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Exploring bekasam, an indigenous fermented fish product of Indonesia: original South Sumatra region

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Abstract

Fermentation is a traditional method of food preservation that is widely used for improving shelf life, food safety, and sensory and nutritional properties. Fermented fish are an integral part of numerous food cultures and are produced in different parts of the world. Bekasam is an Indonesian traditional fermented fish commonly used as a condiment in Indonesian dishes because of its umami taste. This review tries to elaborate on various aspects of bekasam. The emphasis of this work is related to cultural history, microfunctional properties, manufacturing processes, biochemical and nutritional properties, as well as their health benefits and safety concerns. Moreover, some challenges and directions for future research regarding bekasam are also discussed in this review. Further investigation into fermented fish products is not only crucial for the food industry, but also for human health. Nevertheless, comprehensive in vivo and toxicological investigations are imperative prior to the utilization of fermented fish products that are abundant in bioactive compounds for the purpose of human health benefits.

Keywords Bekasam, Fermented fish, Indonesia, South Sumatra, Traditional

Introduction

Fish and fish-based products are good sources of nutrients such as essential amino acids and polyunsaturated fatty acids, making them a vital component of the human diet. These products supply almost 20% of the daily average animal protein intake of 3.1 billion people [1, 2]. A beneficial relationship between consumption of fish products and human health has also been reported in a number of studies, e.g., preventing cardiovascular diseases and reducing metabolic syndrome [3, 4]. Furthermore, fish product consumption also has a considerable correlation with a lower incidence of obesity in Japan [5]. Although global demand for fish and fish-based products is increasing, several challenges, such as susceptibility to oxidation, vulnerability to corruption, and seasonal availability, have driven the development of preservation methods [6, 7]. Particularly among preservation techniques such as smoking, chilling, and salting, fermentation has been the most prevalent [8]. It is an economical, practical, and energy-efficient technique for preserving fish.

Fermentation plays an important role in many parts of the world in the production of traditional fish products. Fermented fish products have a lengthy historical presence in Southeast Asia [9]. However, fermented fish prepared in the different countries are unique in their characteristics because of the differences in

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environmental factors, food preference, geographical location, and the availability of fish sources [10, 11]. Fermented fish are defined as fish that have been subjected to a series of desirable biochemical transformations via enzymatic or microbial processes. These changes include carbohydrates catabolism, degradation of proteins and lipids, and gelation of myofibrillar and sarcoplasmic proteins in fish muscle [12–14]. Acidification often yields antimicrobial compounds, which serve to prolong the expiration life of the substance and mitigate the risk of contamination. The gelation of muscle proteins changes the elasticity, cohesion, and hardness of the final products. Protein and lipid degradation liberates flavorful-tasting compounds and nutrients that exhibit enhanced digestibility and absorption capabilities [15].

One of Indonesia's fermented fish products is bekasam. Bekasam has an umami taste due to its high glutamic and aspartic acid content [16], and this product has a distinctive taste with other fermented fish products. Bekasam is widely known in South Sumatra and is commonly made from freshwater fish. The manufacturing of bekasam utilizes the activity of lactic acid bacteria (LAB) through spontaneous fermentation [17]. Some general reviews of bekasam have been published, and most of them outline the processing techniques and LAB characterization of the products. Herein, this review aims to primarily elaborate on the various aspects of bekasam including cultural history, microfunctional characteristics, fermentation process, biochemical and nutritional characteristics, functional activities, undesirable impacts on health, as well as their future prospects and challenges, which are also compared to other fermented fish product from another countries.

Methods

The literature review collected, analyzed, and synthesized crucial information from many sources such as books, journal articles, and other published materials. The materials provided an overview of the current knowledge on bekasam, identifying research gaps and proposing areas for future study. This literature review examined research on the cultural background of bekasam, the microorganisms in fermented bekasam, nutrient content, fermentation method, health advantages, safety issues, problems, and prospects. The sources were gathered from many databases and search engines often used for academic research, including Google Scholar, Garuda Kemdikbud, Web of Sciences, Springer, Science Direct, and Scopus. The criteria for inclusion were studies published in peer-reviewed journals, proceedings, or books that addressed microbial and nutritional aspects, traditional preparation methods, cultural significance of bekasam, as well as bioactivity and safety aspects. The exclusion criteria included studies not available in English or Indonesian. The database searches focused on topics such as bekasam, fermented fish, microorganisms in bekasam, cultural factors, nutritional aspects, health potential, and safety of fermented fish. The publishing year was restricted to the range of 1980 to 2024. The scholarly papers gathered from the searches used mixed methodologies incorporating both qualitative and quantitative data for analysis.

Cultural history of fermented fish products in Asia

Fish that has been fermented has historical, regional, and cultural significance. Fish fermentation is an ancient practice, and there is evidence that fermented fish were popular in Japan during the Yayoi period (300 BCE to 300 CE) [18]. In a number of countries, fermented fish products have also been a staple part of diets [12]. However, the properties of fermented fish prepared in different countries are unique [11, 19]. Moreover, fermented fish products are closely associated with the culinary cultures of different countries, particularly in many Asian countries, where they are a part of the culture of numerous ethnic groups.

Since the widest variety of fermented fish products and their principal dietary role occur in continental Southeast Asia, this area should be regarded as one of their origins. In that region, the earliest human settlements occurred in the areas most conducive to rice cultivation. Therefore, freshwater fish species naturally occurring in local hydrological systems would have been fermented. These products continue to be developed most effectively from the region west of the Annamite Mountains to Lower Burma, where the main populations are Thai-Lao, Burmese, and Khmer Cambodia. It is likely that fermented fish products were made in the Indo-Chinese peninsula before the in-migration of the various ethnic groups [20].

Various types of fermented fish products are available in Asian markets, including fermented whole fish or fish pieces that retain their original structure as far as possible [21], fermented fish paste where the fish are converted into paste-like products [22], and fermented fish sauces where the fish is thoroughly transformed into a liquid form [23]. At present, fermented fish products are also popular in Asian countries, with their own distinctive characteristics and different names (Table 1). This distinction is a result of the particular combination of raw materials, environmental conditions, microorganisms, and dietary traditions.

In Indonesia, fermented fish products are called bekasam (Fig. 1). Generally, fish and salt are the major ingredients used in bekasam production, and additional ingredients such as cooked rice or brown sugar are commonly added to the mixture of fish and salt

Table 1 Fermented fish products in Asian countries

Name	Origin	Fish species	Types	Fermentation period	Salt concentration (w/w)	Reference
Bakasang	Indonesia	*Engraulis japonicus*	Fermented fish sauce	40 days	10–20%	[105]
Bekasam	Indonesia	*Cyprinus carpio, Clarias batrachus, Puntius javanicus, Oreochromis mossambicus, Trichogaster trichopterus, Chanos chanos, Oreochromis niloticus*	Fermented whole fish	3–6 weeks	15–20%	[30]
Budu	Malaysia	*Stolephorus spp.*	Fermented fish sauce	3–12 months	20–30%	[106]
Jeotgal	Korea	-	Fermented whole fish	2 months or a few years	5–30%	[107]
Katsuobushi	Japan	*Euthynnus pelamis, Katsuwonus pelamis, Euthynnus affinis, Auxis rochei, Auxis thazard, Sarda orientalis*	Fermented whole fish	3–4 months	10–15%	[108]
Nam-pla	Thailand	*Stolephorus spp., Rastrelliger spp., Cirrhinus spp.*	Fermented fish sauce	5–12 months	> 20%	[109]
Patis	Philippines	*Clupea spp., Decapterus spp., Leiognathus spp.*	Fermented fish sauce	3–12 months	22–26%	[65]
Pekasam	Malaysia	*Puntius gonionotus, Oreochromis mossambicus*	Fermented whole fish	2–3 weeks or 12 month	> 10%	[110]
Plaa-som	Thailand	*Puntius sophore*	Fermented whole fish	8–12 days	6–11%	[111]
Shidal	India	*Puntius sophore, Setipinna phasa*	Fermented whole fish	3–5 months	–	[75]
Suan yu	China	*Cyprinus carpio*	Fermented whole fish	30–60 days	3%	[21]
Yu-lu	China	*Engraulis japonicus, Channa asiatica*	Fermented fish sauce	6 months	33%	[112]

Fig. 1 Documentation of bekasam, a traditional Indonesian fermented fish product originating from South Sumatra, **A** bekasam fermented product before cooked **B** bekasam fermented product after cooked

during preparation [24]. Bekasam has existed since the era of the Sriwijaya Kingdom in South Sumatra, Indonesia (Fig. 2). This region has abundant freshwater fish resources due to its historical human and geographical dependence on rivers, so freshwater fish products are also often found [25]. Bekasam manufacturing was started by local residents along the Musi River during the *Seluang Mudik* season [26]. This annual season is characterized by the decrease in river water levels and the abundant arrival of fish, particularly seluang fish. This season has seen a notable increase in the quantity of fish caught by fisherman. People have constraints in preserving their catches due to their susceptibility to deterioration. Because of the high quantity of fish available during that time and the absence of preservation technologies, people developed bekasam as a fermentation method to preserve fish [27]. Bekasam is now easily accessible, particularly in South Sumatra, due to its delicious taste. This product is commonly prepared by sautéing it with chopped shallots, garlic, and red chilies, and then served as a side dish with cooked rice. Additionally, Bekasam is commonly served at festivals, religious events, and weddings. This meal is usually given as a present to foreign tourists because of its durability and has become a typical culinary delicacy that provides food security for the people of South Sumatra [28].

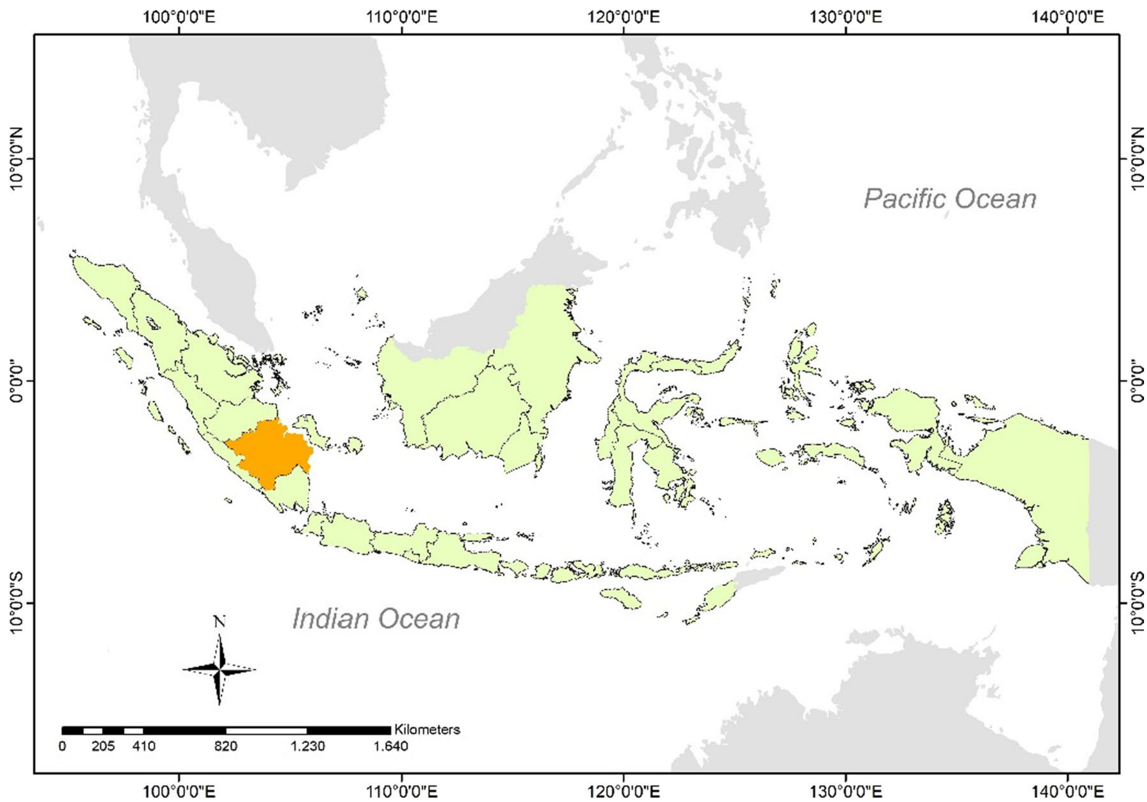

Fig. 2 Geographical map of the origin of bekasam, fermented fish from South Sumatra Indonesia (South Sumatra is highlighted with orange color)

Fermentation process of bekasam

The main raw material used for bekasam processing in South Sumatra is *seluang* fish (*Rasbora argyrotaenia*) [29]. However, some other freshwater fish, such as common carp (*Cyprinus carpio*), catfish (*Clarias batrachus*), java barb (*Puntius javanicus*), tilapia (*Oreochromis mossambicus*), and spotted gourami (*Trichogaster trichopterus*), are also appropriate raw materials [30]. Candra (2006) also prepared bekasam using milk fish (*Chanos chanos*) [31], and Vonistara et al. (2010) using Nile tilapia (*Oreochromis niloticus*) as a raw material [32]. Different from bakasang originating from North Sulawesi and Moluccas Island, this product used the internal organs (viscera and roe) of tuna and tuna-like fish as a raw materials. Some small marine fish, such as sardine (*Sardinella* sp.), anchovy (*Stolephorus* sp. or *Engraulis* sp.), and orange sunkist shrimp (*Caridina wycki*), are also suitable for bakasang production [33, 34].

Bekasam is a salted product that produced under spontaneous fermentation conditions and no specific microorganisms are inoculated into the fish. The addition of salt would often be an essential step to lower water activity and eradicate putrefying microorganisms [35]. The traditional production of bekasam begins with eviscerating and rinsing the freshwater fish. If the larger fish used, the fish is split into a butterfly shape. The fish then soaked in a brine solution containing 15–20% salt for 2–3 days at room temperature. The soaked fish is drained to remove excess brine solution and then combined at a ratio of 3:4 with a carbohydrate sources. The addition of carbohydrate sources such as cooked rice and brown sugar is a specific part of bekasam production and can be used as an energy sources for the growth of the desired microorganisms [24, 29, 36, 37]. The mixture of salted fish and cooked rice is placed into traditional clay or plastic jars and stored for 3–6 weeks at room temperature [38]. The Maillard reaction will occur at this stage, because the carbohydrate source will be degraded into simple sugars by microbial enzymes, which can then react with amino acids resulting from fish protein degradation in brine fermentation to produce melanin and flavor substances [39]. This process is almost similar to bakasang production, but no carbohydrate sources are added. In bakasang production, the internal organs of fish are appropriately washed with seawater and drained to remove excessive seawater. The raw materials are then mixed with 15–20% salt and poured into bottles. The bottles are stored for 3–6 weeks to enable fermentation to occur and produce a dark and viscous liquid. Traditionally, the bottles are stored in a warm location, usually near a source of fire [30].

Bekasam fermentation typically utilizes a brine solution with a high concentration with the fermentation period might range from several days to several weeks, resulting in either whole or pieces product. The lack of standardized processing procedures and hygiene practices is the primary factor that impacts product quality and safety. For ethical purposes and due diligence, good-quality raw materials in the production of bekasam are desirable. However, the general practice is that processors resort to fermentation in an attempt to salvage deteriorating fish, especially during periods of excess. Consequently, inferior quality raw fish is often processed as fermented bekasam products, which are acceptable by traditional quality standards but increase the risk of foodborne illness [11]. The addition of salt during fermentation, proper hygiene and good manufacturing practices may contributed to the absence of pathogenic bacteria during bekasam fermentation.

The microbiological characteristics of bekasam and other fermented fish products

The microbiological characteristics regarding the microbiota composition of bekasam and other fermented fish products in Asian countries are summarized in Table 2. As salt-fermented fish are produced under spontaneous fermentation conditions and no specific microorganisms are inoculated, a variety of microorganisms can be found. In these fermented fish, in which salt fermentation is the primary process, the majority of microorganism populations are halophiles or halotolerant [40]. The determination of total aerobic bacteria in fermented fish products revealed a high level of microbial activity, with counts up to 9.3 log CFU/g. The total halophilic bacteria, which were highly favored by the common addition of salt, had values as high as 7.5 log CFU/g [41–43]. *Tetragenococcus halophilus* was the most represented halophilic bacteria found. This species is described as taste and flavor enhancers in fermented foods characterized by high salinity levels [44, 45]. Detailed halophilic microorganisms of bekasam are still limited, but an approach with fermented fish products can shed light on the potential dangers that may also be found in bekasam.

Significantly, regardless of the type of fermented food, LAB was also dominant, due to sufficient carbohydrates as growth substrates for LAB, with concentrations as high as 9.5 log CFU/g. In addition, *Staphylococcus* and *Bacillus* were frequently detected, with values up to 5.9 and 5.0 log CFU/g, respectively [41–43]. *Lactobacillus*

Table 2 Microorganisms found in bekasam and other fermented fish products

Name	Microorganisms	Reference
Bakasang	*Enterobacter, Micrococcus, Lactobacillus, Moraxella, Eriococcids., Pseudomonas, Staphylococcus, Streptococcus*	[33]
Bekasam	*Staphylococcus sp., Erysipelothrix or Lactobacillus sp.*, and *Streptococcaceae* family (*Aerococcus, Streptococcus, Pediococcus, Gemella*)	[31]
Budu	*Lactobacillus casei, Lactobacillus plantarum, Lactobacillus paracasei*	[113]
	Tetragenococcus spp., Halanaerobium spp., Staphylococcus spp., Acinetobacter spp., Weissella spp., Pseudomonas spp., Bacillus spp., Psychrobacter spp., Corynebacterium spp., Lentibacillus spp., Kocuria spp., Paracoccus spp., Brevibacterium spp., Comamonas spp.	[114]
Jeotgal	*Lactobacillus* spp., *Lactobacillus sakei, Weissella* spp., *Pseudomonas* spp., *Serratia* spp.	[61]
Katsuobushi	*Aspergillus amstelodami, Aspergillus chevalieri, Aspergillus pseudoglaucus, Aspergillus ruber*, and *Aspergillus sydowii*	[115]
Nam-pla	*Tetragenococcus halophilus, Tetragenococcus muriaticus*	[116]
Patis	*Bacillus sp., Pediococcus sp., Leuconostoc mesenteroides, Lactobacillus plantarum*	[117]
Pekasam	*Bacillus megaterium, Pediococcus pentosaceus, Lactobacillus plantarum, Lactobacillus pentosus*	[118]
Plaa-som	*Lactobacillus plantarum, Lactobacillus fermentum, Pediococcus pentosaceus, Weissella cibaria, Streptococcus bovis, Lactococcus garvieae*	[111]
	Lactobacillus plantarum, Lactobacillus acidophilus, Lactobacillus alimentarius, Lactobacillus farciminis, Lactobacillus kimchii, Lactobacillus plantarum, Pediococcus pentosaceus, Staphylococcus spp., Weissella confusa, Lactococcus garvieae	[119]
Shidal	*Lactobacillus plantarum, Pediococcus pentosaceus, Pediococcus acidilactici, Pediococcus lolii, Enterococcus hirae, Enterococcus lactis, Enterococcus faecium, Enterococcus faecalis*	[120]
Suan yu	*Lactobacillus spp., Lactobacillus plantarum, Lactobacillus brevis, Lactobacillus alimentarius, Lactobacillus farciminis, Lactobacillus acidipiscis, Tetragenococcus spp., Weissella spp., Staphylococcus spp.*	[121]
Yu-lu	*Halanaerobium spp., Halomonas spp., Fusobacterium spp., Photobacterium spp., Tetragenococcus spp., Halanaerobacter spp., Vibrio spp., Salinivibrio spp.*	[112]
	Halococcus spp., Halanaerobium spp., Halomonas spp., Tetragenococcus spp., Candidatus Frackibacter spp.	[122]
	Halanaerobium spp., Psychrobacter spp., Photobacterium spp., Tetragenococcus spp., Photobacterium spp., Pseudomonas spp., Vibrio spp., Shewanella spp., Halococcus spp., Halobacterium spp.	[123]

plantarum was the most commonly found *Lactobacilli* in fermented fish products. It is frequently linked to the enhancement of nutritional value in foods and the promotion of human health [46]. The prevalence of LAB in the majority of fermented fish products indicates that these bacteria originated in the aquatic environment via the raw materials [47]. As for yeasts, counts up to 8.7 log cfu/g were reported. Yeasts are one of the predominant microbial populations in fermented foods and are typically implicated in enhancing sensory quality through remarkable lipolytic and proteolytic activities [48]. Lastly, the occurrence of molds, which are commonly associated with food spoilage, discoloration, aroma and flavor deterioration, and reduced expiration life, was rarely reported in fermented fish products [49].

Based on culture-dependent methods, commercial bekasam made from milk fish (*Chanos chanos*) contained LAB, including *Lactobacillus sp., Aerococcus sp., Streptococcus sp.*, and *Pediococcus sp.* Additionally, *Staphylococcus sp., Erysipelothrix*, and *Gemella* were also present [31]. Bekasam made from sepat rawa fish (*Trichopodus trichopterus*) reported contain *Pediococcus acidilactici* [50]. Ijong and Ohta [51] also reported that *Staphylococcus sp.* and *Lactobacillus sp.* were the predominant bacteria isolated from bakasang. Other bacteria isolated in bakasang are *Micrococcus sp*., *Streptococcus sp*., *Bacillus sp*., and *Clostridium sp*. Bakasang prepared from small sardines (*Engraulis sp*.) contained additional microorganisms, including *Enterobacter sp., Moraxella sp*., and *Pediococcus sp*. [33]. Culture-based techniques require a large amount of time and material cost and fail to provide an accurate and complete enumeration of the microbial community present. Nevertheless, this method has been used for a long time to investigate the dynamics of food-associated microorganisms [52]. In order to research the microbiota of complex food matrices, it is usually more accurate to combine culture-dependent and independent methods, the latter based on the identification of microbial genomically conserved regions [53].

Biochemical and nutritional properties of bekasam and other fermented fish products

Biotransformation of proteins and carbohydrates occurs during the process of bekasam fermentation, as these substances are degraded into simpler compounds by microorganisms or the enzymes produced by them. Additionally, indigenous enzymes present in the fish facilitate the hydrolysis of fish protein and carbohydrate sources, which is responsible for the alteration in texture and flavor observed in the final product [54]. Fermented fish products from Asia usually have an alkaline pH [55]. In alkaline fish products, ammonia is naturally produced during the hydrolysis of proteins into peptides and amino acids. The release of ammonia elevates the pH of the final product and the growth of a few dominant bacteria, thereby facilitating the anaerobic decomposition of proteins that liberate amine compounds. The presence of ammonia, the high pH, and the rapid growth of essential microorganisms prevent the growth of bacteria that could potentially spoil the product, so that the product is very well preserved and stable when dried [56, 57]. Fermentation also induces carbohydrate degradation, which yields simple sugars that are capable of undergoing a Maillard reaction with amino acids derived from protein degradation. This reaction culminates in the formation of melanin and flavoring substances. Simple sugars can also be metabolized to organic acids and further converted into flavor substances via enzymes secreted by salt-tolerant microorganisms [39].

Numerous variables influence the nutritional properties of fermented fish, such as the percentage of salt in the product, the fermentation time, and the presence of microorganisms in the product. The nutritional properties of various fermented fish products are summarized in Table 3. For bekasam, this product is in semisolid form with a high moisture content. It also contains a high nutritional composition, including a high amount of

Table 3 Nutritional properties of bekasam and other fermented fish products

Name	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)	Reference
Bakasang	57.15	25.97	14.77	1.11	1.00	[58]
Bekasam	66.95	5.76	4.81	14.3	8.23	[124]
Hentak	35.00	–	37.63	9.91	–	[75]
Jeotgal	64.30	11.40	12.90	3.20	8.20	[125]
Ngari	29.72	–	42.87	13.51	–	[75]
Shidal	25.93	14.67	49.23	8.62	1.55	[126]
Suan Yu	55.82	5.98	20.72	1.08	16.4	[21]

fats and carbohydrates, followed by ash and protein. In contrast, bakasang, in the form of fermented fish sauce, contains a high amount of protein and ash, comparable to shidal and jeotgal. The ash content is derived from the ingredients used and incorporated during processing, and also comes from the addition of salt during fermentation. High salt content in many fermented fish products can control the growth of pathogenic microbes and produce preferred flavors and aromas. The protein content of fermented fish products is derived from fish meat, and their hydrolysis during the fermentation process also produces a number of amino acids and short-chain peptides [58].

It has been widely reported that fermented fish products may contain both essential and non-essential amino acids [59, 60]. The essential amino acids consist of threonine, valine, histidine, arginine, lysine, phenylalanine, leucine, isoleucine, tyrosine and methionine, while non-essential amino acids include glutamic acid, aspartic acid, serine, glycine, alanine, proline and cysteine. The amino acid compositions of bekasam and other fermented fish products are given in Table 4. Leucine and lysine were the most abundant essential amino acids in bekasam, while glutamic and aspartic acid were the most non-essential amino acids. Glutamic and aspartic acid are umami-eliciting amino acids, and their presence in bekasam may contribute to its umami taste [16]. Similar findings were observed in bakasang, where lysine and leucine were identified as amino acids present in quite significant amounts. Unlike bekasam, bakasang has the highest histidine content, surpassing lysine and leucine, while bekasam has the lowest concentration of histidine compared to other amino acids. The predominant non-essential amino acids in bakasang were glutamic acid, aspartic acid, and alanine [58]. Yu-lu, fermented fish from China, provides dominant amino acids, including glutamic acid, lysine, leucine, valine, proline, and a small amount of alanine [61]. Bakasang and other fermented fish products such as budu, shidal, and rusip also produce umami amino acids in relatively high concentrations that serve as flavor enhancers in the presence of sodium salt [62]. The provision of vital nutrients, including essential amino acids and potentially health-promoting bioactive peptides, is an additional benefit of the bekasam consumption culture in South Sumatra.

Table 4 Amino acid compositions of bekasam and other fermented fish products

Fermented fish products	Bekasam	Bakasang	Budu	Hentak	Ngari	Rusip
Type of fish	Nile tilapia (*Oreochromis niloticus*)	Skipjack tuna (*Katsuwonus pelamis*)	Anchovies (*Stolephorus* sp.)	Cyprinid fish (*Puntius sophore*)	Cyprinid fish (*Puntius sophore*)	Anchovies (*Stolephorus* sp.)
Composition	Nile tilapia fish, roasted rice, salt	Skipjack tuna, salt	Anchovies, salt	Sun-dried cyprinid fish powder and petioles of aroid plants	Cyprinid fish, salt	Anchovies, palm sugar, salt
Asp	1.86	2.30	0.82	3.84	3.64	1.04
Glu	2.97	3.30	1.74	3.35	2.28	2.30
Ala	1.23	1.76	0.57	4.09	2.64	0.67
Gly	1.17	1.62	0.51	5.72	4.95	0.58
Ser	0.87	1.33	0.32	0.72	0.59	0.36
Thr	1.00	1.25	0.46	0.47	0.48	0.54
Val	1.07	0.91	0.55	2.55	1.52	0.66
Met	–	0.85	0.30	1.86	1.12	0.36
Ile	0.95	0.81	0.46	1.87	1.03	0.56
Leu	1.58	2.06	0.71	4.79	2.46	0.88
Tyr	0.58	0.97	0.32	3.65	2.58	0.39
Phe	0.94	1.18	0.38	4.91	3.23	0.46
His	0.53	3.36	0.31	1.00	0.80	0.40
Arg	1.19	1.68	0.17	–	–	0.35
Pro	0.75	0.82	0.35	4.45	3.15	0.40
Cys	–	0.04	0.06	–	–	0.10
Lys	1.41	2.72	0.75	3.81	3.00	1.04
Reference	[16]	[58]	[127]	[128]	[128]	[127]

In contrast, the cultural practice of incorporating chile sauce (*sambal*) into cooked rice in several region in Indonesia [63] satisfies a significantly lesser extent of nutritional requirements in comparison to bekasam [64].

The bioactive and functional properties of bekasam and other fermented fish products

Fermentation has traditionally been utilized for preserving fresh fish, but nowadays, in many cases, it also exhibits functional properties and health benefits. These functionally active substances are primarily derived from

Table 5 Functional properties of bekasam and fermented fish products

Name	Bioactivity	Method of analysis	Result	References
Bakasang	Antimicrobial	In vitro	*Pediococcus acidilactici* BksC24 isolated from bakasang had the highest ability to produce antimicrobial compound inhibiting the growth of pathogenic and spoilage bacteria (*Escherichia coli* ATCC 35218, *Staphylococcus aureus* ATCC 25923, *Pseudomonas fluorescens* FNCC 0070)	[129]
Bekasam	Antibacteria	In vitro	Bacteriocin isolated from bekasam inhibit the growth of *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, and *Salmonella* sp	[67]
	Antimicrobial	In vitro	Bacteriocin isolated from bekasam inhibit the growth of *Escherichia coli*, *Bacillus cereus*, *Pseudomonas aeruginosa,* and *Staphylococcus aureus*	[68]
	Antihypertensive	In vitro	Bekasam possesses ACE inhibitory activity which is thought to come from peptides formed during the fermentation process	[76]
	Anticholesterol	In vitro	*Lactobacillus acidophilus* present in bekasam produce statin and peptide which act as HMG-CoA inhibitors, a key enzyme for cholesterol biosynthesis	[69]
Budu	Antioxidant	In vitro	Two novel antioxidant peptides, LDDPVFIH and VAAGRTDAGVH, were isolated from Budu. The presence of hydrophobic amino acids (Ile and Leu), acidic (Asp) and basic (His) amino acids in the peptide sequences is believed to contribute to the high antioxidant activity of Budu extract	[130]
Fermented small cyprid fish	Anticoagulant	In vitro	Fermented small cyprid fish possesses fibrinolytic activity	[82]
Fish meat fermented by *Bacillus subtilis*	Antioxidant	In vitro	Fermented fish meat protein hydrolysate possesses free radical scavenging and antioxidant potential in vitro assays (DPPH radical method, reducing power assay, β-carotene bleaching and DNA nicking assay)	[72]
Heshiko	Antihypertensive	In vivo	Heshiko extract at low doses decreases systolic blood pressure in spontaneously hypertensive rats. ACE inhibitory peptides derived from heshiko extract are closely involved in the antihypertensive effect	[77]
Jeotgal	Anticancer	In vivo	Jeotgal possesses strong antiproliferative effects against the liver hepatocellular carcinoma cell HepG2	[81]
Katsuobushi	Antihypertensive	In vivo	Oligopeptides derived from Katsuobushi possesses ACE inhibitory activity and can effectively control blood pressure	[79]
Pekasam	Antioxidant	In vitro	Two novel peptides IAEVFLITDPK and AIPPHPYP from Pekasam demonstrated antioxidant activity. The presence of hydrophobic amino acids (Ile, Ala and Pro), and basic amino acids, (Lys) in the peptide sequences is believed to contribute to the high antioxidant activity	[74]
Plaa-som	Antimicrobial	In vitro	*Weissella cibaria* 110 isolated from Plaa-som produced a novel bacteriocin active (Weillicin 110) against some gram-positive bacteria	[131]
Shidal	Antioxidant	In vitro	Punti and Phasa Shidal exhibited antioxidant activity against DPPH radical scavenging and ferric-reducing power (FRAP)	[75]
Suan yu	Antimicrobial	In vitro	Enterocin P producing *Enterococcus faecalis* Gr17 isolated from suan yu shows the antimicrobial effects against the *L. monocytogenes, E. coli, S. aureus and B. cereus*	[132]

the extensive degradation of proteins during fermentation [65, 66]. Many studies have reported that fermented fish products may exert a variety of functional functions, including antimicrobial, antioxidant, anticholesterol, antihypertensive, anticoagulant, and anticancer activity (Table 5). For the bekasam product, bacteriocin isolated from this product inhibited pathogenic bacteria such as *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella* sp. [67]. The isolate of lactic acid bacteria from bekasam also possessed antibacterial activity against *E. coli*, *S. aureus*, *Pseudomonas aeruginosa*, and *Bacillus cereus* [68]. Rinto et al. (2017) also reported that *Lactobacillus acidophilus* present in bekasam is responsible for the production of statins and peptides that act as anticholesterols by inhibiting HMG-CoA [69].

According to recent research, uncontrolled free radicals such as peroxyl radicals, hydroxyl radicals, superoxide anion radicals, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals, and peroxynitrite anions have been implicated as causative agents of numerous pathologies, including neurodegenerative disorders, cancers, and autoimmune diseases [70, 71]. Protein hydrolysates prepared from fish meat fermented by *Bacillus subtilis* were found to possess interesting antioxidant potential in vitro assays by donating protons to free radicals and also having antibacterial activity against Gram-positive bacteria [72]. According to Siddegowda et al. (2016), bioactive peptides derived from fermented fish products may possess functional properties [73]. New antioxidative peptide sequences (AIPPHPYP and IAEVFLITDPK) rich in acidic, Glu (E) and Asp (D), basic Lys (K), and hydrophobic Ile (I), Ala (A), Val (V), and Pro (P) amino acids were identified in bekasam. These peptides can be used to improve public health and prevent ROS-related chronic diseases [74]. Low-molecular-weight peptides were also found in Shidal, and this product showed antioxidant properties against DPPH radical scavenging activity and ferric-reducing antioxidant power (FRAP) [75].

Fermented fish products can also be a source of antihypertensive activity. Bekasam from *Chanos chanos* was perceived to have ACE inhibitory activity due to the bioactive peptide from the degradation product of fish protein by endogenous-proteolytic enzymes or from the proteolytic activity of lactic acid bacteria [76]. Substantial quantities of peptides exhibiting angiotensin I-converting enzyme (ACE) inhibitory activity may be generated during the processing of fermented fish, and these peptides may possess antihypertensive properties [77, 78]. The oligopeptides derived from Katsuobushi have demonstrated efficacy in blood pressure regulation without causing detrimental effects on human health [79]. Katsuobushi is also regarded as a dietary supplement that can facilitate fatigue recovery [80]. In addition, peptides derived from salted mackerel by fermentation, *heshiko*, are closely involved in the antihypertensive effects [77]. Lim et al. (2001) reported that several fermented fish products, including *kajami-sikhae* (flat fish) and *chuneo-bamjeot* (shad gizzard), the main types of Jeotgals, can be considered potential anti-carcinogens due to their potent antiproliferative effects against the liver hepatocellular carcinoma cell HepG2 [81]. Furthermore, it has also been reported that fermented small cyprinid fish (*Puntius sophore*) contains fibrinolytic enzymes and can be considered anticoagulant and antiplatelet drugs [82].

Safety concern of bekasam and fermented fish products

The presence of biogenic amines in fermented fish products has been documented and presents a significant safety hazard [83]. Histamine, tyramine, putrescine, and cadaverine are the most prevalent biogenic amines found in fermented fish products [84]. Bacteria that are naturally present in decaying fish produce these nitrogenous compounds by decarboxylating the corresponding free amino acids [85]. Biogenic amines exhibit a lack of toxicity when consumed in low concentrations, yet their excessive consumption can lead to severe health consequences [86]. However, in individuals with diminished detoxification, ingestion of even a low or moderate biogenic amines may lead to food intolerance. Among biogenic amines, histamine and tyramine are the most functionally active amines [81]. Histamine regulates and modulates numerous functions by binding to four subtypes of membrane receptors in distinct tissues, including those of the cardiovascular, respiratory, gastrointestinal, hematological, and immunological system tissues, as well as the skin [87]. Tyramine is a vasoactive amine involved in hypertensive crises [88]. Individuals who are hypersensitive to this amine may experience allergy symptoms, headaches, respiratory disorders, vertigo, and tachycardia [89]. Close monitoring of biogenic amine levels in fermented fish products including bekasam is imperative to safeguard human health. The accumulation of biogenic amines is involved as precursors of nitrosamines, known as carcinogens [90]. Nitrosamines are typically produced by combining secondary amines found in fish with nitrite, which is frequently used for coloring, flavoring, and preserving fish [90, 91]. Moreover, crude (impure) salt and heating may enhance nitrosamine formation in bekasam. The relatively high concentrations of nitrosamines have been reported in traditionally fermented fish products in Thailand [92] and South Korea [93, 94].

Bekasam is usually produced by natural fermentation on a household scale. They operate individually or as family units, and occasionally hire laborers to assist them [95]. This can be attributed to the absence of responsible authorities supervising the appropriate implementation of hygienic conditions. For example, fish may be held under a person's foot on the ground, which can lead to microbial contamination. The lack of potable water is a problem for washing. Frequently, water from lagoons, rivers, lakes, or the ocean is used to wash fish, but these water sources are often polluted with all types of waste, making them a potential source of chemical and microbial contamination. The absence of education and awareness of hygiene also have a role in the propagation of health hazards from bekasam fermented product. Another study also reports that the occurrence of pathogens in numerous fermented fish products, such as *Staphylococcus aureus*, *Salmonella* sp., *Clostridium botulinum*, and *Listeria* sp., could have severe health implications [96]. Detailed safety aspects of bekasam are still limited, but an approach with fermented fish products can shed light on the potential dangers that may also be found in bekasam.

Future challenges and prospects

Although bekasam is a prevalent delicacy in the regions of South Sumatra, it has yet to achieve significant commercialization in Indonesia or even internationally. However, the globalization of indigenous fermented fish products, including bekasam, will persist as a result of increased comprehension regarding the fermentation process. Furthermore, the health benefits associated with the consumption of fermented fish could expand the market for bekasam. The future focus of bekasam products is to enhance the fermentation process by modifying and optimizing fermentation parameters. In order to maximize the potential of bekasam, the fermentation duration, temperature, and pH must be optimized in accordance with the type of fish utilized and the intended product. Additionally, further comprehensive research should be undertaken to analyze additional microchemical constituents in bekasam to develop a stronger foundation and direction on how to improve its sensory attributes. Systematic measures, such as basic good manufacturing and hygiene practices and the implementation of the Hazard Analysis Critical Control Point (HACCP) system, could effectively address safety concerns related to bekasam and other fermented fish products. The future perspectives of bekasam depend on technological advancements in the fermentation process and quality assessment. Most studies cited in this review focused on the characterization of fermented fish, including bekasam, in terms of biochemical, microbial, and functional properties, as well as their safety. The utilization of omics studies in assessing the microbial community of bekasam is expected to be more prominent. The advancement of technology in fermented fish processing is also an important direction, where the goals are to enhance the processes and address the issue of sustainability.

The role of microbes during fish fermentation has also garnered considerable interest, and numerous innovative methodologies have been devised to enhance comprehension of microbial ecological communities. However, to date, the majority of microbe-related research has been descriptive, consisting of preliminary microflora identification. The correlation between microbial metabolites and the regulation of flavor production is still not fully comprehended. Furthermore, the manufacturing of traditional fermented fish products is a time-honored sector on a global scale, and only a limited number of manufacturing methods have been commercialized. Future research investigations are required to explore the detailed mechanisms of microbial influence on the quality of fermented fish. The safety and nutritional value of fermented fish products constitute an additional area requiring investigation. A greater understanding of these is warranted due to the growing global and domestic demand for fermentation products.

Fish industry has also generated huge amounts of byproducts such as fish head, skin, bones, thorns, and viscera. Research on the reuse of fish by-product can contribute to increase industrial growth through sustainable development. Many other high-value bioactive compounds can be recovered from these [58, 97, 98]. Fermentation can also be applied to fish waste to obtain antioxidants and preservatives [99, 100], bioactive peptides [101], biocides [102, 103], flavor enhancer, or other products [104]. Hence, fish waste may serve as a important source of compounds for the pharmaceutical and food industries. This is an effective method for the valorization of fish by product, which contributes to the sustainability of fisheries production while minimizing environmental impact and benefiting the economy. Furthermore, the potential sustainability of fermentation as a technological process for generating these compounds should be acknowledged.

Conclusion

As a multicultural country, Indonesia possesses an extensive variety of cultural heritage. Bekasam, for example, is a traditional fermented fish product that is usually consumed and has been an integral part of Indonesian food culture for centuries, especially in the area of South Sumatra. The fermentation of bekasam is also strongly associated with local culture and natural resources, which vary greatly in other countries. The microbial profiles revealed a diverse microbial population in bekasam, which was different from other fermented fish products but was generally dominated by halophilic bacteria and lactic acid bacteria. Bekasam has been found to have essential nutrients and an extensive array of advantageous functional activities, but certain bacteria produce biogenic amines, which may be poisonous if consumed in large quantities. As a result, monitoring the quality of bekasam before consumption is critical. This review would help and support further research related to bekasam.

Abbreviations

ACE	Angiotensin I-converting enzyme
BA	Biogenic amines
CFU	Colony forming unit
DPPH	2,2-diphenyl-1-picryl-hydrazyl-hydrate
FRAP	Ferric-reducing antioxidant power
HACCP	Hazard analysis critical control point
HMG-CoA	3-hydroxyl-3-ethylglutaryl-coenzyme A
LAB	Lactic acid bacteria
ROS	Reactive oxygen species

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Declarations

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