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Processing technologies of various ethnic fish products consumed in Asian countries: a review

Kapil Deb Nath[a], Deepayan Roy[b] & Sankar Chandra Deka[a,*]

[a]Department of Food Engineering and Technology, School of Engineering, Tezpur University, Assam, India
[b]Department of Fisheries, Government of Tripura, India

[*]E-mail: sankar@tezu.ernet.in

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Since time immemorial, various communities across different countries have developed their own techniques of preparing traditional fermented ethnic fish products either by drying, smoking, or fermenting them together, or by combining the processes of drying, smoking, and fermentation. Fermentation is a common food preservation technique that improves safety of food, its shelf life, mouth feel, aroma, palatability and nutritional qualities. Fermented foods are those foods that are prepared through the regulated escalation of microbes and the enzymatic alteration of dietary components. Fermented fish is produced and consumed throughout the world, and it is an integral feature of many cuisines. It is also an affluent resource of microorganisms as well as a major industry in several countries of the world. These fish items are produced using an environment friendly preservation technology and natural packaging. As a result, food preservation technology becomes low-cost and accessible to the economically weaker section, and it also addresses the issues of food deterioration and food-borne infections. This review primarily aims to underline the process technology of various fermented fish products of some Asian countries and their preparation procedures. In addition, it also highlights the biochemical, microbial, nutritional quality and ethno-medical properties of various fermented fish products.

Keyword: Drying, Fermentation, Preservation, Quality, Smoking, Traditional ethnic foods

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Fish is one of the excellent sources of protein along with various nutrients such as fat, vitamins, and minerals that are meant for human physiology[1,2]. It plays an important part in the country's nourishment, revenue, employment, and overseas trade earnings. In our day-to-day diet, fish and shellfish are considered to be the most important resources of animal protein as they supply a large amount (typically ≥70%) of high-quality protein, particularly sulphur-containing amino acids[3].

People throughout the world have access to a wealth of traditional knowledge. Many ethnic fish-based ready-to-cook foods are made using diverse species of fish prevalent in the rivers, sea, tributaries, and hill streams. Drying is a time-honored, cost-effective, and efficient method of food preservation. The distinct flavor of each product has fueled demand for dried fish and shrimp[4]. Fish drying might take up to a week, depending on the weather. Nevertheless, drying for an extended period of time causes substantial damage, including blowfly infestation, shattered fragments, and dirt and dust infiltration. However, when products are dried in a restricted environment, such as under solar tent drier, it dries faster and is protected from dust, filth, bird, rodent, and insect infestations[5].

Fermentation is a cheap and time-tested process of food preservation. Because the fermentation of fish involves a variety of bacteria, it is possible that people have been inadvertently consuming microbes through their ethnic foods[6]. During fermentation, bacteria or enzymes present in fish tissues break down organic molecules into simpler chemicals[7]. Fermented foods undergo chemical and textural changes as a result of the microbial population, which can originate either naturally or via outside "starter cultures"[8]. Despite the fact that fermented foods involve naturally occurring living microbes (probiotics), the health benefits of regularly consuming them are still unclear[9]. In the process of fermentation of food, bioactive phenolics and volatile chemicals are bio transformed into new edible forms with increased odours and flavours[10,11].

*Corresponding author

Humans have been eating fermented fish since time immemorial in many societies throughout the world. Although they were most likely created for the purpose of preservation, it would have been obvious that these meals had other desirable qualities. Fermented fish have definite tastes, textures, appearances, and functions when judged against the unprocessed components from which they are produced. Fermented rations were purposely made many millennia ago, far before nutrition research, as a regular supply of vitamins, minerals, calories, and supplementary nutrients[12,13]. Various nations use a conventional process of preserving fish that involves salting and sun drying. The most basic method of preserving fish is curing[14].

Fermented fish items are quite popular in several provinces around the globe, particularly in Eastern and Southeastern part of Asian continent. Malaysia, Thailand, Vietnam, Myanmar, Cambodia, Indonesia, Laos, Philippines, Japan and China are among the countries in this group. '*Burongisda*' is a long-established Filipino dish popular in Philippines' middle region, especially in Pampanga, Bulacan, Cavite, and Nueva Ecija. Cambodian '*Prahok*', Malaysian '*Pekasam*' and '*Cencalok*', Korean '*Sikhae*' and Japanese '*Narezushi*' are all examples of similar Southeast Asian foods[15,16]. The preparation formula of '*Bagoong*' and '*Patis*' are almost akin, with the exception that the latter is allowed to ferment until the fish flesh has disintegrated into a liquid form. '*Bagoong*' is made from the solid state in the fermentation mixture, while '*Patis*' is made up of the liquid phase. The quality of these items varies according to the manufacturing method and the type of fish utilized. '*Bagoong*' is a fish paste having salty taste with a reddish brown colour and cheese-like aroma[17]. Indonesian '*Trassi*', Malaysian '*Belachan*', Thai '*Kapi*', Burmese '*Ngapi*', and Vietnamese '*Nam-ca*' are all similar goods[15,16].

The techniques of fermenting fish and the culinary applications of these products have been improved over many generations. This priceless cultural practice reflects the technological, social, and economic conditions of the location from where various products are generated. There is a lack of information about the history, production methods, culinary applications, and cultural relevance of traditional fermented foods outside of their native regions[18]. Researchers conducted a variety of studies and among these; there are a few that are worth mentioning. India, for example, has a plethora of fermented fish items for example '*Shidal'*, '*Ngari'*, '*Hentaak'*, '*Lonailish'*, '*Tungtap'*, '*Napham'*, '*Hukoti'*, '*Numsing'* etc. Among them '*Shidal'*, '*Ngari'*, and '*Hentaak'* are some of the most accepted long-established fermented fish dishes in Northeastern part of India. '*Shidal*' has long been regarded to have anti-malarial properties, and despite its unpleasant odour, it is still used to treat fevers[19].

The present review attempts to document and describe the traditional preparation processes/methods associated with important ethnic fish-based products all around the world *vis-à-vis* its biochemical, microbial, nutritional quality and the ethno-medicinal properties.

Fermented fish products

Since time immemorial, various communities across different countries are preparing traditional fermented ethnic fish products either by drying, smoking, or fermenting them together, or by combining the processes of drying, smoking, and fermentation. Fermentation is a common food preservation technique that improves safety of food, its shelf life, mouth feel, aroma, palatability and nutritional qualities. Fermentation is a cheap and time-tested process of food preservation. Since the fermentation of fish involves a variety of bacteria, it is possible that people have been inadvertently consuming microbes through their ethnic foods[6]. Fermented fish items are quite popular in several provinces around the globe, particularly in some Asian Countries and the most prominent ones are mentioned below:

India

Shidal

'*Shidal*' is a well-established fish product of Northeastern part of India prepared through fermentation technology having no salt. It is made solely from *Puntius* sp. (usually *Puntius sophore*), also referred as '*Puntishidal*', or from the estuary fish *Setipinnaphasa*, also termed as '*Phasa Shidal*'[20,21]. Because of its powerful flavour, the product is extremely popular. It is popularly called '*Shidal*' in Tripura, Mizoram and Nagaland; '*Sepaa*' in Assam; '*Verma*' in Arunachal Pradesh. Northeast India is notably the leading manufacturers of '*Shidal*'. Its powerful flavour comes from the decomposition of fish proteins and lipids and it generates peptides,

amino acids, fatty acids, indole, skatole, and other compounds that give the product its distinct aroma. The product has a solid, compressed, pasty look, and the form of the fish is nearly unchanged except for some disintegration at the abdomen and caudal section (Fig. 1). Upon prolonged exposure to the atmosphere, the colour of the top-grade material changes from a dull white to a mild brown to a deep brown tint. TVBN content of Punti and Phasa '*Shidal*' was 62.53±1.61 and 120.27±1.24 mg%, and TBA was 0.99±0.06 and 1.10±0.14 mg malonaldehyde per kg meat for both the products[20]. The authors revealed that such high TVBN limit could be related to the *Shidal*'s typical strong scent disguising the ammonical odour. Ahmed *et al.*[22] selectively isolated lactic acid bacteria (LAB) from '*Shidal*' and isolated *Lactobacillus plantarum* which was found to be the bacteriocin positive possessing antibacterial property[23] (Table 1). Kakati and Goswami[24] reported that, the spoilage indicators like total volatile basic nitrogen (TVBN), peroxide value (PV) were within the acceptable limit. In their analysis of pathogenic contamination, they detected *Staphylococcus aureus, Staphylococcus* sp. and *Escherichia coli* (Table 1) and they concluded that the presence of these contaminants may be due to improper handling and faecal contamination throughout processing and storage. If the growth of microbes cannot be controlled during storage of such products, it may increase the chances of allegation in terms of product excellence and wellbeing[25].

Lonailish

Majumdar *et al.*[20] reported a product, made entirely of estuarine fish Hilsha (*Tenualosailisha*) using elevated dose of salt called '*Lonailish*'. Due to its distinct aroma and flavour, the product is extremely famous in Northeast India. The product is made by slicing the hilsa fish, which is roughly 1.50-2.00 cm thick. A normal *'Lona ilish'* has a symmetrical pink colour with a shiny aspect when removed from the brine (Fig. 2). The flesh retains its strong structure and does not readily detach out of its bone. Salt fermented fish product '*Lona ilish*' was characterized which is consumed by Northeastern region of India and shown a high peroxide value in the product, but it did not impart objectionable spoilage of the product[26]. The high range of PV may be an indication of lipid peroxidation. The total viable count isolated from '*Lonailish*' comprised of *Micrococcus* and *Bacillus* and found to be 60% and 40% of the total bacterial flora, respectively (Table 1).

Ngari

'*Ngari*' is a prominent Manipuri fermented fish product which has high demand due to its several contributions to the primary diet[27]. For its production process, the sundried fish *Puntius sophore*, *Puntius ticto* and *Setipinna* sp. locally known as '*Phoubu*' is cleaned in water and let to drain for one night using permeable bamboo baskets. In the next morning, fishes are spread, covered with gunny bags, and squeezed by legs to eliminate extra water. The fishes are then placed into an earthen pot (capacity 45-50 kg) and a coating of mustard oil is rubbed to the pot's inner side, if it is an older one. But if the pot is new then 8-10 coatings are required in 7-10 days interval. After stuffing, containers are wrapped with plastic sheet, fish scales, oil slurry, clay, and cattle droppings slurry. For maturation of these packed containers, it is stored in dark for about 6-12 months at ambient temperature[28] (Fig. 3). Taorem and Sarojnalini[27] studied on the biochemical and microbiological qualities of '*Ngari'* prepared from *Puntius sophore* in different temperature ranges. TBA value lied within the acceptable limit but reached a higher range up to 1.11 at 20°C, 0.73 at room temperature and 1.20 at 40°C. In their study they divulged that the

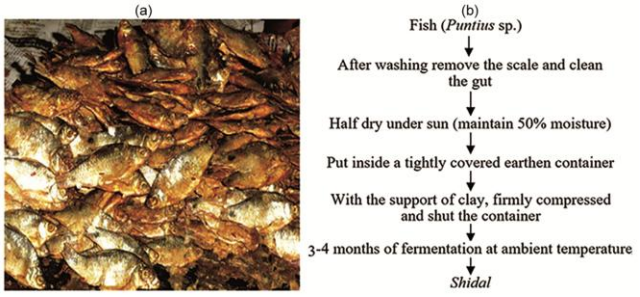

Fig. 1 — *Shidal* (a) *Shidal* product, (b) Flowchart of preparation of *Shidal*

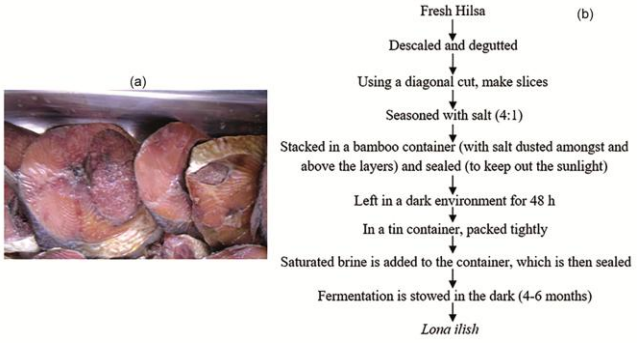

Fig. 2 — *Lona ilish* (a) *Lona ilish* product, (b) Flowchart of preparation of *Lona ilish*

concentrations of TVBN steadily increased as the storage period lengthened, and it was concluded that this was attributable to a change in temperature and subsequent microbiological and chemical alteration in the fish tissues. A slow decline of fungal count corresponding to the dying of total microbes' population was observed during the 6 months period of fermentation at different temperatures. They could not perceive the fecal coliform and *Salmonella* in analyzed samples of '*Ngari*'.

Hentak

'*Hentak*' is a paste like fermented fish product of Manipur and is prepared from *Esomus denricus*[29]. For its preparation process the fishes are dried under sun and ground into powder. Semi dried petioles of aroid plant *Alocasia macrorhiza* is mixed with the fish powder at an equal amount and crushed together to formulate a sticky paste. The paste is subsequently made into tiny balls and shifted to clay pots. These containers are then stored at ambient temperature for about 2 weeks for fermentation (Fig. 4). After that the product becomes ready to consume as curry or condiment. The changes of oxalate content from 0.32 to 0.05 mg/g were noticed during the 7 days incubation period and this loss could be inhibited significantly by treatment with antibodies. They claimed that some microbes that thrive in this environment could play a substantial impact in deterioration of oxalate in the paste. Lactic acid bacteria (LAB) were higher than that of other microorganisms in both '*Ngari'* and '*Hentak'*. On the basis of sugar fermentation process using the API (analytical profile index) system the Heterofermentative LAB as *Lactobacillus fructosus* and homofermentative LABs as *Lactobacillus amylophilus, Lactobacillus coryniformis* subsp. *torquens* and *Lactobacillus plantarum* were identified (Table 1). There was no mould count found in both the products[30].

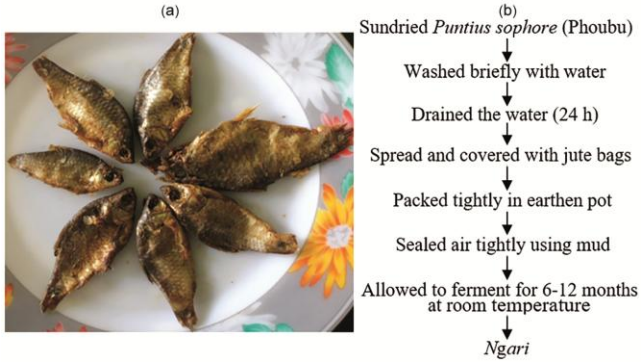

Fig. 3 — *Ngari* (a) *Ngari* product, (b) Flowchart of preparation of *Ngari*

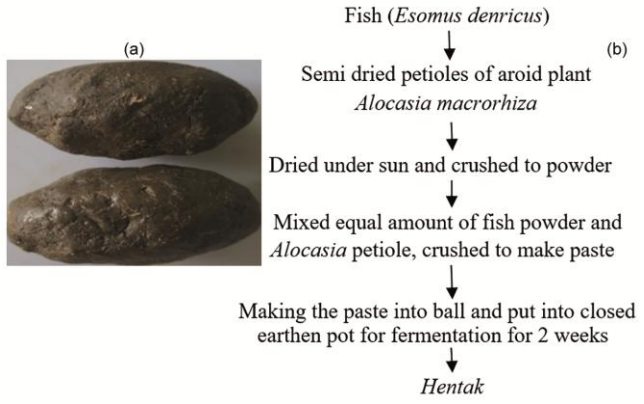

Fig. 4 — *Hentak* (a) *Hentak* product, (b) Flowchart of preparation of *Hentak*

Tungtap

'*Tungtap*' is a traditional fermented fish consumed by *Khasi* tribe of Meghalaya[31]. Fishes like *Puntius* sp. and *Denio* sp. are dried under sun for half a week and then mixed with salt at a proportion of 1:10 (salt: fish). The salted dried fishes are then supplemented with some amount of fish fat and crammed in clay pot, made airtight by means of fish scale, sludge or plastic sheet and allowed for fermentation for 2-6 months at ambient temperature (Fig. 5). *Lactobacillus* sp., *Enterococcus faecalis, Enterococcus* sp., *Streptococcus* sp., *Staphylococcus aureus,* and *Staphylococcus saprophyticus* were among the bacteria found in this fermented product[31] (Table 1). Yeast from the samples was identified as *Candida* and *Saccharomycopsis* sp.

Numsing

Muzaddadi *et al.*[32], investigated the conventional knowledge pertaining with '*Numsing*', an Assamese ethno-cultural fish product made by the *Missing* community. They reported that, '*Numsing*' is

Fig. 5 — *Tungtap* (a) *Tungtap* product, (b) Flowchart of preparation of *Tungtap*

prepared by small sized fish species such as *Puntius* sp., *Amblypheryngodon* sp., *Lepidocephalus* sp., *Channa* sp., *Trichogaster* sp., *Danio* sp., *Mastacembelus* sp., *Mystus* sp., *Rasbora* sp. etc. According to them, to manufacture the product, flame dried and smoked species are mashed together with petioles of arum (*Alocasia macrorrhiza*), placed in hollow bamboo containers, and allowed to mature for a month (Fig. 6). The entire procedure consists of various distinct processes, and the ultimate product is stored by suspending the fermenting bamboo container over a fire oven. In their study they stated that '*Numsing*' is normally prepared during the monsoon season when the trash fish and arum are abundantly available in the villages. *Namsing*'s microflora included both Gram-positive and Gram-negative bacteria, which steadily decreased as fermentation progressed. Mineral availability in '*Namsing*' was maximum during the third week of fermentation, then gradually reduced. The breakdown of the substrate by the available microorganisms is assumed to contribute to the availability of nutrients[33].

Napham

'*Napham*' is a fish-based fermented food specially prepared by Assamese *Bodo* people. It is one of their highly important and popular delicacies[34,35]. Dry fish, tender colocasia (*Colocasia esculanta*) shoots, mature bamboo tube, clay paste, and straw are used as raw materials in its production procedure. For the production of '*Napham*' small fishes are cleaned, washed, and dried for around 2 h for partial removal of moisture. The fishes are next smoked over low heat with dry rice chaff until they are completely dried. These fishes are then crushed using hand pound. The colocasia stems are also inserted during the grinding process. According to *Bodo* tradition, it is customary to use chilly in this concoction to eliminate awful odour. When the concoction is finished, it is poured into a one-plane-open bamboo tube. After that, the fish mixture is coated by means of dry leaves and the bamboo jar's entrance is sealed by a soil paste. The entire concoction is then fermented for 2 to 3 months and after this period of maturing; '*Napham*' is ready to be served as a condiment (Fig. 7). '*Napham*' is good source of mineral content and the compositions were estimated as calcium (68.90±0.16 µg/mL), sodium (67.26±0.150 µg/mL), magnesium (32.20±0.9 µg/mL), potassium (10.68±0.74 µg/mL) and iron (9.10±0.30 µg/mL). It consists of 32% essential amino acids, 40% non-essential amino acid and others included 28% out of all amino acids. The fatty acid such as pentadecanoic acid (C15:0) contribute 50%, tetradecanoic acid (C14:0) 24.67% and tridecanoic acid (C12:0) about15.04% and amongst monoenoic acid 4-octadecenoic acid (C18:1n-14) contributes about 3.65%[36].

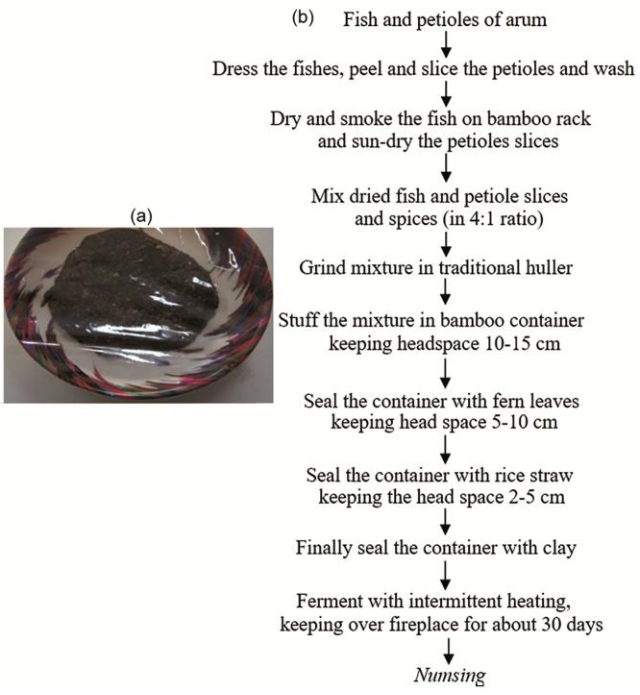

Fig. 6 — *Numsing* (a) *Numsing* product, (b) Flowchart of preparation of *Numsing*

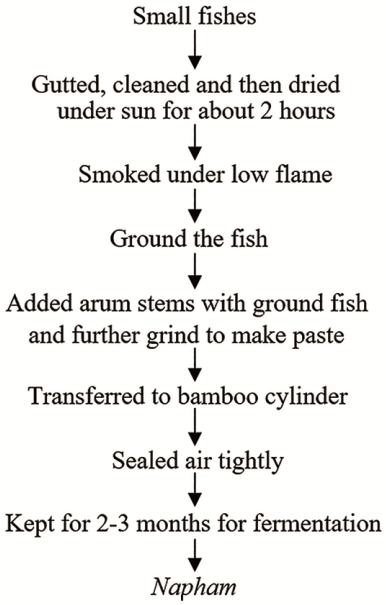

Fig. 7 — Flowchart of preparation of *Napham*

Cambodia

Prahok* and *Toeuk trey

The majority of Cambodians eat fermented and preserved fish as part of their diet. Most fermented dishes, for instance '*Prahok'* (fish paste) and '*Toeuk trey*' (fish sauce), are made from freshwater fishes. '*Prahok*' is Cambodia's national fermented and salted fish, and it's noted for its distinct taste and flavour. This product is prepared by crushing fish (*Channa striata* or other small fish) and mixed them with 150-200 g kg^{-1} of salt before being stored and fermented, and it ranges in colour from grey to brown (Fig. 8). '*Toeuk trey*' is a fish sauce that is prepared organically by fermenting small freshwater or marine fish which is light brown in colour. This is combined with salt in a 3:1 (fish: salt) ratio and can be preserved for a year. After being stored for more than 3 months, the liquid supernatant is filtered multiple times before being utilized or bottled[37]. The major organic acids in '*Prahok*' and '*Toeuk trey*' were acetic acid, lactic acid, pyroglutamic acid, and propionic acid. The presence of these organic acids in both fermented meals might be attributed to the presence of numerous Gram-positive rods and cocci[37]. Glutamic acid (2.31%), alanine (2.16%), valine (1.47%), leucine (2.85%), and lysine (2.64%) were the most common amino acids in '*prahok*'.

China

Suanyu

'*Suanyu*' is a classic South Chinese fermented fish dish. It is mostly made using whole or chopped freshwater fish or other grains, salt, and spices[38]. For preparation of '*Suanyu*', fishes need to be degutted, eviscerated, scaled, and rinsed. According to the tastes of the consumers, the proper proportions of salt, fish, and other spices are blended. The combinations are then cured for 12-24 h at ambient temperature prior to partial drying for 1-2 days. The cured fish is then combined well with roasted rice. In addition, part of the roasted rice is placed inside the fish stomachs. The combinations are placed in miniature pickle pots, which are then sealed properly. After that, the product is kept for fermentation at ambient temperature for about 2 months[39] (Fig. 9). Zeng *et al.*[40] isolated and identified bacteria from '*Suanyu*'. '*Suanyu*' starter culture, comprised of three species *viz.*, *Lactobacillus plantarum*, *Staphylococcus xylosus*, and *Saccharomyces cerevisiae*, which functioned as inoculums for the commencement of fermentation at 24°C. '*Suanyu*' treated with various mixed starter cultures recorded fast lactic acid bacteria (LAB) growth, decreased pH, suppressed thiobarbituric acid reactive substances (TBARS) and increase in total volatile base nitrogen (TVB-N), as well as proliferation of spoilage bacteria and pathogens. *Lactobacillus plantarum* and *Pediococcus pentosaceus* accounted for the majority of the LAB isolated from '*Suanyu*', followed by *Leuconostoc* and *Lactobacillus paralimentarius*. *Saccharomyces cerevisiae* and *Hansenula anomala* made up the majority of the yeast. *Staphylococcus saprophyticus* and *Staphylococcus xylosus* were the most common Staphylococcus isolates from '*Suanyu*'[41] (Table 1).

Yu-lu

'*Yu-lu*' is a typical fermented fish sauce common in China's Southern and Eastern provinces, especially Guangdong and Fujian, as a cuisine component. It is

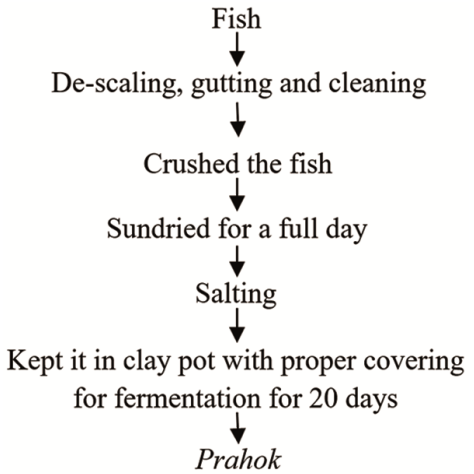

Fig. 8 — Flowchart of preparation of *Prahok*

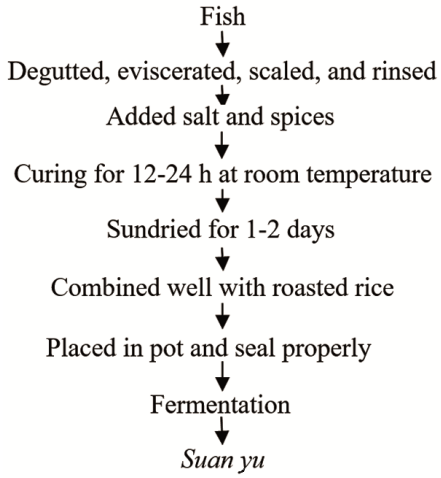

Fig. 9 — Flowchart of preparation of *Suanyu*

prepared by fermenting tiny fish that have been salted in a 3:1 ratio (fish: salt, w/w.) and the apparent brown fluid component produced from fermentation fish is the '*yu-lu*'[42]. The primary biogenic amines (>100 mg kg^{-1}) detected were putrescine, cadaverine, histamine, and tyramine, whereas the minor biogenic amines (<25 mg kg^{-1}) were tryptamine, spermidine and spermine[43].

Myanmar

Ngapi

'*Ngapi*' is a well-known Myanmar's fermented fish product which is prepared using high dose of salt. In order to prepare it, fish or shrimp are combined with 15% salt and then dehydrated. The dehydrated fish is then chopped and packed securely in wooden tubs, where it ferments within 1-4 weeks[44] (Supplementary Fig. S1). Based on the 16S rDNA sequences, the two organisms were identified as *Bacillus subtilis* and *Bacillus* sp[10]. On the basis of 16S rRNA gene sequencing and PCR-restriction fragment length polymorphism analysis of this gene, the majority of the isolates were identified as the halophilic LAB *Tetragenococcus muriaticus*. Molecular-analysis-based techniques revealed that spore-forming and non-spore-forming anaerobic bacteria such as *Clostridium* and *Halanaerobium*, as well as *Tetragenococcus muriaticus*, were commonly identified in bacterial communities[44] (Table 1).

Laos

Pa-som

'*Pa-som*' is a well-established fermented fish product and is indigenous to Laos. Descaled, eviscerated, and well rinsed fish or fish fillets are combined together with salt, garlic, and cooked in sticky or non-sticky rice; and allowed for fermentation. After 2 or 3 days of maturation, the product is considered ready to consume (Supplementary Fig. S2). Slightly prolonged fermentation (5 or more days) may also be favoured, if the temperature is low due to weather circumstances[45]. *Tetragenococcus, Lactobacillus, Pediococcus, Weissella, Halanaerobium, Clostridium* and *Sphingomonas* are the dominant microorganisms[46] (Table 1).

Nepal

Masular

The Nepalese *Tharu*group is preparing an indigenous fish product named '*Masular*' from old ages[47]. It is made by collectively crushing dry fish (*Sidra*) and leaves of bottle gourd (*Lagenaria siceraria* Standl.) in Okhali/Dikki, then shaping it into a pan cake-like shape and drying under sun (Supplementary Fig. S3). The final product bears its characteristics of dry fishy odor as it is prepared from *Sidra*. It is mainly prepared for consumption during "Deepawali", but it can be prepared in any season of the year and it serves as side dish or main dish (in unavailability of vegetables). Total Plate Count (TPC) value of $9.6\pm1.6\times10^5$ cfu/g, total mould count of $2.5\pm1.2\times10^2$ cfu/gm, and Staphylococcal count of $6\pm1.5\times10^5$ cfu/g were found in the microbial composition but no pathogenic bacteria *viz.*, Salmonella and Shigella were detected[47].

Saudi Arabia

Hout-Kasef

The '*Hout-Kasef*' is a typical fermented fish product produced from natural fermentation of salted mullet collected from the coast of Saudi Arabia's Jazan region[48]. The fresh fish is washed, dissected, and salted before being layered in wooden boxes and depending on temperature; they are kept on the fishing boat for a month or more for fermentation[11] (Supplementary Fig. S4). The most commonly used fish for preparation of '*Hout-Kasef*' is Mullet (*Valamugil scheli*). Nutritional value of '*Hout-Kasef*' includes protein content 25.71%, moisture 49.13%, fat 7.42%, ash 19.60%[48].

Philippine

Balao-balao

'*Balao-balao*' is a conventional Filipino dish prepared by means of using garlic and onion and served as a sauce or main course[17]. Live shrimps such as *Penaeus indicus* or *Macrobrachium* sp. are used for preparation of '*Balao-balao*'. For this, after proper washing live shrimps are added with salt (20%) and allowed the mixture to sit for 2 h before draining. After that, the salt free shrimps are mixed with cooked cooled rice at the ratio of 4.8:1 (rice to shrimp) and then mixed carefully with 3% salt before packing into the glass jar. The concoction is left to ferment at 28°C for 7-10 days (Supplementary Fig. S5). The dominated microorganisms of '*Balao-balao*' are *Leuconostoc mesenteroides* cocci, *Pediococcus cerevisiae* and *Lactobacillus plantarum*[17].

Table 1 Microorganisms associated with the various traditional fish products across various countries

Sl. No.	Fish product	Country of origin	Microorganisms associated	References
1	*Shidal*	India	*Staphylococcus aureus, Streptococcus* sp. *Escherichia coli* and *Lactobacillus plantarum*	Kakati and Goswami (2017)[24]; Ahmed *et al.* (2015)[22]
2	*Ngari*	India	*Lactococcus plantarum, Bacillus cereus, Staphylococcus aureus, Enterobacteriaceae, Candida* sp. *and Saccharomycopsis* sp.	Thapa *et al.* (2004)[30]
3	*Hentak*	India	*Lactobacillus fructosus, Lactobacillus amylophilus, Enterococcus faecium, Bacillus subtilis Bacillus cereus, Staphylococcus aureus, Enterobacteriaceae, Candida* sp. *and Saccharomycopsis* sp.	Thapa *et al*. (2004)[30]
4	*Tungtup*	India	*Lactobacillus coryniformis, Lactococcus lactis, Lactobacillus fructosus Enterococcus faecium, Bacillus subtilis Bacillus cereus, Staphylococcus aureus, Enterobacteriaceae, Candida* sp. *and Saccharomycopsis* sp.	Thapa *et al*. (2004)[30]
5	*Gunchi*	India	*Lactobacillus plantarum, Lactobacillus lactis, Lactobacillus mesenteroides, Candida bombicola, Enterococcus faecium, Enterococcus faecalis, Pediococcus pentosaceus, Candida chiropterorum, Saccharomycopsis* sp.	Thapa (2016)[58]
6	*Lonailish*	India	*Micrococcus* sp., *Bacillus* sp.	Majumdar and Basu (2010)[26]
7	*Namsing*	India	*Providenciaalc alifaciens, Staphylococcus xylosus, Kurthia gibsonii, Bacillus thuringiensis, Klebsiella pneumonia, Bacillus siamensis, Bacillus cereus, Bacillus subtilis, Bacillus tequilensis, Wohlfahrtiimonas chitiniclastica, Vagococcus fluvialis, Lactobacillus plantarum, Bacillus megaterium, Paenibacillus polymyxa*	Chowdhury *et al.* (2019)[33]
8	*Sidra*	India	*Lactobacillus lactis, Lactobacillus plantarum, Enterococcus faecium, Leuconostoc mesenteroides, Enterococcus faecalis, Pediococcus pentosaceus, Weissella confusa, Candida chiropterorum, Candida bombicola, Saccharomycopsis* sp.	Thapa (2016)[58]
9	*Sukakomaacha*	India	*Lactobacillus lactis, Lactobacillus plantarum, Enterococcus faecium, Leuconostoc mesenteroides, Enterococcus faecalis, Weissella confusa, Pediococcus pentosaceus, Chrysosporium chiropterorum, Candida bombicola, Saccharomycopsis* sp.	Thapa (2016)[58]
10	*Suanyu*	China	*Lactobacillus plantarum, Pediococcus pentosaceus, Saccharomyces cerevisiae, Hansenula anomala, Staphylococcus saprophyticus, Staphylococcus xylosus*	Zeng *et al.* (2013b)[40]
11	*Ngapi*	Myanmar	*Bacillus subtilis, Bacillus* sp., *Tetragenococcus muriaticus*	Kobayashi *et al.* (2016)[44]
12	*Pa-som*	Laos	*Tetragenococcus, Lactobacillus, Pediococcus, Weissella, Halanaerobium, Clostridium, Sphingomonas*	Marui *et al*. (2015)[46]
13	*Balao-balao*	Philippine	*Leuconostoc mesenteroides cocci, Pediococcus cerevisiae, Lactobacillus plantarum*	Sanchez (1999)[17]
14	*Burongisda*	Philippine	*Bacillus subtilis, Bacillus cereus, Lactobacillus brevis, Streptococcus faecalis, Leuconostoc mesenteroides, Pediococcus cerevisiae, Lactobacillus fermentum, Lactobacillus plantarum*	Sanchez (1999)[17]
15	Patis	Philippine	*Bacillus pumilus, B. coagulans, B. megaterium. B. subtilis, B. licheniformis, Micrococcus colpogenes, M. roseus, M. varians*	Sanchez (1999)[17]
16	*Tinabal*	Philippine	*Pediococcus pentosaceus, Streptococcus equines*	Sanchez (1999)[17]
17	*Pla-ra*	Thailand	*Tetragenococcus, Halanaerobium, Lactobacillus. Tetragenococcus muriaticus, Halanaerobium fermentans, Lactobacillus rennini*	Rodpai *et al.* (2021)[49]
18	*Terasi*	Indonesia	*Bacillus, Pseudomonus, Micrococcus, Kurthia, Sporolactobacillus*	Surono and Hosono (1994)[56]

Burongisda

'*Burongisda*' is a classic Filipino dish popular in Pampanga, Bulacan, Cavite, and Nueva Ecija. Several kinds of fish e.g., *Ophicephalus striatus* (burongdalag), *Tilapia plumbeus* (burong tilapia), Chanoschanos (burongbangus), and *Leiopotherapon plumbeus* (burongayungin), are used to create different variations of the product, with or without the inclusion of red rice[17]. Other Southeast Asian countries manufacture similar items, such as '*Phaak*'*or* '*Manchao*' in Cambodia, '*Pla-ra*' in Thailand, '*Pekasam*' and '*Cencalok*' in Malaysia, '*Sikhae*' in Korea, and '*Narezushi*' in Japan[15,16]. *Bacillus subtilis*, *Bacillus cereus*, *Lactobacillus brevis*, *Streptococcus faecalis*, *Leuconostoc mesenteroides*, *Pediococcus cerevisiae*, *Lactobacillus fermentum*, and *Lactobacillus plantarum* are the predominant microbes of '*Burong isda*'[17] (Table 1).

Bagoong, Patis* and *Tinabal

The preparation technique of '*Bagoong*' and '*Patis*' are almost similar, with the exception that the latter is allowed to ferment until the fish flesh has disintegrated into a liquid form. '*Bagoong*' is made out of the solid state in the fermentation mixture (Supplementary Fig. S6), while '*Patis*' is made up of the liquid phase (Supplementary Fig S7). The quality of these items varies according to the manufacturing method and the type of fish utilized. '*Bagoong*' is a paste with a slightly cheesy odour and a reddish-brown colour[17]. Indonesian '*Trassi*', Malaysian '*Belachan*', Thai '*Kapi*', Burmese '*Ngapi*', and Vietnamese '*Nam-ca*' are all similar[15-16]. Depending on the fish species used, the colour of '*Patis*' ranges from straw-yellow to amber. The product is prepared by slowly digesting or fermenting salted fish and then separating the solid and liquid portions of the hydrolysate. '*Patis*' is salty and has a cheese-like flavour, as well as a distinctive appetite-stimulating scent[17]. A kind of fish known as Molmol in local Visayan language is generally used for making an indigenous product '*Tinabal*'. Except for the cooking method, this fermented fish is nearly identical to fish paste. It has a specific flavour or taste that is distinct from other fermented fish products such as '*Bagoong*'[17]. There are 15 amino acids in '*Patis*', but no cystine or proline. The most abundant amino acids are lysine (1083 mg %), histidine (976 mg %) and glutamic acid (960 mg %). *Bacillus pumilus*, *Bacillus coagulans*, *Bacillus megaterium* and *Bacillus subtilis* are among the microorganisms responsible for the initial phases of fermentation of '*Patis*' while *Bacillus licheniformis*, *Micrococcus colpogenes, Micrococcus roseus, Micrococcus varians* and species of Staphylococcus are responsible for the later stage of fermentation[17] (Table 1). The most common lactic acid bacteria found in '*Tinabal*' between 0-21 days of fermentation were *Pediococcus pentosaceus* and *Streptococcus equines*[17] (Table 1).

Thailand

Pla-ra

'*Pla-ra*' is a traditional Thai dish that is popular in all parts of Thailand, particularly in the North and Northeast. It is mostly prepared from freshwater fishes like *Channa striata*, *Trichogaster trichopterus*, *Trichogaster leeri*, *Cyclocheilichthys repasson*, *Puntius gonionotus* and marine fishes such as *Johnius argentatus*, *Rastrelliger neglectus*, *Rachycentron canadus*, *Caranx leptolepis* etc. '*Pla-ra*' is made by fermenting raw fish with rice bran or roasted rice flour and salt for at least 6 months to a year in a sealed container[49] (Supplementary Fig. S8). According to the ingredients used, '*Pla-ra*' is divided into two sorts. '*Pla-ra Khao-kuo*' was the name given to '*Pla-ra*' that has roasted rice added to it, whereas '*Pla-ra Ram*' is the name given to '*Pla-ra*' that has rice bran added to it[50]. *Tetragenococcus muriaticus*, *Halanaerobium fermentans*, *Lactobacillus rennini*, *Staphylococcus nepalensis*, *Lactobacillus sakei*, *Lactobacillus pentosus*, *Weissella confusa*, and *Bifidobacterium bifidum* are the common bacteria found in '*Pla-ra*'[49] (Table 1).

Vietnam

Mam caloc

'*Mam ca loc*' is a sour fermented paste produced from *Channa maculata*, a snakehead fillet fishes. It is made by fermenting fish with salt (20% w/w) and rice powder (10% w/w) for an extended period and finally sugar is added to the product to season it[51]. '*Mam ca loc*' was found to have five halophytic strains of bacteria that are able to resist 17% salinity and produced protease. *Lactobacillus* sp. and *Bacillus* sp. were the strains with the highest protease activity (1.18 tyrosine unit/mL)[52].

Mam chuaca sac

'*Mam chuaca sac*' is also a fermented sour fish paste prepared from gourami fish (*Trichogaster trichopterus* and *Trichogaster microlepis*). The fish is cleaned and the head and digestive organs are detached, but the fins are kept. After soaking for 16 h in water, the organs are rinsed, drained, and dried up for 6 h before being mixed with sugar, 10% salt, rice powder, chilli, garlic, and 5% rice beer (v/w). The organs are then stored in sealed jars and matured at 28-30°C for 20-30 days. The shape of the fish is preserved, but the skeleton softens, leaving the dish boneless. It is best served as a side dish because the completed product is sweet, sour, and salty[53]. *Pediococcus acidilactici*, *Lactobacillus farciminis* and *Staphylococcus hominis* were among the bacteria recovered from '*Mam chua ca sac*' that produced amylases; however, only two strains, *Pediococcus acidilactici* and *Lactobacillus farciminis*, produced proteases[54].

Indonesia

Terasi

'*Terasi*' is a traditional Indonesian condiment made from fermented shrimp paste and the planktonous shrimp is used to make it. For most Indonesians, shrimp paste (*Terasi-udang*) is preferred over fish paste (*Terasi-ikan*). '*Terasi-udang*' is commonly blended with chilli, garlic, and salt, and is known as '*Sambal-terasi*'[55]. '*Petis-udang*' is another Indonesian shrimp paste that is extensively consumed. The trash (heads and shells) from the manufacture of Indonesian shrimp crackers (*Krupuk-udang*) is boiled to make '*Petis-udan*'[55]. Shrimp paste is known as '*Seinsanga-pi*' or '*Hmyinnga-pi*' in Myanmar. It is a pink to crimson paste created from tiny Mysis or planktonic shrimps. The paste prepared from first-class shrimp is known as '*Seinsanga-pi*', while the rest is known as '*Hmyinnga-pi*'. The nutritional value of '*Terasi*' comprises an average protein, sodium chloride, fat, and carbohydrate contents of 25.42%, 16.75%, 6.11%, and 1.94%, respectively. *Bacillus* is the most common microflora in '*Terasi*', followed by *Pseudomonus, Micrococcus, Kurthia,* and *Sporolactobacillus*[56] (Table 1).

Bangladesh

Nga-pi

'*Nga-pi*', an ethnic fermented delicacy historically created by *Rakhine* people in Cox's Bazar area of Bangladesh, and it is a popular cuisine item in that region. This product is mostly prepared, sold, and consumed as trendy food stuff in the country's Southeast region, primarily by Rakhaing tribal people. Small fish or shrimp are cleaned thoroughly before being mixed with salt and sun dried and pounded in a wooden mortar. After that, the mixture is then wrapped in leaves and placed in a bamboo container to age for 7-10 days before forming the end product, '*Nga-pi*' (Supplementary Fig. S9). The nutritional content of '*Nga-pi*' comprises of moisture, crude protein, crude lipid and ash 78.40%, 15.22%, 3.5% and 0.99%, respectively[57].

Conclusion

Most of the fermented fish products are very rich in proteins, essential fatty acids, essential amino acids, minerals and vitamins and in addition these products have very unique distinct flavour which attracts the consumers. These products are also having probiotic behavior and these organisms are extremely beneficial to human digestive system. Unlike the canned fish products which are extremely popular throughout the world, these fermented fish products can further be popularized especially among the urban masses and therefore it needs more detailed investigation, and it can be a multibillion-dollar market especially in the developing countries.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at https://nopr.niscpr.res.in/jinfo/ijtk/IJTK_23(04)(2024)324-335_SupplData.pdf

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Conflict of Interest

There is no issue of competing interest.

Author Contributions

The first author (KDN) and the second author (DR) have collected the data and written the whole manuscript except abstract and conclusion section. The third author (SCD) has written the conclusion, and abstract sections of the study, and has checked the manuscript. All authors read and approved the final manuscript.

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