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Tinjauan tentang makanan fermentasi berbahan dasar kedelai tradisional dari Indonesia

[Review of traditional soy-based fermented foods from Indonesia]

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ABSTRACT

Traditional Indonesian soy-based fermented foods most notably tempeh, oncom (red and black varieties), tauco, and kecap (sweet soy sauce) represent a rich intersection of culinary heritage, microbial ecology, and nutritional innovation. This review synthesizes current knowledge on the production methods, microbial communities, biochemical transformations, and potential health implications of these products. Fermentation by molds (e.g., Rhizopus spp. and other filamentous fungi), bacteria (including Bacillus spp. and lactic acid bacteria), and yeasts drives proteolysis, carbohydrate modification, vitamin biosynthesis, and the breakdown of antinutritional compounds such as phytic acid, leading to improved protein digestibility, increased amino acid availability, and the generation of bioactive peptides and other metabolites with antioxidant, antihypertensive, and immunomodulatory potential. We examine traditional and modernized processing practices, strain-level functionality, and analytical approaches used to characterize metabolite profiles and microbial succession. Critical challenges and gaps are identified: inconsistent product quality, microbial safety concerns (including mycotoxins and opportunistic contaminants), limited strain characterization, and the tension between standardization for scale-up and preservation of local artisanal knowledge. We highlight emerging solutions that control starter cultures, integrate omics (metagenomics, metabolomics), and pilot clinical assessments to substantiate health claims and improve process control while maintaining cultural authenticity. By bringing together ethnographic, microbiological, and biochemical perspectives, this review provides a roadmap for interdisciplinary research and responsible commercialization of Indonesian soy-based fermented foods as nutritious, sustainable ethnic foods.

Keywords: fermentation, microorganisms, soy-based, traditional foods

ABSTRAK

Makanan fermentasi berbahan dasar kedelai tradisional Indonesia, terutama tempe, oncom (varietas merah dan hitam), tauco, dan kecap (kecap manis), mewakili perpaduan yang kaya antara warisan kuliner, ekologi mikroba, dan inovasi nutrisi. Ulasan ini mensintesis pengetahuan terkini tentang metode produksi, komunitas mikroba, transformasi biokimia, dan potensi implikasi kesehatan dari produk-produk ini. Fermentasi oleh jamur (misalnya, Rhizopus spp. dan jamur berfilamen lainnya), bakteri (termasuk Bacillus spp. dan bakteri asam laktat), dan ragi mendorong proteolisis, modifikasi karbohidrat, biosintesis vitamin, dan pemecahan senyawa antinutrisi seperti asam fitat, yang mengarah pada peningkatan daya cerna protein, peningkatan ketersediaan asam amino, dan pembentukan peptida bioaktif dan metabolit lainnya dengan potensi antioksidan, antihipertensi, dan imunomodulator. Kami mengkaji praktik pengolahan tradisional dan modern, fungsionalitas tingkat strain, dan pendekatan analitis yang digunakan untuk mengkarakterisasi profil metabolit dan suksesi mikroba. Tantangan dan kesenjangan kritis diidentifikasi: kualitas produk yang tidak konsisten, kekhawatiran tentang keamanan mikrobiologis (termasuk mikotoksin dan kontaminan oportunistik), karakterisasi strain yang terbatas, dan ketegangan antara standardisasi untuk peningkatan skala dan pelestarian pengetahuan artisanal lokal. Kami menyoroti solusi yang muncul yang mengontrol kultur starter, mengintegrasikan omics (metagenomik, metabolomik), dan penilaian klinis percontohan untuk mendukung klaim kesehatan dan meningkatkan kontrol proses sambil mempertahankan keaslian budaya. Dengan menggabungkan perspektif etnografi, mikrobiologi, dan biokimia, tinjauan ini memberikan peta jalan untuk penelitian interdisipliner dan komersialisasi yang bertanggung jawab dari makanan fermentasi berbasis kedelai Indonesia sebagai makanan etnis yang bergizi dan berkelanjutan.

Kata kunci: fermentasi, mikroorganisme, berbasis kedelai, makanan tradisional

Introduction

Soybean (*Glycine max* L.) is among the most extensively cultivated oilseed crops worldwide and serves as an affordable, abundant source of plant-based protein used in various foods and dietary supplements (Do Prado et al., 2022). Its composition typically includes about 40% protein, 20% fat, 35% carbohydrates, 5% minerals, and 10% moisture, along with other bioactive compounds such as fatty acids, vitamins, flavonoids, isoflavones, phenolic acids, and saponins (Baroh et al., 2024). Indonesia has one of the richest traditions of fermented foods in the world, reflecting its archipelagic geography, cultural heterogeneity and millennia-old food practices. Traditional fermentations made from soy-based are tempeh, tauco, oncom (from peanut or soybean press cake or by-products), kecap (fermented sweet soybean sauces), and a diverse array of regionally specific condiments and snacks contribute substantially to daily diets, local economies and culinary identity (Surya, 2024). These foods are not only are important as low-cost sources of calories and protein but also function as vehicles for microbial biodiversity (Graham & Ledesma-Amaro, 2023), organoleptic variety and culturally embedded knowledge systems that sustain food security across rural and urban communities (Britwum & Demont, 2022).

Fermentation refers to the process in which microorganisms degrade complex organic compounds, particularly carbohydrates, into simpler molecules under anaerobic conditions (Cakmak et al., 2025). Historically, fermentation was used to prolong the shelf life of perishable foods and to improve the digestibility of certain compounds, such as lactose, that can cause intolerance (Dimidi et al., 2019). According to (Marco et al., 2021), fermentation transforms raw materials into more nutritious, palatable products with enhanced sensory qualities. In the case of soy-based products, fermentation produces distinct variations in aroma, texture, and functional or nutraceutical properties (Do Prado et al., 2022).

Soybean proteins and isoflavones are the primary functional components of fermented soybean products. Soybeans are among the richest plant sources of isoflavones, compounds often referred to as phytoestrogens due to their structural similarity to estrogen and their ability to bind to estrogen receptors (Zhu et al., 2020). Isoflavones exist in two main forms: glycosides and aglycones. The aglycone forms are considered more bioactive and are absorbed more efficiently by the human body. In unfermented soybeans, aglycone isoflavones, mainly β-glucoside derivatives represent only about 2–3% of the total isoflavone content (Cao, 2019). During fermentation, microbial β-glycosidases convert glycosidic isoflavones into aglycone forms, increasing their biological activity; in fermented soy products, aglycones can account for 40–100% of the total isoflavones. Additionally, soy proteins contain inhibitory enzymes such as protease and trypsin inhibitors that reduce digestibility. Fermentation enhances protein quality as microbial proteolytic enzymes hydrolyze proteins into peptides and free amino acids, improving digestibility and contributing to antioxidant activity (Sanjukta & Rai, 2016).

Materials and Methods

This review comprehensively examines various Indonesian traditional soy-based fermented products through a systematic literature review approach. The method involved identifying, selecting, and critically evaluating published studies on Indonesian soy-based fermented foods. More than forty scientific articles that met the inclusion criteria were analyzed. Relevant studies were retrieved from major academic databases, including Web of Science (WOS), ScienceDirect, PubMed, Scopus, and Google Scholar. The literature search employed keyword combinations such as “soybean,” “fermentation,” “soy-based foods,” and “Indonesian traditional fermented foods.” Articles were initially screened based on their titles and abstracts, followed by a detailed assessment of their relevance to the review objectives.

Results and Discussion

Microorganisms and starter cultures involved in soy-based ferment foods

The microbiological aspect of fermentation is essential, as diverse microorganisms, including lactic acid bacteria, yeasts, and molds, contribute to flavor development, texture modification, and extended shelf-life (Fatima, 2025). These microbial interactions lead to complex biochemical changes, including the breakdown of macronutrients, the synthesis of vitamins and antioxidants, and the formation of unique flavor compounds (Fatima, 2025). Initially, fermentation occurred spontaneously, driven by microorganisms naturally present on the raw materials (Sionek et al., 2023) the exact composition of these microbial communities was often largely uncharacterized. In recent years, however, controlled use of specific microorganisms, including probiotic strains, has been adopted in food production to standardize and enhance fermentation outcomes.

Fermented foods worldwide contribute substantially to essential nutrient intake. Plant-based fermentations are well suited for delivering probiotic strains and generate bioactive metabolites including prebiotic fibers that can enhance probiotic effects (Sionek et al., 2023). A range of filamentous fungi is used in soybean fermentations, for example *Rhizopus oligosporus*, *R. stolonifer*, *R. oryzae*, *Neurospora sitophila*, and *Amylomices rouxii*; *Rhizopus spp*. are especially valued in industry for their amylase and protease production (Ardiani et al., 2024). Certain lactic acid bacteria (LAB) are applied as probiotic cultures, either alone or in combination, and play a central role in determining product quality. As probiotics, LAB may help preserve intestinal homeostasis and mitigate gastrointestinal conditions such as diarrhea, inflammatory bowel disease, and lactose intolerance (Latif et al., 2023). Research by (Soleha & Hanifa, 2024) revealed that the LAB from tempoyak samples collected in South Sumatera are *Lactobacillus sp*., *Lactobacillus kefri*, and *Lentilactobacillus buchneri*.

Table 1. Microbial communities found in Indonesian soy-based fermented foods

Products	Origin	Microorganisms	Reference
Tempeh	Central Java	*Rhizopus* spp. (*R. oligosporus*, *R. oryzae*, *R. stolonifer, R. chinensi,* and *R. arrhizus*)	(Teoh et al., 2024); (Romulo & Surya, 2021a)
Oncom	West Java	*Neurospora intermedia, Rhizopus oligosporus* or *Rhizopus oryzae*	(Nout & Aidoo, 2011)
Tauco	Cianjur, West Java	*Rhizopus oligosporus, Aspergillus oryzae, Pediococcus halophilus*	(Pawiroharsono, 2012)
Kecap (soy sauce)	Java	*Aspergillus oryzae*, *Rhizopus* spp.	Praveen & Brogi, 2025; Machida et al., 2008

Soy-based fermented foods

Soybeans are an important commercial source of both protein and oil. Soy protein is valued for its nutraceutical properties rich in essential amino acids, folate, isoflavones (plant-derived compounds with estrogen-like activity such as genistein and daidzein), saponins, phytic acid, and trypsin inhibitors while containing relatively low levels of saturated fat (Teoh et al., 2024). Soy is highly versatile as an ingredient and serves as the basis for many Indonesian fermented products including tempeh, oncom, tauco, and kecap. Fermentation of soybean not only improves texture and flavor but also enhances its nutritional profile (Harahap et al., 2025). Fermentation can also reduce the concentration of phytic acid concentration which is the antinutritional compound found in soybean (Dimidi et al., 2019). Research by (Fatima, 2025) showed that fermentation of soybean with Enterococcus faecium contributed to flavor development. Fermented soy products boast high levels of resistant starch and galactooligosaccharides to stimulate the growth and survival of probiotics (Khayatan et al., 2024).

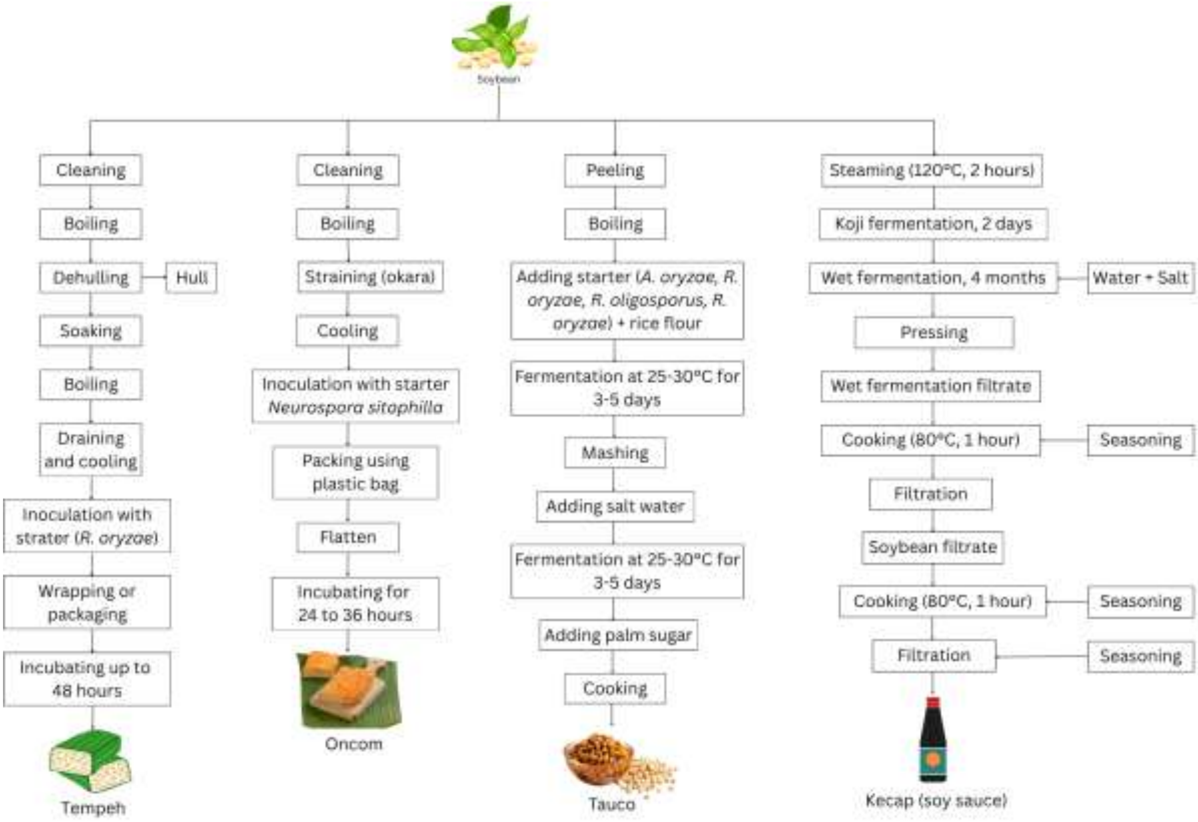

Figure 1. Flow chart of the process of making soy-based fermented foods

a) Tempeh

Indonesia is renowned for its rich diversity of fermented food products. Among them, one of the traditional fermented foods originating from Indonesia that has gained international recognition is tempeh. Historical records reveal that the term "tempeh" was first mentioned in the classical Javanese literary work Serat Centhini, written in 1815. As part of Indonesia's culinary heritage, tempeh has become an important component of Javanese culture, particularly as a plant-based protein source commonly consumed as a side dish (Kusumawati & Astawan, 2020). It can be prepared and consumed through diverse methods such as frying, boiling, steaming, or grilling. Tempeh is produced primarily from soybeans (*Glycine max* L.) through a fermentation process involving the use of laru, a starter culture containing molds of the genus Rhizopus spp. (Romulo & Surya, 2021).

In general, the production of tempeh has passed through generations, resulting in variations across different regions and even among producers within the same area. Nevertheless, the principal production steps are relatively consistent, including washing, soaking, dehulling, boiling, inoculating, packaging, and fermentation (Ahnan-Winarno et al., 2021). Broadly, the production process can be divided into two phases: the wet process and the dry process. The wet process involves washing, soaking, dehulling, and boiling, while the dry process consists of inoculation with starter culture, packaging, and fermentation (Kusumawati & Astawan, 2020). Tempeh production is affected by several factors, including humidity, temperature, duration of fermentation, and type of packaging (Magdalena et al., 2024).

The production of tempeh begins with washing the soybeans to remove impurities and ensure the cleanliness of the raw material. Once cleaned, the soybeans are soaked for a minimum of 6 hours and up to 24 hours. During the soaking stage, lactic acid fermentation occurs, which lowers the pH of the water to approximately 5.0. This condition helps suppress the growth of spoilage microorganisms while supporting the tempeh starter, including Klebsiella pneumoniae, which contributes to the synthesis of vitamin B12 (Kustyawati et al., 2020). In addition, soaking serves to hydrate and soften the soybeans, thereby facilitating the dehulling process. The dehulled soybeans are then boiled for 30 to 40 minutes to eliminate pathogenic bacteria, remove antinutritional compounds, and denature proteins (Teoh et al., 2024).

After boiling, the soybeans are cooled to 25–38 °C, the optimal temperature range for the growth of tempeh starter cultures. Under these conditions, inoculation with Rhizopus spp. initiates fermentation. The incubation process was carried out for 18–72 hours on wrapped soybeans. Limited air flow due to packaging causes *Rhizopus spp*. sporangia to form a dense, white, cotton-like mycelium, resulting in the formation of a compact cake. During fermentation, the soybeans undergo chemical and biochemical transformations, including the hydrolysis of lipids and proteins. These reactions lead to increased concentrations of free fatty acids and amino acids, accompanied by a reduction in carbohydrate content. Furthermore, the tempeh production process has been shown to significantly reduce phytic acid levels and activity of trypsin inhibitor, compounds known to interfere with nutrient absorption (Romulo & Surya, 2021).

Traditionally, tempeh has been packaged from various types of leaves, such as banana leaves and teak leaves. However, in modern practice, plastic is more commonly used as a packaging material because of economic considerations. Studies have shown that the type of packaging plays a role in the formation of volatile compounds that influence the aroma of tempeh. Tempeh packaged in banana leaves has been reported to contain α-pinene, a compound that imparts a characteristic nutty and savory aroma. In contrast, tempeh wrapped in plastic contains sec-butyl nitrite, which produces a cereal-like aroma (Harahap et al., 2018). Comparative studies between natural leaf-based and plastic packaging have indicated that tempeh wrapped in plastic tends to be more favored by consumers (Magdalena et al., 2024). This preference may be attributed to the fact that foods packaged with natural materials, such as leaves, often develop distinctive aromas and flavors that may not align with the preferences of certain consumer groups (Ng, 2015).

The nutritional composition of tempeh varies depending on the type of substrate used. Fresh tempeh (100 g) generally contains approximately 20.3–20.8 g of protein, 7.6–13.5 g of carbohydrates, 8.8–10.8 g of fat, 1.4 g of dietary fiber, and 234–412 mg of potassium (Sadewa & Murtini et al., 2020). In addition to protein, tempeh also provides various vitamins, including vitamin B1 (0.19 mg), vitamin B2 (0.59 mg), and vitamin B3 (5.9 mg). Notably, the presence of vitamin B12 in tempeh is unique, as it is not naturally found in soybeans but is synthesized during fermentation by specific microorganisms such as *Klebsiella pneumoniae* and *Citrobacter freundii*. Vitamin B12 is essential for neurological function and erythropoiesis (Astuti et al., 2000). Furthermore, during fermentation, the enzyme β-glucosidase is produced, which hydrolyzes isoflavone glycosides into their aglycone forms, such as daidzein, compounds recognized for their antioxidant activity (Kustyawati et al., 2020). These findings indicate that the fermentation process not only enriches the nutritional profile of tempeh but also enhances its functional potential.

Tempeh is recognized as a superfood because of its numerous health-promoting properties, which are primarily related to its isoflavone content and bioactive peptides. Isoflavones possess antioxidant activity that helps protect cells from oxidative stress and lowers the risk of several chronic illnesses (Liguori et al., 2018). In addition to isoflavones, bioactive peptides in tempeh have been reported to exhibit antihypertensive, antimicrobial, antioxidant, antidiabetic, and even anticancer activities, depending on their amino acid sequences (Puteri et al., 2018). Numerous in vivo studies have supported the health claims of tempeh. Animal studies have shown that tempeh supplementation can positively affect the gut microbiota and strengthen immune function (Soka et al., 2015). Additional findings indicate that tempeh has protective effects, including improving lipid metabolism (Astawan et al., 2018), lowering blood pressure (Ansarullah et al., 2017), enhancing memory (Handajani et al., 2022), and preventing alcohol-induced hepatic injury (Ari-Agung et al., 2013). Therefore, tempeh functions not only as a plant-based protein source but also as a functional food with potential protective effects against a wide range of chronic health conditions.

Although tempeh is classified as a functional food and is generally considered safe for consumption, its production process currently does not fully comply with adequate hygiene and sanitation standards, and regulatory oversight remains minimal. This condition significantly increases the potential for contamination in the final product. Specifically, improper soybean soaking can promote the growth of pathogenic microorganisms. In tempeh produced from inadequately soaked soybeans, the growth of Bacillus cereus has been detected, reaching high concentrations of up to 10^8 CFU/g (Ahnan-Winarno et al., 2021). Furthermore, contamination can also arise from Rhizopus microsporus var. microsporus (R. microsporus), a mold strain closely related to the preferred starter culture, Rhizopus oligosporus (R. oligosporus). The presence of the bacterium Burkholderia rhizoxinica within R. microsporus presents a risk of rhizoxin toxin production, which is known to possess antimitotic properties (Dolatabadi et al., 2016).

To minimize these risks, strict implementation of hygiene and sanitation principles is required at every stage of tempeh production, starting from raw material selection, soaking, boiling, and fermentation to packaging. The application of good manufacturing practices (GMP) and sanitation standard operating procedures (SSOP) represents an essential step in ensuring product safety. In addition, providing education to small-scale household tempeh producers regarding the hazards of rhizoxin toxins and the prevention of hazardous food additives should be further strengthened. Regular inspections by food safety authorities also play a critical role in ensuring that products in circulation comply with safety standards. With proper control measures, tempeh can be developed not only as a highly nutritious food but also as a safe product for public consumption.

b) Oncom

One of the traditional Indonesian soyfood originally from West Java is oncom, which has been known to be involved in Sundanese cuisine for centuries (Surya & Romulo, 2023). Oncom is a traditional Indonesian fermented food that stands out for its unique use of byproducts from the food industry, such as tofu residue, soybean pulp, and peanut press cake. The choice of these ingredients reflects not only local wisdom in turning waste into value-added food but also a form of sustainable innovation in line with the circular economy. Oncom is produced by inoculating the substrate with specific molds, followed by incubation for two to three days until the raw material is covered by mycelium. Depending on the mold used, there are two main types of oncom: red oncom, which employs Neurospora intermedia, and black oncom, which is typically made with Rhizopus oligosporus or Rhizopus oryzae (Nout & Aidoo, 2011).

From the perspective of microbial ecology, Neurospora intermedia plays a central role, as it not only produces natural orange pigments but also secretes enzymes capable of degrading proteins, carbohydrates, and lipids. On the other hand, Rhizopus species exhibit protease, amylase, and lipase activities that improve nutrient availability in the substrate (Nout & Aidoo, 2011). These molds are essential, since fermentation not only alters the texture and flavor of the final product but also enriches it with bioactive compounds that support health. However, because fermentation is still commonly performed in open environments, the risk of contamination by unwanted microorganisms such as lactic acid bacteria or wild molds remains a challenge that can compromise both quality and safety (Liu et al., 2019).

Nutritionally, fermentation enhances the value of oncom by making proteins more digestible and transforming soybean isoflavones into aglycone forms that are easier for the body to absorb (Rohimah et al., 2021). In addition, oncom provides B-complex vitamins, dietary fiber, and secondary metabolites such as bioactive peptides and carotenoids with antioxidant activity. As a result, its consumption may contribute to lowering cholesterol, supporting digestive health, and protecting against oxidative stress (Sundari & Efriwati, 2015). These benefits highlight oncom's potential as a functional food derived from Indonesia's rich fermentation traditions.

Despite its promise, the development of oncom still faces significant hurdles, particularly in terms of safety and standardization. One concern is the possibility of mycotoxin contamination if fermentation is not properly managed (Aidoo et al., 2006). Moreover, oncom is often perceived as a low-class food, which limits its market value. To address these issues, modern approaches are needed, such as purification of inoculum, optimization of fermentation conditions, strict adherence to food safety standards, and innovations in packaging and product diversification, are needed. With these strategies, oncom could not only maintain its cultural significance but also be positioned as a competitive functional food alongside other well-known soybean-based fermented products such as tempeh and natto.

c) Tauco

Tauco is one of the food seasonings in Indonesia that is produced through the fermentation of soybeans. This fermentation enhances the flavor of tauco and can also increase the nutritional value of soybeans. Soybeans are known to have biological activities that include antioxidant properties, estrogenic effects, protection against osteoporosis, and the potential to fight cancer (Larasati et al., 2017). Tauco, which has the best protein and fat content is found in the treatment with a 20% (w/v) sodium chloride solution, with protein and fat contents of 33.19% and 18.37%, respectively (Djajasoepena et al., 2014).

Tauco is a food seasoning made from boiled, ground soybean seeds (*Glycine max* L.) that have been allowed to ferment. Tauco fermentation is performed by soaking the mixture in saltwater and then drying it for several weeks until the characteristic tauco aroma emerges or the soaking water turns reddish-brown. Midway through this process, soaking often results in a strong smell, such as rotten fish or shrimp paste. Some traditional tauco producers say that during the soaking process, the soaking water that is processed into soy sauce, while the soybean seeds become tauco. There are various ways to process taucos, each with its own unique characteristics. The example of tauco circulating in the Riau region differs from tauco in Java and Kalimantan. Each region has its own unique characteristics. In experience, tauco can be stored for years and will not spoil or spoil as long as it is not exposed to raw water or contaminated with other organic materials during storage. To date, there has been no more detailed research on tauco. In some areas, tauco is used by manual laborers (especially the Chinese community) as a side dish with every meal, particularly when eating clear porridge. It is commonly used as a seasoning or flavoring in making side dishes, such as chicken with tauco sauce, tauco fried rice, stir-fried fish with tauco, etc. (Joe, 2011). Tauco is a processed food made from soybeans. Although tauco has a high protein content, it can only be used as an alternative source of protein energy for the body. Because of its use, tauco is only used in small quantities. Tauco has good nutritional value and is also beneficial for health, especially for digestion. The nutritional content of tauco is generally as follows: protein 10.4%, fat 4.9%, carbohydrates 24.1%, water content 56-65%, salt content 17.8%, ash content 7.4%, total sugar 9.2%, pH 4.9, and acidity as lactic acid 0.9% (Koswara, 2009).

The microbial ecology of tauco does not exist in isolation but rather interacts with each other within a consortium. Fungi provide enzymes to break down macromolecules into simple substrates. This substrate is then used by lactic acid bacteria and proteolytic bacteria to produce organic acids and amino acids. Moreover, yeast uses the resulting hydrolyzed sugar to produce aromatic compounds. This interaction creates a balance in the microbial ecosystem that shapes the distinctive flavor, aroma, color, and texture of tauco.

The emergence of contaminants in tauco production is highly influenced by environmental factors, particularly salt concentration, temperature, and the cleanliness of ingredients and equipment. A salt concentration that is too low (<15%) is unable to inhibit the growth of pathogenic bacteria, whereas high humidity triggers the growth of contaminating molds. Therefore, prevention can be achieved by maintaining the quality of raw materials, using a pure starter (Aspergillus oryzae), ensuring that the salt concentration meets standards (17–20%), and practicing hygiene during fermentation. The environment during the fermentation process can pose a risk of contamination from many sources, such as the water used during fermentation, an environment contaminated with human waste, unhygienic personnel during production, disease sources carried by insects or other organisms, and the presence of toxic substances or pathogens in the raw materials that may not be eliminated owing to imperfect processing (Steinkraus, 2002).

d) Kecap (sweet soy sauce)

Sweet soy sauce, a viscous condiment with a characteristic dark brown color, is a prominent component of Indonesian cuisine. Its origin is linked to early Chinese settlers who introduced soybean fermentation to the Indonesian archipelago around the 3rd century BC (Judoamidjojo et al., 1985). The initial fermentation process yielded a simple salty soy sauce composed mainly of hydrolyzed soybean proteins. The Javanese community subsequently adapted this product by incorporating palm sugar, an abundant local sweetener, thereby producing a sauce with a distinct balance of sweetness and umami. This modification differentiated it from the original Chinese formulation and reflected the local adaptation of fermentation technology using region-specific raw materials (Kristoforus Kewuel et al., 2016). Over time, sweet soy sauce has evolved from a basic seasoning to a staple condiment and cultural symbol of Indonesia. It is widely applied to enhance flavor in a variety of dishes such as grilled meats, fried noodles, and traditional soups (Meutia, 2015). In addition to its use as a flavor enhancer, it commonly serves as a marinade for meat and tofu or as a dipping sauce mixed with sliced chili and onion. Its widespread consumption demonstrates the integral role of sweet soy sauce in the sensory and cultural identity of Indonesian cuisine.

The principal raw material of sweet soy sauce is soybean (Glycine max), a legume rich in protein and essential amino acids. Black or yellow soybean varieties are typically used, as their proteins are readily hydrolyzed during fermentation into amino acids and peptides that contribute to the characteristic umami flavor (Etza Setiani et al., 2024). In addition to soybeans, palm sugar or coconut sugar serves as the primary carbohydrate source, imparting both sweetness and distinctive dark coloration to the final product. Salt is incorporated to regulate osmotic balance, enhance flavor, and ensure microbial stability, whereas water functions as the solvent medium for ingredient dispersion and fermentation. Certain formulations also include spices such as cloves, coriander, or cinnamon after fermentation to enhance the aromatic profile; however, their inclusion is optional and dependent on regional preference. In general, the production of sweet soy sauce involves the addition of soybeans, salt, palm or coconut sugar, water, and a mold inoculum during the initial fermentation stage. The selection of high-quality soybeans has been demonstrated to significantly influence product quality, yielding soy sauce with icreased soluble protein content, optimal pH, and improved sensory characteristics (Diez-Simon et al., 2020).

Sweet soy sauce is produced through a multistage fermentation process involving both solid-state and brine fermentation. Initially, the soybeans are cleaned, soaked, and boiled until they soften. The cooked soybeans are then inoculated with filamentous molds such as Aspergillus oryzae or Rhizopus spp. to initiate the solid-state (koji) fermentation stage (Praveen & Brogi, 2025) (Machida et al., 2008). During this phase, extracellular enzymes secreted by the molds, primarily proteases, amylases, and lipases, hydrolyze proteins into amino acids and peptides responsible for the umami flavor, while carbohydrates are converted into fermentable sugars (Chancharoonpong et al., 2012; Devanthi & Gkatzionis, 2019). After several days, the mature moromi (mold-fermented soybean mass) is mixed with salt solution and brown or crystal sugar and subjected to secondary fermentation for several weeks. This brine fermentation enhances flavor complexity and aroma development through enzymatic and microbial activity (Zhao G et al., 2021). In the final stage, the fermented mixture is boiled to concentrate the product and inhibit microbial growth. The combined action of mold enzymes and salt during fermentation is critical in developing the characteristic aroma, taste, and color of sweet soy sauce (Devanthi & Gkatzionis, 2019; Röling et al., 1994).

Sweet soy sauce primarily serves as a flavor enhancer and seasoning agent. Its complex aroma profile is attributed to a diverse range of volatile compounds, including alcohols, organic acids, esters, aldehydes, ketones, phenols, furanones, pyrazines, pyrones, and sulfur-containing molecules (Diez-Simon et al., 2020). The overall taste is dominated by umami and salty notes, resulting from the presence of free amino acids, nucleotides, and low-molecular-weight peptides, which are recognized as key taste-active compounds (Lioe et al., 2020). In culinary applications, sweet soy sauce imparts a characteristic sweet–savory flavor and dark coloration to various dishes such as fried rice, noodles, stews, satay, and grilled meats, thereby increasing their palatability and visual appeal.

Nutritionally, sweet soy sauce contains both macronutrients and trace minerals. One hundred grams of sweet soy sauce comprises approximately 63 g of water, 5.7 g of protein, 1.3 g of fat, and 9 g of carbohydrates, providing 71 kcal of energy. It also contains minor amounts of iron (0.006 g), phosphorus (0.1 g), and calcium (0.1 g). In addition to these nutrients, fermentation contributes bioactive compounds such as peptides and isoflavones with antioxidant potential. Furthermore, an antioxidant derived from soybeans, called melanoidin has been identified as a natural antioxidant capable of scavenging free radicals. Melanoidins are formed during fermentation and the final heating stage, when amino acids derived from soybean protein hydrolysis react with sugars originating from palm sugar, cane sugar, or molasses. This reaction not only produces the characteristic dark brown color of soy sauce but also generates bioactive compounds with antioxidant, antiglycation, and metal-chelating activities (Li et al., 2025). However, owing to their relatively high sugar and salt contents, sugar levels ranging between approximately 40–65% depending on formulation, and moderate consumption are recommended. Overall, sweet soy sauce contributes not only contributes to the sensory quality of foods but also provides limited nutritional and functional benefits to human diet.

Recent studies have increasingly focused on the quality of the raw materials and production processes involved in sweet soy sauce manufacturing. (Agustin et al., 2024)reported that soybean quality plays a critical role in determining final product characteristics, with high-quality soybeans yielding soy sauce containing relatively high soluble protein levels and superior sensory attributes. (Lusihanne et al., 2023) examined biochemical transformations during koji fermentation with Aspergillus oryzae, demonstrating the enzymatic hydrolysis of proteins and carbohydrates into amino acids and simple sugars that enhance flavor development (Lusihanne et al., 2023). From an economic perspective, (Wahyuni et al., 2018) analyzed the marketing and consumption trends of soy sauce, reporting an annual growth rate of approximately 10–20%, reaching 130 million liters in 2009. Socioeconomic assessments further indicate an increasingly competitive market landscape characterized by numerous local and national brands. Product innovation has also emerged, including the development of coconut palm sap–based soy sauce formulated for health-conscious consumers (Surya, 2024).Moreover, ongoing research exploring fermentation optimization, raw material diversification, and functional product development highlights sweet soy sauce as a continuing subject of interest in food science and technology due to its traditional and economic significance within Indonesia.

Conclusion

Traditional Indonesian soy-based fermented foods such as tempeh, oncom, tauco, and kecap (sweet soy sauce) embody a rich blend of cultural heritage, microbial diversity, and nutritional benefits. Fermentation enhances protein digestibility, increases bioactive isoflavones, and results in the production of compounds with antioxidant and health-promoting properties. However, challenges remain in ensuring consistent quality, hygiene, and microbial safety, especially among small-scale producers. Strengthening good manufacturing practices, using controlled starter cultures, and applying modern analytical tools can improve safety and standardization while preserving traditional authenticity. With these measures, Indonesia’s soy-based fermented foods can be developed sustainably as nutritious and globally competitive ethnic foods.

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