Journal of Ethnic Foods

REVIEW ARTICLE

Open Access

Nutritional, chemical, and prospect of "*mandai*," traditional fermented food of Kalimantan

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Abstract

Mandai, a traditional fermented delicacy, is produced from the inner peel of the *cempedak* fruit (*Artocarpus champeden*). This unique food is a culinary heritage of the Banjar ethnic group residing in Kalimantan, and is part of Indonesia's rich collection of traditional fermented foods. This study aimed to analyze *mandai* by examining its fermentation processes and chemical and nutritional composition. It also discusses the potential and prospects of *mandai* development in the future. Through a narrative literature review, this study synthesized insights into *mandai*, emphasizing its significance as a functional food with rich antioxidant and probiotic properties. This review also shows that processing *mandai* through starter-induced fermentation can improve its quality and standards. This study serves as an important foundation for future *mandai* research by emphasizing the functional benefits and processing methods of *mandai*.

Keywords *Mandai*, Mandai nutrition, *Mandai* chemical, Potentials *mandai*, Prospect *mandai*, Traditional fermented food

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Introduction

Fermented foods have long been an important part of the civilization of nations in the world and are evidence of the long history of human creativity (i.e., *kimchi, pao cai, doenjang, kinema, basturma, sufu, minced meat and steak, sauerkraut,* etc.*)* [1–5]. Researchers have conducted studies on fermented foods from all over the world, especially Asian countries, and have shown significant progress in the Journal of Ethnic Food [6–9].

In Indonesia, Surono summarized various traditional fermented foods and drinks and showed unique characteristics according to the cultural and ethnic background of the island nation [10]. Likewise, recent researchers have described the diversity of typical traditional fermented foods and drinks in various provinces (i.e., *bekasam*, *ina sua*, *naniura*, *tempoyak*, *dadih*, *tauco*, *peuyeum*, *terasi*, *tuak*, *tempeh*, *tapai ketan*, *rusip*, *jukut*, *bodek*, and *cincalok*) [11–18] (Fig. 1).

This study sheds light on famous traditional fermented foods on the island of Kalimantan, one of which is *mandai*, made from the endocarp of *cempedak* fruit (*Artocarpus champeden*), which is known as *dami* [19]. The production of *mandai* entails fermenting the *dami* in a saline solution or applying a salt coating, resulting in a distinctive sour taste and a one-of-a-kind texture [20, 21]. *Mandai*, a traditional fermented food, has been extensively enjoyed by indigenous communities, particularly the Dayak and Banjar, for millennia as a side dish with rice [22]. In addition to its distinct taste, *mandai* is renowned for its uncomplicated yet efficient fermentation method for food preservation. *Mandai* has a long shelf life, making it a valuable choice when fresh ingredients are limited and expensive [23].

Mandai holds great cultural importance for the indigenous people of Kalimantan, especially among the Banjar ethnic group [24]. The production and consumption of *mandai* is a fundamental aspect of indigenous gastronomic heritage, showcasing the ingenuity and resourcefulness of the local population in exploiting the many natural resources at their disposal [22, 25]. The historical utilization of *mandai* is based on the necessity of conserving food, particularly when refrigeration is unavailable [26]. This practice not only avoids unnecessary disposal of food, but also guarantees the long-term availability and viability of food resources. Furthermore, *mandai* is frequently presented during significant events and cultural festivities, serving as a representation of cultural legacy and identity. Its production frequently entails the participation of family and community members, fostering moments of solidarity and the intergenerational transmission of knowledge [22, 25]. The existence of *mandai* has enriched the collection of traditional fermented foods owned by the Indonesian people and provides strong historical evidence of the fermented food tradition in this archipelagic country.

Exploring the fermentation process of *mandai* is particularly intriguing because of the involvement of many microorganisms and their nutritional implications [27]. *Mandai* fermentation commences by thoroughly cleaning and salting *dami*. Subsequently, the *dami* is set aside for fermentation [26, 28, 29]. Lactic acid bacteria (LAB), including Lactobacillus plantarum and Lactobacillus casei, are crucial in this fermentation process because they produce lactic acid, which reduces the pH and inhibits the growth of harmful microbes that cause spoiling [22, 28]. The assortment of microorganisms present during fermentation plays a crucial role in determining the taste characteristics and potential health benefits of *mandai* [25]. The fermentation of *mandai* enhances its nutritional profile by increasing the levels of phenolic

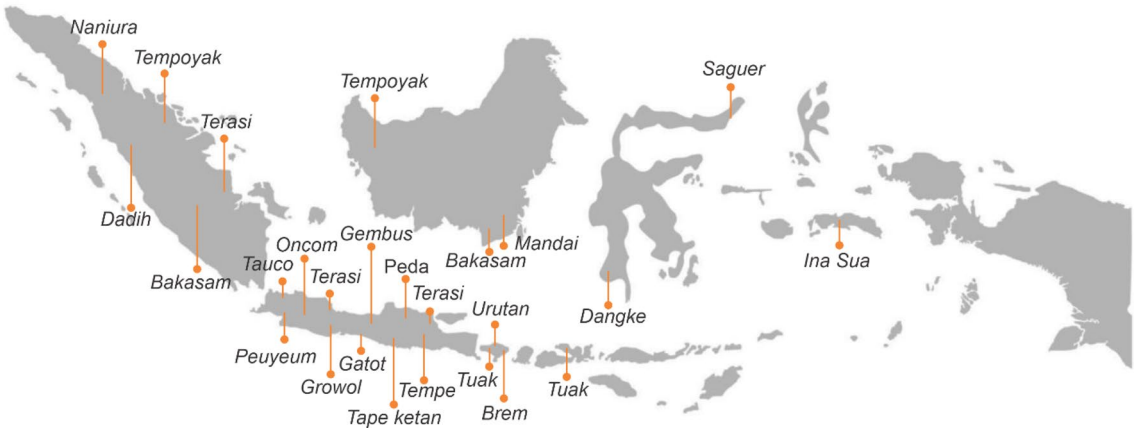

Fig. 1 A map of ethnic fermented foods and beverages in Indonesia illustrates the diverse variety of traditional fermented products found across different regions, highlighting the rich cultural and culinary heritage of the archipelago

compounds and flavonoids, which are recognized for their health-promoting properties, particularly as antioxidants [22, 30, 31].

Mandai is renowned not only for its distinctive taste, but also for its possible therapeutic advantages. *Mandai*, abundant in lactic acid bacteria (LAB), can function as a probiotic source that promotes gastrointestinal well-being [29]. Consuming *mandai* can contribute to the maintenance of healthy gut flora, enhance digestion, and fortify the immune system. Furthermore, the fermentation process yields phenolic chemicals and flavonoids with antioxidant properties, which effectively mitigate oxidative stress within the body [25, 29]. *Mandai* represents the regional identity and preservation of local culinary traditions from a cultural perspective. Hence, *mandai* can serve as a viable option for food diversification to fulfill the requirements of the population. Culinary development in *mandai* can be more diverse to cater to the demands of both the local people and tourists.

Studies on *mandai* have been reviewed by researchers, but the results remain limited and cannot comprehensively describe this topic [32]. *Mandai* is not widely known internationally. Therefore, this study attempts to examine this carefully by exploring several aspects (i.e., *mandai* processing, spontaneous versus starter-induced fermentation methods, chemical and nutritional analysis, and the potential of *mandai*). In addition, this study reviews the prospects for developing *mandai* to support the sustainable tourism development. It is hoped that the results of this study will enrich knowledge about traditional fermented foods and be useful for stakeholders in the development of traditional fermented foods in the future.

Methodology

To fill the gaps in the current research and propose new subjects not yet covered in the study of *mandai*, this study employs a narrative literature review approach [33], which seeks to find and compile information or knowledge previously published from a variety of sources. This approach is applied to explore various important aspects *of mandai*, starting from processing, chemical and nutritional aspects, *mandai*'s potential, and *mandai*'s prospects. Sources were collected from databases such as Google Scholar and Scopus using the keywords "*mandai*," "fermented *mandai*," "*mandai cempedak*," and "*mandai* Kalimantan." Library sources include scientific articles published in peer-reviewed journals, conference proceedings, and books published from to 2000–2024. Articles were selected based on their suitability for this research and were taken in English and Indonesian: seven articles from Scopus, ten articles from Google Scholar, and three scientific books.

Result and discussion

Mandai processing

Mandai is a traditional meal that is produced by fermentation, which involves the use of a significant amount of salt. The raw material utilized was the endocarp of the *cempedak* fruit (*Artocarpus champeden*). *Mandai* is produced by spontaneous fermentation and is typically stored at ambient temperature. Mandai manufacturing involves three main stages (Fig. 2): (1) peeling and washing of the inner fruit peel of *cempedak*, (2) salting with 25% salt, and (3) processing by soaking *mandai* in a highly concentrated salt solution during fermentation. The introduction of salt into organic substrates triggers spontaneous fermentation and microbial selection, resulting in the progression of microbial succession [26, 31]. Elevated salt levels can impede the proliferation of spoilage and harmful microorganisms [20, 29].

The production of *mandai* begins by carefully choosing mature and high-quality *cempedak* fruits. It is important to use fresh fruits that are not overly ripe to have a desirable texture during fermentation. The utilized component is the inner epidermis of the *cempedak* fruit, referred to as the *dami*. The exocarp of the *cempedak* fruit was removed, revealing the mesocarp, which is the softer, pulpy inner component. The *dami* are subsequently divided into pieces of preferred dimensions, often ranging from 3 to 5 cm, to aid the fermentation process [21].

Once the *dami* is cut, the next step is salting. Traditional methods involve two main approaches: direct salting and soaking in a salt solution (brine). In direct salting, *dami* are evenly sprinkled with salt and left for some time. In the soaking method, *dami* pieces are immersed in a salt solution of varying concentrations, generally between 5 and 25% [28, 29]. Salt inhibits the growth of pathogenic bacteria and favors the development of lactic acid bacteria (LAB), which are important for fermentation.

Mandai fermentation can occur either naturally or by the introduction of starter cultures. Spontaneous fermentation occurs naturally without the introduction of specialized bacterial cultures. The fermentation process is driven by the growth and dominance of microbes naturally found in the environment or on the surface of fermented materials [21]. Starter culture induction involves the addition of a known bacterial culture, such as Lactobacillus casei, to initiate fermentation in the combination [22, 28, 29]. The use of a starter culture guarantees uniformity in the outcome of the fermentation process, encompassing aspects such as taste, consistency, and microbiological integrity.

The temperature and duration of fermentation play a crucial role in shaping the ultimate attributes of *mandai*. Fermentation is typically conducted at ambient

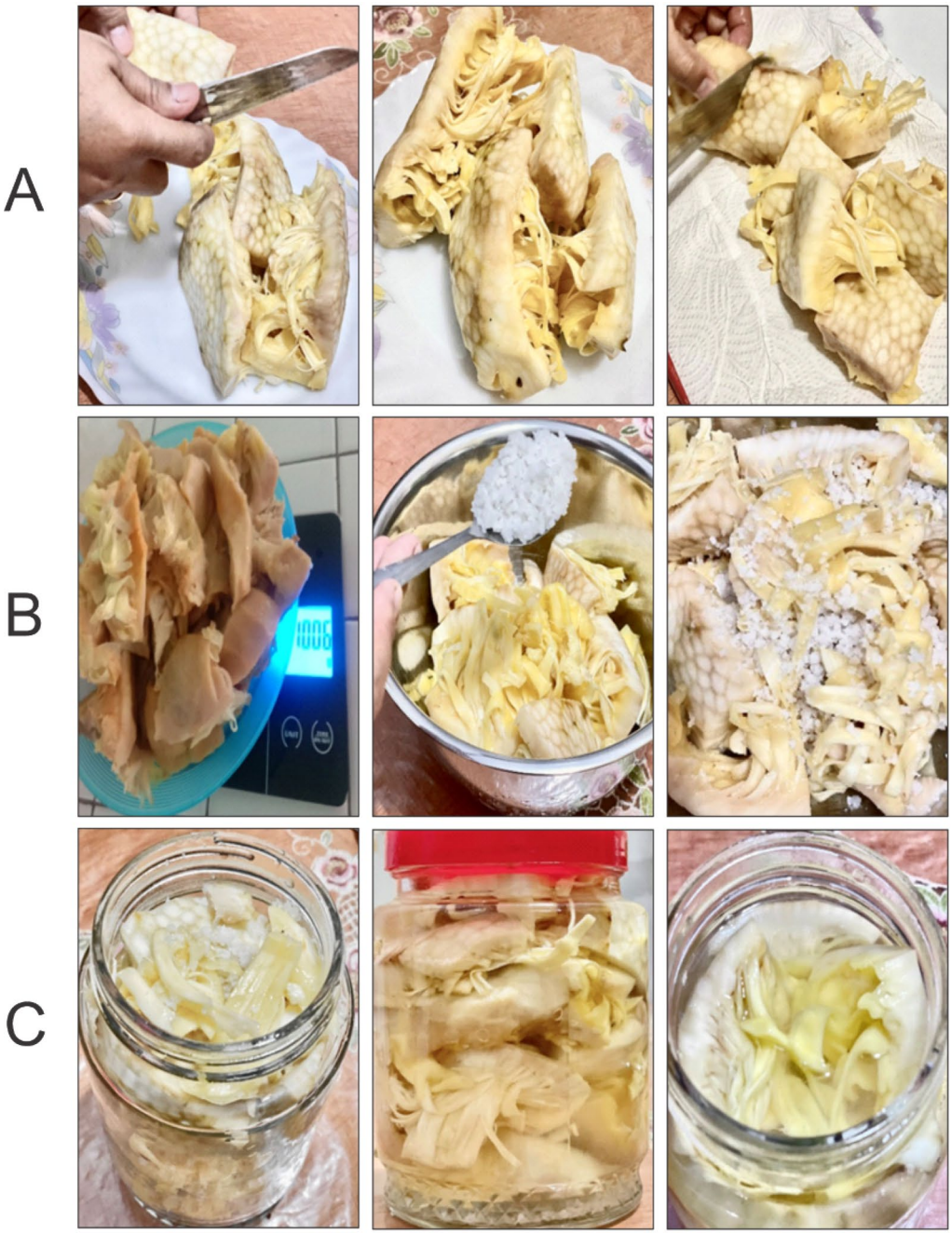

Fig. 2 Traditional processing of *mandai:* **A** peeling and washing the inner peel of cempedak fruit, **B** salting process with 25% concentration, and **C** fermentation process by soaking the cempedak peel in salt solution at room temperature for 7 days

temperature, approximately 25–30 °C [25, 28]. However, to improve regulation, fermentation can be performed at 37 °C, especially when starter cultures are used [21, 31]. The fermentation time varies based on the technique and environmental factors, typically spanning from a few days to a few weeks. Increased fermentation durations typically lead to tangier end products with tender consistency.

Lactic acid bacteria (LAB) are an important group of bacteria that play an important role in the *mandai* fermentation process. LAB strains commonly found in *mandai* fermentation include Lactobacillus plantarum,

Lactobacillus casei, and Pediococcus pentosaceus. These bacteria metabolize the sugars present in *dami* and produce lactic acid, which lowers the pH and helps preserve the product [34, 35]. However, the utilization of starter cultures enables enhanced regulation of the specific type and quantity of LAB involved, leading to a product that exhibits uniform properties [21, 31]. Research indicates that the use of starter cultures in fermentation often leads to increased and consistent levels of LAB, as well as safer and more reliable products.

Spontaneous fermentation versus starter-induced fermentation in m*andai cempedak*

Mandai cempedak fermentation occurs naturally through the activity of microorganisms present in the raw materials or the surrounding environment uses a closed jar (Fig. 3). During this fermentation process, the proliferation of lactic acid bacteria (LAB) is typically characterized by a sluggish growth rate, allowing the flourishing of many bacterial species. Fermentation leads to the production of a product that exhibits a broader range of quality, which is influenced by environmental conditions, including temperature and microbial infection [31]. However, fermentation initiated by a starter culture, such as the utilization of Lactobacillus casei, allows for a more precise regulation of the fermentation procedure. Utilizing a starter guarantees the prevalence of specific desirable lactic acid bacteria (LABs), expedites the decrease in pH, and enhances the generation of phenolic compounds and antioxidant activity. These findings demonstrate that the utilization of L. casei in the fermentation process led to the production of products with elevated phenolic content and enhanced antioxidant activity in comparison to the products obtained by spontaneous fermentation. These findings indicate that the fermentation process initiated by the starter is more efficient in enhancing the nutritional quality and stability of the product [36].

Starter-induced fermentation offers notable benefits for creating uniform and superior food products.

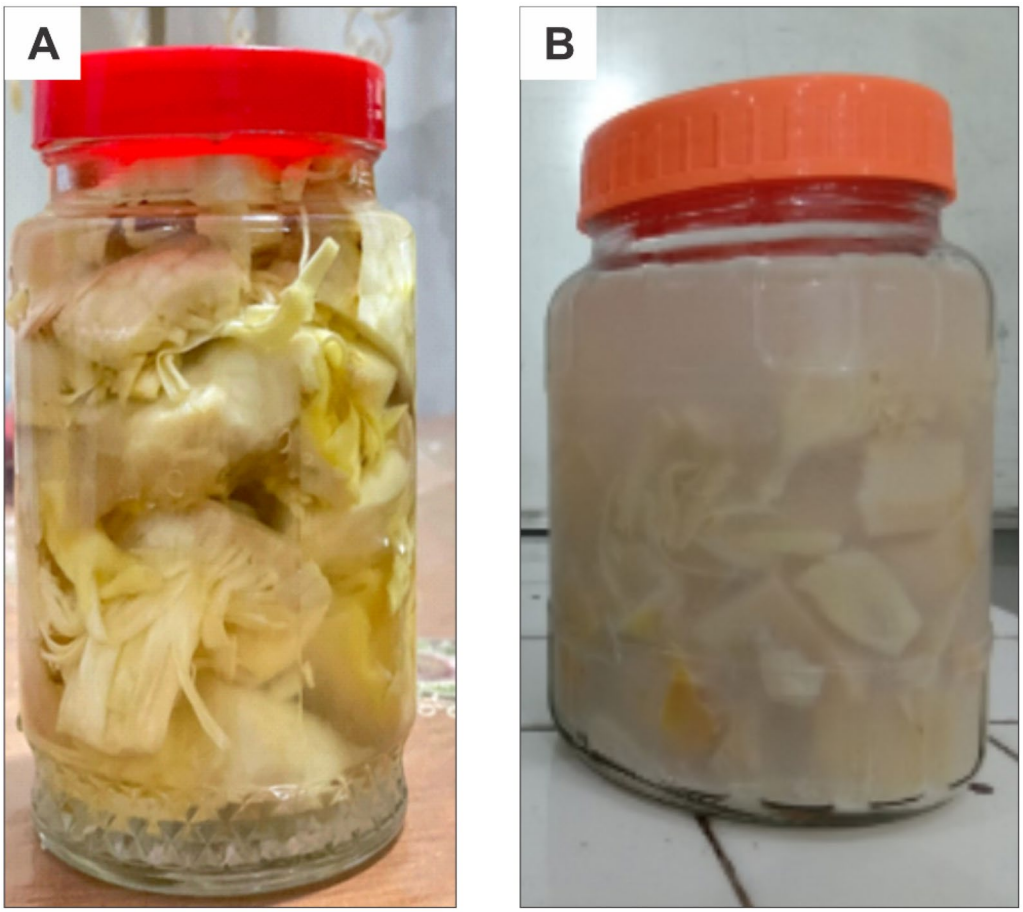

Fig. 3 Fermentation of mandai cempedak through two methods was carried out in a closed jar: **A** Spontaneous fermentation with salting, where the fruit is left to ferment naturally with the addition of salt to initiate the fermentation process. **B** Starter-induced fermentation, in which a microbial starter culture is introduced to accelerate and control the fermentation process, results in consistent and predictable outcomes

Fermentation of *mandai cempedak* enables precise regulation of its sensory and nutritional attributes while minimizing the potential for harmful microbial contamination. Thus, this technology is preferable for industrial applications and the creation of stable and secure products [36].

The fermentation process had a considerable impact on the chemical, phytochemical, and microbiological contents of *mandai cempedak*, as shown in Table 1. The utilization of a starter culture, such as Lactobacillus casei, during fermentation improves the liberation of phenolic compounds and enhances antioxidant activity compared to fermentation that occurs naturally. This procedure also stimulates the proliferation of lactic acid bacteria (LAB), which is essential for enhancing the efficiency and safety of fermentation, leading to decreased pH levels and increased phenolic content. The inclusion of LAB contributes to the establishment of a regulated setting, diminishing the likelihood of contamination by undesired microorganisms and guaranteeing greater uniformity in the quality of the fermented product [36].

The analysis of *mandai cempedak* has identified several Lactobacillus species, which demonstrate significant potential as probiotic bacteria (Table 2). Using molecular techniques, it has been verified that Lactobacillus casei is the primary strain present. This strain is well-known for its capacity to increase antioxidant activity and enhance the overall quality of fermented products [34]. Additional research has demonstrated that these strains can prevent the growth of detrimental bacteria, thereby enhancing the safety and health advantages of *mandai cempedak* [36]. In addition, the utilization of Lactobacillus casei as a starter culture not only assists in obtaining a favorable microbial equilibrium, but also improves the nutritional composition by augmenting the phenolic content and antioxidant capability [31].

Chemical and nutritional analysis of *mandai*

Mandai cempedak, derived from the inner skin of *cempedak (Artocarpus champeden)*, is a fermented product that exhibits a fascinating chemical composition and nutritional profile. The process of fermentation leads to substantial alterations in the chemical makeup of *mandai*, resulting in an augmentation of phenolic component levels and antioxidant activity. According to previous research, utilizing a salt concentration of 10% during the fermentation process of *mandai cempedak* results in the highest nutritional content [20]. *Mandai* had a protein

Table 1 Effect of fermentation method on chemical, phytochemical, and microbial contents of *mandai*

Fermentation method	Key findings
Starter-Induced	These benefits include heightened antioxidant qualities, reliable chemical features, and enhanced safety through the inhibition of dangerous microbes [36]
Spontaneous	Isolating several strains of lactic acid bacteria (LAB) that have potential probiotic advantages is important. However, it is crucial to note that the heterogeneity in the microbial population can have an impact on the uniformity and safety of the final product [29]
Spontaneous	The utilization of salt solutions improves the sensory properties and vitamin C concentration, although the fluctuation in microbial activity results in unreliable outcomes [20]
Spontaneous	The presence of a wide range of microorganisms enhances the complexity of flavors, but also presents difficulties in maintaining uniform product quality and assuring microbiological safety [37]
Both	Conducted a comparative analysis of various drying temperatures to determine the ideal conditions for maintaining antioxidant activity throughout both spontaneous and starter-induced fermentation [30]

Table 2 Identification of probiotic bacteria in *mandai*

Method	Bacteria Identified	Results
Isolation and Characterization (API 50 CHL and PCR)	*Lactobacillus plants*	85 LAB isolates were obtained from *mandai* on day 4, 8, and 12 of fermentation, showing potential probiotic properties, including tolerance to low pH and bile salts [29]
Molecular Identification (DNA Fingerprinting)	*Lactobacillus vaccinostercus*, *Lactobacillus harbinensis*, *Lactobacillus perolens*	Twenty-six Lactobacillus isolates showed acid tolerance, 17 were bile salt tolerant, and 15 isolates exhibited strong inhibitory properties against pathogens [34]
Probiotic Screening and Antimicrobial Testing	*Lactobacillus casei*, *Lactobacillus paracasei*	Identified isolates demonstrated strong probiotic potential, with isolate F71 showing similarity to *L. casei* and *L. paracasei* [34]

content of 1.47%, lipid content of 16.22%, carbohydrate content of 2.28%, and dietary fiber content of 23.78% at this concentration. These findings indicate that elevating salt concentration during fermentation significantly enhances both sensory attributes and dietary fiber content [34]. Meanwhile, the levels of fat and carbohydrates tend to decrease, which can be advantageous for individuals seeking high fiber intake with reduced fat content [34].

Furthermore, notable alterations were observed not only in the chemical composition, but also in the levels of phenolic compounds and antioxidant activity. The investigation revealed that *mandai cempedak* had a total phenolic content of 348.8 ± 55.6 mg GAE/kg, hydrolyzed tannins content of 143.8 ± 9.3 mg TAE/kg, and total flavonoids content of 17.5 ± 1.3 mg CAE/kg. The antioxidant activity of the substance was assessed using an IC50 value of 56.96 ppm, indicating a noteworthy level of antioxidant activity [30].

The presence of bioactive components, including flavonoids, phenols, and tannins, significantly enhanced the nutritional quality of *mandai cempedak*. These substances possess antioxidant capabilities that can safeguard the body against oxidative damage while also offering additional health advantages, such as diminishing the likelihood of chronic diseases [38]. The significant antioxidant activity observed in *mandai* suggests that it can be utilized as a functional food additive.

Potential of *mandai*

Mandai is a traditional food in Indonesia that has great potential for development. However, the main challenges faced by *mandai* are its short shelf life and variations in quality. Therefore, it is important to explore new techniques that can enhance the quality and shelf life of *mandai* and seek alternative products that can be derived from *mandai*. Utilization of the drying process is an efficient approach to enhance the longevity of *mandai*, a fermented food derived from *cempedak* skin. One technique employed is low-temperature drying, which is conducted at approximately 45 °C. Studies have demonstrated that this approach effectively maintains the phenolic content and antioxidant activity in *mandai*, thereby preserving its nutritional value and sensory quality. This process additionally enables enhanced drying efficiency, mitigates the potential for microbiological contamination, and prolongs the shelf life of *mandai* while preserving its unique flavor [30].

Another technique that can be considered is the encapsulation method. Encapsulation is a technique used to protect the active ingredients in food products, including *mandai*, by encasing them in a protective matrix. This technique has been used to improve the stability and extend the shelf life of bioactive components in *mandai*, such as antioxidants and phenolic compounds, which are susceptible to deterioration due to heat exposure and oxidation. In a recent study, *mandai cempedak* was packaged using encapsulation with maltodextrin and chitosan as wall materials [39]. This process was performed using a spray-drying technique, which allows the preservation of bioactive compounds and provides a stable texture to the final product.

In addition to improving quality and shelf life, the exploration of alternative products from *mandai* is also important for market diversification. Several studies on *Mandai* product diversification based on probiotics and bioactive components have been conducted. Table 3 shows a tree diagram of *Mandai* product diversification.

Prospect and future development of *mandai*

Mandai, not just fermented food, but also a journey of flavors rich in the traditions and history of the Kalimantan people, which contain elements of culinary arts and gastronomy that must be preserved to support sustainable tourism development [32, 43]. The development of *mandai* in the future will drive innovation and

Table 3 *Mandai* product diversification

Product	Method	Result
Serundeng *mandai*	Dry roasting	Achieves a dry and crispy texture with an appealing flavor [40]
Dodol *mandai*	Cooking with continuous stirring	Accepted by the public for its unique aroma, color, texture, and taste [41]
Mandai ice cream	Stirring method using a mixer	Produce a new ice cream flavor with acceptable sensory characteristics [21]
Encapsulated *mandai* Vinegar	Encapsulation with maltodextrin and chitosan using spray drying	Maintains high phytochemical activity, and increases shelf life [23]
Mandai powder	Drying	Retains nutritional value, high phytochemical activity and increases shelf life [23]
Encapsulated *mandai* powder	Encapsulation with maltodextrin and chitosan using spray drying	Maintains phytochemical activity and increases shelf life [30]
Seasoning mushroom *mandai*	Drying	A new flavoring product with a savory taste with a distinctive *mandai* aroma [39]
Serundeng *mandai*	Dry roasting	Achieves a dry and crispy texture with an appealing flavor [42]

creative ideas in creating more diverse products, so that the development of recipes or *mandai* derivative products becomes more varied, which indirectly increases sales value and competitiveness in the market. Moreover, the development of traditional fermented foods has the potential to create new job opportunities in the creative economy sector (e.g., tourism, restaurants, and street food) and has been recognized as making a significant regional and national economic contribution [44–46]. However, future development *mandai* must receive government policy support and serious attention from stakeholders, including the universities, hotels, local communities (chef association, food influencer, media, etc.), and micro, small, and medium enterprises (MSMEs) [47–49].

Conclusion

This study presents a comprehensive examination of *mandai*, encompassing its processing methodologies, including spontaneous and starter-induced fermentation, potential, and chemical and nutritional characteristics. The distinctive fermentation process of *mandai*, facilitated by lactic acid bacteria, not only enhances its organoleptic properties and extends its shelf life, but also augments its nutritional profile with increased phenolic content, flavonoids, and antioxidant activity. This study also outlines prospects for the future development of *mandai*, with the aim of contributing to the creative economic sector through stakeholder collaboration. This review highlights these points and advocates for additional research on *mandai*.

Abbreviations

LAB	Lactic acid bacteria
MSMEs	Micro, small, and medium enterprises
API 50 HCL	Analytical profile index 50 lactic acid bacteria
PCR	Polymerase chain reaction
IC50	Inhibitory concentration
GEA	Gallic acid equivalent
TAE	Tannic acid equivalent
CAE	Catechin equivalent

Acknowledgements

We thank Prof. Dr. Ir. Eni Harmayani, M.Sc., Dr. Mohamad Yusuf, MA., and Dr. rer.pol. Dyah Widiyastuti, ST., MCP., (Gadjah Mada University, Yogyakarta, Indonesia), who has shared knowledge of writing scientific articles, Indonesian traditional fermented food and drink.

Author contributions

SY, NA, and GG collaborated on this project and created the research concept, methodology, and writing the original draft. HP, YY, and RES were involved in data collection and analysis. EDK, SS, and STW assisted with reviewing, editing, and visualizing the manuscript. SRM, DW, and SS elaborated on the research methods and revised them accordingly. SY and NA prepared the manuscript in English and enhanced the manuscript. YY and HP wrote the final manuscript. GG reviewed the final manuscript and supervised the study. NA is the main author of this manuscript. All authors have read and approved the final manuscript.

Funding

This study was funded by the Indonesian Education Scholarship (BPI), Center for Higher Education Funding and Assessment Ministry of Higher Education, Science, and Technology of Republic Indonesia, and Indonesian Endowment Funds for Education (LPDP) (Grant No. 00587/J5.2.3./BPI.06/9/2022).

Availability of data and materials

All data and materials are included in this paper.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors have read and approved the content of this manuscript for Journal of Ethnic Foods.

Competing interests

All authors declare that they have no competing interests regarding this publication.

Received: 21 November 2024 Accepted: 19 February 2025
Published online: 02 April 2025

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