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Characteristics of Indonesian traditional fermented seafood paste (*terasi*) made from shrimp and anchovy

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Abstract

Fermented seafood paste, *terasi*, is a ubiquitous ingredient in Indonesian traditional cuisine. It is commonly used as a flavor enhancer due to its unique, strong, and complex flavor. Traditionally, *terasi* is made using planktonic shrimp (*Acetes indicus*) but some regional varieties of *terasi* include other seafoods, such as fish in their recipes. The present study aimed to explore the cultural and ethnic significance of *terasi*, investigating the current traditional preparation of *terasi*, and analyze the characteristics of *terasi* made from shrimp and fish. The traditional practice of *terasi* making in Cirebon, its birthplace, often includes the use of anchovy (Engraulidae) as an additional ingredient besides shrimp, as observed among more than 70% of local producers. Therefore, we characterized several aspects of *terasi* made from shrimp and anchovy (fish) under different proportions. Higher proportion of fish in *terasi* was associated with darker color due to browning reactions and higher microbial load, particularly proteolytic and lactic acid bacteria. Nutritionally, higher proportion of fish increased the protein content of *terasi* but decreased its fat content. A series of chemical analyses revealed that the addition of fish in *terasi* significantly increased protein hydrolysis, lipid peroxidation, and non-enzymatic browning (Maillard) reaction, thus resulting in a significant formation of toxic compounds such as histamine and acrylamide. Interestingly, organoleptic analysis showed that *terasi* made from an equal proportion of shrimp and fish was preferred by the panelists. Therefore, this study suggested that mixing shrimp and fish could be used as a strategy to increase consumer's acceptance toward *terasi*. However, for food safety reasons, some adjustments in the fermentation period should be made in future studies since the addition of fish in *terasi* would increase microbial activity and accelerate chemical reactions.

Keywords *Terasi*, Shrimp paste, Fish paste, Fermentation, Ethnic food, Indonesian food

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Introduction

Terasi (Fig. 1A) is a traditional fermented seafood paste indigenous to Indonesia. It is traditionally made from finely crushed planktonic shrimp (*Acetes indicus*, Fig. 1B) locally known as *udang rebon* mixed with salt and fermented for several weeks to months [1]. Historically, *terasi* originated from the city of Cirebon in West Java, Indonesia (Fig. 2) and is believed to have been around in Java before the sixth century according to ancient Sundanese scriptures [1]. Related products are also found in other Asian countries, such as *belacan* in Malaysia, *kapi* in Thailand, *bagoong alamang* in the Philippines, *ngapi*

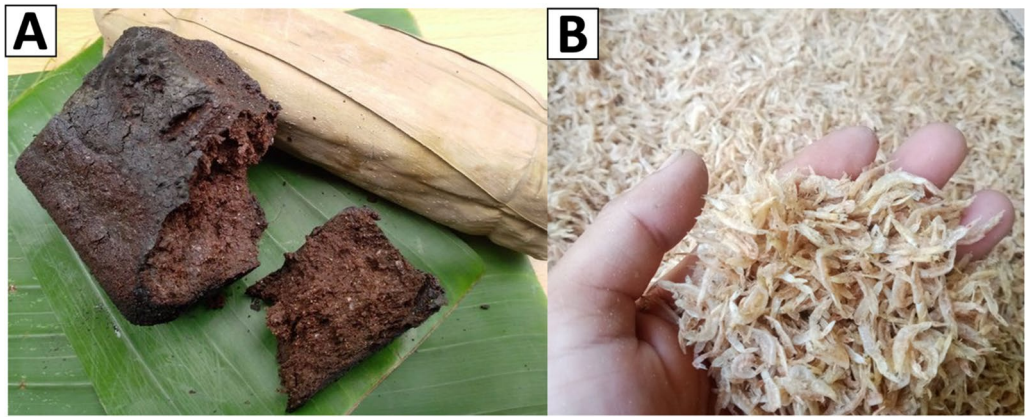

Fig. 1 **A** *Terasi*, a traditional fermented seafood paste from Indonesia. **B** Planktonic shrimp (*Acetes indicus*) locally known as *udang rebon*, the main basic ingredient of *terasi*

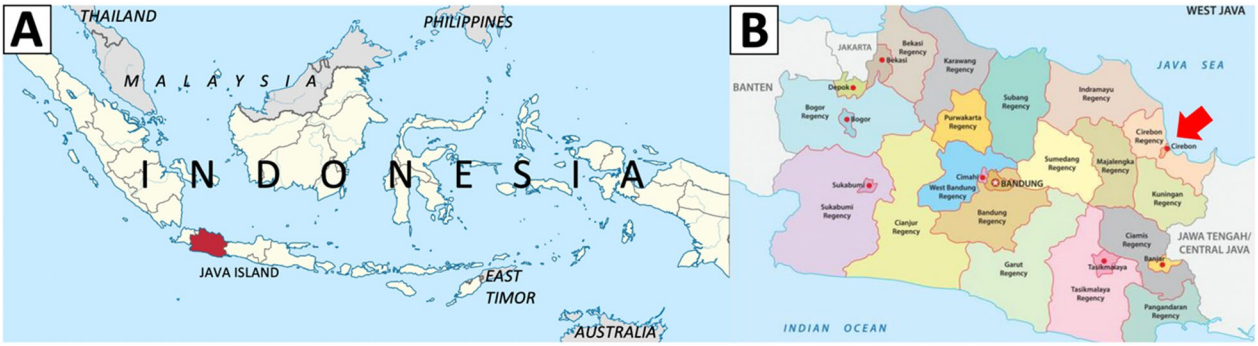

Fig. 2 **A** Map of Indonesia with the area of West Java Province filled with red. **B** Map of West Java indicating the location of Cirebon (red arrow), the city from which *terasi* is believed to originate

seinsa in Cambodia, *mam tom* in Vietnam, *shiokara* in Japan, *sae woo jeot* in Korea, *xiajiang* in China and *nappi* in Bangladesh [2]. *Terasi* possesses a complex flavor due to a myriad of different microbial activities and chemical reactions taking place mostly during the fermentation [3]. In Indonesian traditional cuisine, *terasi* is mainly used as flavor enhancer in many dishes, such as sweet and sour vegetable soup (*sayur asem*), peanut sauce served with vegetable salad (*gado-gado* or *lotek*) and spicy fruit salad (*rujak*) [4]. It is most extensively used as an ingredient to *sambal terasi*, a traditional Indonesian chili sauce made from crushed chili pepper, *terasi,* and other seasonings [5].

Being a famous basic ingredient in Indonesian cuisine, *terasi* has gone through a series of regional development in many areas in Indonesia. Different coastal regions in Indonesia adapted and created their unique recipes of *terasi* based on the local people's taste and the availability of raw materials in their surroundings [6]. In Bangka Island in Sumatera, *terasi* is mainly made of only shrimp and exhibits a bright red or purple color. The production of *terasi* in Belitung Island in Sumatra is unique since it entails burying small shrimp in beach sand for several days and the final product is presented in woven baskets made from pandan leaves. In Lombok, West Nusa Tenggara, *terasi* is made using a mixture of shrimp and other seafoods, such as fish, shellfish, or squid. In Rembang, Central Java, *terasi* is made with *petis*, a sticky paste produced from evaporated shrimp or fish extract [7].

Currently, international scientific literature about *terasi* is quite rare. Thus, the present study aimed to explore the cultural and ethnic significance of *terasi*, as well as to investigate the current traditional preparation of *terasi* in Cirebon, the birth city of *terasi*. In addition, through interview sessions with local *terasi* producers and literature review, we explored the cultural, historical, and ethnic food perspectives of *terasi*. Ingredient is one of the key factors that determine the characteristics and quality of *terasi*. Besides shrimp, fish is also commonly used as an additional ingredient in the production of *terasi*. Currently, there have been limited studies on the evaluation of different ingredients on the characteristics of

terasi and its derived product, *sambal terasi*. Therefore, this study also aimed to identify the physical, chemical, nutritional, and microbiological characteristics of *terasi* made from shrimp and fish under different proportions. The fish used in this study was anchovy (Engraulidae) naturally abundant in the northern waters of Java [8] and commonly used as an additional ingredient of *terasi* among the local producers in Cirebon. Furthermore, the consumer acceptance of *sambal terasi* was analyzed through a hedonic sensory analysis. The present study would enrich gastronomic knowledge, particularly in the production of *terasi* as an ethnic food that has been very little studied.

Methodology

Discussion, interviews, and literature review

To obtain information regarding the cultural, historical, and ethnic perspectives of *terasi*, a focus group discussion was held by inviting a local culture expert, a food expert, a university professor in Traditional Food Development, a local high school teacher in Art and Culture, two local *terasi* producers, a head of village, and two local citizens who consumes *terasi* regularly. Additionally, literature study on written scientific sources (books, online databases, and scientific publications) was also performed to collect additional information regarding the cultural, historical, and ethnic aspects of *terasi*. Separated semi-structured interview sessions involving 87 local *terasi* producers were also held to investigate the local production method of *terasi*. Information regarding the ingredients used in *terasi* production was recorded and the data were quantified descriptively. All the discussion and interview sessions took place in Cirebon, West Java, Indonesia by personal visits in March to April 2023.

Preparation of seafood paste (terasi)

In the present study, *terasi* was traditionally prepared as previously published [9] based on the described from a local *terasi* producer from Pantai Indah Kejawanan, Cirebon, West Java, Indonesia. Briefly, planktonic shrimp and Japanese anchovy were bought from a local fish market. These two main ingredients of *terasi* are later called simply as shrimp and fish in this manuscript. The whole shrimp and fish were blanched in boiling water for 5 min, drained and mixed with solar salt (15%). Five formulae of *terasi* were prepared in this study based on different proportion of shrimp and fish in the mixture: 1) formula with 100% shrimp, 2) formula with 75% shrimp and 25% fish, 3) formula with 50% shrimp and 50% fish, 4) formula with 25% shrimp and 75% fish and 5) formula with 100% fish. The salted mixture of shrimp and fish was fermented in an enclosed glass jar for 48 h at room temperature prior to grinding using a blender. The fermented paste was then formed into flattened balls (diameter 8–10 cm) manually and oven-dried (40 °C, 4 h). The dried paste was covered in recycled paper packaging and left fermented at room temperature for 60 days.

Color analysis

The color of the *terasi* samples was determined using a colorimeter (WF30-4 mm, Mingyi, Henan, China) according to the manufacturer's instructions. The color measurement scales included L* (light vs. dark), a* (red for positive number vs. green for negative number) and b* (yellow for positive number vs. blue for negative number) [10].

Proximate analysis

The proximate analysis of the terasi samples was performed according to the standardized methods established by the Association of Official Analytical Chemists (AOAC) and American Oil Chemists Society (AOCS) as previously described [11]. The moisture content was measured by gravimetry following oven-drying (135 °C, 2 h). The protein content was analyzed using the Kjeldahl method. The fat content was analyzed by gravimetry following sample extraction in Soxhlet apparatus with petroleum ether at 60 °C. The ash/mineral content was determined by gravimetry following calcination at 550 °C. The carbohydrate content was obtained by difference. All the results were expressed in percentage relative to dry basis.

Microbial load analysis

The total viable count was analyzed using a standard plate count agar containing 10% NaCl (pH 7.5) according to BAM (Bacteriological Analytical Manual) as previously described [12]. The *terasi* samples were diluted in peptone water containing 10% NaCl in serial tenfold steps prior to application onto agar by the spread plate technique and followed by incubation. The proteolytic bacteria content was analyzed using casein agar plates flooded by 0.0015% bromocresol green reagent [13]. The lipolytic bacteria content was determined using tributyrin agar (mTBA) enriched in Ca (2.5 mM) and Mg (5.0 mM) [14]. The lactic acid bacteria count was performed using MRS agar containing 1% $CaCO_3$ and 10% NaCl [15]. All the samples were incubated for 5 days at 35 °C.

Chemical analysis

For pH measurement, the *terasi* samples were diluted in distilled water with the *terasi*:water ratio of 1:10 (w/v) prior to pH measurement using a pH meter (Type 766, Knick International, Berlin, Germany) as previously described [9]. The amount of trichloroacetic (TCA)-soluble peptides in the *terasi* samples

was determined as previously described [16] based on the Lowry method using a UV–Vis spectrophotometer (Spectroquant Prove 100, EMD Millipore, MA, USA) at 650 nm. The results were expressed as mmol tyrosine equivalent/g dry sample. The thiobarbituric acid reactive substances (TBARS) assay expressing the lipid peroxidation end-products in the *terasi* samples was examined using a commercial TBARS assay kit (QuantiChrom, BioAssay Systems, CA, USA) according to the manufacturer's instructions followed by UV–Vis spectrophotometry (Spectroquant Prove 100, EMD Millipore, MA, USA) at 532 nm. The results were expressed as mg malondialdehyde (MDA)/kg dry sample. The histamine analysis in the *terasi* samples was performed using a commercial histamine assay kit (Megazyme, Dublin, Ireland) according to the manufacturer's instructions followed by UV–Vis spectrophotometry (Spectroquant Prove 100, EMD Millipore, MA, USA) at 492 nm. The results were expressed as mg histamine/kg dry sample. The acrylamide analysis in the *terasi* samples was analyzed using a commercial Acrylamide-ES ELISA kit (Life Technologies, Delhi, India) according to the manufacturer's instructions. Following incubation with acrylamide-linked antibody solution and substrate (color) solution, the absorbance was read using a microplate ELISA photometer (Infinite 200 PRO, Tecan, Männedord, Switzerland) at 450 nm. The results were expressed as mg acrylamide/kg dry sample.

Preparation of chili sauce and sensory analysis

The chili sauce (*sambal terasi*) was prepared from the *terasi* samples according to a published recipe [17] with some modifications. Briefly, Cayenne peppers (150 g), garlic (15 g), shallots (15 g) and toasted terasi (10 g) were mixed and stir fried in heated palm oil for 3 min. All the stir-fried ingredients were added with granulated sugar (10 g) and salt (5 g) prior to crushing using a blender until a smooth paste was formed. The chili paste was then heated until boiling and let cool down. The sensory analysis (hedonic rating analysis) was performed using 229 untrained Indonesian panelists aged 18–48 years old who confessed to like sambal and be used to consuming sambal on daily basis. The human study has been reviewed by the Ethics Committee at Bina Nusantara University (Jakarta, Indonesia). Each panelist was asked to rate 4 attributes (color, texture, aroma and taste) of *sambal terasi* samples (± 5 g) presented with commercial fish crackers (Brand Finna, Sidoarjo, East Java, Indonesia) according to their preference using the hedonic scale of 1–7 (1 for strongly dislike and 7 for strongly like). A glass of plain milk was provided for each panelist to neutralize their tongue between sample tastings.

Statistical analysis

The data obtained from interviews were analyzed descriptively. All data derived from laboratory and sensory analysis ($n \geq 5$) were reported as mean ± SD and were analyzed by one-way ANOVA followed by Tukey's HSD post hoc test in case of significant difference ($p < 0.05$). The software Systat 10 for Windows was used to perform statistical data analysis.

Results and discussion

Historical, cultural, and ethnic aspects of terasi

> *"Terasi is an integral part of the history of Cirebon. It has been, is, and will always be present on our land. It is in the blood of every local person of Cirebon."*
> *Interview, 21 April 2023*

Historically, *terasi* is believed to have existed in West Java before sixth century according to two ancient Sundanese scriptures, *Carita Purwaka Caruban Nagari* (1720) and *Mertasinga* (1880) [18, 19]. *Terasi* is believed to be invented by Prince Walangsungsang Cakrabuana (1430–1479), one of the founders of Cirebon Sultanate. According to these literature works, Cirebon had angered the King of Galuh Kingdom (now West Java Province and Banyumasan region of Central Java Province in present-day Indonesia) after its people stopped paying a tribute to in the forms of *terasi* to the king. Afterwards, it was mentioned that Galuh Kingdom attacked Cirebon due to such an act of disobedience.

Terasi was one of Java's most popular export commodities bought by traders from other islands or abroad. According to *Carita Purwaka Caruban Nagari*, Zheng He (alias Cheng Ho, 1371–1433) of Yunnan, a famous Chinese Muslim explorer, used to buy *terasi* during his visit to Cirebon and brought it back to his homeland [18]. He was believed to be the one introducing *terasi* to China, a foreign condiment that later became popular in China and was later modified by the Chinese locals before finally being incorporated in Chinese traditional cuisine.

In 1707, William Dampier, an English explorer, described *terasi* as "a salted shrimp preparation with a strong odor, but it renders any foods savory and is liked by the indigenous people" in his book entitled *A New Voyage Round the World* [20]. F. de Haan in his book entitled *Priangan, De Preanger-regentschappen onder het Nederlansch Bestuur tot 1811* wrote that there was a small land in Pamotan, East Java belonging to a local king that was dedicated to growing fish and shrimp for the *keraton* (royal palace) [21]. In 1820, John Crawfurd, a Scottish doctor and diplomat, narrated in his book

entitled *History of the Indian Archipelago* that smelling *terasi* would render foreign people not used to smelling it nauseated and that the local people used *terasi* in the local cuisine very commonly, like the Japanese using soy sauce in their food [22]. In the 1880s, Anna Forbes, the wife of Henry Ogg Forbes, a Scottish explorer and naturalist, wrote about her personal experience regarding *terasi* during their visit to the Dutch East Indies (now Indonesia) in her travel journal entitled *Insulinde* (that was reprinted a century later with the title *Unbeaten Tracks in Islands of the Far East: Experiences of a Naturalist's Wife in the 1880s*) [23]. She recorded her conversation with an Indonesian cook about her discovery of *terasi*.

The cultural and ethnic significance of *terasi* is strongly related to the geographical condition of Cirebon as a coastal city (Fig. 2). The abundance of seafood from Java Sea has shaped the local food culture that is strongly based on seafood. Indeed, *terasi* is made from ubiquitous tiny shrimp (*Acetes indicus*) locally known as *rebon*, the origin of the city's name [24]. For the people of Cirebon, *terasi* is much more than a people's food. It represents the city and people's identity. Etymologically, the word *terasi* is believed to be derived from the word *terasih*, where *asih* meaning admiration and the affix *ter* meaning most, thus their combination results in a word signifying the most admired [1].

Terasi also contributes to the socio-economic aspect and welfare of the local people in Cirebon. *Terasi* was identified as one of the most important factors influencing the economic growth in Cirebon in 2011–2021 [25]. Today, *terasi* is present in most local dishes from Cirebon and has become an important food additive in many Indonesian dishes, such as chili sauce (*sambal*), soup, salad, fried rice, etc. Due to its seafood-related flavor and salty taste, *terasi* is mainly used in savory dishes in relatively small amount. However, its strong flavor usually dominates and defines the overall flavor of the dishes into which *terasi* is added as an ingredient.

> *"Terasi is everywhere here in Cirebon. It is literally present in any salty and savory dishes. It is an integral part of Indonesian local food culture."*
> *Interview, 21 April 2023*

Local practice and production of terasi in Cirebon

> *"For the people of Cirebon, terasi is a symbol of pride and identity. The local people here know how to make terasi and the knowledge of making terasi is inherited from generation to generation in a family."*
> *Interview, 21 April 2023*

The local knowledge of *terasi* production is considered as a local heritage that is transferred through different generations. The local practice of *terasi* making and recipes of *terasi* may differ from one producer to another since the recipes are mostly passed down from the locals' ancestors. Basically, the main ingredient of *terasi* is planktonic shrimp (*Acetes indicus*) ubiquitous in Java Sea. They are classified as small prawns, 1–4 cm in long, translucent, but with a pair of black eyes and red spots of pigment on the uropods [26]. This species of wild marine shrimp has been reported to be the most heavily fished crustacean in the world in terms of total tonnage, reaching 402,000 tonnes in 2019 [27]. Currently, *A. indicus* is present in abundance in Java Sea owing to its high reproducibility and there is no management undertaken for its conservation by the local government. However, control the fishing *A. indicus* should be controlled to prevent decrease in its population or extinction, such as the extinction of giant featherback or *belida* (*Chitala lopis*) previously experienced in South Sumatra due to overfishing related to its massive use as the main ingredient of popular local fishcake [28].

The variation in the ingredients of *terasi* is mainly the incorporation of other seafood as ingredients besides shrimp. This practice is currently very common among the local producers. According to the local producers, combining shrimp with other seafood, mostly fish, would reduce production cost of *terasi* since fish costs generally lower than shrimp. In addition, the presence of fish would somehow modify the fermentation process and enrich the final flavor of *terasi*, thus contributing to different flavors of *terasi* produced by different producers.

Among the 87 interviewed local producers, only 13 (14.9%) admitted to produce only *terasi* made of shrimp (without any fish as an additional ingredient) while 48 (55.2%) of them produced *terasi* from a mixture of shrimp and fish. As many as 26 (29.9%) local producers produced both shrimp *terasi* and *terasi* made from shrimp and fish. Figure 3 shows the common seafood ingredients used in addition to shrimp in the production of *terasi* by the local producers in Cirebon. These seafoods, abundant in Java Sea, were mostly the main catch of the local fishermen [26]. Planktonic shrimp (*Acetes indicus*), locally known as *rebon*, was used by all local producers (100%) as the primary ingredient of *terasi*. Anchovy (Engraulidae), locally known as *ikan teri*, appeared to be the most used fish as an additional ingredient of *terasi* besides shrimp (71.3%). Other seafoods used as ingredients of terasi included Ariidae or *ikan manyung* (65.5%), Caesionidae or *ikan ekor kuning* (50.6%), squid or *cumi-cumi* (41.4%), mackerel tuna (*Euthynnus affinis*) or *ikan tongkol* (40.2%), snapper (Lutjanidae) or *ikan kakap* (24.1%), pomfret (Bramidae) or *ikan bawal* (13.8%), different types of clams or *kerang*

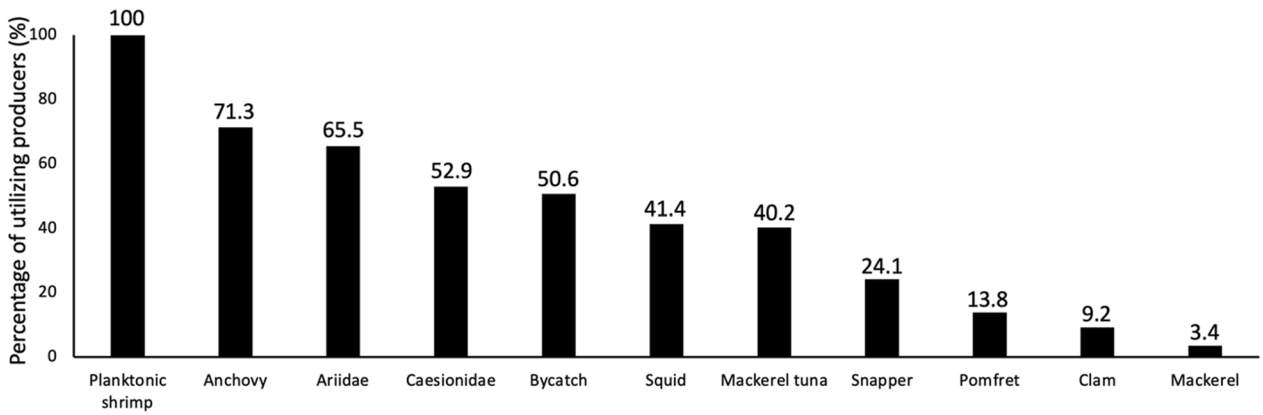

Fig. 3 Utilization of planktonic shrimp and other seafoods as additional ingredients of *terasi* among the local producers in Cirebon, West Java, Indonesia

(9.2%), and mackerel (Scombridae) or *ikan tenggiri* (3.4%). It is noteworthy that 52.9% local producers used bycatch as additional ingredients of *terasi*, thus meaning that they used a mixture of any unwanted and undefined marine creatures caught during commercial fishing for a different species. They performed such a practice to minimize food waste. However, such a practice could lead to an uncontrolled and inconsistent quality of *terasi* from an industrial point of view.

The production of *terasi* in Cirebon was mainly done using the traditional manner among all the interviewed local producers by mostly women. Due to the constant abundance of planktonic shrimp, the production of *terasi* happens all year long in Cirebon, Indonesia. Most local *terasi* producers (96.6%) were part of fishing families in coastal areas in Cirebon. This means that all the production steps were performed mainly using hands with traditional utensils (Fig. 4A–C). The traditional production of *terasi* consists of five main processes: materials preparation, salting, first-step fermentation, drying, and second-step fermentation (Fig. 5). The quality of raw materials is paramount for the final quality of shrimp paste [1]. The raw materials should consist of fresh shrimp and fish that have not exhibited any signs of spoilage. Sometimes, sorting process is required to remove unwanted fish or impurities.

Fig. 4 **A** Traditional preparation of planktonic shrimp as the raw materials for *terasi* production. **B** Mixing and grinding of ingredients and salt for *terasi* production using traditional pestle and mortar. **C** Sun-drying of *terasi* blocks. **D** Packaged *terasi* blocks sold in a traditional market

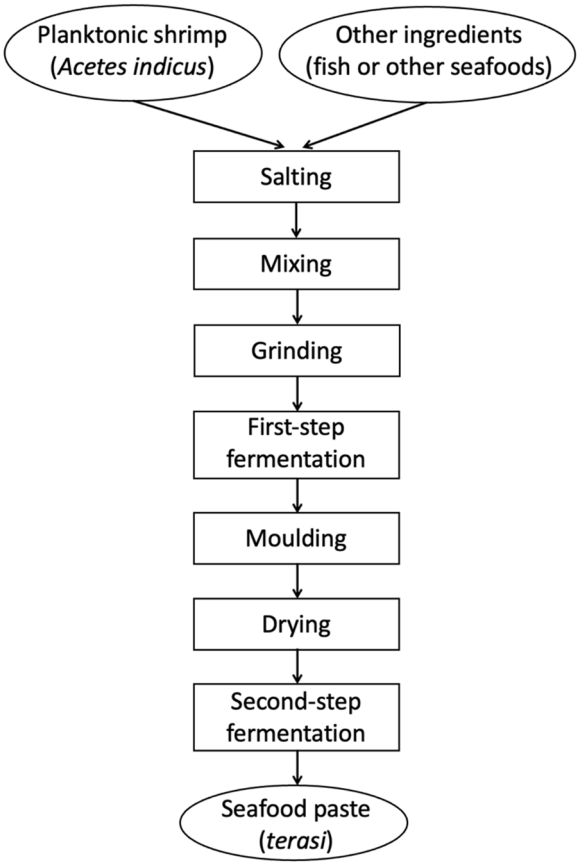

Fig. 5 Simplified flowchart of traditional production of *terasi*

Blanching in boiling water is performed by some local producers to kill pathogens and ensure food safety. Salting is a crucial step to produce *terasi* of high quality [1]. The amount of salt used among the local producers varied from as little as 2% to 20%. Usually, all the ingredients are ground with salt to produce a homogenic dough. The dough is then stored overnight (18–24 h) to incite the growth of beneficial microorganisms that will in turn develop the flavor of *terasi*. Following the first fermentation, the dough is usually formed into bricks-resembling blocks prior to drying under the sun (67.8%) or in the oven (32.2%) until their surface is subtly dried, leaving the filling still moist to allow microbial activities and further fermentation process. The dried blocks are then wrapped in banana leaves or paper packaging and left fermented for the second time at room temperature for 2–3 months to allow flavor development. During the second fermentation, the microorganisms present in *terasi* are mainly lactic acid bacteria that produce lactic acid, amino acids, and other metabolites that contribute to the distinctive flavor of *terasi* [9, 29]. These bacteria also inhibit the growth of other pathogenic and spoilage bacteria due to their ability to reduce pH value [29].

When ready, *terasi* is then sold by the local producers to vendors, middlemen or distributors who package it for resale to consumers. *Terasi* is widely marketed and ubiquitous in traditional and modern markets in Cirebon and other cities in Indonesia (Fig. 4D). Since *terasi* is categorized as an intermediate moisture food [9], the shelf life of terasi is quite long (3–6 months after the second fermentation when kept at room temperature). However, a study has reported that a prolonged storage of *terasi* at room temperature is highly correlated with the accumulation of toxic compounds (*e.g.,* histamine and acrylamide) and microorganisms that could be harmful toward human health [30].

With regard to the COVID-19 pandemic that altered the face of food system in humanity in 2019–2022 [31–33], terasi as a traditional food has shown a resistance by contributing to the local economy in a stable manner and being little affected by the pandemic, as admitted and evidenced by the local producers participating in the focus group discussion. Such a fact enhanced the positioning of traditional food, including *terasi* as an essential element in the local food culture of Cirebon. Furthermore, *terasi* as a gastronomic heritage is also expected to adapt with changes, develop, and undergo innovations, particularly in the post-pandemic era [34].

Physical characteristics of terasi

Since anchovy was the most common fish used as an additional ingredient of terasi besides shrimp (Fig. 3), this study focused on the formulation of terasi using different proportions of shrimp and anchovy. The production method was similar for all formulations.

The proportion of shrimp and fish strongly influenced the appearance of *terasi*, particularly color as shown in Fig. 6. The *terasi* made from only shrimp had a reddish brown color while the *terasi* made from only fish exhibited a very dark color (dark brown to black). Therefore, the higher the proportion fish in *terasi*, the darker its color as confirmed by the color quantitative analysis using the HunterLab values (Table 1). A higher proportion of fish in *terasi* led to a decrease in lightness (L*) but an increase in the a* (redness) and b* (yellowness) values, thus indicating the tendency of a darker and duller color. The dark color developed in *terasi* was due a series of chemical browning reactions during fermentation involving the enzymatic oxidation process that results in brown pigments such as quinones and the non-enzymatic browning process known as Maillard reaction between reducing sugars and amino acids [9, 29]. The proteins present in a relatively high amount in fish are prone to such browning reactions. In the production of

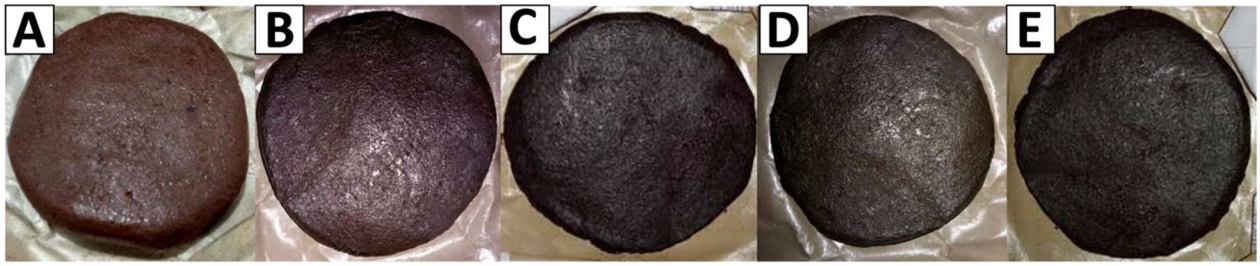

Fig. 6 Physical appearance of the *terasi* samples: **A** *terasi* made from 100% shrimp, **B** *terasi* made from 75% shrimp and 25% fish, **C** *terasi* made from 50% shrimp and 50% fish, **D** *terasi* made from 25% shrimp and 75% fish, **E** *terasi* made from 100% fish

Table 1 Color parameters of *terasi* samples, including L* (lightness), a* (redness) and b* (yellowness)

Formula	L*	a*	b*
S:F = 100:0	43.31 ± 1.74[a]	32.73 ± 1.67[a]	13.36 ± 0.84[a]
S:F = 75:25	39.32 ± 1.26[b]	45.81 ± 1.83[b]	35.17 ± 1.31[b]
S:F = 50:50	31.54 ± 1.49[c]	62.47 ± 2.07[c]	51.24 ± 2.25[c]
S:F = 25:75	30.37 ± 1.02[c]	63.56 ± 2.19[c]	66.47 ± 2.34[d]
S:F = 0:100	19.64 ± 1.28[d]	74.53 ± 2.42[d]	69.84 ± 2.57[d]

Data ($n = 5$) were expressed as mean ± SD. Different letters in the same column indicate significant difference ($p < 0.05$) following one-way Anova and Tukey's HSD post hoc test. S: shrimp, F: fish

terasi, Maillard reaction occurs mainly during the drying process in the oven due to the presence of heat and leads to the formation of a complex mixture of molecules [9], including the major brown pigments called melanoidins and the carcinogenic acrylamide [35]. The red color of shrimp *terasi* was related to the presence of astaxanthin, the main red pigment in *Acetes indicus* [36].

Nutritional characteristics of terasi

Figure 7 demonstrates the proximate composition of shrimp, fish and *terasi*. It is noteworthy that shrimp

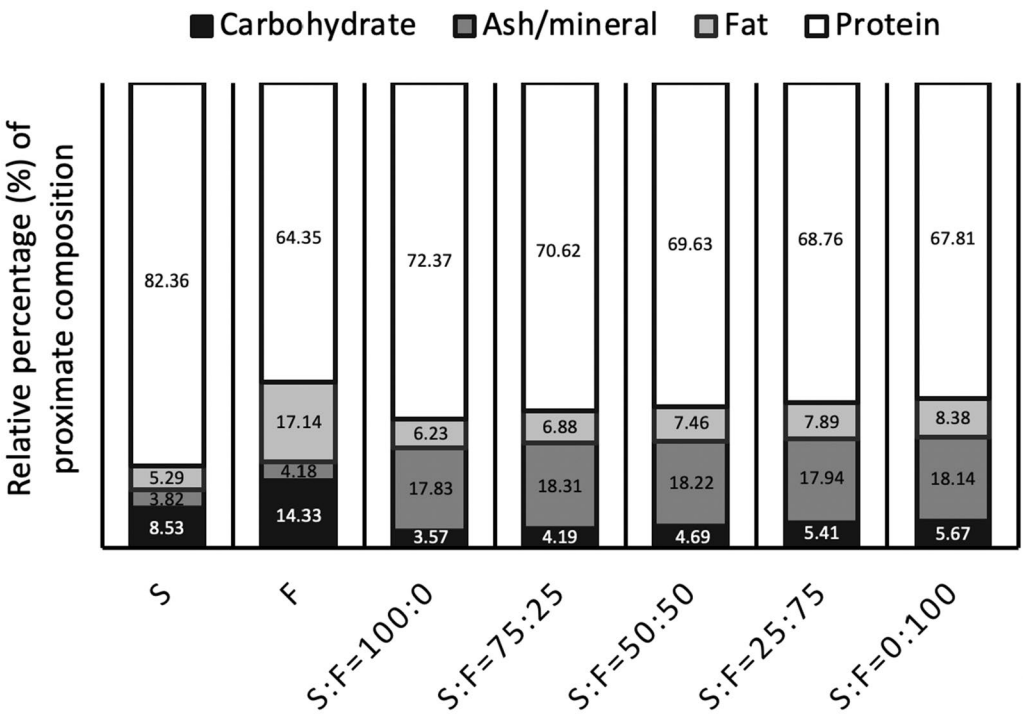

Fig. 7 Nutritional composition of *terasi* dry matters acquired from proximate analysis ($n = 5$). S: shrimp, F: fish

and fish had different nutritional profiles. Compared to fish dry matter, shrimp dry matter contained a higher level of protein but a lower level of fat and carbohydrate. As a result, the nutritional characteristics of *terasi* were strongly determined by the proportion of shrimp and fish used in its production. A higher proportion of fish in the shrimp-fish mixture tended to decrease the protein level of *terasi* but increase its carbohydrate and fat level. *Terasi* is indeed an excellent source of protein since protein composes the majority of its dry matter (67–73%). In addition to its high amount of protein, *terasi* also has a complete amino acid profile since shrimp and fish are good sources of essential amino acids that cannot be synthesized by human body [37]. Shrimp and fish are also rich in essential and polyunsaturated fatty acids, mainly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) [38]. However, fish and shrimp contain a considerable level of cholesterol and the consumption of cholesterol at high level is a known risk factor of cardiovascular diseases [39]. Minerals composed almost 20% of *terasi* dry matter. This high amount of minerals was mainly associated with the generous use of salt (NaCl) added during the production of *terasi*. High consumption of sodium (Na) is associated with increase in blood pressure and cardiovascular diseases [40]. However, *terasi* is generally used in cuisine in low amounts as flavor enhancer. Therefore, despite its nutritional content, *terasi* would not contribute significantly to human daily nutritional requirements [9].

Microbiological characteristics of terasi

A plethora of microogranisms and their metabolites contribute to the unique and complex flavor of *terasi*. Figure 8 represents the microbiological profile of *terasi* samples with various shrimp-fish proportion. Raw shrimp and fish contained relatively low number of microorganisms (1.6–1.8 log CFU/g dry matter). This number increased significantly during the fermentation process, resulting in shrimp paste with a total number of microorganisms of 5.5–7.5 log CFU/g dry matter. Interestingly, the number of total microorganisms, proteolytic bacteria, and lactic acid bacteria increased along with the higher proportion of fish in *terasi*. However, the number of lipolytic bacteria did not seem to be influenced by the shrimp-fish proportion in *terasi*. The higher number of proteolytic bacteria in the shrimp paste with higher fish proportion could be related to the higher amount of protein present in fish compared to shrimp as previously shown in Fig. 7. Some major bacterial genus present in terasi include *Tetragenococcus*, *Aloicoccus*, *Atopostipes*, *Alkalibacillus*, and *Alkalibacterium* [30]. Their proteolytic and lipolytic activities affect the aroma and flavor of *terasi* by inducing the formation of volatile low molecular weight compounds, including peptides, amino acids, organic acids, aldehydes, amines, fatty acids, etc. [41].

Chemical characteristics of terasi

Numerous chemical reactions occurring during the fermentation of *terasi* contribute to the complex flavor development in terasi. In the present study, we observed that the chemical characteristics of *terasi* were influenced by the proportion of shrimp and fish used as ingredients

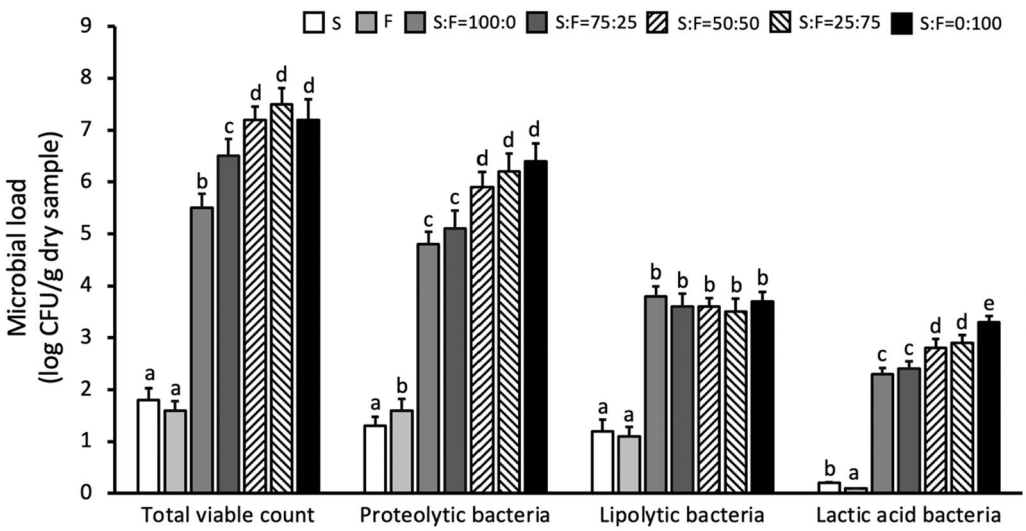

Fig. 8 Microbial load in shrimp (S), fish (F) and *terasi* samples made from shrimp and fish under different proportions. Data ($n = 5$) were expressed as mean ± SD. Different letters in a group indicate significant difference ($p < 0.05$) following one-way Anova and Tukey's HSD post hoc test

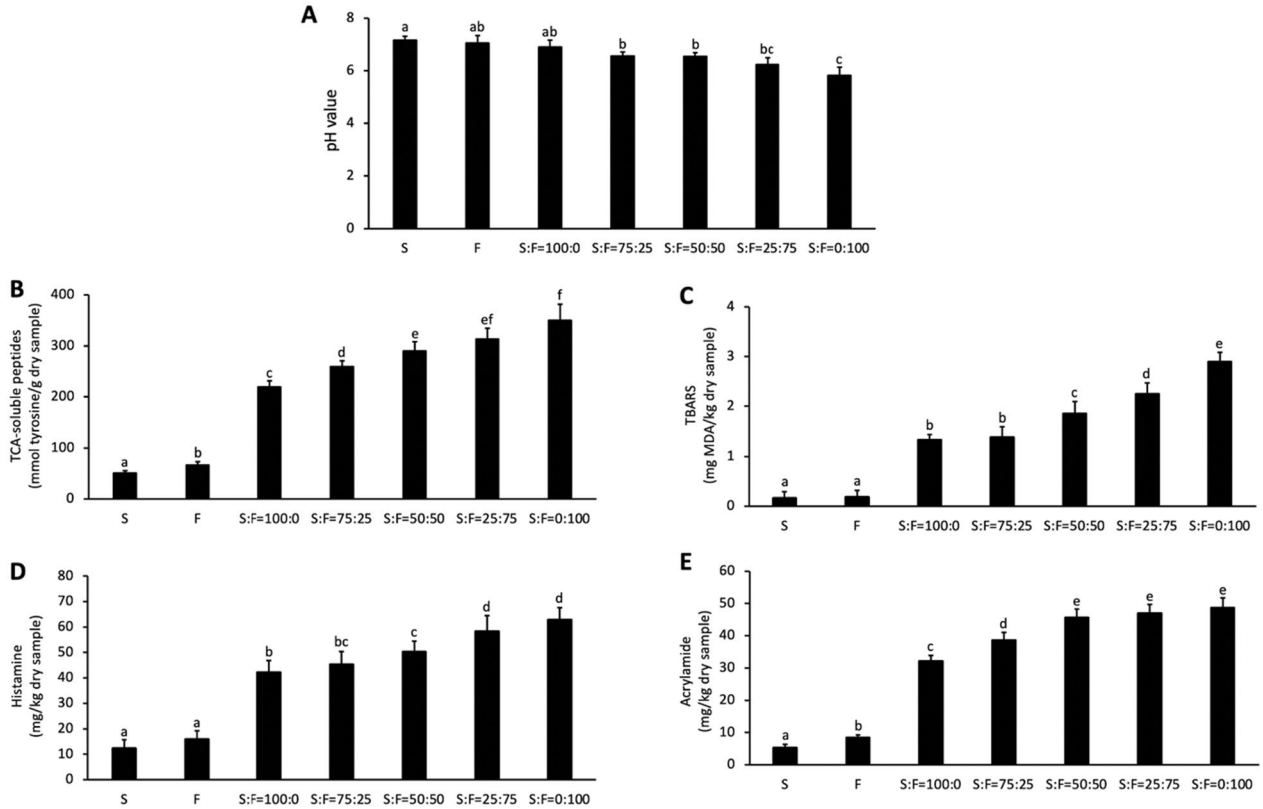

Fig. 9 Chemical characteristics of *terasi* samples made from shrimp (S) and fish (F) under different proportions, including: **A** pH value, **B** concentration of trichloroacetic (TCA)-soluble peptides, **C** concentration of thiobarbituric acid reactive substances (TBARS), **D** concentration of histamine and **E** concentration of acrylamide. Data ($n = 5$) were expressed as mean ± SD. Different letters indicate significant difference ($p < 0.05$) following one-way Anova and Tukey's HSD post hoc test

(Fig. 9A–E). Higher proportion of fish in *terasi* resulted in a product with a higher acidity (lower pH) as demonstrated in Fig. 9A. These findings were in accordance with Fig. 5 showing a higher number of lactic acid bacteria found in fish *terasi* compared to shrimp *terasi*. Since proteolytic and lipolytic bacteria were found in a higher amount in fish *terasi* compared to shrimp *terasi* (Fig. 8), the amount of soluble peptides and lipid oxidation byproducts (TBARS) increased along with the increasing proportion of fish in the *terasi* (Fig. 9B, C). Protein hydrolysis in *terasi* may contribute to increase amino acid bioavailability and develop the umami flavor of *terasi*, mainly due to the liberation of glutamic acid [42]. In addition, peptides in terasi, such as γ-glutamyl-valyl-glycine play an important role in determining the flavor of *terasi* [43]. The high level of TBARS resulting from lipid oxidation may indicate rancidity in *terasi* [44]. Histamine, a common biogenic amine derived from histidine, may lead to scombroid food poisoning that resembles an allergic reaction in humans [45]. Acrylamide, classified as a probable carcinogen (Group 2A) by the International Agency for Research on Cancer (IARC) under the World Health Organization (WHO) [46], is a byproduct resulting from the non-enzymatic browning (Maillard) reaction between the non-essential amino acid asparagine and reducing sugars [47]. In the present study, the level of histamine and acrylamide increased with a higher proportion of fish in the *terasi* (Fig. 6D, E). The US Food and Drugs Administration (FDA) considers fish and fishery products with a histamine level of 200 ppm or more to be injurious to human health [48]. The tolerable daily intake of acrylamide is set at 2.6 μg/kg body weight to avoid cancer risk [49]. However, it is noteworthy that *terasi* is commonly consumed in a low amount as food seasonings and therefore, the presence of histamine and acrylamide in the final food product containing *terasi* is suggested to be not significant [9].

Organoleptic characteristics of terasi and sambal terasi

In Indonesia, *terasi* is mainly used in cuisine to make *sambal terasi*, a traditional chili paste made from chili pepper ground with terasi and other ingredients, including salt and sugar [5]. Therefore, the organoleptic testing in the present study was performed to measure the

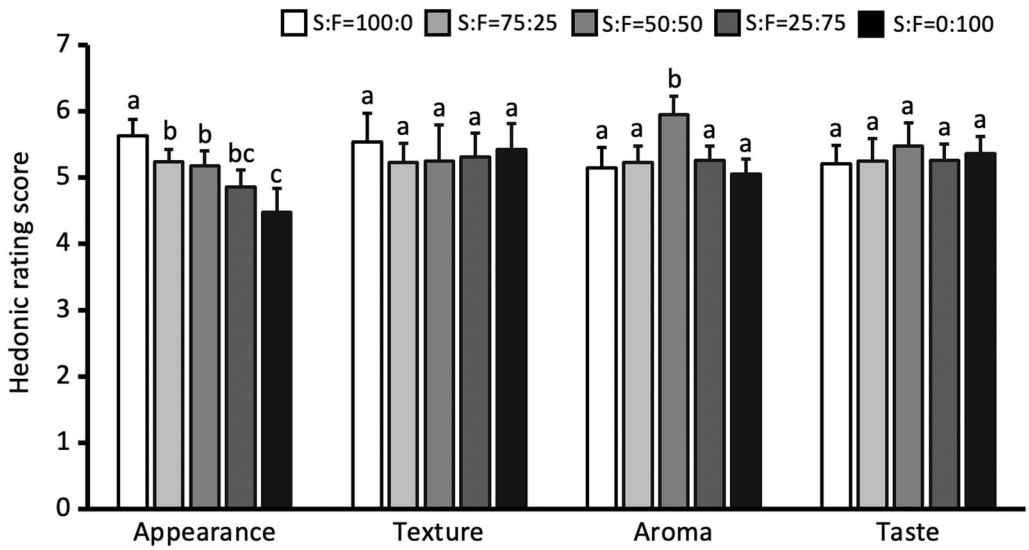

Fig. 10 Sensory acceptance of *terasi* and *sambal terasi* analyzed using hedonic rating analysis (Likert scale 1–7, higher score indicates higher preference). Data ($n = 229$) were expressed as mean ± SD. Different letters indicate significant difference ($p < 0.05$) following one-way Anova and Tukey's HSD post hoc test. *Terasi* samples were assessed for their appearance and texture while *sambal terasi* samples were assessed for their aroma and taste

preference of panelists toward *terasi* and *sambal terasi* through a hedonic rating test (hedonic scale 1–7). In a previous study, longer fermentation time of terasi was shown to be positively correlated with the hedonic rating of *sambal terasi* [9]. Figure 10 shows that the preference toward the appearance of *terasi* decreased with an increasing proportion of fish in *terasi*. We suspected that this phenomenon could be due to the darker color exhibited in *terasi* containing fish that appeared to be unpleasant for the panelists. While the texture of *terasi* and the taste of *sambal terasi* did not differ among the panelists, the *sambal terasi* made from *terasi* containing an equal proportion of fish and shrimp (50:50) showed the highest preference among panelists with regard to aroma (Fig. 10). Based on our observation, the *terasi* containing fish had a stronger flavor and fishy aroma compared to the shrimp *terasi*. Thus, our findings suggested that mixing shrimp and fish as the main ingredients of *terasi* could increase consumer's acceptance toward *sambal terasi*.

Conclusions

In summation, this present study showed that the proportion of fish and shrimp in the formulation of *terasi* affects the fermentation process and the characteristics of the final product. Higher proportion of fish is associated with higher microbial activities that lead to a plethora of chemical reactions contributing to the final physical and chemical characteristics of *terasi*. While the addition of fish in *terasi* formulation may increase consumer's acceptance, it is noteworthy that the presence of fish in *terasi* promotes the formation of histamine and acrylamide that could be dangerous for human health. Therefore, we recommend establishing a set of standards with to ensure the safety of commercial *terasi*.

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Author contributions
RS conceptualized the study and was the principal writer of this manuscript. RS, DN and NK were involved in data collection and data analysis. KP helped in manuscript review and editing.

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Availability of data and materials
The data and materials related to this study are available upon request.

Declarations

Ethics approval and consent to participate
The protocol for human experiments in this study has been approved by the Ethics Committee of Bina Nusantara University (Jakarta, Indonesia).

Consent for publication
All the authors have read and approved the content of this manuscript for a publication.

Competing interests
The authors declare no competing interests.

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