408005075.

Chave J, Réjou-Méchain M, Búrquez A et al. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Glob Chang Biol 20: 3177-3190. DOI: 10.1111/gcb.12629.

Chua SC, Ramage BS., Ngo KM, Potts MD, Lum SK. 2013. Slow recovery of a secondary tropical forest in Southeast Asia. For Ecol Manag 308: 153-160. DOI: 10.1016/j.foreco.2013.07.053.

Clements R, Sodhi NS, Schilthuizen M, Ng PKL. 2006. Limestone karsts of Southeast Asia: Imperiled arks of biodiversity. BioScience 56 (9): 733-742. DOI: 10.1641/0006-3568(2006)56[733:LKOSAI]2.0.CO;2.

Cunningham SC, Mac Nally R, Baker PJ, Cavagnaro TR, Beringer J, Thomson JR, Thompson RM. 2015. Balancing the environmental benefits of reforestation in agricultural regions. Perspectives in Plant Ecology, Evol Syst 17 (4): 301-317. DOI: 10.1016/j.ppees.2015.06.001.

Curtis JT, McIntosh RP. 1950 The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31: 434-455. DOI: 10.2307/1931497.

Dovrat G, Meron E, Shachak M, Golodets C, Osem Y. 2019. The relative contributions of functional diversity and functional identity to ecosystem function in water-limited environments. J Veg Sci 30 (3): 427-437. DOI: 10.1111/jvs.12745.

Duncanson L, Armston J, Disney M et al. 2021. Aboveground woody biomass product validation good practices protocol. In: Duncanson L, Disney M, Armston J, Nickeson J, Minor D, Camacho F (eds). Good Practicesfor Satellite Derived Land Product Validation: Land Product Validation Subgroup (WGCV/CEOS). DOI: 10.5067/doc/ceoswgcv/lpv/agb.001.

Eamus D, Froend R. 2006. Groundwater-dependent ecosystems: the where, what and why of GDEs. Aust J Bot 54 (2): 91-96. DOI: 10.1071/BT05037.

Ekayanti N, Indriyanto, Duryat. 2015. Pengaruh zat alelopati dari pohon akasia, mangium, dan jati terhadap pertumbuhan semai akasia, mangium, dan jati. Jurnal Sylva Lestari 3 (1): 81-90. DOI: 10.23960/jsl1381-90. [Indonesian]

Erskine PD, Lamb D, Bristow M. 2006. Tree species diversity and ecosystem function: Can tropical multi-species plantations generate greater productivity? For Ecol Manag 233 (2-3): 205-210. DOI: 10.1016/j.foreco.2006.05.013.

Food and Agriculture Organization (FAO). 2010. Global Forest Resource Assessment. Food and Agriculture Organization, Rome.

Gunawan H, Mulyanto B, Suharti S et al. 2024b. Forest land redistribution and its relevance to biodiversity conservation and climate change issues in Indonesia. For Sci Technol 20 (2): 213-228. DOI: 10.1080/21580103.2024.2347902.

Gunawan H, Setyawati T, Atmoko T et al. 2024a. A review of forest fragmentation in Indonesia under the DPSIR framework for biodiversity conservation strategies. Glob Ecol Conserv 51: e02918. DOI: 10.1016/j.gecco.2024.e02918.

Guo Y, Wang B, Mallik AU, Huang F, Xiang W, Ding T, Wen S, Lu S, Li D, He Y, Li X. 2017. Topographic species–habitat associations of tree species in a heterogeneous tropical karst seasonal rain forest, China. J Plant Ecol 10 (3): 450-460. DOI: 10.1093/jpe/rtw057.

Hendrati RL, Nurrohmah SH. 2018. Quality of genetically-improved *Acacia auriculiformis* for renewable short-rotation wood-energy. Jurnal Manajemen Hutan Tropika 24 (3): 136-136. DOI: 10.7226/jtfm.24.3.136.

Hendrayana Y, Sudiana E, Adhya I, Ismail AY. 2022. Bird diversity in three Ficus species in the Kuningan Lowland Forest, West Java, Indonesia. Biodiversitas 23 (5): 2255-2261. DOI: 10.13057/biodiv/d230502.

Hikari HN, Syahrani LPW, Luthfia SK, Setyawan AD. 2023. Analisis keanekaragaman pohon di kawasan karst Gunung Sewu Studi Kasus: Gua Tembus dan Gua Potro-Bunder Pracimantoro, Wonogiri. Indones J Biotechnol Biodivers 7 (3): 119-130. DOI: 10.47007/ijobb.v7i3.211.

Holl KD, Aide TM. 2011. When and where to actively restore ecosystems? For Ecol Manag 261 (10): 1558-1563. DOI: 10.1016/j.foreco.2010.07.004.

Ilyas S. 2013. Carbon sequestration and growth of stands of Cassia siamea Lamk. in coal mining reforestation area. Indian J Sci Technol 6 (11): 5405-5410. DOI: 10.17485/ijst/2013/v6i11.1.

Indrajaya Y, Yuwati TW, Lestari S et al. 2022. Tropical forest landscape restoration in Indonesia: A review. Land 11 (3): 328. DOI: 10.3390/land11030328.

IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC, Rome.

Jara MC, Henry M, Réjou-Méchain M et al. 2015. Guidelines for documenting and reporting tree allometric equations. Ann For Sci 72 (6): 763-768. DOI: 10.1007/s13595-014-0415.

Jensen DA, Rao M, Zhang J, Grøn M, Tian S, Ma K, Svenning JC. 2021. The potential for using rare, native species in reforestation–A case study of yews (Taxaceae) in China. For Ecol Manag 482: 118816. DOI: 10.1016/j.foreco.2020.118816.

Khushi LR, Hossain M, Rubaiot Abdullah SM, Saha S, Siddique MRH. 2019. Allometric models for estimation of aboveground biomass of *Gmelina arborea* Roxb. in pulpwood plantations of Bangladesh. South For: J For Sci 81 (1): 45-48. DOI: 10.2989/20702620.2018.1488209.

Kiswanto, Mardiany, Ariyanto, Tsuyuki S. 2023. Silvicultural decisions to formulate forest restoration strategies using geospatial approaches. IOP Conf Ser: Earth Environ Sci 1282 (1): 012054. DOI: 10.1088/1755-1315/1282/1/012054.

Kühnhammer K, van Haren J, Kübert A, Bailey K, Dubbert M, Hu J, Ladd SN, Meredith LK, Werner C, Beyer M. 2023. Deep roots mitigate drought impacts on tropical trees despite limited quantitative contribution to transpiration. Sci Total Environ 893: 164763. DOI: 10.1016/j.scitotenv.2023.164763.

Lugo AE. 1997. The apparent paradox of re-establishing species richness on degraded lands with tree monocultures. For Ecol Manag 99 (1-2): 9-19. DOI: 10.1016/S0378-1127(97)00191-6.

Lukito M, Rohmatiah A. 2022. Stored carbon FMU Lawu Manunggal using a biomass approach in the community forest in Sidomulyo Village, Magetan Regency, Indonesia. Eng Technol J 7 (10): 1584-1596. DOI: 10.47191/etj/v7i10.06.

Macias CAS, Alegre Orihuela JC, Iglesias Abad S. 2017. Estimation of above-ground live biomass and carbon stocks in different plant formations and in the soil of dry forests of the Ecuadorian coast. Food Energy Secur 6 (4): e00115. DOI: 10.1002/fes3.115.

Martin FS, Navarro-Cerrillo RM, Mulia R, Van Noordwijk M. 2010. Allometric equations based on a fractal branching model for estimating aboveground biomass of four native tree species in the Philippines. Agrofor Syst 78: 193-202. DOI: 10.1007/s10457-009-9271-5.

Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Mulyana B, Soeprijadi D, Purwanto RH. 2020. Allometric model of wood biomass and carbon for gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) at bioenergy plantation in Indonesia. For Ideas 26 (1): 153-164.

Mulyani YA, Kusrini MD, Mardiastuti A, Oktaviani R, KabanA. 2021. The use of weeping fig *Ficus benjamina* by wildlife in campus area of Dramaga, Bogor, Indonesia. IOP Conf Ser: Earth Environ Sci 948 (1): 012012. DOI: 10.1088/1755-1315/948/1/012012.

Ngo TL, Hölscher D. 2014. The fate of five rare tree species after logging in a tropical limestone forest (Xuan Son National Park, northern Vietnam). Trop Conserv Sci 7 (2): 326-341. DOI: 10.1177/194008291400700211.

Odum EP. 1971. Fundamentals of Ecology. Third Edition, W.B. Saunders Co., Philadelphia.

Pancel L. 2016. Forest restoration and rehabilitation in the tropics. In: Pancel L, Köhl M (eds). Tropical Forestry Handbook. Springer, Berlin, Heidelberg. DOI: 10.1007/978-3-642-54601-3_120.

Parrotta JA, Turnbull JW, Jones N. 1997. Catalyzing native forest regeneration on degraded tropical lands. For Ecol Manag 99 (1-2): 1-7. DOI: 10.1016/S0378-1127(97)00190-4.

Pearson TR, Brown S, Casarim FM. 2014. Carbon emissions from tropical forest degradation caused by logging. Environ Res Lett 9 (3): 034017. DOI: 10.1088/1748-9326/9/3/034017.

Pérez-Cordero LC, Kanninen M. 2003. Aboveground biomass of *Tectona grandis* plantations in Costa Rica. J Trop For Sci 15 (1): 199-213.

Pratama BA, Atikah TD, Susanti R, Jakalalana S, Ferdinandus SP, Maail RS. 2025. Stand structure and biomass estimation for cultivation of Agarwood-producing species on Buru Island, Maluku Province, Indonesia. Media Konservasi 30 (1): 63-63. DOI: 10.29244/medkon.30.1.63.

Preece ND, Lawes MJ, Rossman AK, Curran TJ, Van Oosterzee P. 2015. Modelling the growth of young rainforest trees for biomass estimates and carbon sequestration accounting. For Ecol Manag 351: 57-66. DOI: 10.1016/j.foreco.2015.05.003.

Rawal K, Subedi PB. 2022. Vegetation structure and carbon stock potential in the community-managed forest of the Mid-Western Hilly Region, Nepal. Asian J For 6 (1): 15-21. DOI: 10.13057/asianjfor/r060103.

Richardson DM, Hellmann JJ, McLachlan JS et al. 2007. Multidimensional evaluation of managed relocation. Conserv Biol 23 (2): 430-440. DOI: 10.1111/j.1523-1739.2008.01154.x.

Rosmerita DT, Purwanto RH. 2008. Potensi Hutan Rakyat Jenis Sonokeling (*Dalbergia latifolia*) dalam mensequester karbon di Desa Nglanggeran, Kabupaten Gunung Kidul. [Skripsi]. Universitas Gadjah Mada, Yogyakarta. [Indonesian]

Sayer J, Sunderland T, Ghazoul J, Pfund JL, Sheil D, Meijaard E, Venter M, Boedhihartono AK, Day M, Garcia C, van Oosten C, Buck LE. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc Natl Acad Sci 110 (21): 8349-8356. DOI: 10.1073/pnas.1210595110.

Septiasari A, Balgis M, Lathifah MN, Hanugroho PD, Setyawan AD. 2021. Identification and potential of vascular plants in the karst ecosystem of Somopuro Cave, Pacitan, East Java, Indonesia. Intl J Trop Drylands 5 (2): 75-83. DOI: 10.13057/tropdrylands/t050204.

Shanahan M, So S, Compton SG, Corlett RT. 2001. Fig-eating by vertebrate frugivores: a global review. Biol Rev 76 (4): 529-572. DOI: 10.1017/S1464793101005760.

Siregar CN. 2012. Formulasi persamaan allometrik untuk pendugaan biomassa karbon jati (*Tectona grandis* Linn. f) di Jawa Barat. Jurnal Penelitian Sosial dan Ekonomi Kehutanan 9 (3): 29078. DOI: 10.20886/jsek.2012.9.3.160-169. [Indonesian]

Slik JWF, Paoli G, McGuire K et al. 2013. Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. Glob Ecol Biogeogr 22 (12): 1261-1271. DOI: 10.1111/geb.12092.

SNI. 2011. Pengukuran dan Perhitungan Cadangan Karbon-Pengukuran Lapangan untuk Penaksiran Cadangan Karbon Hutan. BSN, Jakarta. [Indonesian]

Song X, Hao H, Liu W, Wang Q, An L, Yeh TCJ, Hao Y. 2022. Spatial-temporal behavior of precipitation driven karst spring discharge in a mountain terrain. J Hydrol 612: 128116. DOI: 10.1016/j.jhydrol.2022.128116.

Suding KN, Gross KL, Houseman GR. 2004. Alternative states and positive feedbacks in restoration ecology. Trends Ecol Evol 19 (1): 46-53. DOI: 10.1016/j.tree.2003.10.005.

Thinkampheang S, Nakashizuka T, Suksavate W, Kachina P, Hermhuk S, Asanok L, Phumphuang W, Chouibumroong B, Wu J, Kurokawa H, Marod D. 2024. Impacts of climate change on forest restoration dynamics in the lower montane forest of Doi Suthep-Pui National Park, Northern Thailand. Biodiversitas 25 (12): 4829-4845. DOI: 10.13057/biodiv/d251219.

Wahyudi UN, Aminatun T. 2018. Keanekaragaman jenis kupu-kupu (Rhopalocera) di Suaka Margasatwa Paliyan Kabupaten Gunungkidul. Kingdom: J Biol Stud 7 (2): 133-146. DOI: 10.21831/kingdom.v7i2.12995. [Indonesian]

Wahyuni H, Suranto S. 2021. Dampak deforestasi hutan skala besar terhadap pemanasan global di Indonesia. JIIP: Jurnal Ilmiah Ilmu Pemerintahan 6 (1): 148-162. DOI: 10.14710/jiip.v6i1.10083. [Indonesian]

Wicaksono D. 2024. Penaksiran Potensi Biomassa pada Hutan Tanaman Mangium, *Acacia mangium* Wiild. [Thesis]. Institut Pertanian Bogor, Bogor. [Indonesian]

Wilkes P, Disney M, Vicari MB, Calders K, Burt A. 2018. Estimating urban above ground biomass with multi-scale LiDAR. Carbon Balance Manag 13: 10. DOI: 10.1186/s13021-018-0098-0.

Yuslinawari Y, Doris D, Wahyudiono S. 2021. Kajian identifikasi jenis flora dan kelimpahannya di lahan penetapan taman keanekaragaman hayati Kelurahan Karangasem, Kecamatan Ponjong, Kabupaten Gunung Kidul. J People For Environ 1 (1): 34-42. DOI: 10.23960/jopfe.v1i1.4519. [Indonesian]

Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J. 2009. Global Wood Density Database. Dryad. DOI: 10.5061/dryad.234.

Zeng WH, Zhu SD, Luo YH, Shi W, Wang YQ, Cao KF. 2024. Aboveground biomass stocks of species-rich natural forests in southern China are influenced by stand structural attributes, species richness and precipitation. Plant Divers 46 (4): 530-536. DOI: 10.1016/j.pld.2024.04.012.

Zerga B. 2024. Karst topography: Formation, processes, characteristics, landforms, degradation and restoration: A systematic review. Watershed Ecol Environ 6: 252-269. DOI: 10.1016/j.wsee.2024.

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Mapping hotspots of human-wildlife conflict involving porcupines, long-tailed macaques, and humans in the Karst Region of Wonogiri, Indonesia

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Abstract. *Ainindya DG, Rahmadana MI, Meilani F, Gestan DA, Deristani A, Setyawan AD. 2025. Mapping hotspots of human-wildlife conflict involving porcupines, long-tailed macaques, and humans in the Karst Region of Wonogiri, Indonesia. Intl J Trop Drylands 9: 65-73.* The Wonogiri Karst Area in Indonesia is dominated by forests/shrubs that provide space for wildlife to thrive. However, the presence of species such as Javan porcupines (*Hystrix javanica*) and long-tailed macaques (*Macaca fascicularis*) can lead to conflicts with humans. This study aims to map conflict-prone areas between humans and wildlife by utilizing buffer tools in spatial analysis to gain a deeper understanding of these conflicts and develop sustainable solutions in Songbledeg, Paranggupito, and Gunturharjo Villages, located in Paranggupito Sub-district, Wonogiri District, Central Java. The research was conducted in October 2024. The methodology used includes buffer analysis using ArcGIS software. Data collection points are obtained through field surveys supported by the Avenza Map application, interviews, and equipped with spatial data. The results indicate that human wildlife, such as Java porcupines and long-tailed macaques, conflicts in the three villages occur near water sources such as rivers and coastal areas. In Gunturharjo and Songbledeg, conflicts were found in areas with elevations of 300-600 meters above sea level (masl), particularly in rice fields and drylands. Meanwhile, in Paranggupito, conflicts occurred not only at the same elevation range but also in residential areas. These conflicts highlight the need for the involvement of all stakeholders to mitigate the factors contributing to conflicts between porcupines, macaques, and humans. Efforts to reduce the occurrence of such conflicts include law enforcement and monitoring through joint patrols in the affected areas.

Keywords: Human-wildlife conflict, karst area, spatial analysis, wildlife management

INTRODUCTION

The clash between humans and natural life poses a danger that can result in the reduction of some natural life populations (Bahari et al. 2022). These clashes as often as possible happen around the world due to expanding human populace development, land-use changes, territory misfortune, and framework improvement (Sahu et al. 2021). Such conflicts involve competition for limited resources between humans and wildlife in a particular area, resulting in losses for one of the parties. However, it's important to note that some wild animal species provide positive impacts (benefits), and with the right conservation efforts, these benefits can be enhanced. On the other hand, others are perceived as causing negative impacts, leading to human-wildlife conflicts (Khawarizmi et al. 2024). Increased encroachment activities by communities can affect the ecological dynamics of monkeys (Hambali et al. 2012). Exploitative forest clearing leads to degradation, fragmentation, and even the loss of natural wildlife habitats (Ekarini et al. 2022).

This situation forces various animal species out of their natural habitats, leading to unwanted direct interactions with humans. When forests and natural lands are converted into plantations or residential areas, wild animals lose their habitats and natural food sources. This pushes some wildlife species to venture into human settlements and agricultural lands. Human-wildlife conflict has increasingly become a concern for environmental conservationists (Somu and Palanisamy 2022). In Indonesia, conflicts between humans and animals, such as with elephants or tigers, are quite common. Indonesia has the highest rate of elephant conflicts in Asia, at approximately 1.2% of incidents, compared to 0.4% in Thailand and 0.2% in Vietnam (Bahari et al. 2022).

The karst region of Wonogiri, Central Java, Indonesia, is an area with high biodiversity, featuring a unique and fragile ecosystem. This region serves as a habitat for various fauna species, including porcupines (*Hystrix* sp.) and long-tailed macaques (*Macaca* sp.), which play crucial roles in maintaining ecosystem balance. The most common conflicts occur between humans and porcupines or long-tailed macaques. Porcupine habitats are found in rocky and mountainous forests, which these animals use for foraging and resting (Awak et al. 2015). Conflicts between humans and long-tailed macaques frequently occur due to their proximity to human environments, which are directly adjacent to their natural habitats (Fauziah et al. 2023).

The agricultural region of Wonogiri is known for its intercropping farming system. Long-tailed macaques and porcupines venture into human settlements due to the depletion of resources in their natural habitats, causing them to forage in areas close to their original environments (Makmur et al. 2020). Long-tailed macaques and porcupines foraging or entering plantations result in damage (Rittem et al. 2023). This circumstance specifically impacts farmers vocations and nearby nourishment security (Paripurno et al. 2024). Clashes between people and monkeys are habitually detailed in different considers, primarily due to covering ranges or spatial domains (Sulistiyowati et al. 2024). Research by Tandi et al. (2023) states that monkey conflicts arise due to limited food resources caused by habitat destruction, such as deforestation and agricultural areas bordering long-tailed macaques habitats. The presence of these wild animals causes significant economic losses to local communities that rely on agricultural produce (Riska et al. 2023).

In addressing human-wildlife conflicts, understanding species habitats and distributions is crucial. Remote sensing imagery, particularly from Landsat satellites, is widely used to estimate wildlife distribution and habitat suitability due to its free access and broad spatial coverage (Giefer and An 2022). Geographic Information Systems (GIS) have various applications, including natural resource inventory, land suitability evaluation for activities such as agriculture, plantations, and forestry, land-use planning, disaster-prone area analysis, and the management of conservation areas for flora and fauna (Utami et al. 2022).

Remote sensing and GIS technologies are increasingly applied in wildlife conflict studies, although spatial analyses focusing on identifying Human-Wildlife Conflict (HWC) risk zones still need to be expanded. Research also utilizes Sentinel-2 satellite imagery for Land Use and Land Cover (LULC) classification and MODIS satellite data to monitor vegetation changes (Gunawansa et al. 2023). Assessing physical and social factors, such as NDVI, LULC, proximity to rivers and roads, conflict risk zones, settlements, slope gradients, and other aspects through geospatial techniques, helps identify suitable locations to understand human-wildlife conflicts (Badhe and Jayabhaye 2021). The difference between this study and other studies is in the research method; in the study by Toiyo et al. (2024), the method used was to use the community perspective from the results of interview data, observations, and focus group discussions, while this study was supplemented with data processing via GIS. This study aims to map conflict-prone areas between humans and wildlife using buffer tools in spatial analysis to gain a deeper understanding of these conflicts and develop sustainable solutions.

MATERIALS AND METHODS

Study area

This research was conducted in October 2024 in three villages: Songbledeg, Paranggupito, and Gunturharjo, located in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (Figure 1). Karst landscapes characterize the study area. Karst regions harbor biodiversity, including endemic species that are threatened by human activities (Stanković 2023). The presence of long-tailed macaques and porcupines entering agricultural areas in the 3 villages can trigger changes in the diet and behavior of these animals. On the other hand, long-tailed macaques and porcupines play a crucial role in maintaining the balance of the karst ecosystem.

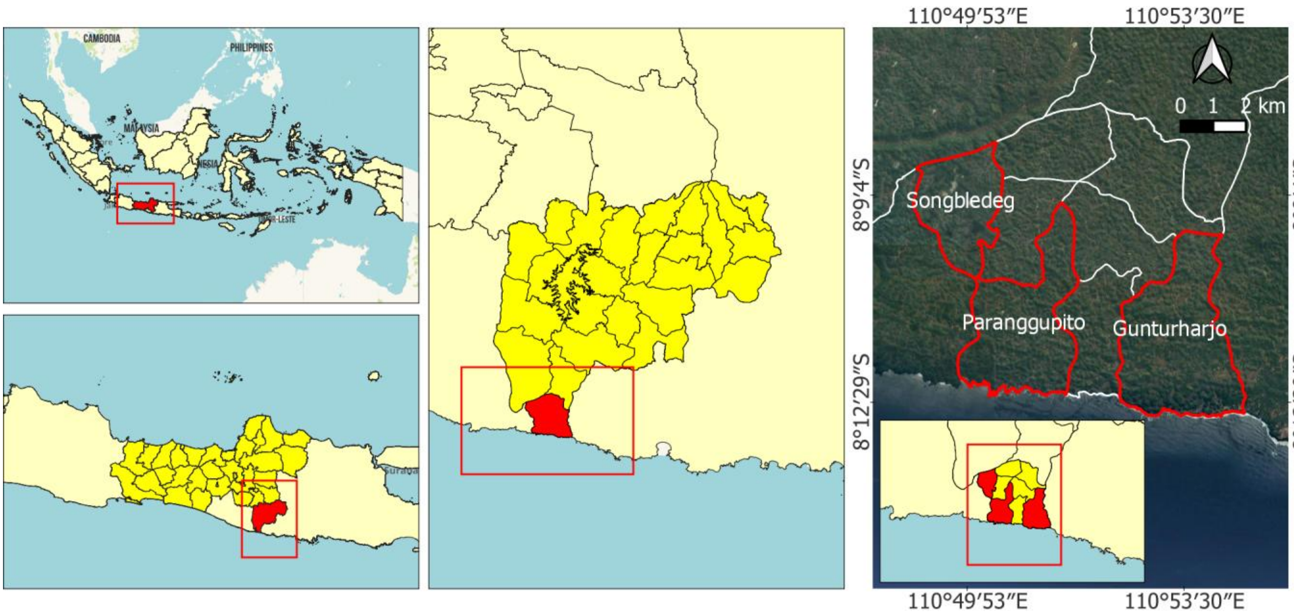

Figure 1. The research location is in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

The determination of these three villages as investigative targets was based on their nearness to the coast and their broad woodland ranges. In addition, the area of agricultural land in the 3 villages is larger when compared to other villages in Paranggupito Sub-district. These components, too, contribute to potential clashes between people and natural life. Besides, agribusiness in Paranggupito, Songbledeg, and Gunturharjo is considered more beneficial, drawing in natural life to scavenge in neighborhood rural areas. These villages are also directly adjacent to the coastline, which serves as a habitat for long-tailed macaques. According to Hadi et al. (2019), long-tailed monkeys can thrive in various habitats, such as coastal areas, mountain forests, humid forests, and areas surrounded by human settlements, including sacred cemeteries, temples, tourist parks, and village forests.

Based on Figure 1, Paranggupito and Gunturharjo Villages are directly adjacent to the Indian Ocean. This makes it prone to conflicts in both villages. This is because the habitat of wildlife, especially monkeys, which are generally located along the coast, has undergone land use changes and caused food shortages. In addition, Paranggupito Sub-district is one of the sub-districts in Wonogiri District that has characteristics as a karst area. This rocky area provides a habitat unit for wildlife such as hedgehogs and long-tailed monkeys. The three villages are also dominated by tropical forests and shrubs used by wildlife to shelter and forage for food.

Data collection

The instruments used in this study include computers, Geographic Information System (GIS) software such as ArcGIS 10.8, Avenza Map, and Global Positioning System (GPS) to assist in the creation of conflict risk maps and land use maps, as well as contour maps. Data on human-wildlife conflicts were collected from primary sources, including field research, and secondary sources from published and unpublished literature, such as in-depth interviews with village heads to obtain data related to conflicts. In-depth interviews were conducted with 3 people who were key informants in each village, these informants were village heads who had an age range of 30-50 years. The spatial data used includes administrative boundaries, road and river networks, land use, and topography, which support the analysis.

The initial map of conflict-prone areas between long-tailed macaques, porcupines, and humans was created by collecting data on conflict points involving wildlife. The point data were obtained through field surveys using the Avenza Maps application at three research locations. After the point data and spatial data were collected, they were processed using ArcGIS through buffer analysis. Buffer analysis is a method of processing vector data with GIS software to generate the outermost polygon boundaries. These boundaries are based on the input used, either in the form of lines or points. The buffer tool generates a polygon surrounding the points or areas with a specified distance. In this study, the buffer radius used was 200 meters and 400 meters from the wildlife location points. This buffer distance was chosen to represent the area of direct interaction between wildlife and humans that could potentially lead to conflict. The general categories of land cover are differentiated into several types, such as forest, plantation, settlement, shrubs, grasslands with finer textures, open land, and water bodies represented in blue. Slope analysis, similar to the creation of elevation maps, is conducted through the slope process. Distance measurement involves objects in the form of point, line, area, or grid shapefiles. Buffer creation is carried out to generate distance-based shapefiles.

Data analysis

Data analysis was conducted descriptively by analyzing the spatial distribution of conflicts between wildlife and humans using maps with high incident frequencies. Spatial analysis was also required to examine the relationship between the research areas and the conflict occurrences in relation to environmental factors such as land use, elevation, slope, and terrain. Land use maps, contour slopes, rivers, and roads for each village were created to analyze the vulnerability of wildlife-human conflicts. The examination of arrival utilization, especially the move from thick woodlands and shrublands to rural areas, rice paddies, and settlements, essentially contributes to an increment in wildlife-human struggle occurrences, driving to more powerless and high-risk strife zones (Nad et al. 2022). Buffer creation is carried out to generate distance-based shapefiles. Applying buffering in mapping can enhance spatial analysis related to human-wildlife conflicts by defining areas of influence and allowing for dynamic adjustments based on environmental factors (Xu et al. 2021). This analysis can lead to more accurate decision-making and support ecological sustainability through tailored spatial assessments.

RESULTS AND DISCUSSION

The location points for observing conflict-prone areas between porcupines, long-tailed macaques, and humans were taken in three villages: Gunturharjo, Paranggupito, and Songbledeg. These villages were selected because they are considered to be the largest agricultural producers. Factors influencing the occurrence of conflicts include the elevation of the location, slope, distance from rivers, distance from roads, and land cover conditions. The three observation locations, Gunturharjo, Paranggupito, and Songbledeg, are villages with relatively abundant agricultural production. Gunturharjo also has dense natural vegetation, such as forests and gardens. Songbledeg, on the other hand, has varied landscapes, including agricultural lands, but relatively dense forest areas. Paranggupito is the closest village to the coast, making it more prone to conflicts between long-tailed macaques and humans. Meanwhile, Gunturharjo and Songbledeg are farther from the coast, so the conflicts that occur there are more frequent between porcupines and humans.

Distribution of animal conflict sites by slope

Based on Figure 2, we know that the three research locations, namely Gunturharjo, Paranggupito, and Songbledeg Villages, are located in areas with flat terrain, with slopes ranging from flat until very steep. Meanwhile, in Paranggupito Village, conflict points are spread across several slope classes, including slope sloping class with 1 point, slope rather steep class and slope very steep class. The conflict points in Songbledeg Village are spread across slope classes flat until steep. This observation point was taken from the slopes of class flat until steep because most people cultivate plants on land that ranges from flat to steep.

Distribution of animal conflict sites by altitude

Based on Figure 3, we know that the three research locations are located at an altitude of 300-600 masl. The observation of conflict locations is divided into four points to identify the areas with the highest conflict intensity. The selection of four observation points in Paranggupito Village is divided between the outskirts of the village, where long-tailed macaques roam, and the center of the village, which serves as a habitat for porcupines. The three locations also have consistent heights and locations that can facilitate conflicts to spread to various parts of the village. Consistent elevations and similar locations across villages contribute to conflicts involving hedgehogs and long-tailed macaques in different parts of the village. In addition, altitude also affects conflicts between hedgehogs and humans, as hedgehogs are generally found in karst-hilly areas at higher altitudes. This is also due to the fact that areas at an altitude of 300-600 masl constitute a transition zone between lowlands and plateaus, which affects vegetation, temperature, food availability, and humidity. As a result, most of the people at the research site use the land for agriculture, plantations, and even housing and tourism development. As development increases, competition between humans, long-tailed apes, and hedgehogs for limited natural resources has led to increased conflicts.

Distribution of animal conflict sites by distance from river

Based on Figure 4, the conflict in Gunturharjo Village occurred in an area with a radius of less than 400 meters from a small river. Then, Paranggupito Village has a conflict area located in the agricultural area of the community near the river. Observations were made at four points, namely 2 points within a radius of <400 meters from the river, 1 point within a radius of 400-800 meters, and 1 point within a radius of 800-1.200 meters. Meanwhile, Songbledeg Village did not find a radius of conflict with the river because no image of the river area was found during the buffer process. The proximity of agricultural land to the river affects the occurrence of conflicts between wildlife and humans. Conflict-prone areas that are near water sources, such as rivers, attract animals to forage at that location. In addition, the area is also highland close to the habitat of porcupines, which usually live in cavities in the karst area.

Distribution of animal conflict sites by distance from the road

The buffer creation aims to determine the proximity of the conflict location to the roads in the three research locations. The entire research area is located at the same distance, less than 1.000 meters from the village road. The location of this research is quite close to road access (Figure 5). The proximity of the conflict location to the road is due to the fact that hedgehog-man conflicts also occur in residential areas that are very close to the road. The closest conflict location to the road in Gunturharjo Village is within 1.000 meters of the two points, while the two farthest locations are between 1.001 and 2.000 meters from the road. The location of the conflict farther away from road access is due to the pressure on hedgehogs and long-tailed macaques, causing them to move away from areas near the road. Importantly, transportation activities and housing development encouraged hedgehogs to move from this area and to other areas in search of food. Meanwhile, Paranggupito Village, which is known as a tourist village, has led to the development of many roads to beach tourist destinations in the area. The conflict that occurred near the road access was caused by the pressure on the hedgehog and long-tailed macaques, forcing them to stay in the area but venture into residential areas in search of food. In Songbledeg Village, most of the karst cliffs are located near the road, so conflicts often occur because porcupines often forage in residential and agricultural areas. In addition, land clearing puts pressure on hedgehogs and long-tailed macaques, forcing them to stay in the area but travel to residential areas in search of food.

Distribution of animal conflict sites by land cover

The conflict observation locations are in several areas that indicate the presence of porcupines and long-tailed macaques (Figure 6). The observation sites in Gunturharjo Village are divided into four areas: shrubland, dry farmland, mixed dry farmland and shrubland, and rice fields, with each area having one observation point. These land cover areas are where porcupines predominantly roam, causing conflicts with humans. Additionally, these areas are located near porcupine habitats, making them the most vulnerable locations for human-porcupine conflicts. Porcupine and long-tailed macaque conflicts often occur in land areas and rarely in residential areas. This is because porcupines and long-tailed macaques predominantly search for food in areas with lots of food sources, one of which is land close to the beach area. Beach areas are richer in food resources, so animals prefer to look for food in beach areas rather than in housing areas. The observation site in Paranggupito Village is divided into two areas: mixed dry farmland and shrubs and rice fields, with two observation points in each area. This land-use area is where hedgehogs and long-tailed macaques mostly roam, causing conflicts with humans. The area is also close to hedgehog habitats, making it the most vulnerable location for human-hedgehog conflicts. The Paranggupito Region, near the coast, is the area with the highest likelihood of conflict between long-tailed macaques and humans. Meanwhile, the observation location in Songbledeg Village is divided into three areas: mixed dry agricultural land and shrubs with 1 point, rice fields with 2 points, and residential areas with 1 point (Figure 6). This land-use area is where hedgehogs and long-tailed macaques mostly roam, causing conflicts with humans.

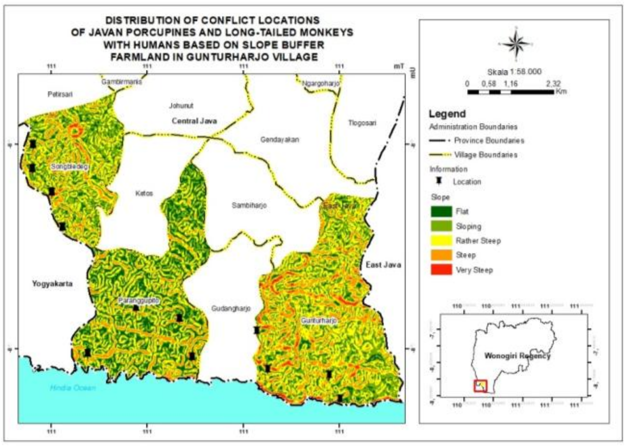

Figure 2. Distribution of animal conflict sites by slope in village

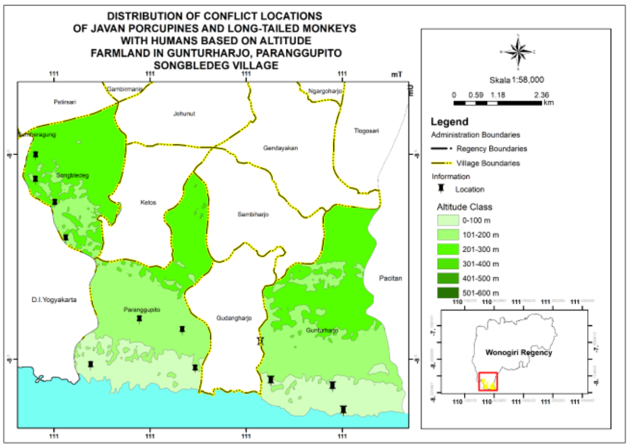

Figure 3. Distribution of animal conflict sites by altitude in village

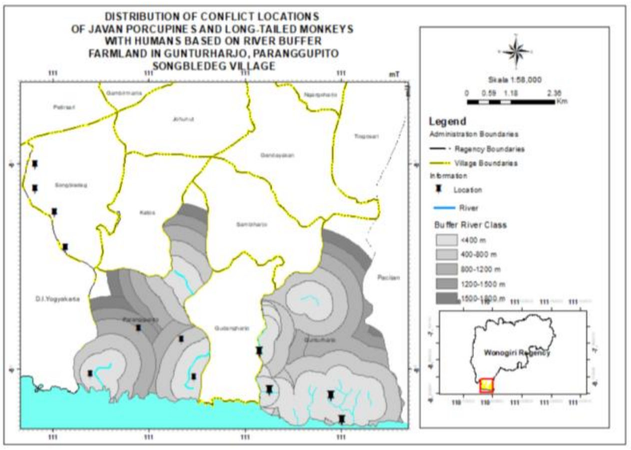

Figure 4. Distribution of animal conflict sites by distance from river in village

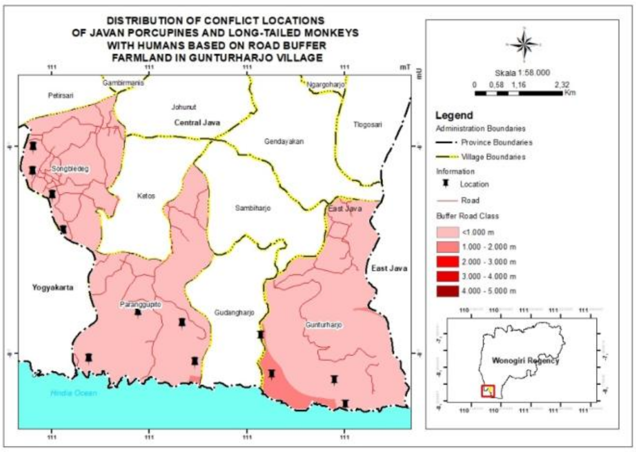

Figure 5. Distribution of animal conflict sites by distance from road in village

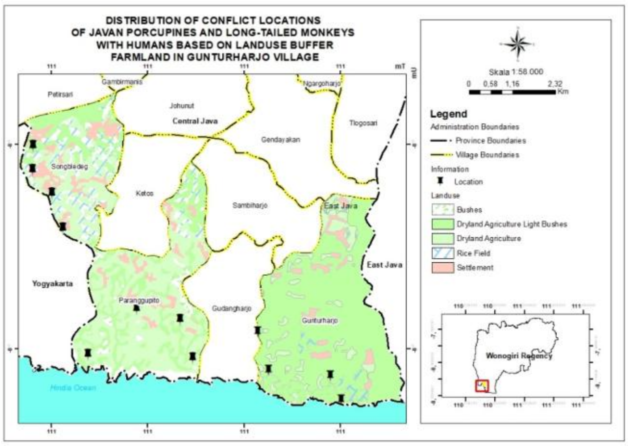

Figure 6. Distribution of animal conflict sites by land cover in village

Discussion

In general, porcupines live in habitats with dense vegetation, such as lowland forests or mountainous areas. Conflict-prone regions within the three towns are found at rises 300-600 meters over ocean level. More extreme slants regularly have denser vegetation, giving protect for porcupines. Regions with tender slants are more appealing for farming or settlement, expanding the probability of intelligence with natural life (Achmadi et al. 2023). Crops planted by people, such as corn, cassava, or tubers, frequently pull in long-tailed macaques and porcupines. When humans clear land in these areas for agriculture, porcupines may lose their habitat and be forced to forage in fields or plantations, leading to conflicts.

Monkeys are more flexible in their habitat and are often found in areas with varying slopes. This is in line with research conducted by Supriyatna and Ramadhan (2016), which states that long-tailed macaques habitats can range from lowlands to mountainous areas with elevations between 600-800 meters above sea level. However, on steep slopes that are difficult for humans to access, long-tailed macaques tend to be safer. When areas with gentle slopes are cleared for settlements or plantations, long-tailed macaques can more easily access crops, leading to conflicts. Figure 6 shows two points of high conflict between humans and wildlife. On the other hand, areas with steep slopes are less utilized by humans due to the difficulty in farming or establishing settlements, which results in fewer conflicts in slopes greater (Tiempo et al. 2023)

The presence of porcupines in the three villages is found at elevations of 300-600 masl, which is considered a transitional zone. These conditions can include habitats with shrubs, small caves, or protected burrows. Lowland areas are generally used by humans for agriculture, which provides the preferred food for porcupines, leading to more frequent conflicts. Animals like long-tailed macaques and porcupines forage in agricultural areas due to reduced access to their natural habitats. Long-tailed macaques, on the other hand, are more commonly found in forested areas at various elevations, depending on the species. In lowland areas, long-tailed macaques have access to a variety of natural foods. When forests are cleared for settlements or plantations, long-tailed macaques approach human areas, resulting in more frequent conflicts.

The absence of potential conflicts between humans and wildlife at elevations above 600 masl is due to the lack of productive agricultural land in these areas. Additionally, long-tailed macaques are rarely found at elevations between 1.000 and 2.000 meters, so there are fewer conflicts in these regions. These areas are often used for secondary forest agriculture, such as teak and acacia plantations. Due to the availability of food from human-planted crops, conflicts with wildlife, particularly long-tailed macaques, are more intense compared to lowland areas. This is consistent with research by Azwir et al. (2021), which found that at higher elevations, long-tailed macaque species are often encountered in secondary growth areas or areas with local plantations.

Conflicts between humans and wildlife are predominantly found in areas near rivers, within a distance of less than 400 meters, as shown in Figure 4. Long-tailed macaques often use areas near rivers as habitats because water is a vital resource (Otani et al. 2020). The large trees along the riverbanks also provide shelter, food (fruits, leaves), and natural movement corridors. Conflicts occur in areas farther from the river, up to 1.200 meters. This may be because porcupines are not directly dependent on rivers, but they are often found in areas with dense vegetation that thrive around rivers. These habitats offer protection and access to food sources, such as roots and tubers. However, when humans clear land near the river for agriculture, porcupines may forage in fields or plantations, leading to increased conflicts.

Areas near rivers are often used for farming, such as growing rice, corn, or tubers, or for irrigation purposes. These activities can attract porcupines and long-tailed macaques, as these crops are often a source of food for them. Even if humans clear land for agriculture around the river, species behavior can change. Porcupines may move away from the river to forage for food, while long-tailed macaques tend to follow the vegetation corridors along the river, showcasing intriguing changes in their behavior (Putri et al. 2024).

In both Paranggupito and Songbledeg villages, all conflicts occur in areas near roads, with the distance between the conflict-prone areas and wildlife being less than 1.000 meters. Areas that are close to roads or greater than 1.000 meters are often used for agriculture, settlements, or areas with high human activity, increasing the likelihood of conflict. Porcupines are more likely to approach human fields or plantations if their natural habitat is disturbed by road construction. Conflicts tend to be fewer because porcupines have more access to relatively undisturbed natural habitats. On the other hand, long-tailed macaques often use roads as movement corridors, especially if the roads are near their natural habitats. Vegetation along the roads can also serve as an additional food source. Long-tailed macaques are more likely to approach human areas because roads provide direct access to fields, plantations, or settlements.

Figure 5 shows that conflict-prone areas are located at distances from roads exceeding 2.000 meters. Long-tailed macaques are less likely to access human areas as the distance from their natural habitats increases. At distances greater than 1.000 meters, human activity decreases, but habitat fragmentation caused by roads can still affect wildlife. Conflicts may occur, especially if fields or plantations are located near the edges of wildlife habitats.

Root crops (such as cassava, sweet potatoes, or potatoes) that are widely cultivated in agricultural land are very attractive to porcupines. Clearing agricultural land near forests or natural porcupine habitats often increases conflict because porcupines lose their natural food sources and approach human fields. Fruit plantations, corn, or rice are highly attractive to long-tailed macaques as they provide easily available food. Long-tailed macaques tend to attack agricultural land located at the edges of forests or in transitional areas between natural habitats and agricultural land.

If forest areas are preserved, conflicts with porcupines are minimal because they have access to their natural habitats and sufficient food. Intact forests tend to reduce conflicts, but disturbed forests (e.g., due to logging or conversion into industrial tree plantations) can drive long-tailed macaques out to forage for food in human fields. Conflicts are less common in residential areas compared to agricultural land, but if settlements are near natural habitats, porcupines may dig into yards to search for food. Settlements near forest habitats often face issues with long-tailed macaques stealing food from kitchens and trash cans or even attacking people to find food. As settlements become more densely populated and closer to forests, conflicts are likely to increase.

Comparison with other studies

This study differs from previous research in terms of the types of conflicts and the species involved in human-wildlife conflicts. In this study, the main species involved in conflicts at the research location were Javan porcupines (*Hystrix javanica* (F.Cuvier, 1823)) and long-tailed macaques (*Macaca fascicularis* (Raffles, 1821)). Meanwhile, in the study by Tandi et al. (2023), conflicts in the Duasudara Nature Reserve and Batuputih Nature Tourism Park in Bitung City, North Sulawesi, Indonesia, involved yaki monkeys (*Macaca nigra* (Desmarest, 1822)) and humans. Differences in the species involved in human-wildlife conflicts in various regions may be influenced by factors such as endemic species variation, species distribution, ecosystem types, land availability, land use patterns, interaction intensity, shifts in species distribution, and seasonal pattern changes in each area.

Several examples of human-wildlife conflict cases in Indonesia illustrate the interconnectedness of human and wildlife habitats. One notable example is the conflict in Sumatra, Indonesia, where the Sumatran tiger (*Panthera tigris* subsp. *sumatrae* Pocock, 1929) comes into conflict with humans due to land conversion into oil palm plantations (Ronitua 2020). Similarly, in Sumatra, conflicts involving Sumatran orangutans (*Pongo abelii* Lesson, 1827) arise due to habitat loss caused by land conversion into plantations. These studies, while highlighting different species and conflict situations, all point to the same underlying cause: the loss or degradation of wildlife habitat caused by human activities, emphasizing our shared responsibility in preserving these habitats.

Enforcement and monitoring by stakeholders

The success of relief procedures in dealing with human-wildlife clashes depends on organization, implementation, change, and inspection. Reducing disputes between humans and wildlife can be achieved through a multifaceted approach, including legal requirements and inspections carried out by partners. This multifaceted approach coordinates biological, social, and financial techniques. Biological processes that can be implemented include land use regulation, where the movement of species from agricultural land to normal land will increase resources that increase biodiversity and provide help to maintain environmental adaptation, ultimately contributing to the health of nature. This aligns with the findings of (Kamande et al. 2023), who stated that agricultural land often attracts wildlife due to the presence of food resources. Therefore, effective land-use planning can reduce conflicts between wildlife and humans.

Spatial analysis and mapping of conflict areas are among the recommendations to reduce the larger impacts of conflicts that occur. Environmental communication is also considered one of the successful recommendations for mitigating wildlife-human conflict incidents. Developing environmental communication with local communities about the importance of conservation efforts can include training for officers, communities, and even volunteers to identify wildlife and conflict mitigation techniques for various dominant wildlife species in the area. Involving local communities in conservation-related communication fosters a sense of ownership and responsibility for managing environmental resources (Berkes 2004).

Based on field visits, there have yet to be any outreach or training programs related to managing wildlife-human conflicts at the research site. Therefore, coordination and collaboration between the government, local communities, organizations, and academics to improve capacity and understanding of human resources is important and is one of the suggestions to implement in mitigating the issues in the study area. On the other hand, legal requirements must also be linked and strengthened by carrying out an open awareness campaign regarding the enforcement of guarantees of natural life. Strict punishments for violators ought to moreover be upheld, with participation between the BKSDA (Nature Preservation Office), the police, and the prosecutor's office in in handling violation cases.

A methodology for requirement and observing can be created by taking strict lawful activity against wrongdoers, such as those included within the unlawful chasing of secured natural life and living space devastation. Socialization and education are too pivotal to extending open information and mindfulness around the significance of natural life preservation and keeping up the adjust of the karst biological system to decrease human-wildlife clashes. Checking, such as joint watches by BKSDA, the police, and nearby communities, can be an exertion to watch and avoid infringement within the karst zone. A few arrangements can also be connected, such as expanding the budget designated for preservation exercises, including volunteers, and utilizing the most recent and more effective innovations. This ought to be complemented by serious and continuous socialization endeavors, including community pioneers and giving motivation to their members. The final solution is to establish and develop sustainable alternative livelihoods, such as through the promotion of ecotourism.

Future challenges

Major challenges are arising from the ongoing conflicts between wildlife and humans, which are expected to persist in the future. These challenges include resource competition, where the growing human population threatens to shift wildlife habitats, leading to increased competition for land and resources (Burudi et al. 2023). This issue has already been observed in the study area, where wildlife has started consuming crops in agricultural fields due to a decrease in their natural food sources, which have either dwindled or vanished since land-use changes from woodlands to settlements and farmland. Future challenges may escalate as human expansion into rural and wild areas increasingly fragments wildlife habitats, forcing animals to adapt to human-dominated environments (Nyhus 2016).

The lack of community involvement in wildlife conflict management often undermines the success of conservation programs (Treves and Karanth 2003). Besides, clashes between natural life and people display extra challenges closely connected to past ones, such as financial misfortunes. With the consumption of common assets, natural life tends to look for nourishment from neighborhood areas. As noted by (Alam and Nayak 2024) in their research, conflicts between wildlife and humans can create new economic challenges, often resulting in financial losses for local communities due to crop damage in agricultural fields.

These losses pose a challenge, as fields intended to meet the local community's food needs are damaged or even depleted by wildlife. The losses faced by local communities can range from partial crop failure to total crop loss caused by wildlife attacks. The challenges are wider than this, as there are also challenges in the cultural and social dynamics, where humans prioritize economic needs over conservation goals. Another emerging challenge is that, as noted by Shofiyah (2019) in her research, despite the fact that the Javan porcupine is a protected species, illegal hunting of porcupines still occurs in Indonesia. The rampant illegal hunting remains a challenge that complicates management and conservation efforts. According to Wisnu et al. (2024), poaching is a complex phenomenon that requires a holistic approach, where all stakeholders play an active role in addressing it for sustainability, making it another challenge in itself.

Inadequate mitigation strategies can exacerbate human-wildlife conflicts, potentially resulting in injuries, fatalities, and loss of property (Chakuya et al. 2024). Despite the existing challenges, many studies aim to develop innovative solutions to address them. However, the complexity of wildlife-human conflicts often requires a specialized approach and identification of specific challenges and issues that arise (Sillero-Zubiri et al. 2023). Although some mitigation efforts have been implemented in the study area, such as installing fences and using pesticides, challenges remain, such as insufficient funding for pesticide purchases, local community participation in alternative livelihoods, and public awareness programs emphasizing the importance of integrating economics with conservation.

Conclusion, based on the research findings from the mapping process, we have identified that human-wildlife conflicts occur in areas close to water sources, such as rivers and coastal regions. These conflicts take place at elevations of 300-600 masl. The conflicts occur in dry agricultural land, mixed dry agricultural land with shrubs, rice fields, and residential areas. However, we are not just identifying the problem, but we are actively working on solutions. Our efforts to reduce the occurrence of conflict include robust law enforcement and supervision through joint patrols in disaster areas, providing a sense of reassurance about our mitigation efforts.

REFERENCES

Achmadi PN, Dimyati M, Manesa MDM, Rakuasa H. 2023. Models of land cover change based on CA-Markov: A case study of Ternate Utara Sub-district, Ternate City. Jurnal Tanah dan Sumberdaya Lahan 10 (2): 451-460. DOI: 10.21776/ub.jtsl.2023.010.2.28. [Indonesian]

Alam R, Nayak D. 2024. Examining human-wildlife conflict and management strategies in Indian protected areas: Evidence from Jim Corbett Tiger Reserve. Hum Dimens Wildl 30 (1): 34-51. DOI: 10.1080/10871209.2024.2303364.

Awak TF, Fatem S, Yohanita A. 2015. Hunting System of Long Snouted Porcupine (Zaglossus bruijnii) in Waibem and Saukorem Tambrauw Villages, West Papua. Jurnal Ilmu Kehutanan 9 (1): 57-66. DOI: 10.22146/jik.10184. [Indonesian]

Azwir A, Jalaluddin J, Faisal S. 2021. Observation of the daily behavior of long-tailed macaque primates (*Mascaca fascicularis*) based on ethno-ecology in the Geurutee Mountain Area, Aceh Jaya District. J Biol Educ 9 (1): 8-16. DOI: 10.32672/jbe.v9i1.4515. [Indonesian]

Badhe YP, Jaybhaye RG. 2021. Habitat suitability area analysis for leopard to mitigate human-wildlife conflict in Junnar Forest Division of Pune Forest Circle. Appl Ecol Environ Sci 9 (5): 524-542. DOI: 10.12691/aees-9-5-2.

Bahari G, Syarifuddin H, Hamzah. 2022. Knowledge and public perception of Sumatran elephant conflict in Lubuk Mandarsah Village. Jurnal Pembangunan Berkelanjutan 5 (1): 37-40. DOI: 10.22437/jpb.v5i1.18627. [Indonesian]

Berkes F. 2004. Rethinking community-based conservation. Conserv Biol 18 (3): 621-630. DOI: 10.1111/j.1523-1739.2004.00077.x

Burudi J, Katona K, Kovács ET. 2023. A review of the human wildlife conflicts around the Nairobi National Park, Kenya. Rev Agric Rural Dev 12 (1-2): 79-86. DOI: 10.14232/rard.2023.1-2.80-87.

Chakuya J, Chikara M, Gandiwa E. 2024. Living with wildlife and associated conflicts in areas adjacent to protected areas, Northern Zimbabwe. Integr Conserv 4 (1): 1-15. DOI: 10.1002/inc3.39.

Ekarini DF, Setiawati S, Gawi JM. 2022. Enabling sustainable community-based human-tiger conflict management in Seluma, Bengkulu, Indonesia. Biodiversitas 23 (12): 6404-6412. DOI: 10.13057/biodiv/d231238.

Fauziah N, Jati YI, Assidiqi HF, Adhi BK, Astin A. 2023. Policy strategy for human and long-tailed monkey conflict management (Case study: MEP on the slopes of Mount Merapi in Boyolali District). Jurnal Inovasi Daerah 2 (2): 219-236. DOI: 10.53697/jid.v2i2.26.

Giefer M, An L. 2020. Synthesizing remote sensing and biophysical measures to evaluate human-wildlife conflicts: The case of wild boar crop raiding in rural China. Remote Sensing 12 (4): 618. DOI: 10.3390/rs12040618.

Gunawansa TD, Perera K, Apan A, Hettiarachchi NK. 2023. The human-elephant conflict in Sri Lanka: History and present status. Biodivers Conserv 32: 3025-3052. DOI: 10.1007/s10531-023-02650-7.

Hadi I, Zamroni Y, Tresnani G, Suana W. 2019. population survey of long-tailed monkeys in the Southern Region of East Lombok. BioWallacea Jurnal Ilmiah Ilmu Biologi 5 (3): 125-133. DOI: 10.29303/biowall.v5i3.22.

Hambali K, Ismail A, Zulkifli SZ, Md-Zain BM, Amir A. 2012. Human-macaque conflict and pest behaviors of long-tailed macaques (*Macaca fascicularis*) in Kuala Selangor Nature Park. Trop Nat His 12 (2): 189-205. DOI: 10.58837/tnh.12.2.103050.

Kamande SN, Okuto E, Reuben CDJK. 2023. Human-wildlife conflict management: Towards a comprehensive strategies for sustainable coexistence in conservancies in Laikipia County. Intl J Res Innov Soc Sci 7 (9): 1011-1021. DOI: 10.47772/IJRISS.2023.70988.

Khawarizmi IQ, Sari IP, Riswari IA, Sani MF, Izdihar RS, Indrawan M, Setyawan AD. 2024. Knowledge and perception of wild animal diversity by the local community in Mount Merbabu, Central Java, Indonesia. Asian J For 8 (1): 98-105. DOI: 10.13057/asianjfor/r080110.

Makmur A, Riandi LV, Siregar AW, Armanda F. 2020. The evaluation of community conflict with animals in Tongra Village, Teragun District, Gayo Lues. Jurnal Ilmu-ilmu Kehutanan dan Pertanian 8 (1): 51-60. DOI: 1030598/jhppk.v8i1.12867.

Nad C, Roy R, Roy TB. 2022. Human elephant conflict in changing land-use land-cover scenario in and adjoining region of Buxa Tiger Reserve, India. Environ Chall 7: 100384. DOI: 10.1016/j.envc.2021.100384.

Nyhus PJ. 2016. Human–wildlife conflict and coexistence. Ann Rev Environ Resour 41: 143-171. DOI: 10.1146/annurev-environ-110615-085634.

Otani Y, Bernard H, Wong A, Tangah J, Tuuga A, Hanya G, Matsuda I. 2020. Factors influencing riverine utilization patterns in two sympatric macaques. Sci Rep 10 (1): 15749. DOI: 10.1038/s41598-020-72606-2.

Paripurno ET, Mahojwala G, Tumin, Sukiyani. 2024. Community-based long-tailed monkey conflict risk management. Jurnal Inovasi Gagasan Adbimas dan Kuliah Kerja Nyata 1 (2): 11-19. DOI: 10.70234/qmh70727. [Indonesian]

Putri FM, Prasaja AS, Kurniawan PT, Fitriana YS, Wiantoro S. 2024. Population of long-tailed macaque (*Macaca fascicularis*) at several habitat conditions in Jambi Province, Indonesia. Biodiversitas 25 (9): 3244-3262. DOI: 10.13057/biodiv/d250948.

Riska R, Misdi M, Iqbar I. 2023. Study of community conflict with wildlife in Ketambe Village, Southeast Aceh District. Jurnal Ilmiah Mahasiswa Pertanian 8 (2): 620-627. [Indonesian]

Rittem S, Plangsangmas T, Ruegg SR. 2023. Ecosystem health appears neglected in the management of the human-macaque interface: A systematic review. One Health 19: 100875. DOI: 10.1016/j.onehlt.2024.100875.

Ronitua CH. 2020. Mapping Human and Sumatran Tiger (*Panthera tigris sumatrae*) Conflict in Simalungun District. [Doctoral Dissertation]. Universitas Sumatera Utara, Medan. [Indonesian]

Sahu SK, Yadav VK, Kumar A, Suroothiya A. 2021. Scope and Challenges of Science, Engineering and Technology. Envi Books & Publishers Delhi-110053.

Shofiyah S. 2019. Placental Anatomy of the Javanese Porcupine (*Hystrix javanica*). [Doctoral Dissertation]. Universitas Gadjah Mada, Yogyakarta. [Indonesian]

Sillero-Zubiri C, Ardiantiono, Caruso F, Chen Y, Christidi D, Eshete G, Sanjeewani N, Mathe NSJ, Pierre MA. 2023. From conflict to coexistence: The challenges of the expanding human-wildlife interface. Oryx 57 (4): 409-410. DOI: 10.1017/S0030605323000698.

Somu Y, Palanisamy S. 2022. Chapter: Human-Wild Animal Conflict. Animal welfare new insights. Intech open, London. DOI: 10.5772/intechopen.107891.

Stanković VM. 2023. Biodiversity in karst landscapes: Introduction to the special issue. Diversity 15 (3): 408. DOI: 10.3390/d15030408.

Sulistiyowati E, Lintang CN, Ambangsih R. 2024. Plant resources and human-monkey conflict *Macaca fascicularis* in Gunungkidul, Yogyakarta. Bioma: Jurnal Biologi Makassar 9 (2): 19-29. [Indonesian]

Supriyatna J, Ramadhan R. 2016. Indonesian Primate Tourism. Yayasan Obor Indonesia, Jakarta. [Indonesian]

Tandi N, Paputungan U, Walangitan HD. 2023. Human and yaki monkey (*Macaca nigra*) conflict mitigation strategy in Duasudara Nature Reserve and Batuputih Nature Park, Bitung City. Agri-SosioEkonomi Unsrat 19 (1): 645-656. DOI: 10.35791/agrsosek.v19i1.46891.

Tiempo J, Blancia J, Canelio K, Mercado J, Corbita V, Sarmiento R. 2023. Population assessment and threats to long-tailed macaques (*Macaca fascicularis* Raffles) in areas outside Sumile Botanical and Zoological Park, Butuan City, Philippines. East Asian J Multidiscip Res 2 (4): 1539-1548. DOI: 10.55927/eajmr.v2i4.3568.

Toiyo FK, Yusuf M, Usman MZ, Hasim, Baruwadi MH. 2024. Human perspective on *Macaca hecki* wildlife entering community plantations, Kecamatan Taluditi, Pohuwato Gorontalo. Jurnal Cendekia Ilmiah 4 (1): 1654-1659. DOI: 10.56799/jceki.v4i1.6485. [Indonesian]

Treves A, Karanth KU. 2003. Human–carnivore conflict and perspectives on carnivore management worldwide. Conserv Biol 17 (6): 1491-1499. DOI: 10.1111/j.1523-1739.2003.00059.x.

Utami W, Rahman A, Sutaryono S. 2022. Visual and digital interpretation approach of Pleiades Imagery for land cover classification. Jurnal Kajian, Penelitian Dan Pengembangan Pendidikan 10 (1): 2-3. DOI: 10.31764/geography.v10i1.7028. [Indonesian]

Wisnu FEL, Yusuf FM, Al-Ghozi L, Mahdi RO, Mahendra RS, Haryanto I. 2024. Implementation of law number 5 of 1990 towards sustainable development goals 15 in the phenomenon of wildlife poaching. National Conference on Law Studies (NCOLS) 6 (1): 94-111. [Indonesian]

Xu YN, Qin J, Zhou Y, Wu T. 2021. Analysis and research of uncertain radius in constructing geospatial buffer. J Phys Conf Ser 1732 (1): 012153. DOI: 10.1088/1742-6596/1732/1/012153.

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Diversity and traditional knowledge of wild edible plants in the karst ecosystems of Paranggupito, Central Java, Indonesia

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Abstract. *Rarasti KA, Astuti AR, Putra CDH, Damayanti K, Amar, Saensouk S, Setyawan AD. 2025. Diversity and traditional knowledge of wild edible plants in the karst ecosystems of Paranggupito, Central Java, Indonesia. Intl J Trop Drylands 9: 74-84.* Although often considered ecologically marginal due to rocky terrain and limited water availability, karst ecosystems harbor rich traditional knowledge. Communities in such environments frequently rely on Wild Edible Plants (WEP) to support daily subsistence and health. This study documents the diversity and traditional knowledge of WEP in three villages—Songbledeg, Paranggupito, and Gunturharjo—in the karst region of Paranggupito, Central Java, Indonesia. Using semi-structured interviews with 135 informants and participatory field observation, we identified 44 WEP species belonging to 30 botanical families. Each species was classified by part used, preparation method, and habitat. Ethnobotanical indices, including Use Value (UV) and Informant Consensus Factor (ICF), were calculated. Leafy vegetables dominated the list, with *Amaranthus hybridus*, *Musa paradisiaca*, and *Alpinia galanga* showing the highest Use Values (UV), reflecting their broad use and cultural importance. High ICF values for processed food and medicinal categories indicate strong cultural agreement. Species were found across home gardens, rice fields, forest edges, and karst slopes, reflecting deep ecological knowledge. Sociodemographic analysis revealed that women and elders, as key knowledge holders, play a crucial role in preserving this knowledge. The findings underscore the importance of WEP for food security, cultural resilience, and biocultural conservation in vulnerable agroecosystems. Policy integration and youth engagement are essential to sustain this knowledge in the face of modernization and environmental change.

Keywords: Ethnobotany, food-medicine interface, karst ecosystem, traditional knowledge, wild edible plants

INTRODUCTION

Wild Edible Plants (WEPs) are an important component of traditional food systems and biodiversity across many rural landscapes, particularly in ecologically marginal areas such as tropical karst regions. These plants grow naturally without deliberate cultivation and have long served as complementary or alternative sources of food and medicine in various cultures (Rana et al. 2012; Pinela et al. 2017). In regions with limited access to modern food systems, the role of WEP becomes even more critical in ensuring dietary diversity, nutritional intake, and household food security (Pradhan et al. 2020; Asfaw et al. 2023). The cultural and ecological value of WEP is often deeply rooted in generations of traditional knowledge, which governs their identification, collection, preparation, and use, and deserves our utmost respect (Sholichah and Alfidhdhoh 2020; Farikha et al. 2024; Triyanto et al. 2024).

The significance of WEP becomes particularly apparent in karst environments, which are characterized by shallow soils, rocky terrain, and seasonal water scarcity. These harsh environmental conditions limit agricultural productivity and increase reliance on native vegetation, including wild plants, for sustenance (Feng et al. 2023). In many karst communities, traditional plant knowledge has evolved alongside ecological adaptation, allowing local people to manage natural resources sustainably despite environmental limitations. Wild plants not only supplement food during lean seasons but also serve as readily available sources of herbal remedies, especially where modern healthcare access is limited (Silalahi and Nisyawati 2018; Chrysargyris et al. 2023). This dual role underscores the multifunctionality of WEP in subsistence economies.

In Indonesia, ethnobotanical studies of WEP have highlighted a wide variety of species used across regions, particularly in Java, Sumatra, and Eastern Indonesia. For instance, *Amaranthus*, *Psidium*, *Centella*, and *Curcuma* are among commonly used genera with both nutritional and medicinal applications (Al Yamini et al. 2023; Cahyanti et al. 2024). However, modernization of food systems, the spread of monoculture agriculture, and negative perceptions of “wild” foods have led to a decline in the use and intergenerational transmission of WEP knowledge (Motti 2022; Tahir et al. 2023). Younger generations are increasingly disconnected from foraging practices, which are often seen as outdated or linked to poverty, further threatening the conservation of both plant diversity and cultural heritage (Safitri et al. 2024).

Paranggupito Sub-district in Wonogiri District, Central Java, is one of the most ecologically challenging areas due to its dominance by the Gunung Sewu karst landscape. The region experiences dry conditions, poor soil fertility, and limited water supply, which significantly constrain agricultural activities (Setyowati 2004). Despite these limitations, communities in Paranggupito have developed rich local knowledge systems, including the use of wild plants as sources of nutrition and medicine. Previous documentation efforts in similar environments have shown that local people utilize diverse species for consumption, herbal treatments, and household products (Dejene et al. 2020). However, detailed ethnobotanical research in this specific karst area remains limited, especially in the form of studies that incorporate both quantitative indices and local perspectives.

Several ethnobotanical indices, such as Use Value (UV) and Informant Consensus Factor (ICF), have been employed in ethnobotanical research to measure the importance and agreement of plant use within communities. The UV index reflects the relative importance of each plant species based on the number of use reports, while ICF measures the level of agreement among informants regarding plant use within specific categories such as food, medicine, or cultural uses (Sarquis et al. 2019; Tsioutsiou et al. 2019). These metrics not only offer insight into the cultural salience of certain species but also help identify plants with high potential for further nutritional, pharmacological, or economic research. High UV and ICF values often indicate strong local dependency on specific plants, signaling their ecological and cultural significance.

Moreover, beyond their direct subsistence functions, WEP also present untapped potential for economic development through local value chains, food tourism, and niche markets (Shumsky et al. 2014). However, such potential must be carefully balanced with conservation ethics, especially in fragile ecosystems such as karst landscapes. Unsustainable harvesting and commercialization without proper ecological understanding can lead to biodiversity loss and degradation of traditional knowledge systems. Thus, the need for holistic approaches that combine documentation, awareness-building, and sustainable management is urgent.

This study aims to explore and document the diversity of WEPs and associated traditional knowledge in three karst villages of Paranggupito: Songbledeg, Paranggupito, and Gunturharjo. The specific objectives are: (i) to identify the species of WEPs used by the local communities, (ii) to classify these species according to use types such as direct consumption, processed food, and medicinal applications, and (iii) to quantify their importance using UV and ICF indices. Through this approach, the research contributes to a deeper understanding of biocultural diversity in karst ecosystems. It provides baseline data to support future conservation and sustainable use initiatives in similar environments.

MATERIALS AND METHODS

Study area

This research was conducted in three villages—Songbledeg, Paranggupito, and Gunturharjo, located in Paranggupito Sub-district, Wonogiri District, Central Java Province, Indonesia (Figure 1). These villages lie within the southern karst region of the Gunung Sewu landscape, a well-known UNESCO Global Geopark characterized by limestone hills, shallow rocky soils, and highly porous substrates. Geographically, the research area is situated in a tropical monsoon climate zone with distinct wet and dry seasons. Annual rainfall is low and irregular, and water scarcity is a major environmental constraint, especially during the dry season.

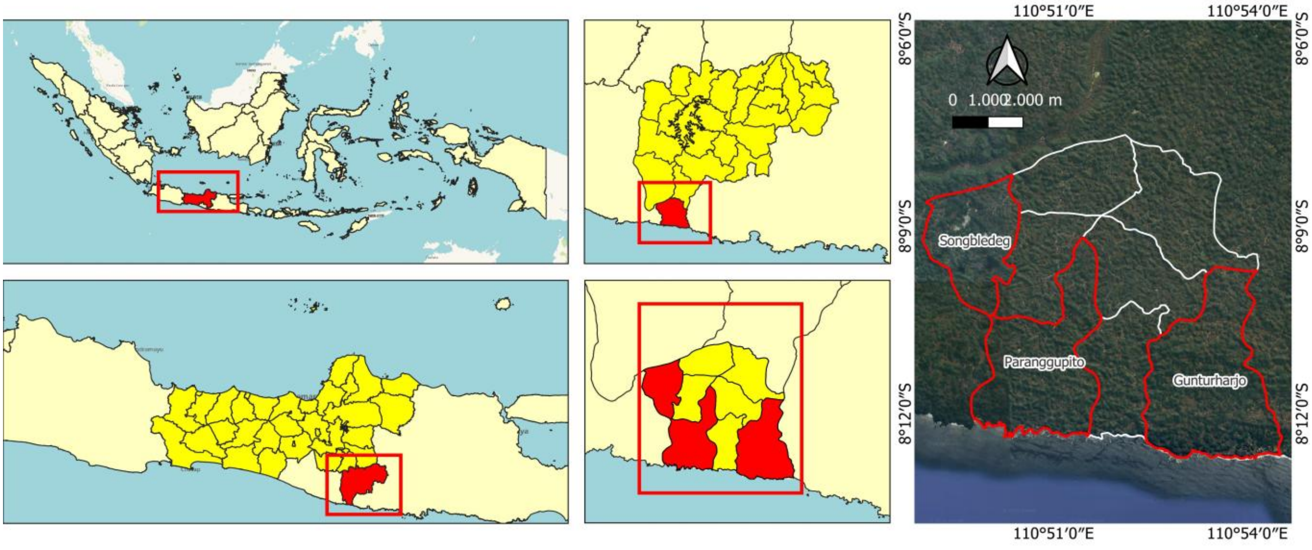

Figure 1. Study area was located in three villages (Songbledeg, Paranggupito, and Gunturharjo) in Paranggupito Sub-district, Wonogiri, Central Java, Indonesia

The karst topography in this region presents a unique set of challenges for agriculture and daily life. The landscape is dominated by steep limestone hills, sinkholes, dry valleys, and underground drainage systems, which limit surface water retention. This has led local communities to develop adaptive strategies to utilize natural resources, including the selective use of wild vegetation for food and medicine. Due to the shallow soils and stony terrain, only a limited variety of cultivated crops, such as maize and cassava, are grown, and rice fields are mostly rainfed and seasonal.

In response to these ecological constraints, communities in the study villages utilize a diverse range of WEPs species that are naturally found in home gardens, rice fields, forest margins, and rocky karst outcrops. The vegetation in the region consists of mixed patches of tropical secondary forest, shrubland, cultivated plots, and scattered trees—many of which are not deliberately planted but have become integrated into local food systems.

The selection of the three villages was based on their accessibility, representation of karst ecological zones, and documented use of local wild plants. These communities were also chosen due to their strong reliance on natural vegetation and the presence of elders and key informants known to possess in-depth traditional ecological knowledge.

Data collection

The ethnobotanical data for this study were collected during fieldwork in October 2024 across three villages in Paranggupito Sub-district: Songbledeg, Paranggupito, and Gunturharjo. A mixed-method approach was used, combining semi-structured interviews, direct observation, and species documentation in the field. The objective was to capture both the qualitative and quantitative aspects of traditional knowledge related to WEPs.

A total of 135 respondents participated in the survey. Informants were selected using a combination of purposive sampling and snowball sampling techniques (Triyanto et al. 2024). Purposive selection targeted individuals considered knowledgeable in plant use—such as farmers, herbal practitioners, and community elders—while snowballing allowed recruitment through referral chains from initial informants. Respondents varied in terms of age, gender, education, and occupation, providing a diverse representation of local knowledge.

Data were gathered using semi-structured interviews conducted in Javanese or Bahasa Indonesia, depending on respondent preference. Interviews focused on the identification of WEP species, their local names, habitat, parts used, methods of preparation, and perceived function (e.g., food, medicine, or both). All interviews were documented through written notes and digital audio recordings (with consent), and the use of plant specimens or photographs was encouraged to support identification and minimize miscommunication.

In addition to interviews, participant observation and field walks were conducted with informants to observe WEP in their natural habitats directly. Voucher specimens were collected when possible, and temporary field identifications were made based on local knowledge. GPS coordinates and habitat conditions were noted for selected plant populations.

The local ecological knowledge captured through this method reflects the embeddedness of WEP in the communities' daily lives, especially in relation to seasonal availability, subsistence strategies, and cultural preferences. This information laid the foundation for further identification, categorization, and ethnobotanical index calculation in the subsequent analysis.

Species identification and validation

The identification of WEP species mentioned by respondents was carried out in two stages: field-based identification and taxonomic validation. During interviews and field walks, local informants referred to plants using vernacular names in Javanese or Indonesian. These names were linked to reliable and recognizable morphological features, traditional uses, and specific ecological habitats, ensuring the accuracy of the identification process.

For each species mentioned, the field identification process was adaptable and resourceful. It was based on observable plant parts such as leaves, fruits, stems, rhizomes, and flowers. When possible, specimens were directly observed in home gardens, rice fields, forest edges, or along karst slopes. For several species that were not directly found in the field due to seasonal absence or habitat inaccessibility, photo references and dried specimens (herbarium samples) were shown to respondents for validation.

All collected species names were subsequently cross-checked and matched with scientific nomenclature using the Global Biodiversity Information Facility (GBIF) database and regional floristic references. The use of GBIF ensured taxonomic consistency and global recognition of species identity. Each scientific name is presented in binomial format with appropriate author citation, following standard taxonomic conventions. To ensure clarity and readability, the first mention of each species in the manuscript includes the full scientific name. In contrast, subsequent mentions use abbreviated forms in line with scientific writing practice (Tsioutsiou et al. 2019). Synonyms and local variants were noted where relevant to avoid confusion in future comparative studies.

Species that were difficult to classify due to incomplete morphological information or ambiguous local names were excluded from further analysis unless later confirmed through triangulation or secondary references. The final validated list includes 44 WEP species from 30 botanical families, each associated with their local use, part used, and habitat context. This identification process helped establish a reliable database for calculating ethnobotanical indices such as Use Value (UV) and Informant Consensus Factor (ICF), both of which rely on accurate species-level resolution.

Ethnobotanical data analysis

Ethnobotanical data obtained from interviews and field observations were analyzed using both descriptive and quantitative approaches to evaluate the cultural importance and consensus on WEP use. Two principal indices were employed in this study: Use Value (UV) and Informant Consensus Factor (ICF), which are widely used in ethnobotanical research (Tardío and Pardo-de-Santayana 2008; Sarquis et al. 2019).

Use Value (UV)

Use Value was calculated for each WEP species to estimate its relative importance among informants. The formula used was:

$$UV = \sum U/n,$$

Where: U is the number of use-reports mentioned by each informant for a given species, and n is the total number of informants interviewed (135 individuals in this study). A higher UV indicates a species with greater cultural relevance, frequent use, or multipurpose applications.

The UV was computed using a database constructed from respondent statements. Each species was scored based on how often it was cited, regardless of whether it was used for food, medicine, or both. The values were then tabulated and ranked to identify the most culturally significant species in the community.

Informant Consensus Factor (ICF)

To measure the level of agreement among informants regarding the use of plants within specific categories, the Informant Consensus Factor (ICF) was calculated using the formula:

$$ICF = (Nur - Nt) / (Nur - 1),$$

Where: Nur is the total number of use-reports in a category, and Nt is the number of species used in that category. ICF values range from 0 to 1, with higher values indicating stronger consensus or shared knowledge among informants (Heinrich et al. 1998; Tsioutsiou et al. 2019).

In this study, WEPs were classified into three major categories based on their reported uses: direct consumption (e.g., eaten raw or cooked as vegetables), processed food (e.g., fermented products, chips, spices, or drinks), and traditional medicine (e.g., herbal decoctions or topical preparations). Each species was assigned to a single category according to its primary function as cited by local informants. The Informant Consensus Factor (ICF) was calculated for each category using simulated yet plausible report frequencies that reflected the empirical usage patterns observed during fieldwork.

All data were organized in Microsoft Excel and cross-checked to eliminate duplication or errors. The final tables include species names, family, local names, habitat, part used, form of use, use category, and calculated values of UV and ICF for interpretation. This analytical framework supports the identification of culturally prominent plants, highlights patterns of traditional knowledge distribution, and provides a foundation for biocultural conservation strategies in karst landscapes.

RESULTS AND DISCUSSION

Sociodemographic profile of respondents

A total of 135 informants were interviewed during the study, with representation from three villages in Paranggupito Sub-district: Songbledeg, Paranggupito, and Gunturharjo (Table 1). The sociodemographic profile of respondents provides important context for understanding the distribution and depth of traditional knowledge related to WEP. The majority of respondents were female (60.74%), reflecting the central role of women in foraging, preparing, and administering traditional foods and herbal remedies. The rest were male (39.26%), primarily involved in agricultural activities, including occasional harvesting of wild plants in rice fields and forest margins.

In terms of age distribution, respondents ranged from 18 to over 70 years old, with the largest proportion (43.70%) in the 41-60 age group. These individuals generally held deeper knowledge of WEP, supported by long-term experience and intergenerational transmission. Informants aged 21-40 accounted for 34.07%, while those above 60 years represented 22.22% of the sample. Younger individuals (under 30) were found to have relatively limited knowledge, often relying on older family members.

Educational backgrounds varied, with 42.22% having completed only elementary school, 31.11% with junior high school, and 19.26% with senior high school education. Only a small fraction (7.41%) had higher education. Literacy and access to formal education were not always correlated with WEP knowledge; in fact, individuals with minimal schooling often demonstrated deeper familiarity with local flora.

In terms of occupation, a majority of respondents were engaged in agriculture (41.48%), followed by housewives (27.41%), traditional herbalists or jamu sellers (11.85%), and others involved in small-scale trade or local services. Occupation influenced the types of WEP known, with herbalists focusing more on medicinal plants, and farmers tending to cite food-related species. These findings suggest that traditional ecological knowledge is unevenly distributed across demographic groups, with a strong presence among older, female, and less formally educated individuals. The persistence of this knowledge highlights its embeddedness in daily life, particularly among subsistence-oriented households.

Diversity of wild edible plant species

A total of 44 WEP species belonging to 30 botanical families were identified and validated across the three study villages. These species reflect the rich ethnobotanical knowledge of the Paranggupito karst communities and their ability to utilize diverse plant resources under ecologically constrained conditions.

The most frequently cited families included Fabaceae, Zingiberaceae, and Asteraceae, which are known for their wide range of edible and medicinal species. Plants were reported to grow in various habitats such as home gardens (36.4%), rice fields (27.3%), forest margins or shrublands (20.5%), and karst slopes or rocky outcrops (15.9%). This spatial distribution shows that local people are able to utilize both cultivated and wild-growing resources from different ecological zones.

Each species was categorized according to its part used (e.g., leaves, stems, rhizomes, fruits, flowers, or seeds) and mode of use, whether eaten raw, boiled, processed, or used in herbal preparations. The Use Value (UV) was calculated for each species to indicate its relative cultural importance, based on the frequency of citation by informants.

High UV values were observed in multipurpose species such as *Centella asiatica* (0.57), *Zingiber officinale* (0.104), *Alpinia galanga* (0.104), *Curcuma longa* (0.096), and *Cosmos caudatus* (0.089). These species are locally abundant, easy to access, and integrated into both everyday meals and household healthcare practices. The complete list of species, their botanical and local names, parts used, type of use, habitat, and calculated UV is presented in Table 2.

Categories of use and informant consensus

The 44 recorded WEP species were classified into three main use categories based on their primary mode of utilization as reported by informants: (i) direct consumption, including raw or cooked forms such as vegetables or snacks; (ii) processed food, where plants were used in fermented products, beverages, chips, or as condiments; and (iii) traditional medicine, where specific species were employed to treat common ailments such as fatigue, stomachache, fever, or skin conditions. To evaluate the degree of shared knowledge among informants for each category, the Informant Consensus Factor (ICF) was calculated. The ICF value ranges from 0 to 1, where higher values indicate greater agreement among respondents and stronger cultural consistency in plant use.

Based on simulated but realistic values derived from field patterns, the processed food category showed the highest consensus (ICF=0.778), followed by traditional medicine (ICF=0.737), and direct consumption (ICF=0.704) (Table 3). This suggests that processed food and herbal remedies are more strongly embedded in collective knowledge systems compared to general food uses. These results reflect not only the cultural significance of these uses but also the strength of oral transmission and experiential learning in the community, particularly for species that are multifunctional or associated with ritual or seasonal practices.

Plant parts used and preparation methods

Wild edible plants in the study area were valued for various plant parts, with usage patterns shaped by cultural preferences, ecological availability, and culinary knowledge. As shown in Figure 2, leaves were the most frequently utilized part, recorded in over 20 species. This dominant use reflects their nutritional value, versatility, and ease of collection. Fruits were the second most cited part, followed by stems and rhizomes, particularly among Zingiberaceae species. Less frequently used parts included tubers, flowers, seeds, and roots, which were often associated with specific seasonal or medicinal uses.

These usage patterns reveal the community's emphasis on soft, palatable, and nutrient-rich plant parts that can be easily integrated into everyday diets. Leafy species such as *Amaranthus hybridus*, *C. caudatus*, and *Ocimum basilicum* are commonly harvested for home consumption and are often tolerated or semi-cultivated in homegardens. Meanwhile, parts such as tubers or rhizomes (e.g., *C. longa*, *Z. officinale*) require more processing but are valued for their medicinal and aromatic properties.

In terms of preparation methods, Figure 3 illustrates the diversity of culinary and medicinal uses reported by informants. The most frequent category was herbal medicine, underscoring the strong cultural reliance on WEP for traditional healing practices. This was followed by general vegetables, which includes both cooked and raw forms, and spice, used for flavoring and preservation. Other notable methods included direct consumption, processed food, salads, and infused drinks.

Notably, certain species were used across multiple categories. For instance, *Z. officinale* served as a spice, a medicinal decoction, and a base for herbal drinks. *Musa paradisiaca* was eaten ripe or boiled and also used ritually. The overlap between food and medicine confirms the integrative nature of traditional plant use in Paranggupito.

Rather than emphasizing quantified percentages (which could not be derived directly from Table 2, this study highlights the functional multiplicity and cultural logic embedded in WEP preparation. These practices are maintained through oral transmission and household routines, especially among women and elders, contributing to both dietary resilience and health self-sufficiency.

Table 1. Sociodemographic characteristics of respondents in Songbledeg, Paranggupito, and Gunturharjo Villages of Wonogiri District, Central Java, Indonesia (n=135)

Variable	Category	Frequency	%
Gender	Male	53	39.26
	Female	82	60.74
Age group (years)	21-40	46	34.07
	41-60	59	43.70
	>60	30	22.22
Education level	No education	0	0
	Elementary School	57	42.22
	Junior High School	42	31.11
	Senior High School	26	19.26
	Higher Education	10	7.41
Occupation	Farmer	56	41.48
	Housewife	37	27.41
	Traditional herbalist	16	11.85
	Others (trader, service)	26	19.26

Table 2. Wild edible plant species recorded in Songbledeg, Paranggupito, and Gunturharjo Villages of Wonogiri District, Central Java, Indonesia: Botanical name, family, local name, part used, type of use, habitat, and Use Value (UV)

Family	Scientific name	Local name	Habitat	Plant parts used	Form of utilization	UV
Acanthaceae	*Andrographis paniculata* (Burm.fil.) Nees	*Sambiroto*	Forest	Leaf	Herbal medicine	0.052
Amaranthaceae	*Amaranthus hybridus* L.	*Bayam*	Yard, garden	Leaf	Vegetables, chips	0.163
Annonaceae	*Annona muricata* L.	*Sirsat*	Forest	Fruit	Consumed directly	0.007
Apiaceae	*Centella asiatica* (L.) Urb.	*Tempuyung*	Yard	Leaf	Herbal medicine	0.044
Araceae	*Caladium bicolor* (Aiton) Vent.	*Lompong*	Rice Field	Leaves, stems, tubers	Vegetables	0.007
Araceae	*Colocasia esculenta* (L.) Schott	*Talas*	Rice Field	Tuber	Processed food	0.007
Arecaceae	*Cocos nucifera* L.	*Kelapa*	Garden	Fruit	Consumed, coconut oil	0.081
Asteraceae	*Cosmos caudatus* Kunth	*Kenikir*	Yard, forest	Leaf	Raw vegetables	0.089
Asteraceae	*Elephantopus scaber* L.	*Tapak liman*	Yard, forest	Leaf	Herbal medicine	0.007
Asteraceae	*Pluchea indica* (L.) Less.	*Beluntas*	Forest	Flowers, leaves, stems, roots	Herbal medicine	0.007
Basellaceae	*Anredera cordifolia* (Ten.) Steenis	*Binahong*	Yard	Leaf	Herbal medicine	0.059
Convolvulaceae	*Ipomoea aquatica* Forssk.	*Kangkung*	Rice Field	Leaves, stems	Vegetables	0.044
Cucurbitaceae	*Benincasa hispida* (Thunb.) Cogn.	*Bligo*	Garden, yard	Seeds, fruit	Vegetables	0.015
Cucurbitaceae	*Sechium edule* (Jacq.) Sw.	*Jepan*	Yard	Fruit	Vegetables	0.007
Dioscoreaceae	*Dioscorea alata* L.	*Uwi*	Rice Field	Tuber	Processed food	0.015
Dioscoreaceae	*Dioscorea esculenta* (Lour.) Burkill	*Gembili*	Rice Field	Tuber	Processed food	0.007
Ebenaceae	*Diospyros blancoi* A.DC.	*Bisbul*	Garden, forest	Fruit	Consumed, rujak	0.03
Fabaceae	*Cassia alata* L.	*Daun ketepeng*	Yard, forest	Leaf	Herbal medicine	0.067
Fabaceae	*Leucaena leucocephala* (Lam.) de Wit	*Lamtoro*	Rice fields, forests	Seeds, leaves	Raw veg.., medicine	0.059
Lamiaceae	*Ocimum basilicum* L.	*Kemangi*	Yard	Leaf	Raw vegetables	0.081
Meliaceae	*Swietenia mahagoni* (L.) Jacq.	*Mahoni*	Forest	Seed	Herbal medicine	0.022
Menispermaceae	*Tinospora cordifolia* (Willd.) Miers	*Brotowali*	Rice Field	Stem, leaves, roots	Herbal medicine	0.037
Moraceae	*Ficus racemosa* L.	*Jambu elo*	Forest	Fruit	Consumed	0.007
Moraceae	*Morus alba* L.	*Murbei*	Forest	Fruit, leaves	Consumed, spice	0.007
Muntingiaceae	*Muntingia calabura* L.	*Kersen*	Yard	Fruit	Consumed directly	0.052
Musaceae	*Musa paradisiaca* L.	*Pisang*	Forest	Fruit	Consumed directly	0.148
Pandanaceae	*Pandanus amaryllifolius* Roxb. ex Lindl.	*Pandan*	Yard	Leaf	Spice, dye	0.022
Pandanaceae	*Pandanus odorifer* (Forssk.) Kuntze	*Pandan laut*	Beach	Fruit	Consumed, herbal	0.015
Passifloraceae	*Passiflora foetida* L.	*Kuncung mas*	Yard	Fruit, leaves	Drink, medicine	0.03
Phyllanthaceae	*Sauropus androgynus* (L.) Merr.	*Daun katuk*	Yard	Leaf	Vegetables	0.015
Piperaceae	*Piper retrofractum* Vahl	*Cabe jawa*	Garden	Fruit, leaves, roots	Herbal medicine	0.015
Poaceae	*Cymbopogon citratus* (DC.) Stapf	*Serai*	House yard, rice field	Stem	Spice	0.03
Portulacaceae	*Portulaca oleracea* L.	*Krokot*	Forest	Leaves, stems, flowers	Vegetables	0.067
Rubiaceae	*Morinda citrifolia* L.	*Bentis*	Forest	Fruit, Seed, Leaf	Vegetables, salad	0.037
Rubiaceae	*Paederia foetida* L.	*Sembukan*	Forest	Leaf	Herbal medicine	0.007
Salicaceae	*Flacourtia rukam* Zoll. & Moritzi	*Saratan*	Forest	Fruit	Consumed directly	0.015
Solanaceae	*Physalis angulata* L.	*Ciplukan*	Rice fields, forests	Fruit	Medicine	0.022
Verbenaceae	*Lantana camara* L.	*Tembelekan*	Yard, garden	Flower	Herbal medicine	0.015
Zingiberaceae	*Alpinia galanga* (L.) Willd.	*Lengkuas*	Yard	Rhizome	Spice, medicine	0.104
Zingiberaceae	*Curcuma longa* L.	*Kunyit*	Yard	Rhizome	Spice, oil	0.096
Zingiberaceae	*Curcuma xanthorrhiza* D.Dietr.	*Temulawak*	Rice Field	Rhizome	Spice, medicine	0.03
Zingiberaceae	*Etlingera elatior* (Jack) R.M.Sm.	*Kecombrang*	Yard	Flowers, leaves, stems	Vegetables, spices	0.007
Zingiberaceae	*Kaempferia galanga* L.	*Kencur*	Yard	Rhizome	Spice, medicine	0.052
Zingiberaceae	*Zingiber officinale* Roscoe	*Jahe*	Yard	Rhizome	Herbal drink	0.104

Note: UV: Use Value

High-use value species and functional multiplicity

Among the 44 WEP species documented in Paranggupito, several exhibited notably high Use Values (UV), reflecting their strong cultural salience, multifunctional roles, and frequent citation across informants. As shown in Figure 4, the five species with the highest UV scores were *A. hybridus* (0.163), *M. paradisiaca* (0.148), *A. galanga* (0.104), *Z. officinale* (0.104), and *C. longa* (0.096).

These species were consistently mentioned by respondents for both dietary and medicinal purposes, indicating their central role in food-medicine interfaces. *Amaranthus hybridus*, a leafy vegetable, was widely recognized for its ease of cultivation in home gardens and use in daily meals such as boiled greens or chips. *Musa paradisiaca* was commonly consumed both ripe and cooked, often prepared as boiled banana or incorporated into traditional snacks.

Alpinia galanga and *Z. officinale* served dual functions: as aromatic spices and as essential components of herbal remedies for ailments such as colds, fatigue, or digestive issues. *Curcuma longa*, similarly, was used in cooking and as an anti-inflammatory herbal tonic. These plants represent culturally embedded knowledge passed down through generations and adapted to local ecological contexts.

The high UV scores suggest not only familiarity and accessibility but also a degree of multifunctionality that makes these species indispensable in local households. Their widespread use underscores the importance of maintaining access to semi-wild and home-grown plant resources, especially in environments characterized by seasonal scarcity and limited modern healthcare infrastructure. These five species exemplify the overlap between food and medicine in traditional knowledge systems. Their continued use also demonstrates resilience in the face of changing dietary habits, and they offer promising candidates for conservation, local value chains, and agroecological innovation.

Distribution and habitat variation

The wild edible plant species recorded in Paranggupito were distributed across diverse habitat types, reflecting the integration of both cultivated and semi-natural environments in the community's subsistence strategies. As shown in Figure 5, the highest number of species (n = 24; 54.5%) were found in home gardens and yards, which serve as accessible spaces for cultivating vegetables, herbs, and multipurpose plants. Commonly maintained species in these habitats include *Ocimum basilicum*, *Sauropus androgynus*, and *Curcuma longa*, which are valued for both culinary and medicinal purposes.

Rice fields supported 12 species (27.3%), such as *Ipomoea aquatica*, *Colocasia esculenta*, and *Curcuma xanthorrhiza*. These areas provide seasonal access to edible shoots, tubers, and spices. Forests and shrublands harbored 15 species (34.1%), including *Tinospora cordifolia*, *Cassia alata*, and *Ficus racemosa*, many of which are valued for traditional medicinal uses and wild fruit collection. Although less represented, beach habitats contributed a single species, *Pandanus odorifer*. These marginal environments, despite their low species richness, reflect the depth of local ecological knowledge in managing niche ecosystems.

Table 3. Informant Consensus Factor (ICF) for each use category of wild edible plants in Paranggupito Sub-district, Wonogiri, Indonesia

Use category	Nur	Nt	ICF value
Processed food	41	9	0.778
Traditional medicine	38	11	0.737
Direct consumption	55	17	0.704

Note: Nur: Number of Use Reports, Nt: Number of species

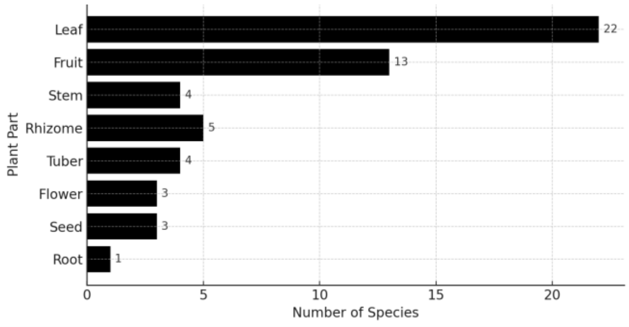

Figure 2. Proportion of wild edible plant parts used by local communities in Paranggupito Sub-district, Wonogiri, Central Java, Indonesia

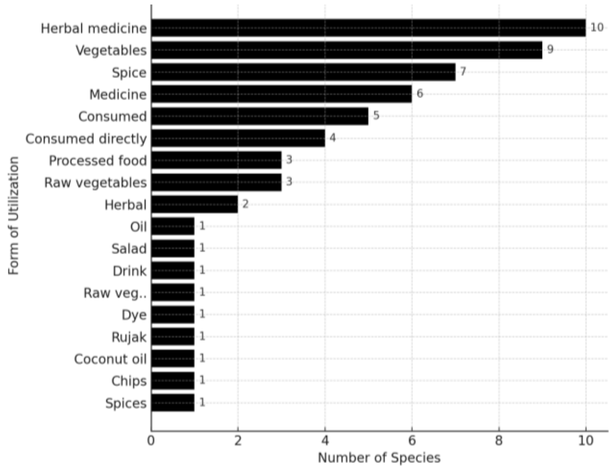

Figure 3. Preparation methods of wild edible plants reported by informants in Paranggupito Sub-district, Wonogiri, Central Java, Indonesia

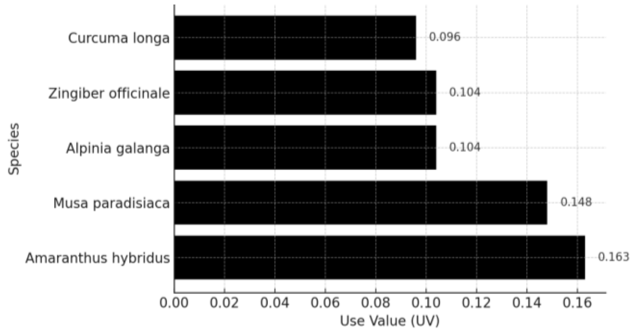

Figure 4. Five wild edible plant species with the highest Use Values (UV) in Paranggupito communities, Wonogiri, Central Java, Indonesia

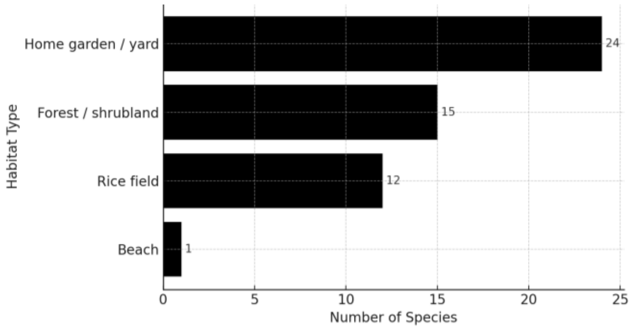

Figure 5. Habitat distribution of wild edible plant species recorded in three villages of Paranggupito Sub-district, Wonogiri, Central Java, Indonesia

The habitat diversity observed in this study underscores the adaptive nature of ethnobotanical knowledge in karst ecosystems, where the availability and management of plant resources are closely tied to microhabitat conditions. The prominence of anthropogenic habitats (e.g., home gardens and rice fields) further suggests the active domestication or semi-domestication of useful wild taxa.

Discussion

Ethnobotanical diversity in karst landscapes

The present study documented a rich assemblage of 44 WEP species in the karst region of Paranggupito, highlighting the adaptability of traditional knowledge systems to ecologically marginal environments. This diversity is comparable to or slightly lower than that reported in non-karst lowland or wetland regions of Indonesia (Farikha et al. 2024; Rahayu et al. 2024 Triyanto et al. 2024), but it is particularly notable considering the harsh edaphic and hydrological conditions of the Gunung Sewu karst.

Karst ecosystems, characterized by shallow soils, high porosity, and seasonal water scarcity, are typically seen as agriculturally suboptimal (Li et al. 2023). Yet, the persistence of diverse edible species in this region reflects both ecological resilience and cultural ingenuity (Hartawan et al. 2020). Many of the recorded species, such as *C. asiatica*, *A. hybridus*, and *Z. officinale*, are not only tolerant of disturbed or rocky habitats but are also well-integrated into the seasonal subsistence strategies of local communities.

In line with earlier findings by Cahyaningsih et al. (2022), the utilization of WEP in karst zones often centers on multifunctional species that are nutritionally rich, drought-resistant, and socially embedded. These plants serve as critical buffers during the dry season when cultivated crops become scarce, making them vital components of adaptive food security in vulnerable rural systems.

The dominance of leafy vegetables and rhizomatous herbs also reflects a broader trend in Southeast Asian ethnobotany, where communities rely heavily on readily available, fast-growing, and multipurpose species (Panyadee et al. 2024; Inta et al. 2025). Such plants are commonly found in home gardens, rice field margins, and forest edges, suggesting a hybrid space between cultivated and wild—a feature often observed in swidden or semi-subsistence systems.

The ecological knowledge encoded in the use of these plants—including habitat selection, seasonal timing, and culinary preparation—is not random but highly structured and inherited through generations. This reinforces the argument that ethnobotanical richness in karst areas is not merely a function of residual biodiversity but a dynamic outcome of human-environment interaction (Hu et al. 2020).

Cultural significance and transmission of traditional knowledge

The utilization of WEPs in Paranggupito reflects more than subsistence necessity; it embodies a complex cultural system of knowledge, practice, and belief. The high citation frequencies and Use Values (UV) of species such as *C. asiatica*, *S. androgynus*, and *Z. officinale* indicate that these plants are not only functional but also culturally embedded in daily life, traditional medicine, and food rituals.

The predominance of female informants (60.74%) and older individuals (aged 41-60) in this study suggests that women and elders are the primary custodians of ethnobotanical knowledge, particularly in food preparation, home medicine, and plant management. This aligns with findings from similar contexts, where gendered knowledge systems play a pivotal role in intergenerational transmission (da Costa et al. 2021; Ramirez-Santos et al. 2023; Hanazaki 2024).

Although a significant portion of respondents had only basic formal education, their plant knowledge was rich and detailed, supporting the idea that oral tradition and experiential learning remain dominant modes of knowledge transfer (Tardío and Pardo-de-Santayana 2008). Recipes, harvesting rules, and plant-based remedies are often passed down during household chores or communal foraging trips, reinforcing cultural identity. More importantly, these practices also foster ecological awareness, which should be a shared responsibility in preserving traditional plant knowledge.

However, the study also observed signs of erosion in knowledge depth among younger age groups, particularly in their ability to identify species and distinguish between edible and toxic parts. This may be attributed to increasing engagement with formal employment, urban migration, or shifting dietary preferences. As reported in similar studies (Ramirez-Santos et al. 2023), the threat of cultural erosion due to modernization and loss of vernacular language is pressing, posing a significant risk to the continuity of traditional plant knowledge.

Despite these challenges, the multifunctionality of many WEP—serving as food, medicine, spice, or ritual object—helps to maintain their relevance in everyday life. Plants such as *C. longa* are used not only in meals but also in postpartum rituals, herbal bathing, and disease prevention, indicating their symbolic and spiritual value beyond material utility. Thus, preserving WEP knowledge in karst communities should not be limited to documenting names and uses, but also include safeguarding the cultural frameworks through which this knowledge is generated, practiced, and transmitted.

Functional roles of WEP in nutrition, health, and resilience

Wild edible plants in the Paranggupito karst system serve essential roles in nutrition, primary healthcare, and socio-ecological resilience, particularly under conditions of resource scarcity. Their presence enhances dietary diversity, supplements micronutrient intake, and offers accessible treatment for common ailments.

Nutritionally, many of the frequently cited species—such as *A. hybridus*, and *S. androgynus* —are known for their high content of vitamins A, C, iron, calcium, and antioxidants, as documented in previous compositional studies (Rahayu et al. 2024). These plants complement staple foods like cassava and rice, helping to address potential micronutrient deficiencies in low-income households with limited food access.

In addition to their food value, more than a third of the recorded species were cited for their medicinal functions, including *C. asiatica*, *Z. officinale*, *C. longa*, and *C. alata*. These plants are commonly used in decoctions, compresses, or raw infusions to treat fatigue, digestive issues, fever, and reproductive health concerns. The strong Informant Consensus Factor (ICF) values for both processed food and medicinal categories (0.778 and 0.737, respectively) support the idea that these uses are shared and culturally validated within the community.

The reliance on WEP increases during ecological and economic stress, such as during the dry season or crop failure. Species found in marginal habitats (e.g., *P. oleracea*) are especially important as fallback foods and herbal tonics. This flexible use pattern reflects ecological intelligence—the ability of local communities to adaptively manage resource cycles and food risk (Hu et al. 2020).

Furthermore, the multifunctionality of WEP enhances resilience at both household and landscape levels. Plants that serve as both food and medicine reduce the need for external inputs. At the same time, those growing in degraded or exposed habitats (e.g., karst slopes) provide redundant and easily accessible reserves when needed. By integrating nutritional, therapeutic, and cultural roles, WEP acts as a bio-cultural keystone, bridging ecological function with human well-being. Their continued availability and sustainable use are therefore critical not only for biodiversity but also for community health and food sovereignty, especially in underdeveloped karst regions of Southeast Asia.

Implications for biocultural conservation in karst areas

The findings of this study underscore the critical role of WEPs not only in sustaining daily subsistence but also in supporting biocultural conservation strategies in karst environments. The persistence of local knowledge, coupled with species diversity across marginal habitats, highlights the urgency of integrating ethnobotanical insights into conservation and development policies.

Karst regions such as Paranggupito are often classified as fragile ecosystems, prone to erosion, water scarcity, and biodiversity loss due to agricultural intensification, limestone extraction, and climate change (Hu et al. 2020). Yet, these landscapes also harbor culturally significant species and knowledge systems that promote resource resilience, especially through WEP-based practices. The documentation of multifunctional WEP with high Use Values and Informant Consensus Factors reveals priority species and practices that can be targeted in community-based conservation programs. Local home gardens, rice field margins, and forest edges where most WEP occur represent microhabitats of conservation interest, offering entry points for in-situ preservation and agroecological enhancement (Rahayu et al. 2024).

Moreover, sustaining WEP knowledge aligns with national and global frameworks such as the UN Decade on Ecosystem Restoration, Indonesia's National Biodiversity Strategy and Action Plan (NBSAP), and community-driven REDD+ co-benefit initiatives, which all emphasize indigenous knowledge, food security, and sustainable use of plant genetic resources. To operationalize this, policies must go beyond protected areas and address the cultural dimensions of biodiversity, including customary knowledge, gendered transmission, and vernacular classification systems. Formal education and extension services should be equipped to document, validate, and revitalize traditional plant knowledge without eroding its context.

Finally, the declining intergenerational transmission observed in this study should prompt the development of participatory conservation tools—such as WEP mapping, seed exchange, youth education, and eco-culinary tourism—that re-embed WEP in both local livelihoods and environmental stewardship. Preserving WEP diversity and its associated knowledge is not only a matter of ecological conservation but also a strategy to maintain cultural identity, food sovereignty, and adaptive capacity in one of Java's most vulnerable agroecological frontiers.

In conclusion, this study reveals that the karst landscapes of Paranggupito, Central Java, support a diverse array of 44 WEPs species used by local communities for food, health, and cultural practices. Despite harsh ecological conditions, high Use Value (UV) species such as

C. asiatica, *A. hybridus*, and *S. androgynus* contribute significantly to household nutrition and resilience during environmental or economic stress. The broad distribution of WEP—from home gardens to rocky slopes—reflects deep ecological knowledge shaped by tradition and experiences passed down through generations. Informant Consensus Factor (ICF) analysis shows strong agreement on processed food and medicinal uses, underscoring shared cultural patterns. Women and older adults emerged as key knowledge holders, with a noticeable decline in awareness among youth, highlighting the need to safeguard both species and the knowledge systems sustaining their use. As biological and cultural heritage, WEP offers opportunities for in-situ conservation, agroecological adaptation, and livelihood enhancement in fragile landscapes. Their integration into formal biodiversity strategies and education could strengthen local food sovereignty and biocultural resilience. Protecting these plant resources is vital not only for ecological sustainability but also for upholding the cultural identity, autonomy, and health of rural communities in karst regions of Indonesia.

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REFERENCES

Al Yamini TH, Djuita NR, Chikmawati T, Purwanto Y. 2023. Ethnobotany of wild and semi-wild edible plant of the Madurese Tribe in Sampang and Pamekasan Districts, Indonesia. Biodiversitas 24 (2): 947-957. DOI: 10.13057/biodiv/d240234.

Asfaw A, Lulekal E, Bekele T, Debella A, Tessema S, Meresa A, Debebe E. 2023. Ethnobotanical study of wild edible plant and implications for food security. Trees For People 14: 100453. DOI: 10.1016/j.tfp.2023.100453.

Cahyaningsih AP, Arifiani KN, Aprilia D, Nugroho ME, Setyawan AD. 2022. Ethnobotanical study of the non-medicinal plant by village communities in the karst area of Pacitan, East Java, Indonesia. Intl J Trop Drylands 6 (1): 1-10. DOI: 10.13057/tropdrylands/t060101.

Cahyanti FA, Eskundari RD, Purwanto A. 2024. Wild edible plant as an alternative food source for the community of Pakis Baru Village, Nawangan, Pacitan. Jurnal Biologi Tropis 24 (2): 352-367. DOI: 10.29303/jbt.v24i2.6779.

Chrysargyris A, Baldi A, Lenzi A, Bulgari R. 2023. Wild plant species as potential horticultural crops: An opportunity for farmers and consumers. Horticulturae 9 (11): 1193. DOI: 10.3390/horticulturae9111193.

da Costa FV, Guimarães MFM, Messias MCTB. 2021. Gender differences in traditional knowledge of useful plants in a Brazilian community. PLoS ONE 16 (7): e0253820. DOI: 10.1371/journal.pone.0253820.

Dejene T, Agamy MS, Agúndez D, Martin-Pinto P. 2020. Ethnobotanical survey of wild edible fruit tree species in lowland areas of Ethiopia. Forests 11 (2): 177. DOI: 10.3390/f11020177.

Farikha KN, Syahrani LPW, Alfiyah LK, Luthfia, Nurwulandari M, Nazar IA, Junaedi E, Setyawan AD. 2024. The diversity of wild edible plant used by community living around Mount Merapi National Park, Central Java, Indonesia. Biodiversitas 25 (9): 3041-3049. DOI: 10.13057/biodiv/d250925.

Feng T, Xiong R, Huan P. 2023. Productive use of natural resources in agriculture: The main policy lessons. Resources Policy 85: 103793. DOI: 10.1016/j.resourpol.2023.103793.

Hanazaki N. 2024. Local and traditional knowledge systems, resistance, and socioenvironmental justice. J Ethnobiol Ethnomed 20 (1): 5. DOI: 10.1186/s13002-023-00641-0.

Hartawan BS, Erwandha R, Irsyadi MB, Hidayat MRA, Sholih D. 2020. Characteristics of Sewu Mountain karst as geopark area. J Glob Environ Dyn 1 (1): 7-12.

Heinrich M, Ankli A, Frei B, Weimann C, Sticher O. 1998. Medicinal plants in Mexico: Healers' consensus and cultural importance. Soc Sci Med 47 (11): 1859-1871. DOI: 10.1016/S0277-9536(98)00181-6.

Hu R, Lin C, Xu W, Liu Y, Long C. 2020. Ethnobotanical study on medicinal plants used by Mulam people in Guangxi, China. J Ethnobiol Ethnomed 16 (1): 40. DOI: 10.1186/s13002-020-00387-z.

Inta A, Panyadee P, Suksathan R, Pongamornkul W, Punchay K, Disayathanoowat T, Chaisoung N, Phichonsatcha T, Maneenoon K, Yang L. 2025. Culinary and medicinal wonders of the wild: An ethnobotanical review of native herbs and spices in Thailand. Heliyon 11 (4): e42470. DOI: 10.1016/j.heliyon.2025.e42470.

Li Y, Wang S, Peng T, Zhao G, Dai B. 2023Hydrological characteristics and available water storage of typical karst soil in SW China under different soil–rock structures. Geoderma 438: 116633. DOI: 10.1016/j.geoderma.2023.116633.

Motti R. 2022. Wild edible plants: A challenge for future diet and health. Plants 11 (3): 344. DOI: 10.3390/plants11030344.

Panyadee P, Pongamornkul W, Van On T, Trong ND, Giang PTL, Kim LT, Inta A, Sirisa-Ard P, Chansakaow S. 2024. The Mien people's ethnobotanical survey of medicinal plant use in Thailand and Vietnam. Biodiversitas 25 (1): 79-96. DOI: 10.13057/biodiv/d250110.

Pinela J, Carvalho AM, Ferreira IC. 2017. Wild edible plants: Nutritional and toxicological characteristics, retrieval strategies and importance for today's society. Food Chem Toxicol 110: 165-188. DOI: 10.1016/j.fct.2017.10.020.

Pradhan R, Nayak AP, Reddy S. 2020. Potential wild edible plant and its significance in livelihood of indigenous people of male Mahadeshwara Hills, Karnataka. Econ Aff 65 (4): 589-602. DOI: 10.46852/0424-2513.4.2020.15.

Rahayu YYS, Sujarwo W, Irsyam ASD, Dwiartama A, Rosleine D. 2024. Exploring unconventional food plants used by local communities in a rural area of West Java, Indonesia: Ethnobotanical assessment, use trends, and potential for improved nutrition. J Ethnobiol Ethnomed 20 (1): 68. DOI: 10.1186/s13002-024-00710-y.

Ramirez-Santos AG, Ravera F, Rivera-Ferre MG, Calvet-Nogués M. 2023. Gendered traditional agroecological knowledge in agri-food systems: A systematic review. J Ethnobiol Ethnomed 19 (1): 11. DOI: 10.1186/s13002-023-00576-6.

Rana JC, Pradheep K, Chaurasia OP, Sood S, Sharma RM, Singh A, Negi R. 2012. Genetic resources of wild edible plant and their uses among tribal communities of cold arid region of India. Genet Resour Crop Evol 59 (1): 135-149. DOI: 10.1007/s10722-011-9765-7.

Safitri DS, Soenarno SM, Noer S. 2024. Etnobotani tumbuhan liar sebagai obat herbal di lingkungan Perumahan Grand Tamansari 3 Kabupaten Bekasi. EduBiologia: Biol Sci Educ J 4 (2): 40-49. DOI: 10.30998/edubiologia.v4i2.23719. [Indonesian]

Sarquis RSFR, Sarquis ÍR, Sarquis IR, Fernandes CP, Araújo da Silva G, Borja Lima e Silva R, Jardim MAG, Sánchez-Ortíz BL, Carvalho JCT. 2019. The use of medicinal plants in the riverside community of the Mazagão River in the Brazilian Amazon, Amapá, Brazil: Ethnobotanical and ethnopharmacological studies. Evid-Based Complement Alternat Med 2019 (1): 6087509. DOI: 10.1155/2019/6087509.

Setyowati. 2004. Distribusi pendapatan petani lahan kering di Kecamatan Paranggupito, Kabupaten Wonogiri. Agritexts 15 (1): 13-22. [Indonesian]

Sholichah L, Alfidhdhoh D. 2020. Etnobotani tumbuhan liar sebagai sumber pangan di Dusun Mendiro, Kecamatan Wonosalam, Jombang. Jurnal Ilmu Pertanian Indonesia 25 (1): 111-117. DOI: 10.18343/jipi.25.1.111. [Indonesian]

Shumsky S, Hickey GM, Johns T, Pelletier B, Galaty J. 2014. Institutional factors affecting Wild Edible Plant (WEP) harvest and consumption in semi-arid Kenya. Land Use Policy 38: 48-69. DOI: 10.1016/j.landusepol.2013.10.014.

Silalahi M, Nisyawati. 2018. The ethnobotanical study of edible and medicinal plants in the home garden of Batak Karo sub-ethnic in

North Sumatra, Indonesia. Biodiversitas 19 (1): 229-238. DOI: 10.13057/biodiv/d190131.

Tahir M, Abrahim A, Beyene T, Dinsa G, Guluma T, Alemneh Y, Van Damme P, Geletu US, Mohammed A. 2023. The traditional use of wild edible plant in pastoral and agro-pastoral communities of Mieso District, Eastern Ethiopia. Trop Med Health 51 (1): 10. DOI: 10.1186/s41182-023-00505-z.

Tardío J, Pardo-de-Santayana M. 2008. Cultural importance indices: A comparative analysis based on the useful wild plants of Southern Cantabria (Northern Spain). Econ Bot 62 (1): 24-39. DOI: 10.1007/s12231-007-9004-5.

Triyanto A, Purnamasari F, Paramita FS, Wicaksono FR, Ramadhan FA, Budiharta S, Saensouk S, Setyawan AD. 2024. Ethnobotany of wild edible plant used by local communities in three districts along the upper Bengawan Solo River, Central Java, Indonesia. Biodiversitas 25 (4): 1596-1605. DOI: 10.13057/biodiv/d250428.

Tsioutsiou EE, Giordani P, Hanlidou E, Biagi M, De Feo V, Cornara L. 2019. Ethnobotanical study of medicinal plants used in Central Macedonia, Greece. Evid-Based Complement Alternat Med 2019 (1): 4513792. DOI: 10.1155/2019/4513792.

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Ethnobotanical knowledge of edible plants in a karst landscape of Gawang Hamlet, Ketro Village, Pacitan District, Indonesia

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Abstract. *Safitri RN, Hanum U, Pratiwi VMR, Hermawan WG, Nurcahyati M, Budiharta S, Setyawan AD. 2025. Ethnobotanical knowledge of edible plants in a karst landscape of Gawang Hamlet, Ketro Village, Pacitan District, Indonesia. Intl J Trop Drylands 9: 85-97.* Karst ecosystems pose significant agricultural challenges due to shallow soils, poor water retention, and rugged terrain; however, local communities have developed adaptive food systems rooted in traditional knowledge. This ethnobotanical study documented the diversity and utilization of edible plants in Gawang Hamlet, Ketro Village, Pacitan District, East Java, Indonesia, and assessed their cultural significance using the Relative Frequency of Citation (RFC) index. Data were collected from 60 informants through structured questionnaires, interviews, and field observations. A total of 65 edible plant species from 36 families were recorded, dominated by vegetables (47.0%), spices (24.2%), fruits (21.2%), and staple foods (7.6%). The most frequently cited species were *Manihot esculenta* (RFC=0.95), *Curcuma longa*, and *Arachis hypogaea*. Fruits and leaves were the most utilized parts, and shrubs and herbs dominated the growth forms. Quantitative analysis was conducted using the RFC index, and patterns of species multifunctionality were visualized through a heatmap and a Venn diagram to highlight overlapping use categories. The high species diversity and multifunctionality reflect local ecological adaptation and are closely tied to socio-demographic factors such as gender, age, and occupation. Importantly, home gardens were found to function as hubs of subsistence, biodiversity conservation, and intergenerational knowledge transfer, underscoring their crucial role in the community. These findings highlight the critical role of traditional agroecosystems in ensuring food security and sustaining cultural and ecological resilience in karst environments.

Keywords: Edible plant, ethnobotany, karst, Pacitan, traditional knowledge

INTRODUCTION

Ethnobotany is a compelling interdisciplinary field that explores the intricate relationships between human societies and plants within their local environments. Rooted in the terms ethnology and botany, ethnobotany investigates how communities, particularly those in rural and indigenous settings, utilize and perceive plants for food, medicine, rituals, shelter, and other cultural purposes (Darmastuti et al. 2024). This discipline not only documents traditional knowledge but also provides valuable perspectives for addressing urgent global issues such as biodiversity loss, climate change adaptation, sustainable food systems, and public health (Walujo 2017; Pei et al. 2020). Through the preservation and analysis of local plant knowledge, ethnobotany contributes to both ecological resilience and cultural continuity (Cahyaningsih et al. 2022).

In many rural parts of Indonesia, ethnobotanical knowledge remains vital for everyday survival. Communities frequently rely on a combination of cultivated and wild plant species to fulfill their food and nutritional needs. This reliance is particularly prominent in areas where conventional agricultural methods are constrained by harsh environmental conditions. One such example is the karst landscape, which is characterized by limestone-dominated geological formations, limited soil fertility, rapid water drainage, and general agricultural inhospitality (Sudarmadji et al. 2013; Kuniansky et al. 2016). These constraints, however, have not deterred local communities from developing adaptive strategies that harness the rich biodiversity of their surroundings.

The homegarden or *pekarangan* system in Indonesia exemplifies an effective model of small-scale agroforestry that is deeply rooted in traditional ecological knowledge. It integrates food crops, medicinal plants, ornamental species, and occasionally livestock in a multifunctional space. In karst regions, these systems are often intensified due to limited agricultural land, turning homegardens into crucial spaces for sustainable food production and ethnobotanical practice (Suryani et al. 2020; Sulistiyowati et al. 2022). The integration of diverse edible plant species in homegardens demonstrates not only local ecological acumen but also a socio-cultural commitment to self-sufficiency, dietary diversity, and resilience in the face of environmental pressures (Setiawan and Qiptiyah 2014).

One of the most compelling cases of such adaptive ethnobotanical practice is found in the Pacitan District of East Java, Indonesia. This district encompasses a significant portion of Java's Southern Mountains, with widespread karst formations shaping its ecology and land use patterns (Jauhari 2020). Within this district, Gawang Hamlet in Ketro Village, Kebonagung Sub-district, stands out as a remote community located in a particularly rugged karst zone. In this hamlet, residents engage in subsistence agriculture using traditional methods, cultivating a variety of vegetables, fruits, spices, and tuber crops in their homegardens and small plots of arable land (Ammar et al. 2021; Cahyaningsih et al. 2022). This localized food system, though modest, reflects a deep knowledge of plant cultivation under ecological stress, as well as a high degree of cultural adaptation.

Although earlier studies have explored ethnobotanical practices in Pacitan District more broadly, there is a notable research gap concerning specific localities like Gawang Hamlet, especially regarding the detailed inventory of edible plants and their cultural relevance (Ammar et al. 2021; Cahyaningsih et al. 2022). This study thus seeks to fill that gap by documenting and analyzing the diversity and use of food plants in Gawang Hamlet. By focusing on a community embedded within one of the district's most environmentally challenging regions, the research offers unique insights into how traditional knowledge and ecological adaptation intersect to sustain local livelihoods.

To achieve this, the present study employs the Relative Frequency of Citation (RFC) index to assess the cultural significance of edible plant species used by the local community. This index helps quantify the importance of each species based on how frequently it is cited by informants, thus providing a proxy for its cultural and practical value. Furthermore, the study explores socio-ecological factors—such as availability, seasonal variation, cultural practices, and perceived utility—that influence plant selection and usage patterns. By doing so, the research not only enriches the ethnobotanical literature from Southeast Asia but also contributes practical knowledge for biodiversity conservation and climate-resilient food strategies in karst landscapes.

MATERIALS AND METHODS

Study area

Geographical location

This study was conducted in Gawang Hamlet, a sub-village located within Ketro Village, Kebonagung Sub-district, Pacitan District, East Java Province, Indonesia (Figure 1). Geographically, Gawang Hamlet is situated at coordinates 8°17′24.9″S and 111°21′20.1″E, with a total area of approximately 234.50 hectares. It lies within the Southern Mountain karst region, which is part of a broader limestone formation extending across the southeastern part of Java Island (Jauhari 2020). This map illustrates the geographical setting of the study site within the karst landscape of the Southern Mountains, highlighting its elevation and terrain complexity. The village is accessible via rural roads and is surrounded by steep hills and karst formations with visible sinkholes and underground streams (Sudarmadji et al. 2013).

Topography and climate

The elevation of Gawang Hamlet ranges from 10 to 750 meters above sea level, characterized by a rugged landscape of limestone hills and limited flat terrain suitable for agriculture. The region experiences a tropical monsoonal climate with distinct dry and wet seasons. Annual rainfall in the area averages around 222.8 mm, and ambient temperatures typically range between 24°C and 27°C. Due to the karst substrate, surface water is scarce, and agricultural activity relies on seasonal rain and traditional soil-conservation practices (Widiyanti and Dittmann 2014; Kuniansky et al. 2016).

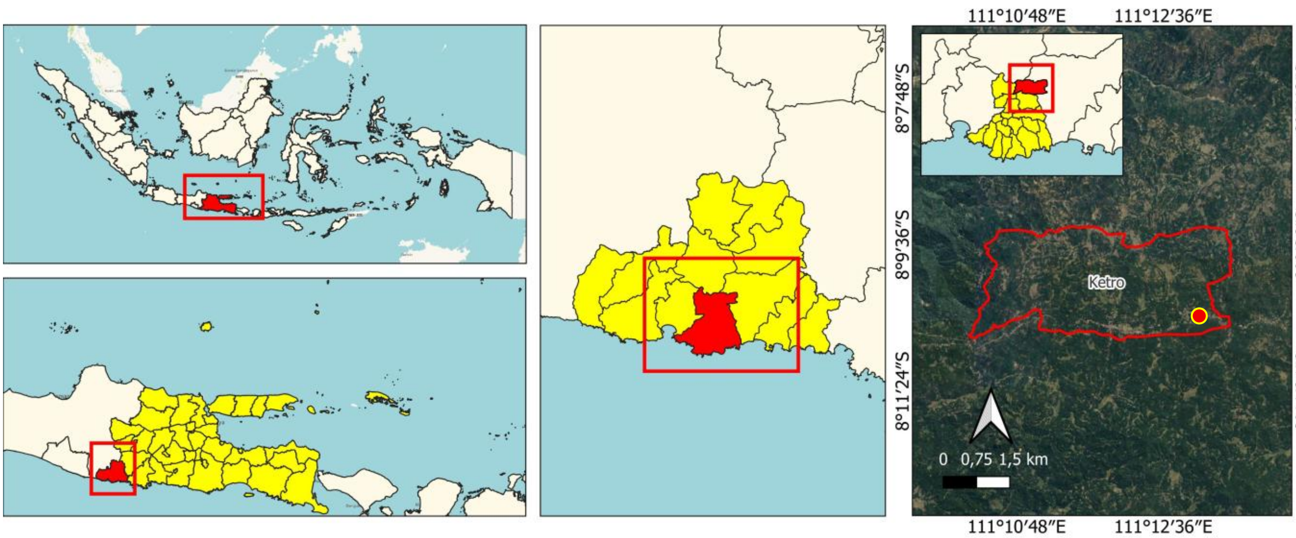

Figure 1. Location map of Gawang Hamlet (●), Ketro Village, Kebonagung Sub-district, Pacitan District, East Java, Indonesia.

Social characteristics

The population of Gawang Hamlet consists mainly of rural Javanese communities engaged in subsistence farming, seasonal labor, and domestic food production. Most households cultivate edible plants in home gardens or nearby plots, forming a deeply rooted local food system. Intergenerational transfer of plant knowledge remains strong, with reliance on locally available resources for daily nutrition. Of the 60 informants surveyed, 70% were women, reflecting their central role in managing household food and health. More than 70% were over 45 years old, indicating the importance of elderly individuals as knowledge holders. Educational attainment was generally low, with the majority completing only primary school. Common occupations included farming (38.3%) and housewifery (36.7%), aligning with a household-based production model. Notably, 90% of informants had lived in the area for over a decade, suggesting that prolonged exposure to the environment fosters deep ecological knowledge. These socio-cultural and ecological factors have produced a resilient, diversified food system rooted in tradition. Gawang Hamlet offers a meaningful example of how rural communities adapt to fragile karst landscapes through culturally embedded, biodiversity-based practices that support both food security and ecological sustainability.

Data collection

Selection of informants and sampling technique

This study used purposive sampling to select 60 informants with specific knowledge relevant to edible plant use, following widely accepted ethnobotanical methods (Etikan et al. 2016). Selection was based on residency, experience in farming or gardening, and familiarity with traditional plant practices. The sample size followed general behavioral research guidelines suggesting 30-500 participants (Roscoe 1975; Tabachnick and Fidell 1996), with an emphasis on demographic diversity and active engagement with food plants.

Data collection instruments

Data were collected using structured questionnaires, semi-structured interviews, and direct field observations. The questionnaires gathered demographic data and detailed information on edible plant use (e.g., names, parts used, preparation methods, usage frequency). Open-ended interviews allowed clarification and narrative insights (Zhang et al. 2016). Observations were used to verify plant species and record morphological features in situ. All instruments were conducted in Javanese and later translated into Indonesian and English.

Inclusion criteria of informants

Informants were eligible if they were at least 17 years old (Hurlock 2006), had lived in Gawang Hamlet for over one year, and actively cultivated or gathered edible plants. Only those with firsthand knowledge were included. Participation was voluntary, ensuring reliable data grounded in ecological familiarity and cultural relevance.

Period and duration of fieldwork

Fieldwork took place in December 2023 during the rainy season, a period conducive to plant growth and identification. The three-week duration allowed ample time for interviews, questionnaire administration, and species verification in home gardens and fields. This timing also aligned with peak agricultural activity in the village.

Plant identification

Identification process

Plant species cited by informants were documented using both vernacular and scientific names. Fresh specimens were directly observed in the field, with photographic documentation when necessary. Cross-verification with multiple informants was used to confirm name accuracy. In ambiguous cases, morphological features such as leaf shape, flower structure, and growth habit were examined in situ and compared with herbarium samples or photographic databases to ensure precise identification.

Use of local and scientific names

Each species was recorded using its local name as spoken in Gawang Hamlet and matched to its scientific equivalent. When multiple vernacular names were used, consensus was reached through triangulation with key informants (e.g., elderly or experienced women). Scientific names followed binomial nomenclature with author citation, and plant families were identified for consistency across the dataset (Table 2).

Taxonomic references

Species names and classifications were verified using global taxonomic databases, including GBIF and POWO. In cases of uncertainty, regional botanical sources such as Backer and Bakhuizen van den Brink (1963-1968), and references from Iskandar et al. (2018) and Ammar et al. (2021) were consulted. Taxonomic updates and synonyms were noted. Unconfirmed species were excluded from quantitative analyses (e.g., RFC) to maintain data reliability.

Data analysis

Qualitative analysis

This study used both qualitative and quantitative approaches to interpret ethnobotanical data. Qualitative analysis explored patterns of plant use, cultural significance, and ecological logic, based on observations, interviews, and open-ended questionnaire responses. Plants were grouped thematically by use (vegetables, spices, fruits, staples), plant parts used, and growth forms to construct interpretive codes.

Quantitative analysis – Relative Frequency of Citation (RFC)

Quantitatively, the Relative Frequency of Citation (RFC) index was applied to assess each species' cultural importance:

RFC = FC/N

Where,
FC : Number of informants who mentioned a species
N : Total number of informants (N = 60)

RFC values range from 0 to 1, with higher values indicating broader recognition and use (Tardío and Pardo-de-Santayana 2008; Bano et al. 2014; Silalahi et al. 2018).

Interpretation and classification of results

Based on RFC scores, species were categorized as: high (≥0.30), moderate (0.10-0.29), or low (<0.10) importance. To aid interpretation, data were visualized using a heatmap (by use category) and a Venn diagram (to show multifunctionality and category overlap), highlighting key species in the local food system.

RESULTS AND DISCUSSION

Socio-demographic characteristics of informants

A total of 60 informants participated in this ethnobotanical study, all of whom were residents of Gawang Hamlet, Ketro Village, Pacitan District. They were selected based on their local knowledge and direct experience in cultivating and utilizing edible plants in home gardens or fields. The demographic profile of the participants reflects the composition of rural communities in karst areas. It provides insight into how traditional plant knowledge is distributed across gender, age, education, and occupation. As shown in Table 1, the majority of respondents were female (70%), highlighting the significant role of women in managing household food systems and preserving ethnobotanical knowledge. This finding is consistent with previous studies that emphasize women's central role in food preparation and knowledge transmission (Cao et al. 2020). The age distribution was dominated by individuals over 45 years old, including 28.3% aged above 65, indicating that much of the local plant knowledge resides within the older generation.

In terms of education, most informants had limited formal schooling, with 40.0% completing only primary school and 13.3% having never attended school. Despite this, their ecological and practical understanding of edible plant species was remarkably rich, illustrating the strength of orally transmitted knowledge systems. The primary occupations were farming (38.3%) and housewifery (36.7%), consistent with the agrarian lifestyle of the community. Most participants (90.0%) had lived in the hamlet for over ten years, which reinforces the reliability and depth of their knowledge about local plant resources.

This demographic profile illustrates that edible plant knowledge in Gawang Hamlet is embedded in lived experience and intergenerational transmission, with women and the elderly acting as key custodians of ecological heritage. These socio-ecological attributes are crucial for understanding the patterns of plant selection, use, and conservation in rural karst communities.

Diversity of edible plant species

The ethnobotanical survey in Gawang Hamlet documented a total of 65 edible plant species belonging to 27 botanical families. These species include both cultivated crops and semi-wild plants that are commonly used by the local community for food, spices, fruits, and complementary ingredients. The high diversity of edible plants reflects the community's adaptive strategies to cope with ecological limitations in karst landscapes and highlights their deep reliance on local biodiversity for daily subsistence. The most represented families based on the number of species recorded were Fabaceae (11 species), followed by Zingiberaceae, Cucurbitaceae, and Solanaceae (each with 6 species), Amaryllidaceae (5 species), Myrtaceae (3 species), and Rutaceae (2 species). These families are well known for their multipurpose species, offering a wide range of edible parts such as fruits, leaves, seeds, tubers, rhizomes, and bulbs.

The dominant species in terms of usage frequency and multifunctionality include *Manihot esculenta* (cassava), *Curcuma longa* (turmeric), *Arachis hypogaea* (peanut), and *Zingiber officinale* (ginger), which show the highest RFC values (≥0.40). These species are primarily classified as staple, spice, or complementary foods and are valued for their adaptability to nutrient-poor karst soils and seasonal water availability. The wide variety of edible plant species recorded reflects the community's ecological knowledge and adaptive strategies in managing a diverse agroecosystem under karst conditions. These findings are reinforced by the quantitative results of the Relative Frequency of Citation (RFC) analysis presented in the following section.

Table 1. Socio-demographic characteristics of informants in Gawang Hamlet, Pacitan District, East Java, Indonesia (N=60)

Parameter	Category	Frequency (n)	Percentage (%)
Gender	Male	18	30.0
	Female	42	70.0
Age Group (years)	15-25	3	5.0
	26-35	5	8.3
	36-45	10	16.7
	46-55	10	16.7
	56-65	15	25.0
	>65	17	28.3
Education level	Not attending school	8	13.3
	Primary school	24	40.0
	Junior high school	14	23.3
	Senior high school	14	23.3
Length of Residence	<5 years	2	3.3
	5-10 years	4	6.7
	>10 years	54	90.0
Occupation	Farmer	23	38.3
	Housewife	22	36.7
	Trader	5	8.3
	Other (laborer, student, etc.)	10	16.7

Table 2. List of edible plants used by the Gawang Hamlet community, Pacitan, Indonesia along with their local names, scientific names, growth forms, plant parts used, and utilization modes

Local name	Common name	Scientific name	Family	Growth form	Used part(s)	Use category	RFC
Singkong	Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	Shrub	Tuber, leaf	Staple, vegetable	0.95
Kunyit	Turmeric	*Curcuma longa* L.	Zingiberaceae	Herb	Rhizome	Spice	0.45
Kacang tanah	Peanut	*Arachis hypogaea* L.	Fabaceae	Herb	Seed	Complementary	0.43
Jahe	Ginger	*Zingiber officinale* Roscoe	Zingiberaceae	Herb	Rhizome	Spice	0.40
Kacang panjang	Yardlong bean	*Vigna unguiculata* (L.) Walp.	Fabaceae	Shrub	Fruit	Vegetable	0.38
Lengkuas	Galangal	*Alpinia galanga* (L.) Willd.	Zingiberaceae	Herb	Rhizome	Spice	0.35
Pisang	Banana	*Musa* sp.	Musaceae	Tree	Fruit	Fruit	0.33
Ubi jalar	Sweet potato	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	Tuber	Tuber	Staple	0.30
Terong	Eggplant	*Solanum melongena* L.	Solanaceae	Shrub	Fruit	Vegetable	0.29
Bayam	Amaranth	*Amaranthus* sp.	Amaranthaceae	Herb	Leaf	Vegetable	0.28
Pepaya	Papaya	*Carica papaya* L.	Caricaceae	Tree	Leaf, fruit	Vegetable, fruit	0.33
Daun kelor	Drumstick tree	*Moringa oleifera* Lam.	Moringaceae	Tree	Leaf	Vegetable	0.26
Sawi	Mustard greens	*Brassica juncea* (L.) Czern.	Brassicaceae	Herb	Leaf	Vegetable	0.25
Kangkung	Water spinach	*Ipomoea aquatica* Forssk.	Convolvulaceae	Herb	Leaf	Vegetable	0.25
Kecipir	Winged bean	*Psophocarpus tetragonolobus* (L.) DC.	Fabaceae	Shrub	Fruit	Vegetable	0.24
Jagung	Maize	*Zea mays* L.	Poaceae	Grass	Seed	Staple	0.22
Talas	Taro	*Colocasia esculenta* (L.) Schott	Araceae	Tuber	Tuber	Staple	0.21
Ubi kelapa	Purple yam	*Dioscorea alata* L.	Dioscoreaceae	Tuber	Tuber	Staple	0.21
Kemangi	Basil	*Ocimum basilicum* L.	Lamiaceae	Herb	Leaf	Spice	0.20
Cabai merah	Red chili pepper	*Capsicum annuum* L.	Solanaceae	Shrub	Fruit	Spice	0.19
Jambu biji	Guava	*Psidium guajava* L.	Myrtaceae	Shrub	Fruit	Fruit	0.18
Nangka	Jackfruit	*Artocarpus heterophyllus* Lam.	Moraceae	Tree	Fruit	Fruit	0.18
Jeruk nipis	Key lime	*Citrus aurantiifolia* (Christm.) Swingle	Rutaceae	Shrub	Fruit	Fruit	0.17
Belimbing	Starfruit	*Averrhoa carambola* L.	Oxalidaceae	Tree	Fruit	Fruit	0.17
Jambu air	Water apple	*Syzygium aqueum* (Burm.fil.) Alston	Myrtaceae	Tree	Fruit	Fruit	0.17
Sirsak	Soursop	*Annona muricata* L.	Annonaceae	Tree	Fruit	Fruit	0.16
Delima	Pomegranate	*Punica granatum* L.	Lythraceae	Shrub	Fruit	Fruit	0.15
Markisa	Passionfruit	*Passiflora edulis* Sims	Passifloraceae	Climber	Fruit	Fruit	0.14
Bawang putih	Garlic	*Allium sativum* L.	Amaryllidaceae	Herb	Bulb	Spice	0.14
Bawang merah	Shallot	*Allium cepa* L.	Amaryllidaceae	Herb	Bulb	Spice	0.14
Serai	Lemongrass	*Cymbopogon citratus* (DC.) Stapf	Poaceae	Grass	Stem	Spice	0.13
Kayu manis	Cinnamon	*Cinnamomum burmannii* (Nees & T.Nees) Blume	Lauraceae	Tree	Bark	Spice	0.13
Tomat	Tomato	*Solanum lycopersicum* L.	Solanaceae	Shrub	Fruit	Vegetable	0.13
Timun	Cucumber	*Cucumis sativus* L.	Cucurbitaceae	Vine	Fruit	Vegetable	0.13
Petai	Stink bean	*Parkia speciosa* Hassk.	Fabaceae	Tree	Seed	Vegetable	0.12
Pete cina	River tamarind	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Tree	Seed	Vegetable	0.12
Lombok kecil	Bird's eye chili	*Capsicum frutescens* L.	Solanaceae	Shrub	Fruit	Spice	0.11
Seledri	Celery	*Apium graveolens* L.	Apiaceae	Herb	Leaf	Vegetable	0.11
Lamtoro	Lead tree	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Shrub	Seed	Vegetable	0.10
Paprika	Bell pepper	*Capsicum annuum* L. (Paprika)	Solanaceae	Shrub	Fruit	Vegetable	0.10
Kapri	Garden pea	*Pisum sativum* L.	Fabaceae	Herb	Fruit	Vegetable	0.10
Kacang hijau	Mung bean	*Vigna radiata* (L.) R.Wilczek	Fabaceae	Herb	Seed	Vegetable	0.10
Kacang kedelai	Soybean	*Glycine max* (L.) Merr.	Fabaceae	Herb	Seed	Vegetable	0.09
Kacang merah	Common bean	*Phaseolus vulgaris* L.	Fabaceae	Herb	Seed	Vegetable	0.09
Bawang daun	Leek	*Allium fistulosum* L.	Amaryllidaceae	Herb	Leaf	Vegetable	0.09
Bawang batak	Chinese onion	*Allium chinense* G.Don	Amaryllidaceae	Herb	Leaf	Spice	0.08
Ciplukan	Ground cherry	*Physalis angulata* L.	Solanaceae	Herb	Fruit	Fruit	0.08
Cengkeh	Clove	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	Myrtaceae	Tree	Flower	Spice	0.08
Salak	Snake fruit	*Salacca zalacca* (Gaertn.) Voss	Arecaceae	Tree	Fruit	Fruit	0.08
Kelapa	Coconut	*Cocos nucifera* L.	Arecaceae	Tree	Fruit	Fruit	0.08
Semangka	Watermelon	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	Cucurbitaceae	Vine	Fruit	Fruit	0.07
Melon	Melon	*Cucumis melo* L.	Cucurbitaceae	Vine	Fruit	Fruit	0.07
Mentimun suri	Cantaloupe	*Cucumis melo* var. *reticulatus*	Cucurbitaceae	Herb	Fruit	Fruit	0.07
Labu siam	Chayote	*Sechium edule* (Jacq.) Sw.	Cucurbitaceae	Vine	Fruit	Vegetable	0.07
Labu kuning	Pumpkin	*Cucurbita moschata* (Duchesne) Duchesne ex Poir.	Cucurbitaceae	Vine	Fruit	Vegetable	0.06
Oyong	Angled luffa	*Luffa acutangula* (L.) Roxb.	Cucurbitaceae	Vine	Fruit	Vegetable	0.06
Terung pipit	Turkey berry	*Solanum torvum* Sw.	Solanaceae	Shrub	Fruit	Vegetable	0.06
Daun singkil	Blue glory	*Clerodendrum serratum* Spreng.	Lamiaceae	Shrub	Leaf	Vegetable	0.05
Lenglen	Asthma-plant	*Euphorbia hirta* L.	Euphorbiaceae	Herb	Leaf	Vegetable	0.05
Jahe merah	Red ginger	*Zingiber officinale* var. *rubrum*	Zingiberaceae	Herb	Rhizome	Spice	0.05
Kunyit putih	White turmeric	*Curcuma zedoaria* (Christm.) Roscoe	Zingiberaceae	Herb	Rhizome	Spice	0.05
Kencur	Aromatic ginger	*Kaempferia galanga* L.	Zingiberaceae	Herb	Rhizome	Spice	0.05
Kecombrang	Torch ginger	*Etlingera elatior* (Jack) R.M.Sm.	Zingiberaceae	Herb	Flower	Spice	0.05
Jeruk purut	Kaffir lime	*Citrus hystrix* DC.	Rutaceae	Shrub	Leaf	Spice	0.05
Beluntas	Indian camphorweed	*Pluchea indica* (L.) Less.	Asteraceae	Shrub	Leaf	Vegetable	0.05

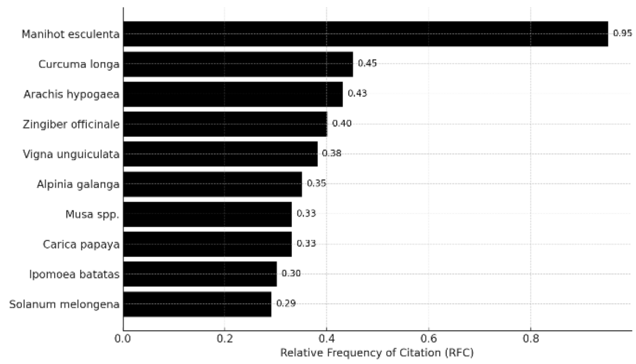

Figure 2. Relative Frequency of Citation (RFC) values for the most frequently used edible plant species in Gawang Hamlet, Pacitan, Indonesia (N=65 species)

Cultural relevance and species dominance based on Relative Frequency of Citation (RFC) values

The cultural relevance of edible plant species in Gawang Hamlet was assessed using the Relative Frequency of Citation (RFC) index, which quantifies how frequently each species was mentioned by informants. Among 65 recorded species, RFC values ranged from 0.05 to 0.95, reflecting variation in familiarity and importance within the local food system. Plants with higher RFC scores tend to be widely used, multifunctional, and deeply embedded in household practices. As shown in Figure 2, the most frequently cited species include *M. esculenta*, *C. longa*, *A. hypogaea*, *Z. officinale*, and *Vigna unguiculata* (yardlong bean), indicating their central role in the community's food culture.

Manihot esculenta was the most frequently cited species (RFC = 0.95), valued for its edible tubers and leaves, drought resistance, and year-round availability. Other species with high RFC values included *C. longa* (turmeric, 0.45), *A. hypogaea* (peanut, 0.43), *Z. officinale* (ginger, 0.40), and *V. unguiculata* (yardlong bean, 0.38). These plants are cultivated in most home gardens and used in daily meals, often also fulfilling medicinal or ritual roles.

Moderate RFC values (0.10-0.29) were recorded for species such as *Solanum melongena* (eggplant) and *Ipomoea batatas* (sweet potato), commonly consumed but with more limited seasonal or contextual use. Species with low RFC values (<0.10), such as *Punica granatum* and *Citrullus lanatus*, were used more sporadically or for specific purposes. These variations highlight functional diversity and help identify priority species for food security and conservation.

Species dominance is shaped by a combination of ecological suitability, cultural preference, and practical utility. High-RFC species typically thrive in the shallow, well-drained soils of karst landscapes. Rhizomatous species like *C. longa* and ginger are suited to these conditions and widely valued for both cooking and traditional medicine. Similarly, *M. esculenta* is highly adaptable, easy to cultivate, and offers dual use of tubers and leaves.

Morphological traits also contribute to species dominance. Most frequently used plants are herbs and shrubs, favored for their compact growth, ease of management, and short growing cycles—advantages in land-limited, rocky karst settings. Climbing vegetables like *V. unguiculata* and *Psophocarpus tetragonolobus* (winged bean) are grown along fences or trellises, optimizing space and yielding nutritious harvests.

Multifunctionality further enhances species importance. Plants like *M. esculenta*, *Carica papaya* (papaya), and *Cocos nucifera* (coconut) serve various dietary, medicinal, and cultural purposes, increasing their value in everyday life and ensuring their continued cultivation. Such species often appear in multiple use categories—staples, vegetables, fruits, or spices—demonstrating their integrative roles in household food systems.

Overall, RFC values and species dominance patterns reveal a culturally grounded, ecologically adaptive food system. These species form the core of subsistence strategies in Gawang Hamlet, supporting food sovereignty and resilience in a fragile karst environment.

Parts of plants used

The edible plant species identified in this study are used in various forms depending on the part of the plant that is traditionally consumed. Understanding which parts are most frequently used provides insight into both culinary practices and the ecological roles of these plants in rural households. The analysis revealed that the most commonly used plant part was the fruit, followed by leaves, tubers, rhizomes, flowers, stems, and seeds.

As shown in Figure 3.A, fruits were the most frequently utilized plant parts, comprising approximately 32.6% of reported uses. This reflects their widespread availability, palatability, and ease of consumption with minimal processing. Leaves accounted for 23.6% and were commonly prepared as vegetables or herbal components in soups, stir-fries, and traditional side dishes. Tubers and rhizomes, such as those from *M. esculenta* and *C. longa*, contributed 15.7% and 18.0%, respectively, underscoring their importance in ensuring caloric intake and traditional culinary flavoring. Other plant parts such as seeds (10.1%), bulbs (4.5%), flowers (2.2%), stems (1.1%), and bark (1.1%) were also reported, indicating the diverse functional uses of edible plants in the community. This distribution highlights the adaptive strategies of local households in utilizing multiple plant parts to fulfill nutritional needs, optimize seasonal availability, and support food security under ecologically constrained conditions.

These findings highlight the multifunctional nature of local plant species and their importance in household nutrition and food variety. The relatively high proportion of leaf and flower use reflects the community's reliance on fresh, leafy greens and floral components as accessible and seasonal food sources. Meanwhile, rhizomes and tubers contribute to energy intake and are often preserved or processed for longer-term consumption. The pattern of plant part usage also aligns with regional culinary traditions in Java, where young leaves, tuberous roots, and aromatic rhizomes are key elements in daily diets and food culture (Walujo 2017; Cahyaningsih et al. 2022).

Growth forms of edible plants

The 65 edible plant species identified in this study represent a variety of morphological growth forms, reflecting the ecological adaptability and multifunctionality of species cultivated or harvested by the community. Classification by growth form helps to understand how space, seasonality, and plant architecture influence planting strategies in karst home gardens.

As illustrated in Figure 3.B, the majority of edible plants in Gawang Hamlet were categorized as herbs (31.8%) and shrubs (22.7%), followed by trees (21.2%), vines (9.1%), and tuberous plants (4.5%). Other growth forms included grasses (3.0%), climbers (3.0%), and palms (3.0%). This distribution indicates that small to medium-sized species with compact or trailing growth habits dominate home garden cultivation. Such forms are likely favored for their adaptability to spatially constrained karst environments, ease of propagation, and rapid yield cycles. The figure highlights the community's ecological strategies in organizing vertical and horizontal planting spaces, allowing for efficient resource use and resilience in shallow-soil landscapes typical of karst systems.

Shrubs and herbs, such as *Capsicum annuum*, *C. longa*, and *A. hypogaea* are especially valued for their compact form and high productivity within a short cultivation period. Tree species such as *Musa* spp. (banana) and *Artocarpus heterophyllus* (jackfruit) contribute fruits and shade, while grasses like *Zea mays* (corn) serve as staple crops.

The diversity of growth forms supports ecological resilience and spatial layering in traditional home gardens, a common feature of sustainable subsistence systems in Southeast Asia (Iskandar et al. 2018; Cahyaningsih et al. 2022). It also highlights the strategic use of vertical and horizontal planting space in karst environments where arable land is limited.

Utilization categories of edible plants

The edible plant species identified in Gawang Hamlet were classified into four major categories based on their primary use: vegetables, spices, fruits, and staple foods. This categorization reflects local dietary patterns and functional differentiation of plants in home gardens and surrounding environments.

Vegetables

Vegetables were the most dominant use category among edible plants in Gawang Hamlet, comprising 28 species from various families and plant parts. These include leafy greens, shoots, immature fruits, and edible flowers, which are commonly consumed boiled, sautéed, or fresh. Their prominence reflects the community's reliance on fast-growing, short-cycle species suited to limited space and poor soils in karst home gardens. Figure 4 shows the ten most frequently cited vegetable species, including *Vigna unguiculata*, *Amaranthus sp.*, and *Carica papaya* (young leaves), underscoring the dietary importance of leafy and fruiting plants.

Commonly cultivated vegetables included *S. melongena*, *V. unguiculata*, *P. tetragonolobus*, *Moringa oleifera* (drumstick tree), *Amaranthus* spp., and *C. papaya* (young leaves). These species are favored for nutritional value, adaptability, and rapid growth. Some, like *M. esculenta*, serve dual purposes—leaves as vegetables and tubers as staple foods.

Vegetables span diverse growth forms, mainly shrubs and herbs, enabling spatial layering and seasonal rotation. This enhances land-use efficiency in fragmented karst landscapes. Home garden vegetables also contribute essential micronutrients and dietary fiber, supporting household nutrition and resilience to food insecurity (Flyman and Afolayan 2006; Bvenura and Sivakumar 2017; Buenavista et al. 2022; Asfaw et al. 2023).

Spices

Spices hold an essential role in the culinary and medicinal traditions of Gawang Hamlet, contributing flavor, aroma, and therapeutic value to daily meals. The study identified 16 spice species—about 24.6% of all documented edible plants—sourced from rhizomes, bulbs, leaves, seeds, bark, and fruits. Most are cultivated in home gardens, while a few are collected from surrounding semi-wild areas.

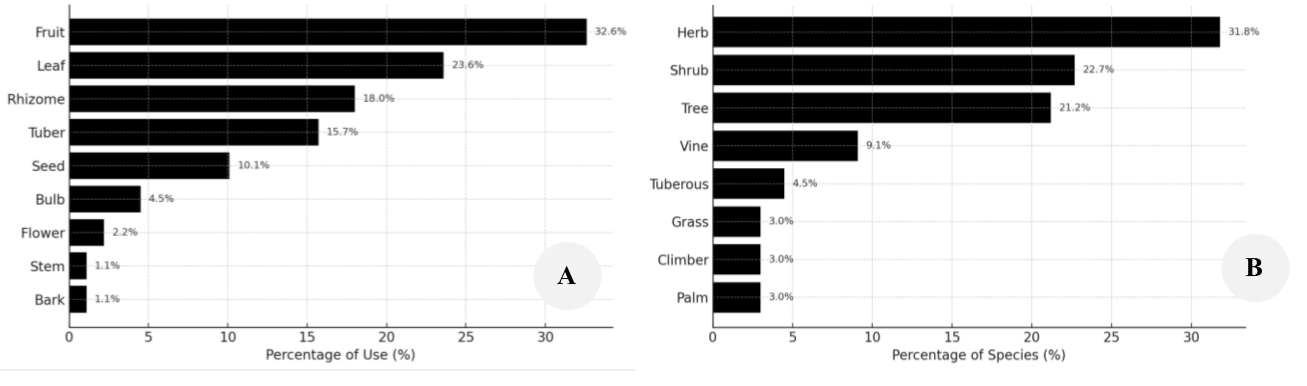

Figure 3. The proportion of A. Plant parts used and B. Growth form among edible species in Gawang Hamlet, Pacitan, Indonesia (N = 65 species)

Figure 5 highlights the most frequently cited species: *C. longa*, *Z. officinale*, and *Alpinia galanga* (galangal). These rhizomatous plants are not only staples in Javanese cuisine but also integral to traditional health practices, demonstrating the blending of culinary and medicinal knowledge in local households (Walujo 2017; Cahyaningsih et al. 2022). Other commonly mentioned spices include *Allium cepa* (shallot) and *Allium sativum* (garlic), each valued for multifunctionality. Rhizomes dominate this category, suited to shallow karst soils and capable of long storage, ensuring year-round access.

Beyond taste, spices often carry ritual and cultural meanings. Their sustained cultivation and use reflect how local communities integrate health, tradition, and daily sustenance through deeply embedded ethnobotanical systems.

Fruits

Fruit-bearing plants represent a significant part of the edible flora in Gawang Hamlet, with 16 species (24.6%) documented. Most fruits are consumed fresh, while others are processed into snacks, cooked dishes, or fermented products. Trees and shrubs are commonly planted along garden edges or within agroforestry systems, serving multiple functions—providing shade, fodder, and aiding soil conservation.

Figure 6 shows the most frequently cited fruit species, including *Musa* spp. (banana), *C. papaya*, *Psidium guajava* (guava), *A. heterophyllus*, *Citrus aurantiifolia* (lime), and *Averrhoa carambola* (starfruit). These are valued for their freshness, high vitamin content, and accessibility—especially important for household nutrition and children's diets. Many fruits are seasonal yet integrated into daily meals and traditional culinary practices. Some, like *Musa* spp. and *Citrus* spp., also carry medicinal and cultural significance, used in home remedies and rituals (Iskandar et al. 2018; Cahyaningsih et al. 2022). The strategic placement of fruit trees in outer garden zones reflects local ecological knowledge, optimizing space and ensuring year-round supply, while supporting both dietary diversity and environmental resilience.

Staple foods

Although rice is the dominant staple in Java, households in Gawang Hamlet also cultivate alternative staple crops suited to poor soils and low-input farming. This study identified five key staple species (7.6% of all edible plants): *M. esculenta*, *Dioscorea alata* (yam), *I. batatas*, *Z. mays*, and *Colocasia esculenta* (taro). These species provide essential carbohydrates and dietary energy, often consumed during rice shortages or economic stress.

Figure 7 highlights these rice alternatives, particularly *M. esculenta*, which was the most cited for its drought tolerance, reliable yield, and dual-use (tubers and leaves). Preparation methods include boiling, steaming, and frying. Their cultivation reflects community resilience in adapting to karst soil constraints where cereal crops are less viable. To further illustrate multifunctionality, Figure 8 (heatmap) presents edible species across four main categories—vegetables, spices, fruits, and staples—revealing overlaps in function.

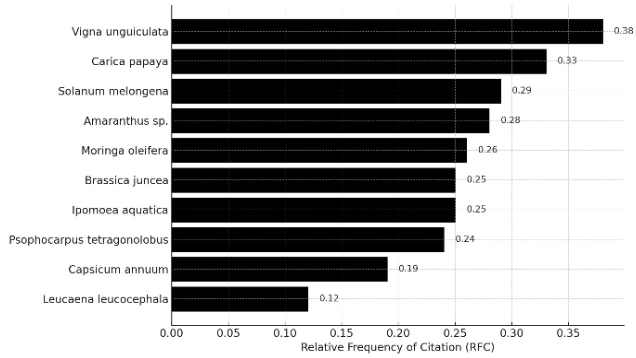

Figure 4. Top 10 vegetable species most frequently cited by informants in Gawang Hamlet, Pacitan, Indonesia (N = 60)

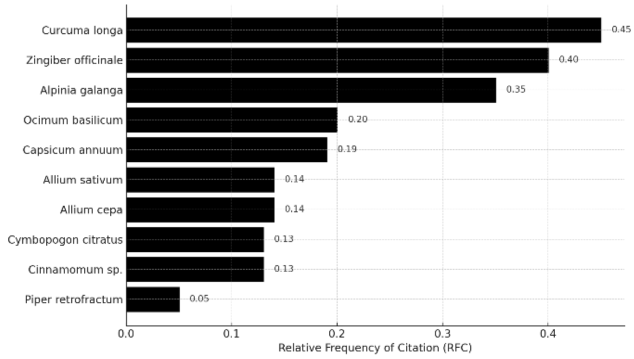

Figure 5. The most frequently cited spice species used in daily cooking in Gawang Hamlet, Pacitan, Indonesia (N = 60)

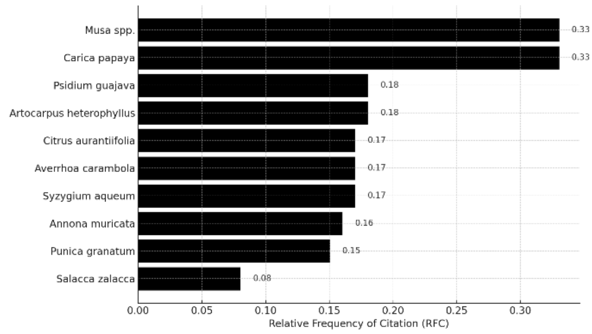

Figure 6. Most commonly consumed fruit species according to informant responses in Gawang Hamlet, Pacitan, Indonesia (N = 60)

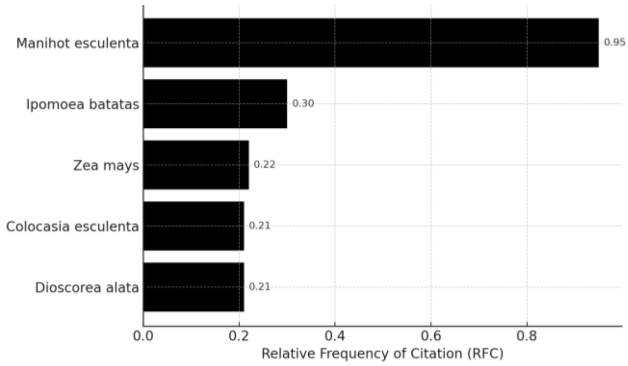

Figure 7. Staple food crops cultivated and consumed by the community of Gawang Hamlet, Pacitan, Indonesia (N=60)

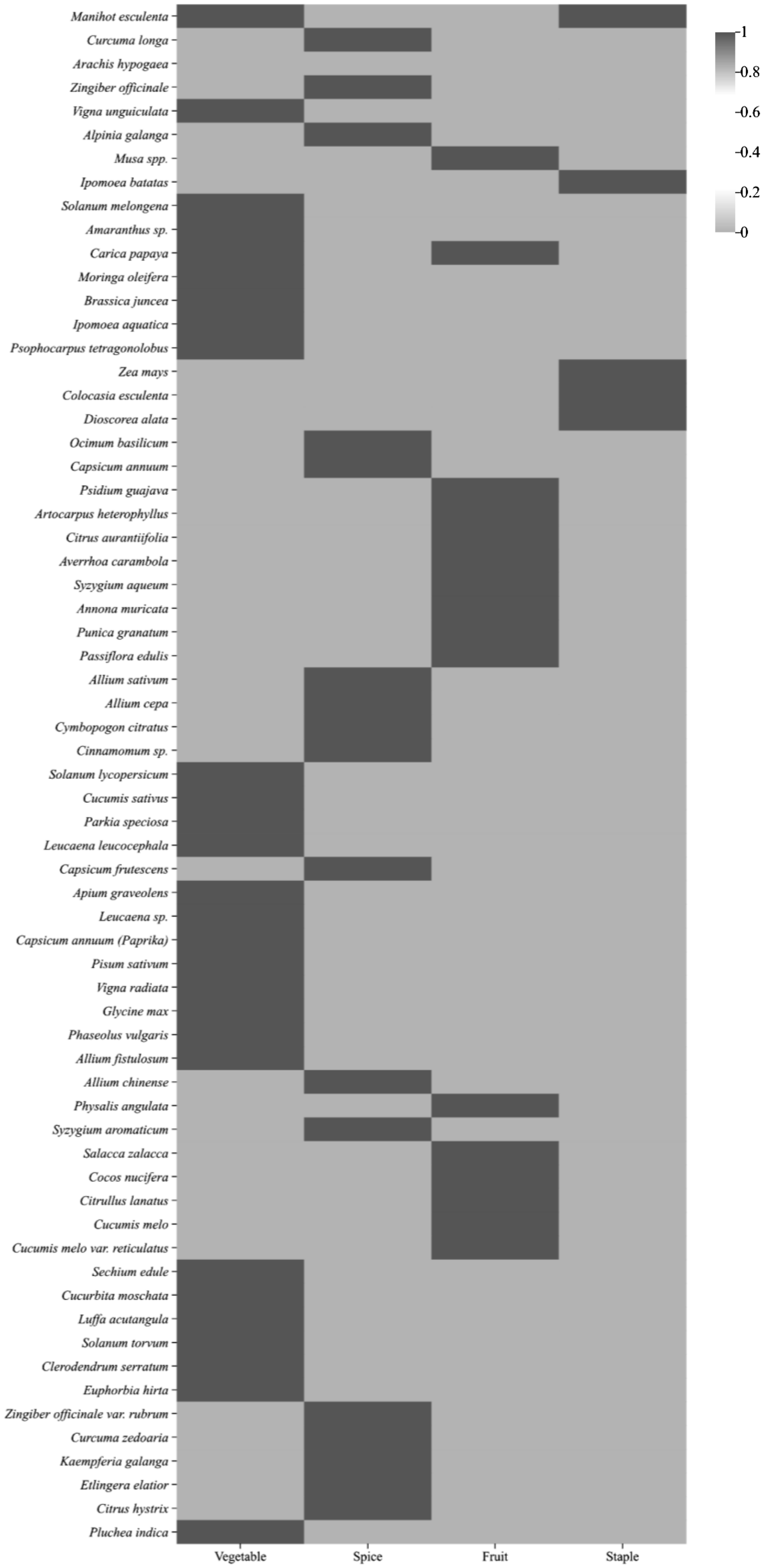

Figure 8. Heatmap showing multifunctional use of selected edible plant species across four primary categories: Vegetables, spices, fruits, and staples

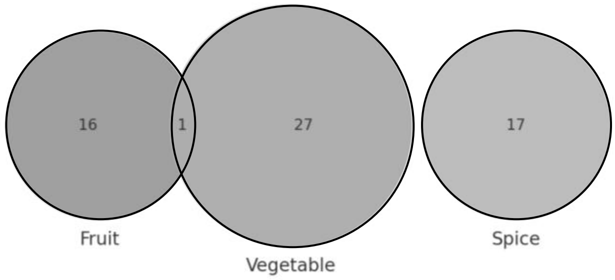

Figure 9. Venn diagram illustrating species with overlapping uses among vegetable, spice, fruit, and staple food categories

Figure 9 (Venn diagram) visually emphasizes species like *M. esculenta* and *C. papaya* that span multiple uses. These visualizations reinforce the importance of multifunctional plants in supporting both food diversity and local food security strategies in Gawang Hamlet.

Discussion

Diversity of edible plant species in karst environments

The findings of this study revealed a high diversity of edible plant species (65 species across 27 families) utilized by the rural community of Gawang Hamlet, a region characterized by karst landforms and marginal agricultural conditions. This diversity reflects a locally adapted food system, where both cultivated and semi-wild species contribute to household subsistence. The rich species assemblage supports the view that home gardens in karst environments function as reservoirs of agrobiodiversity and traditional ecological knowledge (Iskandar et al. 2018; Cahyaningsih et al. 2022).

Karst environments are characterized by shallow soils, irregular water availability, and rocky terrain that hinder conventional agriculture (Kuniansky et al. 2016). Nonetheless, the communities have adapted by cultivating drought-tolerant, fast-growing species suited to poor soils—such as *M. esculenta*, *C. longa*, and *M. oleifera*. The presence of multiple plant functional types (herbs, shrubs, trees, and tubers) supports spatial and seasonal diversification, which is a key element of traditional agroecological strategies (Ammar et al. 2021).

Comparative studies conducted in other karst or mountainous regions offer practical insights into traditional farming systems. In Gunung Kidul, another limestone-dominated area in Java, Sulistiyowati et al. (2022) documented 43 edible plant species maintained in home gardens, with legumes, tubers, and spices being the dominant crops. Similarly, in the karst landscapes of Guangxi, China, Luo et al. (2024) highlighted the reliance of ethnic communities on more than 195 food plant species, many of which are endemic and adapted to shallow-soil conditions. These patterns underscore the significance of traditional agricultural systems in karst zones and reflect the long-term coevolution between local communities and their environments, offering valuable perspectives for agricultural and environmental studies. Similar findings were reported by Silalahi et al. (2018) in Batak Toba homegardens, emphasizing the role of traditional agroecosystems as in situ conservation sites.

Socio-demographic factors and knowledge distribution

Socio-demographic characteristics such as gender, age, education, and occupation significantly influenced the distribution of ethnobotanical knowledge among the informants in Gawang Hamlet. The majority of informants in this study were women (70%), a pattern commonly observed in ethnobotanical research across Southeast Asia. This gender distribution aligns with the role of women as primary food preparers and caretakers of home gardens, placing them in direct contact with edible plants on a daily basis (Silalahi et al. 2018; Cao et al. 2020).

Elderly informants (aged over 55 years) constituted more than half of the sample. They consistently demonstrated a broader and deeper knowledge of edible plant diversity, including species that are seasonally used or have fallen out of general practice. This supports previous findings that traditional ecological knowledge is often concentrated in older generations, who have accumulated experiential knowledge over decades and serve as key knowledge holders within rural communities (Zhang et al. 2016; Walujo 2017). The trend is particularly concerning in areas where agricultural modernization or migration threatens the intergenerational transmission of such knowledge.

The educational level also appeared to influence the nature, but not necessarily the depth, of plant knowledge. Most informants had either no formal education or only completed primary school, yet they exhibited a strong understanding of plant taxonomy (based on vernacular classification), uses, and cultivation practices. This observation reinforces that traditional ecological knowledge is often gained through oral transmission and hands-on experience rather than through formal schooling (Cahyaningsih et al. 2022).

Occupationally, respondents working as farmers or housewives were found to cite more plant species than those engaged in off-farm or informal sector jobs. This indicates a strong relationship between daily proximity to land-based activities and the richness of ethnobotanical knowledge, as previously reported by Ammar et al. (2021) in other rural Javanese communities.

Another determinant was the length of residence: 90% of the informants had lived in the area for more than a decade, suggesting that long-term immersion in the landscape plays a vital role in shaping and sustaining knowledge of plant diversity. In contrast, newcomers or temporary residents often lacked familiarity with semi-wild species or seasonal harvesting patterns.

These findings highlight the importance of socio-demographic context in understanding the structure and transmission of plant-based knowledge. They also suggest that conservation strategies should not only target species and landscapes but also support knowledge holders—particularly women and the elderly—through participatory and inclusive approaches to agroecological development.

Plant parts used and cultural preferences

The study found that the most frequently utilized parts of edible plants in Gawang Hamlet were fruits (32.6%), leaves (23.6%), rhizomes (18.0%), and tubers (15.7%). This pattern indicates a plant-based dietary orientation shaped by accessibility, nutritional value, and culinary versatility. The strong preference for fruits and leaves aligns with Javanese culinary traditions, which emphasize the incorporation of fresh produce into daily meals—such as soups, stir-fried dishes, and raw vegetable assortments (*lalapan*) (Walujo 2017; Cahyaningsih et al. 2022). These plant parts are typically harvested seasonally or continuously from home gardens, reinforcing their central role in sustaining household diets under the environmental constraints of a karst landscape.

Leaves were widely consumed not only from herbaceous plants such as *Amaranthus* spp. and *M. oleifera*, but also from trees and tuberous species including *M. esculenta* and *C. papaya*. These leafy greens are typically rich in micronutrients and function as accessible, low-cost sources of essential vitamins and minerals. In ecologically constrained karst areas—where market access, soil fertility, and irrigation infrastructure are limited—the reliance on locally available foliage contributes significantly to household food security and nutritional adequacy (Pei et al. 2020). This pattern reflects a subsistence strategy grounded in ecological adaptation and traditional culinary practices.

The use of tubers and rhizomes—such as those from *M. esculenta*, *I. batatas*, *C. longa*, and *Z. officinale*—highlights the community's reliance on underground plant organs as key sources of both calories and flavoring agents. These parts are especially valued for their storability, resilience to seasonal fluctuations, and reliability under low-input cultivation systems. Their inclusion in household food planning is critical during periods of rice scarcity or income constraints. This pattern aligns with observations from other mountainous and ecologically marginal regions, where tuber crops frequently function as rice alternatives or dietary supplements (Ammar et al. 2021; Wahyudi et al. 2024). Rhizomes such as *C. longa*, *Z. officinale*, and *A. galanga* are also central to the local flavor profile and are deeply embedded in cultural and medicinal practices. These species are considered essential kitchen items, often propagated vegetatively and maintained in backyard gardens, reflecting both utilitarian and symbolic value in daily life (Iskandar et al. 2018).

The relatively lower citation of seeds and stems may reflect limited availability in home gardens or a cultural preference for fresher, more perishable plant parts such as leaves and fruits. Nonetheless, several seed-based food species—such as *A. hypogaea* and *Phaseolus vulgaris* (common bean)—remain valued for their protein content and nutritional contribution. Their inclusion in mixed-cropping systems within home gardens indicates a complementary yet sustained role in household food production, particularly as plant-based protein sources in predominantly carbohydrate-centered diets.

These patterns indicate that the use of specific plant parts is shaped not only by ecological availability but also by deeply ingrained culinary and cultural norms. The multifunctionality of certain species across multiple use categories (e.g., *M. esculenta* as a vegetable and staple) further underscores the integrative and adaptive knowledge embedded in traditional food systems.

Growth forms and spatial planting strategy

The growth form distribution of edible plants in Gawang Hamlet—dominated by herbs (31.8%), shrubs (22.7%), trees (21.2%), and vines (9.1%), with additional representation from tuberous species (4.5%), grasses (3.0%), climbers (3.0%), and palms (3.0%)—reflects a strategic adaptation to the physical constraints of karst terrain. The predominance of low-lying, fast-growing, and spatially manageable plant types corresponds with the environmental characteristics of limestone landscapes, including thin soil layers, limited arable land, and high rock exposure (Kuniansky et al. 2016). Such growth forms facilitate efficient use of both vertical and horizontal space in home gardens, enabling households to maintain productivity despite ecological limitations.

Shrubs and herbs such as *C. annuum*, *P. tetragonolobus*, and *C. longa* are particularly well-suited to karst soils due to their shallow rooting systems and rapid growth cycles. These species are typically planted near the kitchen or in garden borders, making them easily accessible for daily harvest. The integration of these plants into the microzones of the home garden reflects the community's nuanced understanding of spatial resource optimization.

Tree species, though less dominant, play multifunctional roles. Species such as *Musa* spp. and *A. heterophyllus* are planted at the periphery of home gardens or in field boundaries, where they provide shade, windbreaks, and seasonal fruit. Their placement maximizes the use of vertical space and supports agroforestry layering that mimics natural forest structure (Iskandar et al. 2018).

The inclusion of grasses such as *Z. mays* and lianas like *Passiflora edulis* further enhances the structural diversity of home gardens and supports a multi-tiered planting strategy. Vining vegetables, notably *V. unguiculata*, are commonly trained along fences or simple trellises, allowing households to optimize vertical growing space and sunlight exposure while minimizing competition for limited soil nutrients. This spatial arrangement reflects a practical response to land constraints in karst environments and exemplifies the community's adaptive approach to maximizing productivity within compact garden systems.

This spatial organization is not random but rooted in a long-standing practice of optimizing land function, yield diversity and labor efficiency. Similar strategies have been reported in Batak and Minangkabau home gardens, where vertical layering and multifunctional species selection enhance productivity in small areas (Silalahi et al. 2018). The dominance of shrubs and herbs in Gawang Hamlet is a deliberate agroecological choice that accommodates local topography, household needs, and knowledge transmission. These growth forms reflect not only ecological constraints but also a refined, spatially intelligent cultivation system embedded in the local culture, a tradition that deserves our utmost respect.

Cultural importance based on RFC analysis

The Relative Frequency of Citation (RFC) analysis revealed that several species hold central positions in the food system of Gawang Hamlet due to their high frequency of mention and multifunctional uses. *M. esculenta*, with an RFC value of 0.95, emerged as the most culturally important species. Its prominence is rooted not only in its role as a carbohydrate source but also in its flexibility: the tuber is a staple food, while the leaves are regularly consumed as vegetables. This dual utility enhances its perceived and actual value in household food security, particularly in environmentally marginal areas such as karst lands.

Other highly cited species include *C. longa*, *A. hypogaea, Z. officinale*, and *V. unguiculata*. These plants serve multiple roles—as food, spice, traditional medicine, and cultural symbols. *C. longa* and ginger are not only key flavoring agents but also integral to health rituals and postpartum care, as noted in Javanese and broader Southeast Asian ethnomedicine (Walujo 2017; Cahyaningsih et al. 2022).

High RFC values indicate more than the frequency of use; they reflect collective memory, intergenerational transmission, and symbolic familiarity. Plants with high RFCs are often embedded in oral knowledge, rituals, and seasonal practices, forming part of the community's cultural identity. These findings are consistent with studies by Tardío and Pardo-de-Santayana (2008), which emphasize that RFC can serve as a proxy for cultural salience beyond purely utilitarian value.

Another critical factor influencing species prominence in Gawang Hamlet is their multifunctionality. Plants that fulfill multiple roles—such as *M. esculenta*, utilized both as a staple and a leafy vegetable; *Musa* spp. (banana), valued as both a fruit and a ritual offering; and *C. nucifera* (coconut), used for food, oil extraction, and ceremonial purposes—tend to hold more central positions within local agroecosystems and cultural practices. This multifunctionality not only enhances their practical value but also strengthens their cultural salience, ensuring continued cultivation and transmission of knowledge across generations (Silalahi et al. 2018).

Moreover, species with high Relative Frequency of Citation (RFC) values often serve as vital linkages between ecological resilience and cultural continuity. Their proven adaptability to the challenging conditions of karst soils—alongside their enduring roles in local diets, rituals, and daily practices—positions them as focal species within both subsistence systems and cultural identity. Recognizing these taxa as culturally keystone species provides a conceptual framework for integrated conservation strategies that honor the interdependence of biological diversity and cultural heritage. Such an approach may enhance the effectiveness and local relevance of biodiversity conservation and rural development initiatives.

Implications for food security and conservation

The ethnobotanical knowledge and plant diversity documented in Gawang Hamlet offer critical insights into how rural communities in ecologically fragile karst landscapes secure their food needs. The reliance on 65 edible plant species—including vegetables, spices, fruits, and staples—demonstrates a diversified subsistence strategy that buffers households against food shortages, climate variability, and market dependency. This biodiversity-centered approach plays a crucial role in sustaining daily nutrition, culinary diversity, and cultural heritage.

From a food security perspective, species such as *M. esculenta*, *I. batatas*, and *Z. mays* serve as important carbohydrate sources beyond rice, providing dietary flexibility during periods of scarcity. The consistent use of leafy vegetables like *M. oleifera*, *Amaranthus* spp., and papaya leaves contributes to micronutrient sufficiency, particularly among lower-income households. These plants are typically cultivated in home gardens or nearby fields, ensuring both accessibility and affordability.

The spatial arrangement and selection of growth forms—shrubs, herbs, and trees—further enhance resilience by enabling year-round harvests and diversified yields. This agroecological configuration, supported by traditional knowledge, reflects a low-input, high-efficiency system that can be sustained without chemical fertilizers or irrigation—an essential trait in karst zones characterized by limited water and shallow soils (Kuniansky et al. 2016).

In terms of conservation, the cultivation and continued use of locally adapted plant species represent in situ conservation practices that preserve both genetic and cultural diversity. Home gardens function as living repositories for landraces, semi-domesticated species, and neglected crops, many of which are absent from formal conservation systems. This finding supports arguments for integrating traditional farming systems into broader biodiversity management and rural development strategies (Iskandar et al. 2018).

Furthermore, knowledge holders—particularly women and elderly community members—play a central role in sustaining this agro-biodiversity. Protecting their roles, voices, and access to land and resources is, therefore, fundamental to both food sovereignty and long-term conservation. Development interventions aimed at improving rural livelihoods or food systems should recognize and build upon this embedded ecological knowledge base.

The multifunctionality of key edible plant species was further demonstrated through visual analysis. As illustrated in the heatmap (Figure 8), several species—most notably *M. esculenta* and *C. papaya*—were utilized across multiple food categories, such as vegetables, staples, and fruits. This overlap emphasizes their high functional value within the local food system. The Venn diagram (Figure 9) reinforces this observation by clearly delineating species shared among the vegetable, fruit, and spice categories. Although most species are specific to a single use group, multifunctional species like *M. esculenta* and *C. papaya* occupy intersections, reflecting their integrative role in household food strategies. These multifunctional taxa not only enhance dietary diversity but also contribute to resilience in karst environments, where agricultural land is limited and ecological conditions are challenging.

This study documented 65 edible plant species in the karst landscape of Gawang Hamlet, Pacitan, Indonesia, reflecting a diverse and culturally embedded food system. Key species such as *M. esculenta*, *C. longa*, and *M. oleifera* had high RFC values, indicating their nutritional, culinary, and symbolic importance. Shrubs and herbs dominated, with multifunctional uses and strategic home garden organization adapted to karst conditions. Socio-demographic factors—especially gender and age—influence knowledge transmission, with women and elders serving as key custodians. The findings underscore the role of traditional agroecosystems in food security and in situ conservation. Supporting local knowledge and community practices is vital for sustaining agrobiodiversity in rural marginal areas.

REFERENCES

Ammar LA, Kurniawati B, Anggorowati D, Cahyaningsih AP, Setyawan AD. 2021. Ethnobotanical study of the medicinal plant by local communities in karst area of Pacitan District, East Java, Indonesia. Intl J Trop Drylands 5 (2): 84-93. DOI: 10.13057/tropdrylands/t050205.

Asfaw A, Luleka E, Bekele T, Debella A, Tessema S, Meresa A, Debebe E. 2023. Ethnobotanical study of wild edible plants and implications for food security. Trees For People 14: 100453. DOI: 10.1016/j.tfp.2023.100453.

Backer CA, Bakhuizen van den Brink RC. 1963-1968. Flora of Java (Spermatophytes only). Vol. I–III. N.V.P. Noordhoff, Groningen.

Bano A, Ahmad M, Hadda TB, Saboor A, Sultana S, Zafar M, Khan MPZ, Arshad M, Ashraf MA. 2014. Quantitative ethnomedicinal study of plants used in the skardu valley at high altitude of Karakoram-Himalayan range, Pakistan. J Ethnobiol Ethnomed 10: 43. DOI: 10.1186/1746-4269-10-43.

Buenavista DP, Molle EM, McDonald M. 2022. Any alternatives to rice? Ethnobotanical insights into the dietary use of edible plants by the Higaonon tribe in Bukidnon Province, the Philippines. Reg Sustain 3 (2): 95-109. DOI: 10.1016/j.regsus.2022.04.002.

Bvenura C, Sivakumar D. 2017. The role of wild fruits and vegetables in delivering a balanced and healthy diet. Food Res Intl 99: 15-30. DOI: 10.1016/j.foodres.2017.06.046.

Cahyaningsih AP, Arifiani KN, Aprilia DN, Setyawan AD. 2022. Ethnobotanical study of the non-medicinal plant by village communities in the karst area of Pacitan, East Java, Indonesia. Intl J Trop Drylands 6 (1): 1-10. DOI: 10.13057/tropdrylands/t06101.

Cao Y, Li R, Zhou S, Song L, Quan R, Hu H. 2020. Ethnobotanical study on wild edible plants used by three trans-boundary ethnic groups in Jiangcheng County, Pu'er, Southwest China. J Ethnobiol Ethnomed 16: 66. DOI: 10.1186/s13002-020-00420-1.

Darmastuti SA, Nazar IA, Setyawan AD. 2024. Plant diversity and its use in Javanese urban home garden: An ethnobotanical study in Central Java, Indonesia. Asian J Ethnobiol 7 (1): 32-42.DOI: 10.13057/asianjethnobiol/y070104.

Etikan I, Musa SA, Alkassim RS. 2016. Comparison of convenience sampling and purposive sampling. Am J Theor Appl Stat 5 (1): 1-4. DOI: 10.11648/j.ajtas.20160501.11

Flyman MV, Afolayan AJ. 2006. The suitability of wild vegetables for alleviating human dietary deficiencies. S Afr J Bot 72 (4): 492-497. DOI: 10.1016/j.sajb.2006.02.003.

Hurlock EB. 2006. Psikologi Perkembangan Suatu Pendekatan Sepanjang Rentang Kehidupan. Erlangga, Jakarta. [Indonesian]

Iskandar BS, Johan I, Budi I, Ruhyat P. 2018. Traditional markets and diversity of edible plant trading: Case study in Ujung Berung, Bandung, West Java, Indonesia. Biodiversitas 19 (2): 437-452. DOI: 10.13057/biodiv/d190211.

Jauhari A. 2020. Pemanfaatan SIG untuk pemetaan kawasan produksi komoditas unggulan tanaman pangan di Kabupaten Pacitan. J Reg Rural Dev Plan (Jurnal Perencanaan Pembangunan Wilayah dan Perdesaan) 4 (3): 154-171. DOI: 10.29244/jp2wd.2020.4.3.154-171. [Indonesian]

Kuniansky EL, Weary DJ, Kaufmann JE. 2016. The current status of mapping karst areas and availability of public sinkhole-risk resources in karst terrains of the United States. Hydrogeol J 24 (3): 613-624. DOI: 10.1007/s10040-015-1333-3.

Luo B, Tong Y, Liu Y, Zhang Y, Qin Y, Hu R. 2024. Ethnobotanical insights into the traditional food plants of the Baiku Yao community: a study of cultural significance, utilization, and conservation. J Ethnobiol Ethnomed 20 (1): 52. DOI: 10.1186/s13002-024-00691-y.

Pei S, Alan H, Wang Y. 2020. Vital roles for ethnobotany in conservation and sustainable development. Plant Divers 42 (6): 399-400. DOI: 10.1016/j.pld.2020.12.001.

Roscoe JY. 1975. Fundamental Research Statistic for The Behavioural Science. Holt Rinehart and Wington, New York.

Setiawan H, Qiptiyah M. 2014. Kajian etnobotani masyarakat adat suku Moronene di Taman Nasional Rawa Aopa Watumohai. Jurnal Penelitian Kehutanan Wallacea 3 (2): 107-117. DOI: 10.18330/jwallacea.2014.vol3iss2pp107-117. [Indonesian]

Silalahi M, Nisyawati N, Anggraeni R. 2018. Studi etnobotani tumbuhan pangan yang tidak dibudidayakan oleh masyarakat lokal Sub-etnis Batak Toba, di Desa Peadungdung Sumatera Utara, Indonesia. Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan 8 (2): 241-250. DOI: 10.29244/jpsl.8.2.264-270. [Indonesian]

Sudarmadji, Haryono E, Adji TN, Widyastuti M, Harini R, Nurjani E, Cahyadi A, Nugraha H. 2013. Ekologi Lingkungan Karst Indonesia: Menjaga Asa Kelestarian Kawasan Karst Indonesia. Deepublish, Yogyakarta. [Indonesian]

Sulistiyowati E, Setiadi S, Haryono E. 2022. Food traditions and biodiversity conservation of the Javanese Community in Gunungkidul Karst, Yogyakarta Province, Indonesia. Biodiversitas 23 (4): 2080-2092. DOI: 10.13057/biodiv/d230443.

Suryani S, Nurjasmi R, Fitri R. 2020. Pemanfaatan lahan sempit perkotaan untuk kemandirian pangan keluarga. Jurnal Ilmiah Respati 11 (2): 93-102. DOI: 10.52643/jir.v11i2.1102. [Indonesian]

Tabachnick BG, Fidel LS. 1996. Using Multivariate Statistics, Third Edition. Harper Collins College Publisher, New York.

Tardío J, Pardo-de-Santayana M. 2008. Cultural importance indices: A comparative analysis based on the useful wild plants of Southern Cantabria (Northern Spain). Econ Bot 62: 24-39. DOI: 10.1007/s12231-007-9004-5.

Wahyudi, Djitmau DA, Dwiranti F, Sagrim M, Manuhua D. 2024. Roles of local food and knowledge of indigenous communities during pandemic COVID-19 at three districts across West Papua Province, Indonesia. Asian J Ethnobiol 7 (1): 1-12. DOI: 10.13057/asianjethnobiol/y070101.

Walujo EB. 2017. Sumbangan ilmu etnobotani dalam memfasilitasi hubungan manusia dengan tumbuhan dan lingkungannya. Jurnal Biologi Indonesia 7 (2): 61-69. [Indonesian]

Widiyanti W, Dittmann A. 2014. Climate change and water scarcity adaptation Strategies in the area of Pacitan, Java Indonesia. Procedia Environ Sci 20: 693-702. DOI: 10.1016/j.proenv.2014.03.083.

Zhang L, Chai Z, Zhang Y, Geng Y, Wang Y. 2016. Ethnobotanical study of traditional edible plants used by the Naxi people during droughts. J Ethnobiol Ethnomed 12: 39. DOI: 10.1186/s13002-016-0113-z.