Exploring the Utilization of Fungi in Indonesian Traditional Foods: A review

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Abstract. This review focus on examining the significant role of fungi in Indonesian traditional cuisine. It explores how molds, specifically *Rhizopus sp*. and *Aspergillus sp.,* contribute to the fermentation, preservation, and flavour enhancement of typical Indonesian dishes like tempeh, *Oncom*, and *tape*. Beyond their culinary utility, this study delves into the cultural importance of mold-based food traditions, tracing their historical origins and continued prevalence in Indonesian households. Furthermore, the review discusses the nutritional and potential health benefits associated with mold-fermented foods within the Indonesian dietary context. It also addresses the challenges and future prospects of utilizing mold microorganisms in traditional food preparation, highlighting opportunities for ongoing research and innovation. This analysis underscores the enduring and intricate relationship between fungi and Indonesian food, showcasing their influence on the nation's culinary heritage and identity.

1 Introduction

Indonesia is renowned for its diverse array of natural resources, ethnicities, and cultures. With numerous regions each possessing unique characteristics, the country boasts a wide variety of traditional foods originating from various localities. The abundant natural wealth found throughout the nation contributes to the ever-expanding diversity of traditional cuisine many of which are created through fermentation processes [1].

Fermented foods have been increasingly embraced in recent years, gaining popularity not only in Indonesia but also in the West due to their purported health benefits [2,3]. This trend can be attributed to the rising popularity of ethnic cuisines, growing public awareness regarding the health advantages associated with fermented foods, and the increasing availability of such products [4].

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Fermented foods and beverages, as defined by The International Scientific Association for Probiotics and Prebiotics (ISAPP), are products resulting from meticulously controlled microbial growth and enzymatic conversion of food components [5]. Additionally, fermented foods encompass those whose production involves the action of microorganisms or enzymes, leading to desirable biochemical changes and significant modifications to the food substrates [6].

Fermentation is a versatile process applicable to a wide range of food categories including vegetables, meat, fish, dairy, fruits, cereals, soybeans, and legumes. In food processing, fermentation offers numerous benefits, primarily aimed at enhancing quality and extending shelf life. It has been found that the application of fermentation in food and beverage processing can enhance sensory attributes such as texture and flavour, thus improving overall consumer appeal [7,8]. This process typically involves the utilization of microorganisms such as fungi or mold, yeast, and bacteria. Fungi or mold play a significant role in various food fermentation processes, including many traditional Indonesian dishes as a starter for fermentation. An example of such a traditional food is tempeh, which is crafted from soybeans fermented by *Rhizopus spp.* [9].

A variety of fungal species, such as *Rhizopus sp.* and *Aspergillus sp.*, are essential components of the traditional food fermentation process [10]. The specific role of these fungi in fermentation varies depending on the type of fungus and substrate employed. These microorganisms play a crucial role in breaking down complex compounds into simpler forms, enhancing the digestibility and nutritional availability of fermented foods. Furthermore, fermentation can enrich the nutritional content of foods, potentially providing health benefits [11]. Given their high nutritional value, fermented foods hold promise as future functional foods, capable of offering numerous health benefits [12,13]. Therefore, this review article aims to explore traditional Indonesian foods that utilize fungi or molds in their production and examine the role of these microorganisms in relation to health outcomes.

2 Indonesian Traditional Foods Incorporating Fungi

Fungi are integral to Indonesian culinary practices, serving multiple purposes from enhancing sensory attributes to offering nutritional and health benefits. Several traditional Indonesian foods showcase the innovative use of fungi, either through direct incorporation or fermentation processes. Table 1 presents a variety of Indonesian traditional foods that incorporate fungi.

Table 1. Indonesia Traditional Foods Incorporating Fungi

Traditional Food	Fungi/Mold	Reference
Tempeh	*Rhizopus sp*	[14]
Tape	*Aspergillus*, *Amylomyces rouxii*, *Mucor sp* and *Rhizopus sp*	[15], [16]
Tauco	*Rhizopus oligosporus, Rhizopus oryzae*, and *Aspergillus oryzae*	[17]
Oncom	*R. oligosporus*	[18]

Kecap (Soy Sauce)	*A. oryzae, A. sojae, Rizhopus oryzae, Rizhopus oligosporus.*	[16]
Pliek U	*Aspergillus niger* and *Aspergillus flavus*	[19], [20]

The use of fungi or mold in fermentation has been shown to improve the nutritional value of substrates or foods. For example, soybeans, which are already nutritionally rich, can be transformed into tempeh through fermentation, enhancing their nutritional profile. This process makes them viable as functional foods with health benefits [21]. Fermented soy products are linked to a range of health advantages, including potential anti-carcinogenic, antioxidant, anti-diabetic, anti-inflammatory, and anti-hyper lipidemic properties [2].

Despite the inherent nutritional richness of soybeans, they contain anti-nutritional components that diminish their overall nutritional value, thereby reducing their suitability for human consumption [22]. Components such as saponins, phytic acid, lectin, and trypsin inhibitors present in soybeans can inhibit nutrient absorption and digestion, posing challenges for their utilization [22], [23], [24]. However, fermentation offers a solution by decreasing the levels of these anti-nutrients, thereby enhancing the nutritional content and digestibility of soybeans [22], [24] [25].

Transitioning from the context of soy fermentation, it is noteworthy to consider other fermented foods, such as tape, which also benefit from the process in a similar yet distinct manner. *Tape* may contain molds or beneficial microorganisms capable of acting as probiotics. Through the fermentation process, *tape* can enhance digestion by increasing the production of lactic acid and probiotics [26]. Additionally, the fermentation of *tape* results in the synthesis of bio enrichment vitamins, such as thiamine, by microorganisms involved in the process [27].

3 The Predominant Utilized Fungi in Indonesian Traditional Food

After discussing the Indonesian foods that typically incorporate fungi, we would like to further explore the specific types of fungi predominantly used in Indonesian traditional dishes, as outlined in Table 2.

Table 2. The Predominant Utilized Fungi in Indonesia Traditional Food and The Mechanism

Fungi/Mold Species	Mechanism	Product	Reference
Rhizopus oligosporus	Producing protease enzymes that break down proteins, or converting complex compounds into simpler ones that can be easily absorbed by the body	Tempeh, *tape*, *Tauco*, *Oncom*, soy sauces	[28], [29]
Aspergillus oryzae	Decomposing starch by simplifying amylum, producing amylase and protease enzymes that facilitate the breakdown of proteins and various starches into sugars and amino acids	Soy sauces, *Tauco*	[15], [30]
Rhizopus oryzae	Synthesizing α-amylase enzyme as a starch breaker, while producing amylase, lipase, and protease enzymes to enhance the biodisponibility of the	Soy sauces, *Tauco*, *tape*, tempeh	[29], [31]

	nutrients and generate numerous compounds with sensory and nutritional significance		

Table 2 presented the predominant utilization of molds/fungi in Indonesian cuisine such as *Rhizopus oligosporus*, *Aspergillus oryzae*, and *Rhizopus oryzae*. *Rhizopus oligosporus* is known to produce various enzymes, including lipase, amylase, and protease, which degrade complex compounds into simpler ones [32], [33]. During fermentation, proteins are broken down into amino acids and other metabolites, influencing the taste profile of the final product, including umami, sweetness, or bitterness [34]. Moreover, *Rhizopus oligosporus* fermentation enhances the physicochemical properties of food products like legumes by influencing their colour, texture, and microstructure [32].

Aspergillus oryzae produces a variety of enzymes, including lipase and amylase, which degrade complex compounds into simpler forms [35]. In soy sauce production, *Aspergillus oryzae* plays a crucial role by breaking down proteins into amino acids, thereby imparting the unique flavour and aroma characteristic of soy sauce. Glutamic acid, responsible for soy sauce's umami flavour, is among the amino acids generated from protein breakdown by protease enzymes produced by *Aspergillus oryzae* [36]. Additionally the protease enzymes of *Aspergillus oryzae* contribute to soy sauce's aroma by breaking down proteins into ammonia [36]. As a probiotic-rich fungus, *Aspergillus oryzae* enhances gut health by promoting digestion, boosting immunity, and supporting healthy weight management [37], [30]. Moreover, by enhancing nutrient bioavailability and reducing levels of anti-nutritional agents, *Aspergillus oryzae* improves the nutritional quality of food products [38], [39] [30]. A study reported that rice bran fermented with *Aspergillus oryzae* exhibited elevated levels of bioactive compounds and antioxidant potential, with both antioxidant qualities and phenolic group counts increasing during the fermentation process [40].

Rhizopus oryzae exhibits enzymatic activities including α-amylase synthesis for starch hydrolysis, and the production of amylase, lipase, and protease enzymes, thereby enhancing nutrient bioavailability and generating numerous compounds with sensory and nutritional significance [31], [29]. The utilization of *Rhizopus oryzae* in fermentation processes can reduce the levels of anti-nutritional factors, such as phytic acid, in food products, thereby improving nutrient bioavailability [25], [41]. *Rhizopus oryzae* activities include the synthesis of proteases that degrade substrate proteins into cell biomass. Additionally, *Rhizopus oryzae* growth yields lipase enzymes capable of breaking down triglyceride bonds into diglycerides and fatty acids. This breakdown of complex fat content provides substrates more digestible for mold growth, consequently leading to a reduction in the crude fat content of fermentation products [42].

4 Future perspectives of Fungi Application in Food Product

Fungi are widely utilized across various industries, including food, feed, medicine, nutraceuticals, and enzymes, among others. In the food industry, fungi play crucial roles in the production of koji, soy sauce, citric acid, vinegar, as well as in the fermentation processes for alcoholic beverages such as awamori, beer, and wine [43].

Fungi have been extensively utilized in various food applications, showcasing their adaptability and versatility. For instance, tempeh, traditionally made from soybeans, can be prepared using a diverse array of other legumes, thereby broadening its potential for the production of fermented foods utilizing fungal strains. These alternatives include a range of legumes such as Bambara groundnut, kidney beans, mung beans, and sword beans, among others [43]. Furthermore, fungi hold promise for developing food products characterized by enhanced resistance to spoilage, prolonged shelf life, and improved environmental

sustainability compared to conventional alternatives [44]. These attributes underscore the potential of fungi for fostering innovation in fermented product development.

5 Conclusion

This review concluded that traditional Indonesian foods utilizing fungi/mold include tempeh, *tape*, *Tauco*, *Oncom*, *Pliek U*, and soy sauces. Fungi can offer health benefits, as seen in tempeh, which provides antioxidants and anti-inflammatory properties. Furthermore, this article review presents an excellent opportunity to delve deeper into the nutrient profiles of traditional Indonesian foods enriched by mold microorganisms. Future research could focus on assessing the nutritional benefits of these foods and examining their potential contributions to overall health. Exploring innovative fermentation techniques, even on a larger scale, can preserve the authenticity of traditional foods while upholding their safety and quality standards.

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