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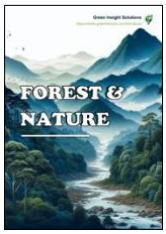

RESEARCH ARTICLE

Harnessing the Blue Economy: Ethnobotanical Insights into Mangrove-Derived Functional Foods for Climate-Resilient Futures

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ABSTRACT

Climate change threatens food security at the local, regional, and global levels. Optimizing the potential of the blue ecosystem, especially mangrove forest products, can contribute to overcoming the food crisis. This study aims to document the ethnobotanical practices related to the utilization of mangroves as a food source in the South Lampung Regency. This study employed the snowball sampling method, utilizing open-ended interviews with respondents. The collected data, including species types, utilized plant parts, processed products, and associated properties, were analyzed using descriptive-analytical methods to identify patterns, relationships, and factors influencing the practice of mangrove-based food utilization. The results reveal that the people of South Lampung Regency utilize four mangrove species as ethnobotanical food sources. These include the fruit (excluding the root) of *Rhizophora mucronata*, which is processed into coffee; the young leaves of *Avicennia marina*, consumed as fresh vegetables; its sap, which is processed into health beverages; and its fruit, which is used to produce flour for cake-making. Additionally, *Acanthus ilicifolius* is processed into tea and *rempeyek*, a traditional cracker made from leaf fragments. Beyond their nutritional value, mangroves possess bioactive properties, including antifertility, antioxidant, analgesic, anticholesterol, antihypertensive, antitussive, and anti-inflammatory effects, highlighting their potential for development into functional foods. Such diversification could address various social and economic challenges in South Lampung Regency. However, limitations in human resource capacity hinder the optimization of mangrove utilization, resulting in a lack of diversity and innovation in the selection of species, utilized plant parts, processed products, and processing techniques.

1. Introduction

Climate change is an increasingly urgent and multifaceted phenomenon affecting local, regional, and global scales. The rise in sea surface temperature, often referred to as the El Niño phenomenon, induces droughts, temperature fluctuations, shifts in precipitation patterns, extreme weather events, and reduced water availability. As a key driver of the global food crisis, climate change disrupts food availability, access, and quality. Its direct and indirect impacts on food security are evident in the escalating levels of poverty and hunger worldwide (Saefudin, 2023; Brown et al., 2015). The Food and Agriculture Organization (FAO) has highlighted that the global food crisis has been further aggravated by the lingering impacts of the COVID-19 pandemic (Canton, 2021).

Optimizing the potential of blue ecosystems presents a viable solution to addressing the global food crisis. The blue ecosystem encompasses marine and coastal components that are integral to maintaining the marine environment's health (Lillebø et al., 2017). Utilizing the blue ecosystem can foster the development of the blue economy, which involves sustainable use of marine resources, job creation, and livelihoods while preserving the health of marine ecosystems (Ebarvia, 2016). Economic activities such as fisheries, land use, and transportation must prioritize the conservation of coastal ecosystems, including coral reefs, seagrass beds, mangroves, and conservation areas. Implementing the blue

economy concept within blue ecosystems can enhance national development, particularly in building food security and independence (Okafor-Yarwood et al., 2020). This is critical given Indonesia's heavy reliance on food imports, spending USD 84.8 billion annually on six of the nine staple commodities: rice, milk, onions, salt, meat, and sugar (CNBC, 2023; Prayuda, 2019; Rahim et al., 2024).

The blue ecosystem concept plays a crucial role in addressing the food crisis through diversification and advanced food processing (Wardhana et al., 2022). According to Bappenas (2007), food diversification involves promoting a varied diet based on balanced nutrition principles (Wardhana et al., 2022). Coastal communities can harness natural resources to enhance food diversification, particularly by utilizing products derived from mangrove forests. Several mangrove species, including lindur (*Bruguiera gymnorhiza*), nipa (*Nypa fruticans*), api-api (*Avicennia* spp.), bakau (*Rhizophora* spp.), tumu (*Bruguiera parviflora*), tancang (*Ceriops tagal*), pidada (*Sonneratia* spp.), and warakas (*Acanthus* spp.), have been or can be utilized as food sources (Paramita, 2012).

In Indonesia, particularly in West Timor, Flores, Sumba, Sabu, and Alor, and parts of Aceh, mangrove utilization is primarily observed during the dry season or periods of food scarcity (October–March). Communities in these regions rely on mangrove fruits such as *B. gymnorhiza* and *Sonneratia* spp. as substitutes for staple crops like rice and corn during these critical months (Kardiman et al., 2017; Priyono et al., 2010). Research by Paramita (2012) further revealed that coastal communities in mangrove areas, such as Muara Angke, Jakarta, and Balikpapan Bay, traditionally consume various mangrove fruits, including *Rhizophora* spp., kerakas (*Aegiceras corniculatum*), and turi (*Sesbania grandiflora*), as vegetables. Similarly, in East Lampung, local communities utilize jeruju (*Acanthus ilicifolius*) leaves to produce crackers and *Sonneratia* spp. fruits to make syrup (Putri et al., 2018). These studies underscore the significant potential of mangroves in addressing food insecurity in Indonesia. However, despite their nutritional and ecological benefits, the role of mangrove-based food remains underexplored, and documentation of its utilization by local communities is still limited. Patil and Chavan (2013) highlighted that mangrove fruits are nutrient-rich and could serve as emergency or famine food sources for coastal populations in the future.

Lampung Province possesses 10,533.676 ha of mangrove forests, with 22 identified mangrove species (Amalia, 2019; Mukhlisi et al., 2013). In South Lampung Regency alone, mangrove ecosystems span 524.8 ha, comprising 14 species (Kuncahyo et al., 2020). Despite this biodiversity, coastal communities in the region continue to experience food insecurity, often linked to poverty (Agpina, 2022). Given the extensive mangrove resources in Lampung, particularly in South Lampung, there is a strong potential for optimizing their utilization. To date, no comprehensive studies or documentation have been conducted on the utilization of mangroves as a food and medicinal resource in South Lampung. This study aims to document the ethnobotanical practices related to the use of mangroves as a food source in the region. By documenting these practices, this research seeks to enhance local community awareness of their role as key stakeholders in coastal resource conservation and optimization. In turn, this could contribute to reducing food imports and strengthening national food security, ultimately preserving foreign exchange reserves.

2. Materials and Methods

2.1. Study Area

This research was conducted from March to June 2024 in South Lampung Regency, Indonesia. Geographically, South Lampung situated between 105° - 105°45' East Longitude and 5°15' - 6° South Latitude (**Fig. 1**). The region's topography varies, with approximately 75% consisting of lowlands and 25% of highlands, making it a diverse ecological zone for mangrove ecosystems.

2.2. Sampling Method

Sampling was carried out using the snowball sampling method, which is particularly suitable for ethnobotanical studies due to the localized and specific nature of traditional knowledge regarding mangrove utilization as a food source. This technique allows researchers to identify key informants through a chain referral process, ensuring the inclusion of individuals with valuable knowledge.

The research began by consulting village officials, who assisted in identifying the first informant. This initial informant then referred the researcher to other relevant individuals, continuing the chain referral process to gather comprehensive ethnobotanical data.

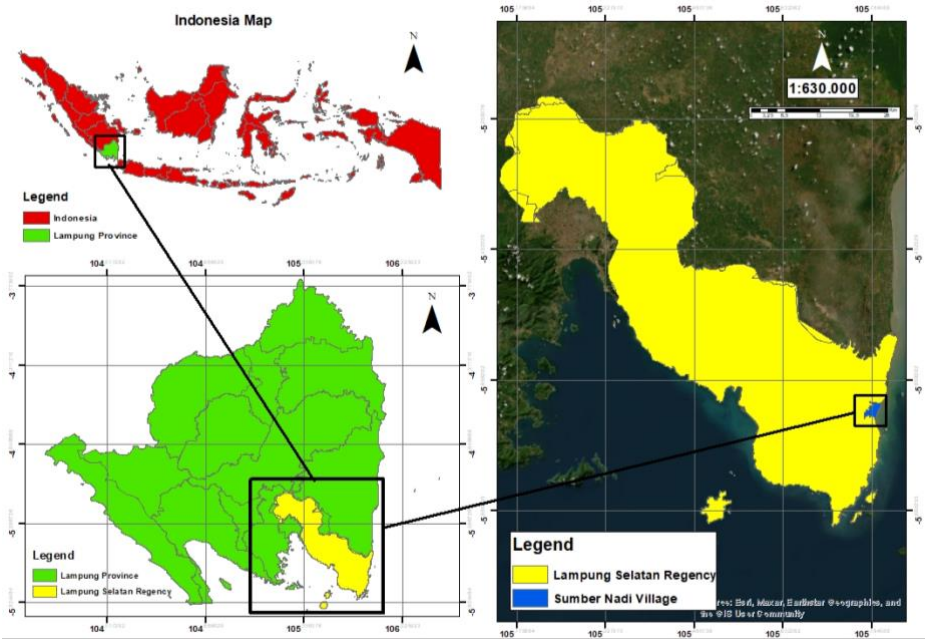

Fig. 1. Research location: coastal area of South Lampung Regency.

2.3. Data Collection

The study primarily collected qualitative data through direct field observations and semi-structured interviews with local community members. The key aspects documented included:

- Mangrove species used as food sources,
- Plant parts utilized (leaves, fruits, and roots),
- Processing methods and derived products,
- Nutritional and medicinal benefits,
- Traditional preparation and consumption practices.

Interviews were conducted using open-ended questions, allowing participants to express their knowledge and experiences regarding mangrove-based food utilization freely.

2.4. Data Analysis

The collected primary data were analyzed descriptively and analytically to identify:

- Patterns of mangrove utilization within coastal communities,
- The relationship between traditional knowledge and utilization practices,
- Factors influencing mangrove use as food sources include accessibility and availability, community knowledge and awareness, socio-cultural influences, and economic considerations.

The analysis aimed to provide insights into the role of mangrove resources in local food security and potential strategies for optimizing their sustainable use.

3. Results and Discussion

3.1. Results

The research findings reveal that several mangrove species in South Lampung are utilized ethnobotanically as functional food sources. These include *Rhizophora mucronata*, *Avicennia marina*, and *Acanthus ilicifolius*. **Table 1** provides a detailed overview of the identified mangrove species, the specific plant parts used, processing methods, derived food products, and associated health benefits.

Table 1. Utilization of mangroves as food sources in South Lampung Regency

No.	Species	Plant parts	Processing method	Food products	Efficacy
1	Bakau (*Rhyzophora mucronata*)	Fruit (without extended propagule)	The mangrove propagule is separated into its tip and base, after which the base is split to extract the seeds from the flesh. The flesh is then soaked in a water and lime solution for three days, with the water replaced daily. After washing, the flesh is thinly sliced and sun-dried until completely dry, then roasted until blackened and sieved. The final product can be brewed with sugar, palm sugar, or cream powder.	Coffee	Antioxidant, antifertility, analgesic, body-warming tonic
2	Api-api (*Avicennia marinna*)	Young leaves	The young shoots of *A. marina* leaves are consumed raw or mixed with sprouts, grated coconut, and, optionally, chili to prepare a traditional salad called *lalap* or *urap*.	Fresh vegetables	Antioxidant, antifertility
		Sap	The bark of mature *A. marina* trees releases sap as an adaptive response. The sap is collected, dissolved in warm water (one teaspoon per cup), and consumed as a health drink.	Health drink	Antioxidant, tonic, remedy for internal diseases
		Fruits	The outer skin is peeled, and the fruit is boiled with rice husks to remove tannins and cyanide. It is then soaked for three days, with the water changed daily. Afterward, it is oven-dried and ground into flour.	Flour (cake ingredient)	-
3	Jeruju (*Acanthus ilicifolius*)	Leaves	The leaves are crushed, and the extract is mixed with tapioca flour, salt, sugar, garlic, and a leavening agent. The mixture is stirred until smooth, then wrapped in banana leaves and steamed. After resting overnight, the cooked dough is thinly sliced, sun-dried, and fried until puffed.	Chips	Anticholesterol, antihypertensive, anti-inflammatory
		Leaves	The spines are removed from the leaves and then boiled with sugar and lime juice. The resulting tea is ready for immediate consumption.	Tea	Anticholesterol, antihypertensive, anti-inflammatory, body-warming

3.2. Discussion

The mangrove plants utilized as food sources by the community in South Lampung consist of three species: *R. mucronata*, *A. marina*, and *A. ilicifolius*. However, the utilization of mangroves for food in this region remains relatively limited. According to Rodiani et al. (2023), South Lampung is home to 12 mangrove species, yet only a fraction is used for food. In contrast, other coastal regions demonstrate a more extensive use of mangrove resources. For instance, in Muara Badak Ulu, Kutai Kartanegara Regency, East Kalimantan, the local community optimizes all six mangrove species available in their ecosystem, processing them into 19 different food products (Diana et al., 2022; Virdianto, 2024). Similarly, in Sungai Apit District, Siak Regency, Riau Province, locals utilize four out of 16 mangrove species to produce 10 processed food products (Titisari et al., 2023). Conversely, in certain regions, such as Sidoarjo Regency, the use of mangroves as food remains minimal. Despite the presence of 18 mangrove species, only four are utilized for food purposes (Handayani, 2019).

Based on **Table 1**, only three out of the 12 mangrove species found in South Lampung are utilized as food sources. This limited utilization has significant implications for the local economy and environmental conservation. A lack of food source diversity reduces economic potential, exacerbating issues of poverty and hunger. Moreover, minimal awareness of mangrove species diversity leads to weakened conservation efforts, a decline in cultural values, and the erosion of local identities associated with mangrove ecosystems. A critical challenge in South Lampung is the lack of community knowledge regarding the role of mangroves as part of the blue ecosystem in addressing food security. This issue is particularly relevant in the context of poverty and hunger, where mangrove-based food resources remain underutilized. As an agrarian and maritime region, South Lampung's economy primarily depends on agriculture. However, the adoption of innovations in sustainable resource utilization remains a complex process for local farmers and fishers, influenced by various factors, including education levels (Warnaen, 2016). According to the South Lampung Bureau of Statistics (BPS, 2023), approximately 33.19% of the population aged 15 and older have either only completed elementary school or did not graduate. This low educational attainment presents a barrier to technological adoption and innovation. Silalahi (2015) highlights that limited education among coastal and mangrove-dependent communities often hinders

their ability to comprehend and implement new technologies or sustainable practices, ultimately affecting their productivity and overall well-being.

The parts of mangroves used as food sources in South Lampung include leaves, fruits, and sap, which are processed into six food products categorized as still lacking in diversity. Upon further exploration, other parts of mangroves have the potential to be processed into food sources. In some areas of Indonesia, such as Pasuruan, flour production from *R. mucronata* propagules has been extensively developed as the base ingredient for cakes, sponge cakes, chips, and even ice cream (Utami et al., 2021). In addition to coffee made from *R. mucronata* propagules, the leaves can be processed into green tea with numerous health benefits, now a flagship product of a small-medium enterprise (SME) group in Tugurejo, Semarang (Suhartono et al., 2021). For Avicennia species, rather than just being consumed as a simple salad, its leaves can be processed into chips and crispy crackers, which are popular in Rembang, Central Java (Shohib, 2021). The Tugurejo community in Semarang also utilizes Avicennia fruit to make sponge cakes and syrup (Suhartono et al., 2021). Several sources even describe methods for processing Avicennia fruit into traditional desserts like compote, pudding, *klepon*, and as a topping for *dawet* (Indonesia's sweet dessert). Besides chips and tea, *A. ilicifolius* can also be developed into refreshing syrup, as practiced by community groups in Kuala Jambi, Tanjung Jabung Timur Regency (Amanda et al., 2024).

Despite the presence of 12 mangrove species in South Lampung, as reported by Rodiani et al. (2023), many of these species remain underutilized by the local community. This contrasts with practices in other regions where mangrove resources are more extensively processed and integrated into local food systems. For instance, in Maitara Island (Ternate), Jambi, and East Lampung, *Sonneratia* spp. are widely processed into syrup and herbal tea, valued for their distinct sweet and sour flavor (Afriansyah, 2019; Putri et al., 2018; Tian et al., 2023). Additionally, in Banjarbaru, South Kalimantan, ketapang (*Terminalia catappa*) seeds are processed into flour, serving as a base ingredient for various cakes (Pitri et al., 2021). Beyond Indonesia, *Sonneratia* spp. serve as staple foods for coastal communities in Papua New Guinea (Imdadul, 2012). Similarly, in India, *R. mucronata* is utilized as a primary food source (Imdadul, 2012). In several West African countries, the leaves and fruits of Rhizophora and Avicennia species are processed into essential food products, which are successfully marketed beyond their regions (Gallup et al., 2020).

The nutritional and bioactive compounds in mangroves offer significant potential for functional food diversification and addressing various public health challenges. In Indonesia, some of the most prevalent diseases include hypertension, diabetes, heart failure, stroke, and tuberculosis. Meanwhile, infectious diseases such as dengue fever, malaria, and acute respiratory infections remain widespread in Lampung. Mangroves contain diverse bioactive compounds with documented antifertility, antioxidant, analgesic, anticholesterol, antihypertensive, antitussive, and anti-inflammatory properties, among others. These compounds present a valuable opportunity to address social and economic challenges in South Lampung and Indonesia. Currently, 90% of raw materials for pharmaceuticals in Indonesia are imported, with a government target to reduce this dependency by 20% by 2026 (Ruskar et al., 2019). Innovation in developing mangrove-based medicinal and functional food products could contribute significantly to achieving this target. Another critical issue in Indonesia is population growth. The national population growth rate is 1.39%, equivalent to approximately 4.2–4.8 million births annually (Sinaga, 2021). One of the government's key strategies is population control, and the antifertility properties found in mangrove species could be developed into natural contraceptives, supporting national efforts to reduce the birth rate sustainably. Developing functional food products derived from mangroves can have far-reaching health, economic, and environmental benefits, aligning with Indonesia's national development goals and fostering greater self-sufficiency in medicine and food security.

The results revealed that mangrove food product processing in South Lampung remains limited and predominantly traditional. In contrast, more advanced mangrove food processing techniques have been implemented in Indramayu, where the community has adopted modern equipment and materials to extend product shelf life. Additionally, they have incorporated technological advancements in packaging design, color catalog development, and marketing strategies to enhance the commercial appeal of mangrove-based food products (Saptaji, 2023). Improving mangrove processing technology in Lampung is crucial for transitioning mangrove-based food from an "emergency food" to a sustainable functional food source. The transformation of processing methods and the adoption of innovative technologies can help shift societal perceptions, demonstrating that staple foods need not be limited to

rice and wheat. Innovations in preservation techniques while maintaining nutritional integrity and product quality are key to the successful diversification of mangrove-based food sources. By expanding mangrove food diversification, efforts to combat hunger and poverty—particularly among coastal communities that depend on mangrove resources—can be significantly strengthened. This, in turn, contributes to national food security, economic development, and reduced reliance on imported food products. Furthermore, a sustainable blue ecosystem cycle can be established as awareness of conservation efforts grows. This cycle ensures ecological balance and enhances community welfare by integrating economic, environmental, and food security objectives into a resilient and sustainable system.

4. Conclusion

The community of South Lampung has traditionally utilized four mangrove species as food sources through ethnobotanical practices. The fruit (excluding roots) of *R. mucronata* is processed into coffee, while the young leaves of *A. marina* are used in salads. Additionally, the sap of *A. marina* is made into a healthy drink, and its fruit is processed into flour for baking. Meanwhile, the leaves of *A. ilicifolius* are processed into tea and crispy snacks. Beyond their nutritional value, mangroves contain various bioactive compounds with antifertility, antioxidant, analgesic, anticholesterol, antihypertensive, antitussive, and anti-inflammatory properties. These bioactive components offer significant potential for developing functional foods, which could play a crucial role in addressing social and economic challenges in South Lampung. However, several limitations hinder the optimization of mangrove utilization as a food source. One of the primary challenges is the low level of human resource development, which restricts innovation and diversity in terms of mangrove species selection, utilized plant parts, processed products, and processing methods. The ethnobotanical practices documented in this study provide a foundation for further development. Implementing comprehensive approaches and innovative training programs—involving government agencies, educational institutions, non-governmental organizations (NGOs), and the private sector—is essential to enhancing productivity and improving the livelihoods of coastal communities. Strengthening mangrove-based food utilization could contribute to food security, economic growth, and environmental sustainability in South Lampung and beyond.

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