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Nutritional composition of tauco as Indonesian fermented soybean paste

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Abstract

Tauco is a fermented soybean paste like miso but typical from Indonesia, commonly used as umami seasoning. This study objective was to evaluate the nutritional composition of diverse tauco products found in Indonesia and to determine a potential tauco product characterized by certain amino acids related to umami peptides (Asp, Glu, Gly, Ser, Thr, Val). Proximate composition, NaCl salt, total sugars, total acids, and total amino acid profiles of 24 tauco products, collected from 24 producers in 7 provinces in Indonesia, were analyzed. The proximate composition mapped tauco into solid (containing 29.2–35.3% moisture on wet weight basis or ww), semisolid (42.2–54.5% ww moisture), and liquid (56.2–68.1% ww moisture). Solid tauco composed of 54.7–65.2% carbohydrates, 10.0–22.8% ashes, 7.13–16.9% NaCl salt, 9.72–11.9% crude proteins, 11.9–27.0% total sugars, 6.98–23.4% crude fats, 1.24–2.18% total acids, and 11.4–17.5% total amino acids on dry weight basis (dw). In contrast, liquid tauco consisted of 8.47–56.5% dw carbohydrates, 17.1–73.8% dw ashes, 10.7–68.4% dw NaCl, 20.4–30.9% dw crude proteins, 4.45–29.9.5% dw total sugars, 1.30–18.9% dw crude fats, 1.65–5.36% dw total acids, and 14.1–24.6% dw total amino acids. All tauco had a slight acidic pH, ranged from 4.38 to 5.91. Glu and Asp were the dominant amino acids of tauco, comprising 25–40% of total amino acids. Mapping of total amino acid profile mentioned a tauco product, characterized by the highest concentration of amino acids related to umami peptides. This finding leads to the exploration of umami peptides to reveal the science behind its traditional use as umami seasoning.

Keywords: Amino acid profiles, Fermented soybean paste, Nutritional value, Principal component analysis, Proximate composition

Introduction

Fermentation is one of the oldest food-processing technologies, not only can improve the storage characteristics of foods but also improve the sensory, nutritional, and functional properties of foods [1, 2]. Traditional fermented foods are generally considered safe and healthy foods that the local communities have consumed for a long time [3, 4]. Soybean is a commodity commonly used to produce various types of fermented foods by using fungi, yeasts, and bacteria. One of fermented soybean products is soybean paste, characterized by a thick liquid or slurry, essentially made from soybean mixed with a lesser amount of cereals than soybean, fermented by fungi at first stage, followed by yeasts and bacteria with the addition of salt solution at relatively high concentration (Table 1). Table 1 shows many types of fermented soybean paste worldwide. Different countries in Asia have different names for their fermented soybean paste, depending on the production process and the type of microbial strain used [5]. In Japan, fermented soybean paste is known as miso [6]; in Korean, doenjang [7]; in China, dajiang [8]; in Thailand, thua-nao [9]; and in Indonesia, tauco [10]. Each product has unique flavor

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Table 1 Various fermented soybean paste worldwide which are produced by two stages of fermentation: koji/meju fermentation followed by brine/moromi fermentation

Fermented soybean paste	Origin	Raw materials	Dominant bacteria	Dominant fungi	NaCl concentration in brine solution	Reference
Miso	Japan	Soybean, steam rice/barley	Koji: *Ochrobactrum, Mycobacterium* Moromi: *Leuconostoc, Weissella, Pediococcus, Lactobacillus, Tetragenococcus, Enterococcus*	Koji: *Wickerhamomyces* Moromi: *Aspergillus, Clavispora Zygosaccharomyces, Pichia*	10% or more	[55, 56]
Doenjang	Korea	Soybean	Meju: *Bacillus, Ignatzschineria, Enterococcus, Corynebacterium, Myroides*, dan *Clostridium* Moromi: *Bacillus, Staphylococcus, Clostridium, Weissella, Tetragenococcus, Oceanobacillus, Lactobacillus*	Meju: *Mucor, Scopulariopsis, Geotrichum, Monascus, Fusarium*, dan *Aspergillus* Moromi: *Debaryomyces, Aspergillus, Scopulariopsis, Fusarium, Mucor, Penicillium*	12–18%	[57, 58]
Dajiang	China	Soybean	Meju: *Enterobacter, Enterococcus, Leuconostoc, Lactobacillus, Citrobacter, Leclercia* Moromi: *Weissella, Tetragenococcus, Oceanobacillus, Bacillus, Staphylococcus, Leuconostoc, Clostridium, Lactobacillus*	Meju: *Penicillium, Rhizoctonia, Geotrichum, Mucor, Aspergillus, Fusarium* Moromi: *Weissella, Tetragenococcus, Oceanobacillus, Bacillus, Staphylococcus, Leuconostoc, Clostridium, Lactobacillus*	20%	[59–61]
Tauco	Indonesia	Soybean and cereal flour	Koji: *Geobacillus, Weissella, Bacillus, Staphylococcus, Streptococcus* Moromi: *Pediococcus, Weissella, Enterococcus, Staphylococcus, Geobacillus*	Koji: *Unidentified Aspergillaceae* Moromi: *Unidentified Aspergillaceae, Trichosporon, Candida*	17–20%	[62]

characteristics. Similar to fermented soy sauce in Indonesia, tauco as fermented soybean paste was originated from China and introduced into Indonesia by Chinese population mostly from Hokkien ethnic several ages ago. Tauco is then popular in Cianjur, West Java, and other coastal area in Indonesia (Fig. 1) where Chinese population is present.

Tauco has long been used as an ingredient to season many dishes in Indonesia because it provides a delicious umami/savory taste. Traditional dishes such as *tauge goreng* in Bogor (West Java), *bubur sop ayam* in Cirebon near Tegal (West Java), *soto pekalongan* (Central Java), *sambal tauco* (West Java and Central Java), also *sayur tauco* and *ikan tauco* (different regions in Indonesia) have used tauco as a typical seasoning for its desired aroma and umami taste. Tauco comes from its pronunciation in the Hokkien dialect of Chinese. The Chinese tauco character is written as "豆醬," which consists of *tau* "豆," which means beans, and *co* " 醬," which means thick soy sauce [11]. According to Shurtleff and Aoyagi, tauco is still associated with the Chinese spice, *Jiang*. *Jiang* is thought to have originated before the Chou Dynasty (722–481 BC), so it can be claimed as the oldest seasoning known to humans [12]. From historical records, tauco in Cianjur (West Java) was first recorded in Indonesia in the nineteenth century due to the acculturation of Chinese culinary culture with the Sundanese Cianjur ethnic group. However, tauco has become part of the identity of the Cianjur community. At present, tauco in Indonesia is developing in various regions. There are at least five known types of tauco in Indonesia: tauco Cianjur, tauco Kalimantan, tauco Pekalongan, tauco Bangka, and tauco Medan. Recent studies have also shown that tauco may have health benefits as it contains phenolic compounds that have antioxidant activity [13, 14].

The production process of tauco is similar to the other fermented soybean pastes, which is divided into two stages of fermentation, *koji*/*meju* fermentation and brine/*moromi* fermentation [5] with microbials presented in Table 1. The detailed production process of tauco involves several steps: soybeans cooking, soybean mixing with roasted flour, *koji* mold fermentation, and followed by brine fermentation. Cooked soybeans mixed with roasted flour (2:1) were inoculated with a starter containing a mixture of molds (mostly *Rhizopus oligosporus*, *Rhizopus oryzae*, and *Aspergillus oryzae*) and fermented for 3–5 days at 30 °C. The mold fermented beans were broken into

Fig. 1 The distribution of tauco products in several regions in Indonesia

pieces and sun-dried (called as *koji or meju*). *Koji* was then mixed thoroughly with a high concentration of brine solution (c.a. 17–20%) at a ratio of 1:3 and stored at room temperature for several weeks. Raw tauco obtained can be cooked with palm sugar solution (c.a. 50%) and filled into packaging (plastic, bottle, or bamboo container). Tauco can also be dried in the oven at 60–80 °C to produce products with the desired moisture content. This process allows the tauco products to have a different consistency and forms [14–16].

Although the fermentation process conducted on an industrial scale has used starter culture, the fermentation process in the tauco production still occurs on a household and small-enterprise scale that involve spontaneous fermentation by various types of microorganisms originally present in the raw food materials [17]. The complex and diverse strains lead to the non-uniform quality of the tauco products, including their nutritional value even from the same region, because they are closely related to the breakdown of the substrate, making it interesting to evaluate. Tauco, as local food of Indonesia has no detailed information on this matter. The studies that have explained the differences in the nutritional value of tauco products in Indonesia were still limited, including the characteristic differences based on the type of tauco (solid, semisolid, and liquid tauco). In fact, this study is needed as a reference in developing potential research related to tauco in the future. Therefore, the objective of this study was to evaluate different tauco characteristics through multivariate analysis with its function as savory seasoning, and to map tauco with other similar soybean paste from different countries.

Materials and methods

Materials and chemicals

Tauco samples (Fig. 2) were obtained from 24 producers in 7 provinces of Indonesia (West Java, Central Java, Bangka, North Sumatera, West Sumatera, South Sumatera, and West Kalimantan). The abbreviated brand names of them were CMC and CBC (from Cianjur, West Java); MNB (Bogor, West Java); SAP, PDP, TKP, MMP, LEP, and CIP (Pekalongan, Central Java); SKT (Tegal, Central Java); SAB, CBB, and BEB (Bangka); CGM, SIM, HAM, SUM, and CBM (Medan, North Sumatera); BMP (Padang, West Sumatera); MIP (Palembang, South Sumatera); and CDS, KES, MIS, and CKS (Singkawang, West Kalimantan). Each sample was pre-packaged in a plastic bottle, glass bottle, or bamboo container, and for analysis, 3 packages of each sample were purchased and then homogenized as a mixture. The visual appearance of the homogenized tauco samples can be seen in Fig. 3A. The homogenized tauco samples were further categorized based on their moisture content as solid tauco (MIS, CKS, SIM), semi-solid tauco (CBC, CBM, MNB, SAP, PDP, TKP, MMP, CIP, LEP, SKT), and liquid tauco (CMC, SAB, CBB, CDS, KES, BMP, MIP, CGM, HAM, BEB, SUM). Representative of the three tauco groups is figured in Fig. 3B. Since the shelf-life of tauco is generally over 6 month, it was difficult to find the same shelf-life for 24 samples. All samples were obtained before their expiration dates. Detail of the tauco samples and lists of ingredients of each tauco are

Fig. 2 Twenty-four tauco products used as samples from 24 producers in 7 provinces in Indonesia

presented in Table 2. Samples were sent to the laboratory and immediately stored at −18 to (−20) °C upon receipt until the time of evaluation for maximum 1 week. Prior to analysis, samples were thawed overnight in a refrigerator (4–5 °C) and crushed and homogenized using blender for 1 min from 3 replicates of sampling (same brand/producer, but different packaging) to obtain a composite sample used for chemical characterizations.

The chemicals used for proximate composition analysis were of analytical grade, including hexane, potassium

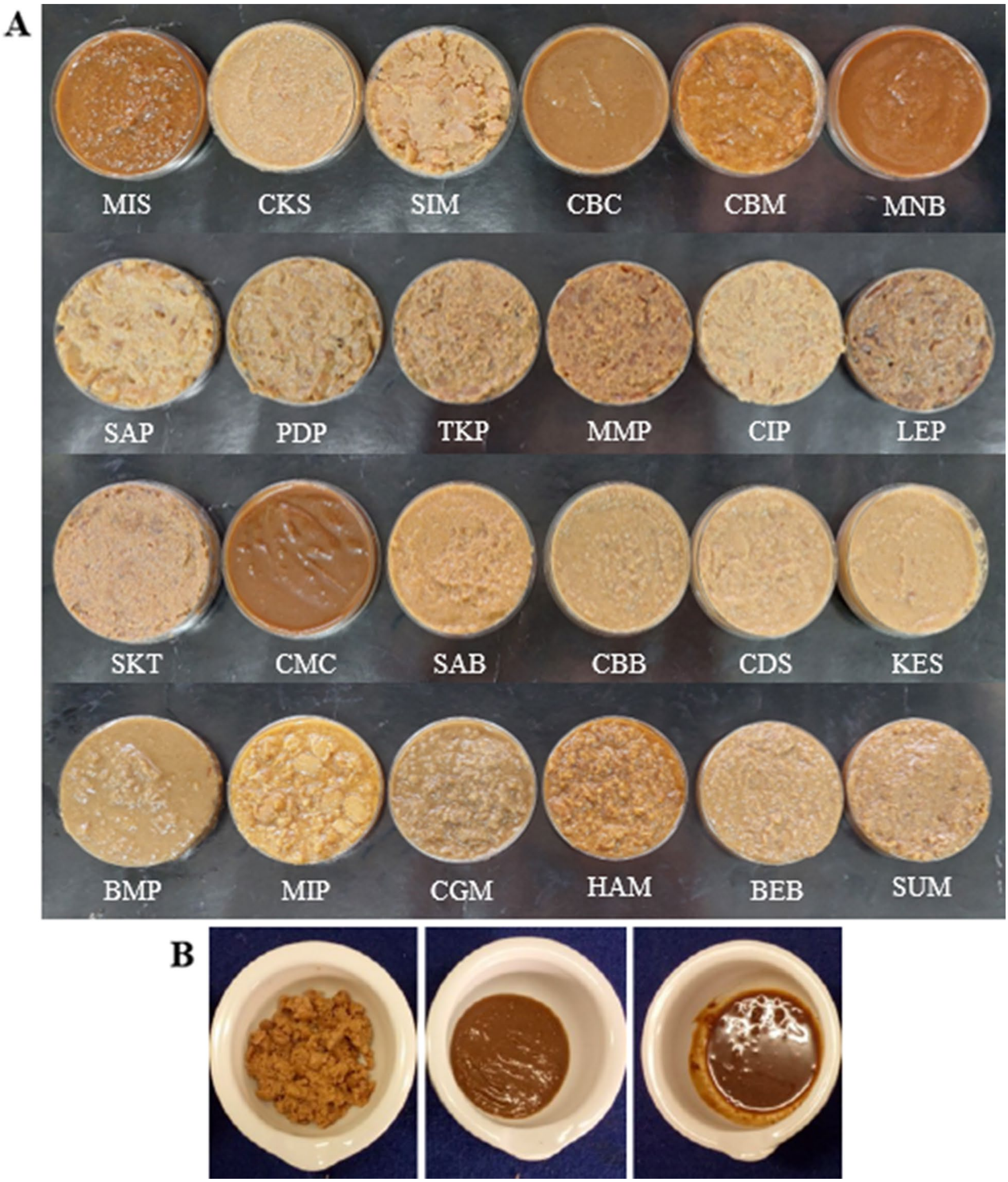

Fig. 3 The homogenized tauco samples (A) and representative physical appearance of the three tauco groups (B): from left to right for solid, semi solid, and liquid tauco

sulfate, mercury oxide, sulfuric acid, sodium hydroxide, sodium thiosulfate, boric acid, and hydrochloric acid (Merck KGaA, Darmstadt, Germany). Potassium chromate and silver nitrate of analytical grade (Merck) were used for salt analysis. D-glucose standard and anthrone reagent (Merck) were used for total sugars

Table 2 Twenty-four tauco products from different producers and their ingredients composition in the packaging label

Sample's brand	Sample code	Region	Ingredients
Tauco Cap Meong Cianjur	CMC	Cianjur, West Java	Soybean, palm sugar, sugar, salt
Tauco Cap Badak Cianjur	CBC	Cianjur, West Java	Soybean, salt, sugar, water
Tauco Mak Neng Nio	MNB	Bogor, West Java	–
Tauco Sari Wangi Pekalongan	SAP	Pekalongan, Central Java	Soybean, flour, water, salt, sugar
Tauco Pulau Djawa Pekalongan	PDP	Pekalongan, Central Java	Soybean, rice flour, salt, water
Tauco Enak Toko Kurnia	TKP	Pekalongan, Central Java	–
Tauco Mangga Mas Pekalongan	MMP	Pekalongan, Central Java	Soybean, glutinous rice flour, sugar, salt
Tauco Lencana Elit Pekalongan	LEP	Pekalongan, Central Java	Soybean, rice flour, palm sugar, salt, seasoning
Tauco Asli Cap Ikan	CIP	Pekalongan, Central Java	Soybean, flour, water, salt, seasoning
Tauco Super Khas Tegal	SKT	Tegal, Central Java	–
Tauco Super Asli Bangka	SAB	Bangka	Soybean, water, salt
Tauco Cap Bunga Seroja	CBB	Bangka	Soybean, sugar, salt, wheat flour, water
Tauco Belinyu Bangka	BEB	Bangka	Soybean, water, salt
Tauco Cap Gajah Dua Medan	CGM	Medan, North Sumatera	Soybean, water, salt, flour, sugar
Tauco Super Izzah Medah	SIM	Medan, North Sumatera	Soybean, salt, palm sugar, flour, spices
Tauco Hati Angsa Medan	HAM	Medan, North Sumatera	Soybean, salt, water, what flour
Tauco Super Medan	SUM	Medan, North Sumatera	Soybean, water, wheat flour, salt, sodium benzoate, food flavoring, and food coloring Cl No.15985 (E110)/19140 E102
Tauco Cap Bebek Medan	CBM	Medan, North Sumatera	Soybean, water, salt
Tauco Bintang Mas Padang	BMP	Padang, West Sumatera	Soybean, salt, water
Tauco Mikado Palembang	MIP	Palembang, South Sumatera	Soybean, water, salt, sugar, sulfite, flavor enhancer MSG, citrate, wheat flour
Tauco Cap 88 Singkawang	CDS	Singkawang, West Kalimantan	Soybean, water, salt, sugar, wheat flour, sodium benzoate
Tauco Kelinci Singkawang	KES	Singkawang, West Kalimantan	Soybean, sugar, wheat flour, salt, sodium benzoate
Tauco Mimie Singkawang	MIS	Singkawang, West Kalimantan	–
Tauco Cap Kambing Singkawang	CKS	Singkawang, West Kalimantan	Soybean, salt, sugar, wheat flour

analysis. Standard buffer solutions (pH 4.00 and 7.00) were used for pH measurement, while potassium hydrogen phthalate, natrium hydroxide, phenolphthalein, and ethanol (Merck) were used for total acids analysis. The chemicals for total amino acids analysis were amino acids standard mixtures, hydrochloric acid, sodium acetate, Na-EDTA, tetrahydrofuran (THF), o-phthalaldehyde reagent (OPA reagent) (Sigma-Aldrich, St. Louis, MO, USA), methanol and acetonitrile HPLC grade (Merck), Whatman No. 1 filter paper, and 0.45 µm filter membrane (Advantech Co., Ltd., Tokyo, Japan). Distilled water for chemical characterizations and redistilled water (IPHA Laboratories, Bandung, Indonesia) for HPLC analysis were used in this study.

Proximate composition

Proximate composition consisting of moisture, ashes, crude proteins, crude fats, and carbohydrate (*by difference*) was carried out in accordance with the AOAC procedure [18]. Moisture content by drying 1–2 g of samples at 105 °C in hot air oven, ash content by igniting 2–3 g of sample using an electric furnace (Furnace 48,000, Thermolyne, USA) at 550 °C, crude fats by extracting dried sample using n-hexane with a Soxhlet extraction unit, crude proteins by using a micro-Kjeldahl system to determine total nitrogen and then using a conversion factor of 6.25 to determine crude proteins, and carbohydrates *by difference* were determined for 24 tauco products. All results were reported in the form of mean ± standard deviation of triplicate analysis for moisture content and ash content, and of duplicate analysis for crude proteins and fats, as % dry weight basis (% dw) or g/100 g dry matters of tauco, except moisture content as % wet weight basis (% ww) org/100 g fresh tauco (as it is).

Salt content, total sugars, total acids, and pH measurement

Salt content (expressed as sodium chloride) was analyzed using Mohr method with modification by dissolving the ashes of the sample in distilled water and then titrated with 0.01 M $AgNO_3$ as the titrant and potassium chromate as an indicator [19]. Total sugars were quantified by spectrophotometry (UV–Vis 160 spectrophotometer) using $_D$-glucose standard and anthrone reagent, which determined total reducing and non-reducing sugars.

Total acids were titratable acids, analyzed by volumetric titration with 0.1 N NaOH as titrant and phenolphthalein as an indicator [18]. The total acids were calculated as lactic acid equivalent, since lactic acid was used as the major indicator of organic acids in a similar fermented soybean product [20]. The pH value was determined by dissolving 5 g of sample in 45 mL distilled water, then measured using a digital pH meter (MW-801, Milwaukee, Romania), which was calibrated by pH 4 and 7 buffer standards [18]. All results were reported in the form of mean ± standard deviation of triplicate analysis, except for total sugars of duplicate analysis, all results were expressed in % dw, except the pH value (no unit).

Total amino acid profiles

The total amino acid composition or total amino acid profile was analyzed by IPB University's Integrated Lab using an *in house* method after acid hydrolysis. Analysis was carried out by pre-column derivatization using o-phthalaldehyde (OPA) reagent and HPLC instrument (Shimadzu SCL 10-A). A total of 1–5 g of sample was weighed in a closed container and hydrolyzed with the addition of 2 mL of 6 N HCl. The sample was then streamed with nitrogen gas for 0.5–1 min and put in an oven at 110 °C for 24 h. The hydrolyzed sample was cooled at room temperature, quantitatively transferred to a rotary evaporator flask, and dried. The dried sample was added with precisely 10 mL of 0.01 N HCl.

Derivatization with OPA reagent was carried out first on the hydrolyzed sample before being analyzed with an HPLC column. OPA reagent was prepared by dissolving 50 mg OPA powder in 1.25 mL ethanol. The OPA solution was then added with 50 µL 2-mercaptoethanol and 11.2 mL sodium borate buffer 0.1 M (pH 9.5). For sample preparation, potassium borate buffer pH 10.4 was added into the hydrolyzed sample in ratio 1:1. A total of 50 µL of this mixture was added with 250 µL of OPA reagent and vortexed for 1 min until complete derivatization. The sample was filtered using a 0.45 µm membrane filter and then injected with the volume of 5 µL into the HPLC instrument (Shimadzu SCL 10-A), equipped with a 195 DGU-20A degasser and a CBM-20A controller, with the following conditions: Thermo Scientific ODS-2 Hypersil (150 mm × 4,6 mm, 5 µm) as a column (Thermo Fisher Scientific, Los Angeles, USA), the mobile phase at flow rate 1 mL/min that consisted of Na-acetate pH 6.5 198 (0.025 M), Na-EDTA (0.05%), methanol (9.00%), THF (1.00%) in deionized water for solvent A, and methanol (95%) and deionized water (5%) for solvent B. For 35 min, the mobile phase was programmed to 0–2 min, 5% B; 2–13 min, from 5 to 35% B; 13–15 min, 35% B; 15–20 min, from 35 to 70% B; 20–22 min, from 70 to 90% B; 22–25 min, from 90 to 100% B; 25–28 min, from 100 to 0% B; 28–35 min, 0% B. The fluorescence detector was set in excitation and emission wavelengths of 350 and 450 nm, respectively. Individual total amino acid was calculated based on its corresponding amino acid standard provided by a standard mixture of amino acids. Total amino acids were also calculated by the sum of individual total amino acids for each sample.

Statistical analysis

One-way analysis of variance (ANOVA) with SPSS v.22 (IBM, NY, USA) was used to determine the differences in the analysis results between samples. Further tests using Duncan's test at a 95% confidence interval were carried out if there was a significant difference. The principal component analysis (PCA) method was performed to map tauco samples based on proximate composition, salt content, total sugars, total acids, and total amino acids, and also based on total amino acid profiles by SIMCA v.17 (Umetrics, Sweden). Pre-treatment of the data using scaling on the tested variables can also be selected to obtain a fit model. The tested variables can have different ranges of values, so it is necessary to determine one coordinate with a length determined by scaling. The scaling used in this study was unit variance (UV-scaling).

Results and discussion

Nutritional and chemical composition of tauco

The nutritional and chemical composition of tauco samples is presented in Table 3. Twenty-four tauco samples had proximate composition, consisting of moisture content ranged at 29.2–68.1% ww, ash content at 10.0–73.8% dw, crude proteins at 9.72–33.6% dw, crude fats at 0.92–23.4% dw, and carbohydrates *by difference* at 6.59–68.4% dw. The wide range of salt content at 7.13–68.4% dw, total sugars at 3.56–42.3% dw, and total acids at 1.58–6.70% dw, were also observed. The salt content described the ash content of tauco samples because most of the ash is in the form of salt which is intentionally added at high concentrations (c.a. 17–20%) in the tauco production process [15].

Tauco samples were mapped with PCA based on the proximate composition (Fig. 4). The four PCs included in the model produced R^2X and Q^2 of 1 and 0.986, respectively. A good model will have an R^2X value greater than the Q^2 value, Q^2 value greater than 0.5, and the difference between the R^2X and Q^2 value is not too large. In this model, PCA has been quite good in presenting the analyzed data. PCA biplot based on the proximate composition of tauco contributed 66.60% of the total variation for the data set, with PC1 and PC2 accounting for 42.20% and 24.40% of variance explained, respectively (Fig. 4). Satisfactory separation was observed for most of tauco samples and categorized into 3 clusters, namely

Table 3 Nutritional and chemical composition of tauco products from different producers throughout Indonesia, and their grouping based on multivariate statistical analysis of their proximate composition

Samples	Group	Moisture content (% ww)	Ash content (% dw)	Crude proteins (% dw)	Crude fats (% dw)	Crude carbohydrates[1] (% dw)	Salt content[2] (% dw)	Total sugars (% dw)	Total acids[3] (% dw)	pH
MIS	Solid tauco	35.3 ± 0.3^{c}	22.8 ± 0.4^{h}	11.7 ± 0.0^{b}	7.09 ± 0.1^{de}	58.4	16.9 ± 0.2^{e}	11.9 ± 0.3^{cd}	1.27 ± 0.0^{a}	5.35 ± 0.01^{r}
CKS	Solid tauco	29.2 ± 0.3^{a}	10.0 ± 0.2^{a}	11.9 ± 0.1^{b}	23.4 ± 0.6^{j}	54.7	7.13 ± 0.1^{a}	27.0 ± 0.6^{i}	1.24 ± 0.1^{a}	5.29 ± 0.01^{q}
SIM	Solid tauco	32.5 ± 0.6^{b}	18.1 ± 0.3^{cde}	9.72 ± 0.0^{a}	6.98 ± 0.3^{de}	65.2	14.2 ± 0.1^{c}	15.1 ± 0.1^{ef}	2.18 ± 0.0^{de}	4.38 ± 0.01^{a}
CBC	Semisolid tauco	42.2 ± 0.5^{d}	13.9 ± 0.3^{b}	16.0 ± 0.1^{d}	1.74 ± 0.0^{ab}	68.4	10.8 ± 0.2^{b}	11.8 ± 0.3^{cd}	1.49 ± 0.1^{b}	5.09 ± 0.01^{n}
CBM	Semisolid tauco	51.9 ± 0.6^{h}	27.9 ± 0.2^{ij}	15.1 ± 0.2^{c}	1.20 ± 0.0^{a}	55.8	24.8 ± 0.3^{ij}	27.6 ± 0.6^{ij}	1.30 ± 0.0^{a}	5.01 ± 0.01^{m}
MNB	Semisolid tauco	51.3 ± 0.3^{h}	19.7 ± 0.3^{ef}	32.6 ± 0.3^{p}	14.0 ± 0.2^{fg}	33.7	15.6 ± 0.2^{d}	22.0 ± 0.3^{g}	5.43 ± 0.0^{m}	4.71 ± 0.01^{h}
SAP	Semisolid tauco	49.3 ± 0.4^{g}	22.3 ± 0.1^{h}	22.9 ± 0.3^{f}	8.17 ± 0.2^{e}	46.7	19.6 ± 0.1^{f}	17.2 ± 0.4^{f}	3.53 ± 0.1^{j}	4.57 ± 0.01^{f}
PDP	Semisolid tauco	48.0 ± 0.4^{f}	36.2 ± 0.3^{m}	24.3 ± 0.0^{i}	2.55 ± 0.7^{ab}	36.9	19.6 ± 0.3^{f}	23.8 ± 0.6^{gh}	2.12 ± 0.0^{d}	5.34 ± 0.01^{r}
TKP	Semisolid tauco	46.8 ± 0.1^{e}	20.0 ± 0.4^{fg}	23.3 ± 0.0^{fg}	5.01 ± 0.2^{cd}	51.7	14.2 ± 0.4^{c}	25.5 ± 2.5^{hi}	3.60 ± 0.0^{j}	4.75 ± 0.01^{i}
MMP	Semisolid tauco	50.1 ± 0.2^{g}	21.6 ± 0.1^{gh}	25.4 ± 0.1^{k}	2.42 ± 0.0^{ab}	50.5	15.6 ± 0.1^{d}	35.5 ± 0.3^{k}	3.00 ± 0.0^{h}	4.93 ± 0.01^{l}
CIP	Semisolid tauco	46.8 ± 1.0^{e}	19.5 ± 0.3^{def}	24.8 ± 0.1^{j}	5.28 ± 0.0^{cd}	50.4	15.6 ± 0.2^{d}	10.9 ± 1.5^{bcd}	4.18 ± 0.0^{kl}	4.48 ± 0.01^{c}
LEP	Semisolid tauco	48.0 ± 0.2^{f}	17.8 ± 0.2^{cd}	25.8 ± 0.1^{k}	4.09 ± 0.1^{bc}	52.3	11.3 ± 0.1^{b}	42.3 ± 0.4^{l}	4.26 ± 0.0^{l}	4.63 ± 0.01^{g}
SKT	Semisolid tauco	54.5 ± 0.2^{i}	21.5 ± 0.5^{gh}	29.4 ± 0.1^{n}	0.92 ± 0.0^{a}	48.1	19.7 ± 0.2^{f}	17.6 ± 1.1^{f}	5.34 ± 0.0^{m}	4.80 ± 0.01^{j}
CMC	Liquid tauco	59.2 ± 0.5^{k}	17.1 ± 0.2^{c}	23.5 ± 0.1^{gh}	2.89 ± 0.1^{abc}	56.5	10.7 ± 0.2^{b}	29.8 ± 0.9^{j}	4.11 ± 0.0^{k}	4.41 ± 0.01^{b}
SAB	Liquid tauco	60.5 ± 0.5^{l}	44.7 ± 0.6^{o}	23.8 ± 0.2^{h}	9.24 ± 0.3^{e}	22.2	25.7 ± 0.4^{j}	6.04 ± 0.2^{a}	1.65 ± 0.0^{c}	5.22 ± 0.01^{o}
CBB	Liquid tauco	62.3 ± 0.4^{m}	28.8 ± 0.9^{jk}	29.3 ± 0.2^{n}	6.87 ± 0.2^{de}	35.0	27.1 ± 0.2^{k}	12.9 ± 4.1^{de}	5.36 ± 0.0^{m}	4.76 ± 0.01^{i}
CDS	Liquid tauco	68.1 ± 0.4^{p}	36.8 ± 1.2^{m}	27.7 ± 0.4^{l}	1.30 ± 0.1^{a}	34.1	14.5 ± 0.3^{c}	27.2 ± 1.6^{ij}	4.09 ± 0.1^{k}	4.54 ± 0.01^{e}
KES	Liquid tauco	67.4 ± 0.4^{op}	33.4 ± 0.8^{l}	28.8 ± 0.4^{m}	19.0 ± 4.9^{i}	18.9	30.6 ± 0.7^{l}	12.9 ± 0.8^{de}	2.16 ± 0.1^{de}	4.88 ± 0.01^{k}
BMP	Liquid tauco	61.5 ± 0.6^{m}	35.8 ± 0.3^{m}	20.4 ± 0.3^{e}	16.8 ± 0.8^{hi}	27.0	23.2 ± 0.5^{h}	8.64 ± 0.6^{b}	2.59 ± 0.1^{f}	5.24 ± 0.01^{p}
MIP	Liquid tauco	66.8 ± 0.3^{o}	26.4 ± 0.5^{i}	25.6 ± 0.3^{k}	17.4 ± 0.2^{hi}	30.7	21.2 ± 0.4^{g}	29.9 ± 0.2^{j}	3.39 ± 0.1^{i}	4.50 ± 0.01^{d}
CGM	Liquid tauco	66.0 ± 0.4^{n}	29.7 ± 1.1^{k}	30.9 ± 0.2^{o}	18.7 ± 0.2^{i}	20.8	24.1 ± 0.4^{hi}	16.9 ± 1.3^{f}	2.87 ± 0.1^{g}	5.91 ± 0.01^{t}
HAM	Liquid tauco	61.5 ± 0.2^{m}	73.8 ± 4.0^{p}	24.0 ± 0.3^{hi}	15.1 ± 0.3^{gh}	8.47	68.4 ± 2.5^{o}	4.45 ± 0.1^{a}	2.23 ± 0.1^{e}	5.28 ± 0.01^{q}
BEB	Liquid tauco	59.4 ± 1.0^{k}	41.3 ± 2.0^{n}	27.6 ± 0.2^{l}	15.7 ± 0.3^{gh}	15.5	33.5 ± 0.6^{m}	9.99 ± 0.2^{bc}	3.30 ± 0.1^{i}	5.01 ± 0.01^{m}
SUM	Liquid tauco	56.2 ± 0.4^{j}	43.1 ± 0.4^{o}	25.5 ± 0.3^{k}	12.3 ± 1.4^{f}	19.1	35.2 ± 0.3^{n}	15.8 ± 1.0^{f}	2.81 ± 0.1^{g}	5.50 ± 0.01^{s}

Mean ± SD of triplicate analysis of each component was reported, except for crude carbohydrates. Numbers in a column that does not share the same alphabetical letter represent significant differences ($p < 0.05$)

[1] Crude carbohydrates were calculated as by difference of wet weight basis and then convert to dry weight basis

[2] Salt content was expressed as sodium chloride (NaCl) concentration, due to the addition of a large amount of NaCl in the tauco fermentation process

[3] Total acids were titratable acids, expressed as lactic acid equivalent, because the main organic acid of soybean paste products is lactic acid

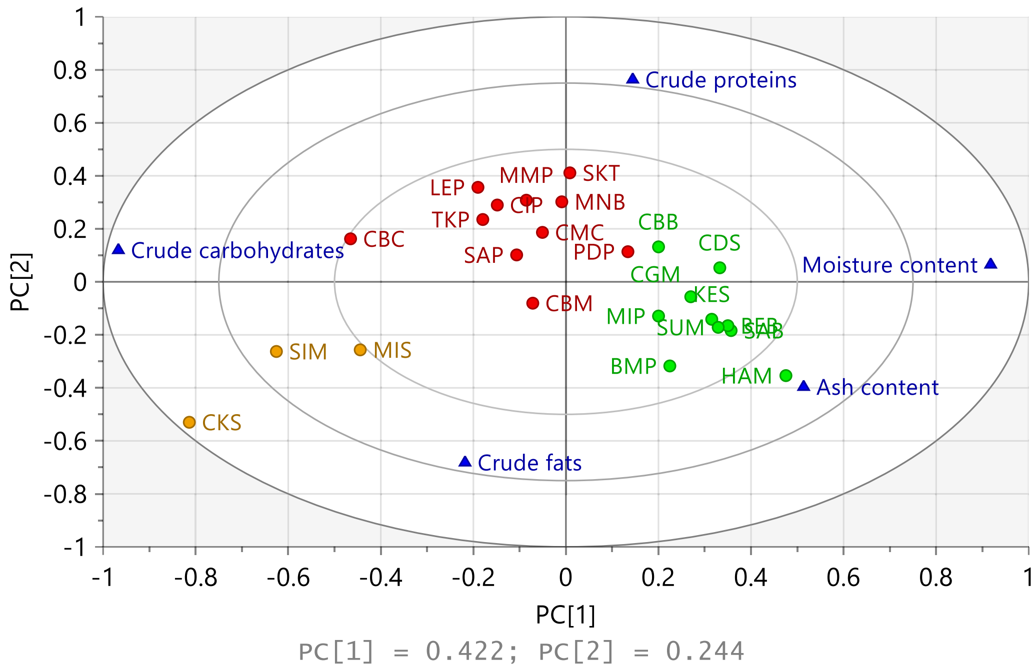

Fig. 4 PCA biplot based on proximate composition of tauco products (N = 24, R^2X: 1, Q^2: 0.986), analyzed by SIMCA v.17 trial version. Tauco samples divided into 3 cluster (solid (violet circle), semisolid (red circle), and liquid (green circle))

liquid (green color in Fig. 4), semisolid (red color), and solid (orange color) tauco, except for CMC which had moisture content at 59.2 ± 0.5% ww but classified as semisolid sample, due to its higher carbohydrate content than liquid samples. However, CMC was categorized as a liquid sample in this study (Table 3). Among the proximate composition, moisture content best described the tauco grouping. The grouping of tauco products by their proximate composition to determine their physical consistency is firstly reported.

According to Wolfe and Dutton [21], moisture content affects the textural properties of fermented soybean products. High moisture content produces a product with a liquid consistency and vice versa. Based on the geographical distribution, tauco products produced in North Sumatera consist of various types of tauco, either solid, semisolid, or liquid. In contrast to North Sumatera, tauco products were only found in a liquid form in West Sumatera, South Sumatera, and Bangka, and in a semisolid form in Central Java. Tauco products produced in West Java, a central of tauco production in Indonesia, were found in semisolid and liquid forms. Moreover, tauco produced in West Kalimantan was found in solid and liquid forms. Tauco products from Cianjur (CBC and CMC) which is popular in West Java (inhabited by one-fifth of Indonesian population) are grouped as liquid tauco (CMC) and semisolid tauco (CBC).

In comparison with other fermented soybean paste, chemical characteristics of tauco were comparable to *doenjang* and *miso*. *Doenjang* had moisture content ranged from 48.5 to 63.1% ww, ash content at 21.6–36.9% dw, crude proteins at 18.8–33.0% dw, crude fats at 3.10–21.9% dw, carbohydrates by difference at 14.9–56.5% dw, salt content at 17.5–39.2% dw, total acids at 2.97–7.46% dw [22], total sugars at 6.88–33.1% dw, and pH values at 5.0–5.8 [14]. Meanwhile, the characteristics of *miso* as follows: moisture content at 44.0–50.0%, crude proteins at 14.3–24.0%, crude fats at 3.57–12.0%, and salt content at 8.93–26.0% [23]. PCA can be used to categorize fermented soybean paste products (tauco, *doenjang, thua-nao, miso,* and *dajiang*) based on the similarities of their proximate composition patterns (Fig. 5). Cumulatively, the first 3 PCs in the model produce goodness of fit (R^2X) and goodness of prediction (Q^2) of 0.980 and 0.665, respectively. The total diversity of data explained by the model was 80.10%, with PC1 at 59.30% and PC2 at 20.80%. This figure is the first report to compare tauco, which mimics a Japanese miso, to other similar products. Tauco in the liquid form had a similar proximate composition to *dajiang* and traditional *doenjang*, while semisolid form was similar to commercial *doenjang*. On the negative side of PC1, solid tauco had a similar proximate composition to miso in Japan, and both had fairly high crude fats. This is the first report to compare tauco with

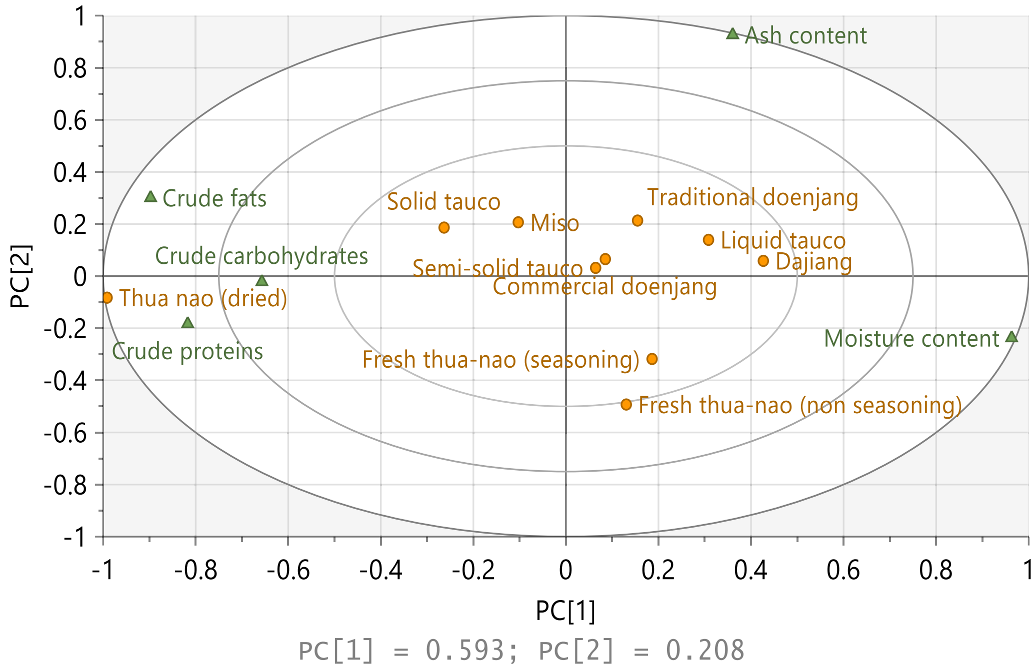

Fig. 5 PCA biplot of fermented soybean paste products in worldwide based on the similarities of their proximate composition patterns (N = 10, R^2X: 0.980, Q^2: 0.665), analyzed by SIMCA v.17 trial version

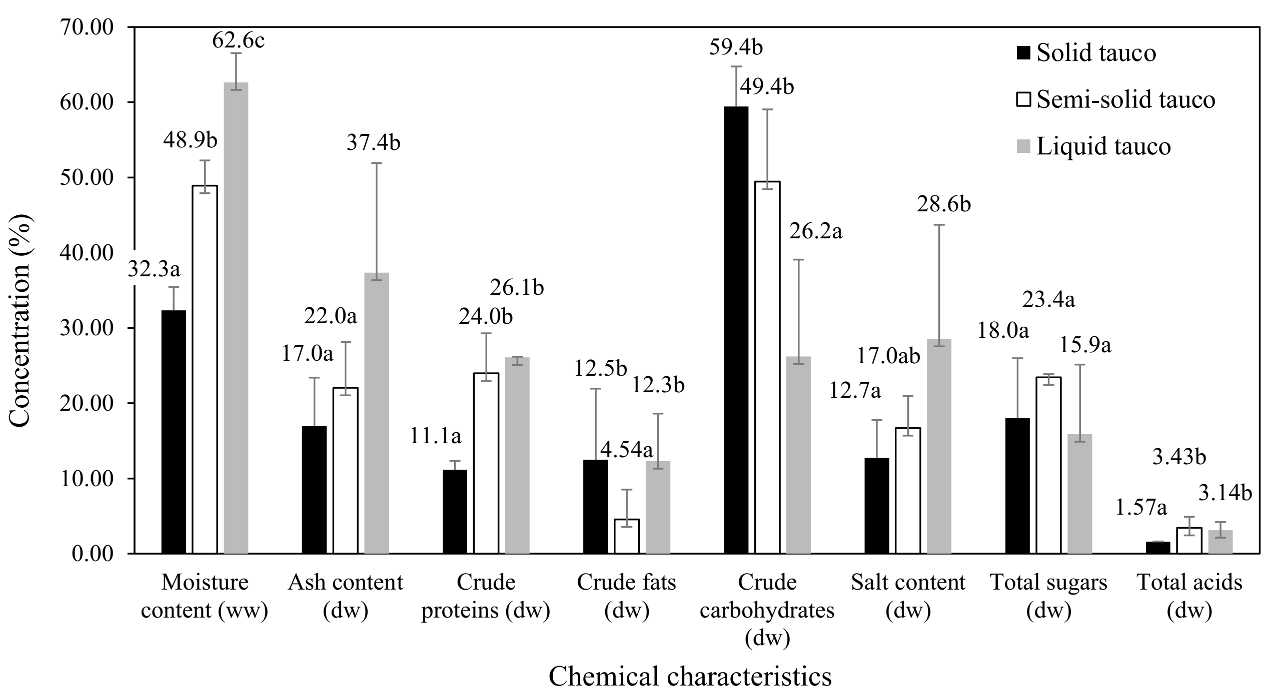

Fig. 6 Chemical composition and the statistical group of solid, semisolid, and liquid tauco. The different letters in each characteristic indicate significant differences ($p < 0.05$), analyzed by one-way ANOVA, followed by Duncan test. Parameters of salt content, total sugars, and total acids are for NaCl content (by titrimetric method using $AgNO_3$ reagent), total reducing and non-reducing sugars (by spectrophotometric method using anthrone reagent), and total titratable acids, respectively

other soybean paste products according to the proximate composition.

In the present study, based on the three groups of tauco products, the chemical composition of all groups is summarized in Fig. 6. Moisture contents of the tauco products, which had a range of 29.2–35.3% ww for solid, 42.2–54.5% ww for semisolid, and 56.2–68.1% ww for liquid tauco (Table 3), showed a significant difference at $p < 0.05$ (Fig. 6). Liquid tauco had the highest moisture content, twice higher than solid form. Meanwhile, semisolid tauco had a moisture content of 1.5 times higher than solid form.

Tauco products contained a wide range of ash content, 10.0–73.8% dw (Table 3). Most of the ash is sodium salt, which was added in a high concentration of brine solution during the fermentation process. The salt content ranged from 7.13 to 68.4% dw (Table 3) or comprising 40–94% of the ash contained in all tauco products. The salt content reached 130–580 times salty taste threshold, that is, 0.0327% [24]. Due to the relatively strong salty taste, tauco is not suitable for direct consumption, but is commonly used as a seasoning ingredient [13]. Solid tauco contained salt ranged from 7.13 to 16.9% dw, while salt in semisolid and liquid tauco ranged from 10.9 to 24.8% dw and 10.7–68.4% dw. Liquid tauco had a significantly higher salt content ($p < 0.05$) than those of solid and semisolid form (Fig. 6). The relatively high salt contents in the tauco products were due to the use of salt solution at high concentrations for the second step of tauco fermentation that could inhibit the growth of undesirable microbes.

Liquid and semisolid tauco had a comparable range of crude proteins, 20.4–30.9% dw and 15.1–32.6% dw, respectively. Meanwhile, crude proteins in solid tauco were relatively lower, ranging from 9.72 to 11.9% dw (Fig. 6). These crude proteins distinguished solid tauco from the other types. Low crude proteins content in solid tauco (in dw) are due to the higher contents of other solid content, carbohydrates, which is discussed below. The proteins found in tauco could be associated with an increase in the number of the fermenting microorganisms [25], or due to proteolytic enzymes produced by the fermenting microorganisms [26, 27], or as a result of the synthesis of protein by microorganisms during fermenting substrates [28]. The protein contents can also be influenced by soybean varieties used as raw materials [29].

The crude fats of solid, semisolid, and liquid tauco ranged at 6.98–23.4% dw, 0.92–14.0% dw and 1.30–18.9% dw, respectively. The lowest crude fats were found in semisolid tauco, and these were significantly different to other tauco groups (Fig. 6). Fats in raw materials could be used as an energy source for microorganisms [30], and thus, the lower crude fats in semisolid tauco may mention the more rigorous growth of microorganisms during the production of the semisolid tauco.

Carbohydrates content of solid, semisolid, and liquid tauco ranged at 54.7–65.2% dw, 33.7–68.4% dw, and 8.47–56.5% dw; meanwhile, their average and standard deviation were at 59.4 ± 5.3%, 49.4 ± 9.6% and 26.2 ± 12.9% dw, respectively. Carbohydrates *by difference* also distinguished liquid tauco from other types of tauco. Liquid tauco contained the lowest carbohydrates content, while solid tauco had the highest carbohydrates content. In solid tauco, carbohydrates seem to be present not only from the raw material used for tauco fermentation but also by later carbohydrate addition used as a thickener or texturizer. Sugars are among soluble carbohydrates which was found in 24 tauco products, ranging from 4.45 to 42.3% dw. The total sugars reached 30–90% of the crude carbohydrates. From this study, there was no significantly difference ($p > 0.05$) between total sugars in solid, semisolid, and liquid tauco.

The tauco products contained total acids (expressed as lactic acid equivalent) at very low concentrations compared to other chemical components, ranging from 1.24 to 5.43% dw. Solid, semisolid, and liquid tauco contained total acids ranging from 1.24 to 2.18% dw, 1.30–5.43% dw, and 1.65–5.36% dw, respectively. The total acids between semisolid and liquid tauco did not show a significant difference ($p > 0.05$), and the acid concentrations of both samples reached more than twice higher as those of solid tauco (Fig. 6). All tauco samples in this study had a slight acidic pH value, ranging from 4.38 to 5.91 (with an average and standard deviation at 4.94 ± 0.39). The pH values of solid, semisolid, and liquid tauco, respectively, ranged from 4.38 to 5.35, 4.48–5.34, and 4.41–5.91. The acid contents in tauco were due to the role of acid-producing microorganisms in the condition of relatively high salt concentration at the second stage of tauco fermentation [31]. The acid-producing microorganisms are mostly from lactic acid bacteria as presented in Table 1.

Amino acid profiles of tauco

The amino acid composition of tauco is shown in Table 4. Twenty-four tauco products contained total amino acids in the range of 11.5–24.6% dw (17.1 ± 3.50% dw), figuring the content of crude proteins. Glutamic acid (Glu) was the primary total amino acid present in tauco (4.00 ± 1.01% dw), followed by aspartic acid (Asp) at 2.07 ± 0.43% dw, and leucine (Leu) at 1.64 ± 0.31% dw. Glu, Asp, and Leu were also the most abundant amino acids in Chinese fermented soybean food, *sufu*, prepared with 8% w/w salt contents [32]. The final salt content in most soybean paste products, especially red and gray *sufu*, was still more than 10% dw [33]. In this present

Table 4 Amino acid profiles of tauco products from different producers throughout Indonesia

Taste attribute	Amino acid	Total amino acid concentration (% dw)										
		MIS	**CKS**	**SIM**	**CBC**	**CBM**	**MNB**	**SAP**	**PDP**	**TKP**	**MMP**	**CIP**
Umami	Asp	1.48	1.85	1.60	2.01	1.73	3.14	1.88	2.09	2.04	1.72	1.83
	Glu	2.57	4.35	2.92	3.78	3.03	6.04	3.82	4.01	3.89	3.36	3.58
	Subtotal	**4.05**	**6.20**	**4.52**	**5.79**	**4.76**	**9.18**	**5.70**	**6.10**	**5.93**	**5.08**	**5.41**
Relative abundance (%)		**35**	**35**	**35**	**38**	**36**	**38**	**37**	**37**	**35**	**38**	**34**
Sweet	Ala	0.73	1.11	0.77	0.81	0.70	1.30	0.87	0.93	1.08	0.90	1.08
	Gly	0.56	0.85	0.63	0.77	0.65	1.25	0.78	0.82	0.80	0.66	0.79
	Ser	0.51	0.78	0.68	0.80	0.75	1.29	0.81	0.93	0.90	0.56	0.88
	Thr	0.48	0.69	0.58	0.69	0.63	1.02	0.70	0.75	0.75	0.53	0.75
	Subtotal	**2.28**	**3.43**	**2.66**	**3.07**	**2.73**	**4.86**	**3.16**	**3.43**	**3.53**	**2.65**	**3.50**
Relative abundance (%)		**20**	**20**	**21**	**20**	**20**	**20**	**21**	**21**	**21**	**20**	**22**
Bitter	Val	0.70	1.15	0.84	1.00	0.88	1.52	0.98	1.07	1.09	0.81	1.05
	Met	0.15	0.23	0.14	0.17	0.16	0.16	0.21	0.23	0.22	0.15	0.20
	Ile	0.65	1.06	0.77	0.95	0.85	1.34	0.89	1.02	1.02	0.73	0.98
	Leu	1.12	1.73	1.16	1.49	1.36	2.13	1.40	1.67	1.71	1.31	1.57
	Tyr	0.36	0.41	0.41	0.42	0.38	0.90	0.48	0.55	0.52	0.29	0.53
	Phe	0.73	1.09	0.76	1.01	0.93	1.50	0.89	1.02	1.05	0.84	1.00
	His	0.43	0.57	0.41	0.56	0.56	0.54	0.56	0.55	0.48	0.44	0.66
	Arg	0.35	0.75	0.65	0.43	0.45	1.05	0.68	0.49	0.46	0.31	0.60
	Subtotal	**4.49**	**6.99**	**5.14**	**6.03**	**5.57**	**9.14**	**6.09**	**6.60**	**6.55**	**4.88**	**6.59**
Relative abundance (%)		**39**	**40**	**40**	**40**	**42**	**37**	**40**	**40**	**39**	**37**	**41**
Other	Lys	0.63	0.91	0.47	0.26	0.32	1.23	0.32	0.50	0.78	0.75	0.64
	Subtotal	**0.63**	**0.91**	**0.47**	**0.26**	**0.32**	**1.23**	**0.32**	**0.50**	**0.78**	**0.75**	**0.64**
Relative abundance (%)		**6**	**5**	**4**	**2**	**2**	**5**	**2**	**3**	**5**	**6**	**4**
Sum of total amino acid conc		**11.5**	**17.5**	**12.8**	**15.2**	**13.4**	**24.4**	**15.3**	**16.7**	**16.8**	**13.4**	**16.1**

Taste attribute	Amino acid	Total amino acid concentration (% dw)												
		LEP	**SKT**	**CMC**	**SAB**	**CBB**	**CDS**	**KES**	**BMP**	**MIP**	**CGM**	**HAM**	**BEB**	**SUM**
Umami	Asp	2.28	2.62	1.88	2.14	1.91	2.78	2.08	1.68	2.77	1.38	2.07	2.21	2.44
	Glu	4.02	4.64	3.71	3.86	4.24	6.18	3.67	3.25	6.31	2.45	3.59	4.21	4.46
	Subtotal	**6.30**	**7.26**	**5.59**	**6.00**	**6.15**	**8.96**	**5.75**	**4.93**	**9.08**	**3.83**	**5.66**	**6.42**	**6.90**
Relative abundance (%)		**35**	**36**	**40**	**34**	**33**	**36**	**34**	**34**	**38**	**25**	**36**	**33**	**37**
Sweet	Ala	1.08	1.26	0.72	0.87	1.27	1.37	1.00	0.99	1.23	1.93	0.85	1.04	1.01
	Gly	0.86	0.98	0.72	0.81	0.85	1.13	0.85	0.71	1.05	0.47	0.74	0.87	0.88
	Ser	0.98	1.11	0.75	0.94	0.87	1.26	0.91	0.75	1.24	0.43	0.84	0.91	1.00
	Thr	0.81	0.92	0.63	0.76	0.78	0.99	0.73	0.63	0.98	0.38	0.70	0.79	0.83
	Subtotal	**3.73**	**4.27**	**2.82**	**3.38**	**3.77**	**4.75**	**3.49**	**3.08**	**4.50**	**3.21**	**3.13**	**3.61**	**3.72**
Relative abundance (%)		**20**	**21**	**20**	**19**	**21**	**19**	**20**	**21**	**19**	**21**	**20**	**18**	**20**
Bitter	Val	1.18	1.35	0.90	1.01	1.12	1.36	1.05	0.91	1.33	1.29	0.98	1.11	1.12
	Met	0.22	0.26	0.16	0.22	0.19	0.31	0.23	0.17	0.26	0.16	0.19	0.25	0.23
	Ile	1.11	1.24	0.87	0.98	1.03	1.32	1.01	0.83	1.31	1.32	0.91	1.01	1.05
	Leu	1.88	2.06	1.34	1.59	1.70	2.19	1.63	1.37	2.08	2.14	1.44	1.65	1.64
	Tyr	0.52	0.67	0.36	0.62	0.51	0.78	0.60	0.44	0.76	0.27	0.51	1.85	0.66
	Phe	1.06	1.21	0.88	1.10	1.22	1.39	1.15	0.86	1.40	1.15	0.89	1.11	1.09
	His	0.51	0.52	0.52	0.61	0.60	0.66	0.50	0.46	0.69	0.28	0.53	0.57	0.58
	Arg	0.66	0.60	0.45	1.05	0.88	1.23	0.75	0.59	1.25	0.44	1.09	0.81	0.76
	Subtotal	**7.14**	**7.91**	**5.48**	**7.18**	**7.25**	**9.24**	**6.92**	**5.63**	**9.08**	**7.05**	**6.54**	**8.36**	**7.13**
Relative abundance (%)		**39**	**39**	**39**	**41**	**39**	**38**	**40**	**39**	**38**	**45**	**41**	**43**	**38**
Other	Lys	0.89	0.94	0.23	1.08	1.22	1.61	0.98	0.86	1.13	1.42	0.57	1.14	1.00

Table 4 (continued)

Taste attribute	Amino acid	Total amino acid concentration (% dw)												
		LEP	SKT	CMC	SAB	CBB	CDS	KES	BMP	MIP	CGM	HAM	BEB	SUM
	Subtotal	**0.89**	**0.94**	**0.23**	**1.08**	**1.22**	**1.61**	**0.98**	**0.86**	**1.13**	**1.42**	**0.57**	**1.14**	**1.00**
Relative abundance (%)		**5**	**5**	**2**	**6**	**7**	**7**	**6**	**6**	**5**	**9**	**4**	**6**	**5**
Sum of total amino acid conc		**18.1**	**20.4**	**14.1**	**17.6**	**18.4**	**24.6**	**17.1**	**14.5**	**23.8**	**15.5**	**15.9**	**19.5**	**18.8**

study, the salt contents of tauco products ranged at 4.38 – 18.7% ww or 7.13 – 68.4% dw, which were higher compared to those of *sufu* and the other similar products, such as *doenjang* (17.5 – 39.2% dw) [22] and *miso* (8.93 – 26.0% dw) [23]. The relatively high salt content in tauco and other similar products are due to salt addition during the second stage of fermentation to provide a selection for halophilic bacteria and yeasts which their growths are desired for the products. The presence of salt in the final products is also important for the desired taste because it could intensify the umami taste of free amino acids (glutamic acid and aspartic acid) contained in final products, as revealed in other salt and amino acids containing products such as soy sauce [34, 35], cheese [36], and *tofuyo* [37]. These studies imply that amino acids together with salt may potentiate the umami taste of tauco. However, total amino acids of tauco (17.1 ± 3.50% dw) showed at lower concentrations compared to those in soybeans, 33.9 ± 2.8% dw, with the dominant amino acids in soybeans including Glu at 7.34 ± 0.06% dw, Asp at 3.88 ± 1.04% dw, arginine (Arg) at 2.84 ± 0.437% dw, Leu at 2.78 ± 0.22% dw, and lysine (Lys) at 2.15 ± 0.30% dw [38, 39]. This change especially happened after the second stage of fermentation. The study by Hong et al. [39] showed that soybean fermentation with *A. oryzae* which mimics the first stage of tauco fermentation did not affect the contents of amino acids as shown by the not significant increase from 39.0% dw to 41.4% dw, but it could provide small-size peptides, which is important for microbials growth at the later stage of fermentation, such as brine fermentation in tauco production. Another study, according to Han et al. [32], also stated that the fermentation of soybeans curd with the mold *Actinomucor elegans* in the manufacture of *sufu* did not show a significant difference in the total amino acids content (from 54.7% dw to 55.1% dw). However, subsequent fermentation with salt could cause a significant decrease in the total amino acids (from 54.7 to 35.1% dw). These results showed that mold fermentation did not affect a significant decrease in the total amino acid content, but brine fermentation provides a significant decrease in the total amino acid content due to the microbial community, dominated by halophilic yeasts and lactic acid bacteria that metabolize short chain peptides into amino acids and utilize amino acids in their metabolism.

During tauco fermentation, especially in brine fermentation, involved microorganisms (yeast and lactic acid bacteria) contribute to the metabolic activity that governs tauco quality. Among fermentation metabolites, small-size peptides and free amino acids are essential that play a role in the metabolism by microorganisms or for nutritional requirements in microbial growth through proteolytic activities [39–42]. Small-size peptides formed by enzymatic reaction during the koji/meju fermentation by fungi and then followed by shorter peptides or free amino acids formed at the early stage of brine/moromi fermentation by the activity of proteolytic enzymes produced by the fungi [39] may promote the growth of lactic acid bacteria observed through proteolytic activities at the later stage [41, 43]. These proteolytic activities are responsible for the organoleptic properties of the final products [44, 45]. Microbial communities found in tauco and similar products to tauco at koji/meju fermentation and at brine/moromi fermentation stages are shown in Table 1.

The free amino acids also contribute directly to taste perception and impart several basic tastes, such as umami taste from Glu and Asp, sweet taste from alanine (Ala), glycine (Gly), serine (Ser), and threonine (Thr), and also bitter taste from valine (Val), methionine (Met), isoleucine (Ile), leucine (Leu), tyrosine (Tyr), phenylalanine (Phe), histidine (His), and arginine (Arg) [46, 47]. In some fermented soybean products, the presence of free amino acids during fermentation, such as Glu and Asp (umami), also Phe and Tyr (bitter) at their subthreshold concentrations, and in the presence of salt, might also play an important role in impressing umami taste of Indonesian soy sauce [34]. On the other hand, the abundant presence of free Glu and Asp and several sweet-taste eliciting amino acids (Ala, Ser) were considered to be the main contributors to the umami taste of shoyu [20, 35] and tofuyo [37].

Accordingly, Table 4 shows that bitter amino acids were in relatively high concentrations, contributing 37–45% of the total amino acids, while umami amino acids account for 25–40%. However, the percentage of bitter amino acids were for a combination of 8 amino acids, while

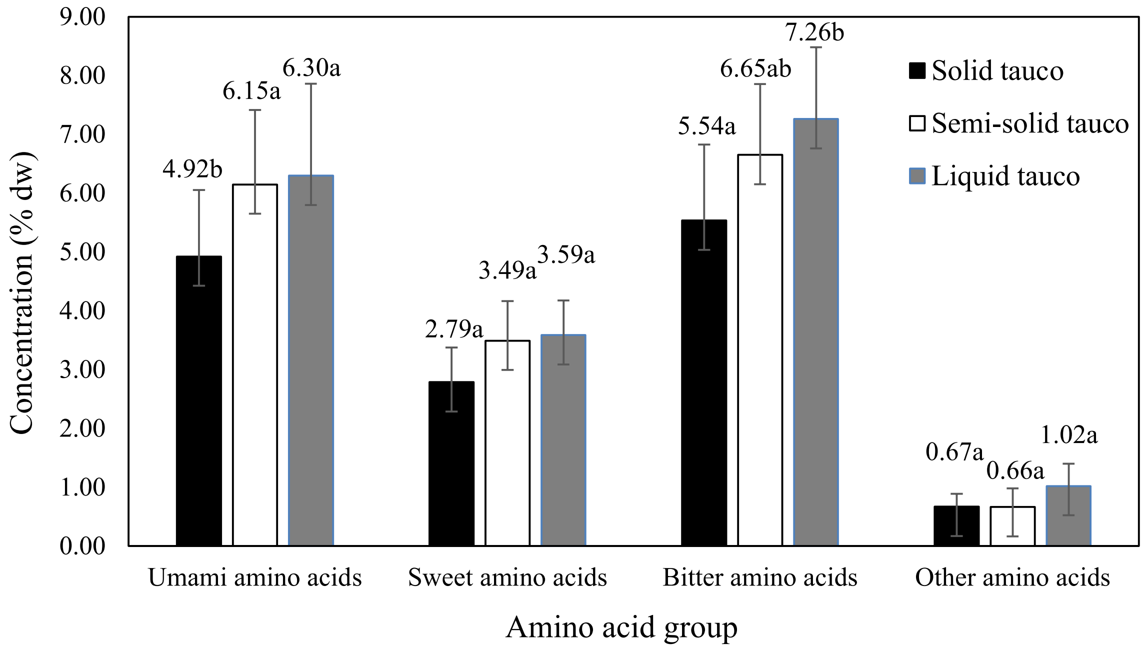

Fig. 7 Concentrations of umami, sweet, and bitter-taste amino acids, and the statistical groups of solid, semisolid, and liquid tauco. The different letters indicate significant differences ($p < 0.05$), analyzed by one-way ANOVA, followed by Duncan test

umami amino acids are a combination of 2 amino acids. Sweet amino acids were in relatively lower concentrations than the others, contributing 18–22% of the total amino acids. The ratio of umami to bitter amino acids in the tauco was 1:1, while their ratio to sweet amino acids was higher, approaching 2:1. This ratio was comparable *to sufu* [32], which may give tauco a pleasant taste [33]. The evaluation of nutritional composition of tauco related to its desired taste is firstly reported. Figure 7 shows no significant difference ($p > 0.05$) between solid, semisolid, and liquid tauco in sweet amino acids content. Meanwhile, semisolid tauco contained umami, sweet, and bitter amino acids content were not significantly different ($p > 0.05$) from the liquid tauco. Perhaps, the taste intensities of these tauco products were not different.

Figure 8 shows the PCA model performed on the amino acid profiles of tauco products. The first 2 PCs in the model produced R2X of 0.846 and Q2 of 0.687. The total variance of the data set was 84.60%, a combination of PC1 and PC2, which was 77.20% and 7.40%, respectively. Based on amino acid profiles, the scores plot was divided tauco products into 3 clusters, but different from those discussed above on their proximate composition. One sample of semisolid tauco, MNB sample, separated as a cluster (orange color). The MNB sample had the highest concentration of amino acids compared to other samples, either for umami, sweet, or bitter amino acids. The sample scores were also close to loadings of Glu and Asp (umami amino acids), Gly, Ser, and Thr (sweet amino acids), and Phe, Val, Ile, and Leu (bitter amino acids). Glu and Asp as well as Gly, Ser, Thr, and Val have been reported as umami-related amino acids which were found in many umami peptides [48–50]. Another study also showed that Arg, Asp, Glu, Gln, and Tyr as amino acid residues of umami peptides were on the binding sites to T1R1/T1R3 receptor, an umami receptor [5, 51, 52]. Therefore, MNB was an important tauco for further investigation to find umami peptides. The umami peptides may also have bioactivities such as antioxidant, antidiabetic, and antihypertensive activities as found in the studies of umami peptides [53, 54]. These could lead to the exploration of umami peptides and bioactive peptides from tauco.

Conclusion

The present study showed that nutritional composition especially the proximate composition best distinguished 24 tauco products produced throughout Indonesia. First, multivariate analysis of proximate composition could classify tauco products into solid, semisolid, and liquid forms, with moisture content best determined this category. Besides this, liquid tauco and semisolid tauco were characterized by crude proteins content, which is important for their desired taste; meanwhile, solid tauco was characterized by carbohydrates content. Second, PCA

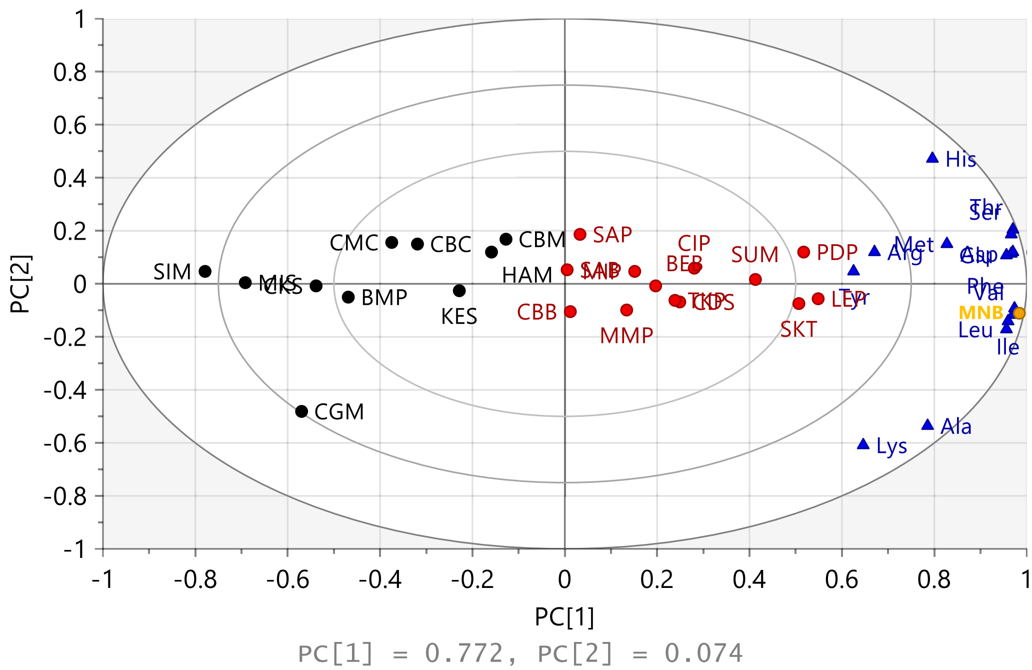

Fig. 8 PCA biplot based on amino acid profiles of tauco products (N = 24, R^2X: 0.846, Q^2: 0.687), analyzed by SIMCA v.17 trial version

mapping based on total amino acid profiles showed a semisolid tauco which had a different amino acid profile from the others, highlighted by the high concentrations of amino acids related to umami peptides. This gives an insight for future research on umami peptides as well as bioactive peptides from tauco, since some umami peptides could exhibit bioactivities.

Abbreviation
PCA: Principal component analysis.

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Author contributions
VTH collected and analyzed the data as well as performed manuscript drafting. HNL devised the main conceptual idea, designed the research, and supervised this study as well as performed manuscript drafting and incorporating revisions. DRA and HDK supervised data analysis and data interpretation as well as performed manuscript drafting. All authors read and approved the final manuscript.

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Availability of data and materials
All data and materials are presented in the manuscript.

Declarations

Competing interests
All authors declared that they have no competing interest arisen from this present study.

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References
1. Panda SK, Sahu L. Innovative technologies and implication in fermented food and beverage industries: an overview. In: Panda SK, Shetty PH, editors. Innovations in technologies for fermented food and beverage industries. Switzerland: Springer; 2018. p. 1–24. https://doi.org/10.1007/978-3-319-74820-7.
2. Cao Z-H, Green-Johnson JM, Buckley ND, Lin Q-Y. Bioactivity of soy-based fermented foods: A review. Biotechnol Adv. 2019;37(1):223–38. https://doi.org/10.1016/j.biotechadv.2018.12.001.
3. Chang HC. Healthy and safe Korean traditional fermented foods: kimchi and chongkukjang. J Ethn Foods. 2018;5(3):161–6. https://doi.org/10.1016/j.jef.2018.08.003.
4. Park K-Y, Park E-S. Health benefits of doenjang (soybean paste) and kanjang (soybean sauce). In: Park K-Y, Kwon DY, Lee KW, Park S, editors. Korean functional foods. Florida: CRC Press; 2017. p. 101–44.
5. Yue X, Li M, Liu Y, Zhang X, Zheng Y. Microbial diversity and function of soybean paste in East Asia: what we know and what we don't. Curr Opin Food Sci. 2021;37:145–52. https://doi.org/10.1016/j.cofs.2020.10.012.
6. Kusumoto K-I, Yamagata Y, Tazawa R, Kitagawa M, Kato T, Isobe K, Kashiwagi Y. Japanese traditional miso and koji making. J Fungi. 2021;7(7):579–96. https://doi.org/10.3390/jof7070579.

7. Shin D, Jeong D. Korean traditional fermented soybean products: Jang. J Ethn Foods. 2015;2(1):2–7. https://doi.org/10.1016/j.jef.2015.02.002.
8. Xie M, An F, Yue X, Liu Y, Shi H, Yang M, Cao X, Wu J, Wu R. Characterization and comparison of metaproteomes in traditional and commercial dajiang, a fermented soybean paste in northeast China. Food Chem. 2019;301:125270. https://doi.org/10.1016/j.foodchem.2019.125270.
9. Chukeatirote E. Thua nao: Thai fermented soybean. J Ethn Foods. 2015;2(3):115–8. https://doi.org/10.1016/j.jef.2015.08.004.
10. Nuraida L. Fermented protein-rich plant-based foods. In: Sankaranarayanan A, Amaresan N, editors. Fermented food products. Florida: CRC Press; 2019. p. 141–61.
11. Surono IS. Ethnic fermented foods and beverages of Indonesia. In: Tamang JP, editor. Ethnic fermented foods and alcoholic beverages of Asia. New Delhi: SpringerIndia; 2016. p. 341–82.
12. Shurtleff W, Aoyagi A History of Miso, Soybean Jiang (China), Jang (Korea) and Tauco (Indonesia) (200 BC-2009). California (USA). Soyinfo Center; 2009.
13. Djajasoepena S, Korinna GS, Rachman SD, Pratomo U. The potential of tauco as a functional food. Chim Nat Acta. 2014;2(2):137–41.
14. Larasati N. The study of antioxidant activity and physicochemical characteristics of tauco in the Malang city. East Java J Food Agro. 2017;5(2):85–95.
15. Nandiyanto ABD, Ismiati R, Indrianti J, Abdullah AG. Economic perspective in the production of preserved soybean (tauco) with various raw material quantities. IOP Conf Ser Mater Sci Eng. 2018;288:012025. https://doi.org/10.1088/1757-899X/288/1/012025.
16. Amar A, Makosim S, Sukotjo S, Ahadiyanti N, Weisman E. Growth dynamics of mold-yeast and bacteria during the production process of saga tauco (*Adenanthera pavonina*). IOP Conf Ser Earth Environ Sci. 2021;741:012019. https://doi.org/10.1088/1755-1315/741/1/012019.
17. Jeong D-W, Kim H-R, Jung G, Han S, Kim C-T, Lee J-H. Bacterial community migration in the ripening of doenjang, a traditional Korean fermented soybean food. J Microbiol Biotechnol. 2014;24(5):648–60. https://doi.org/10.4014/jmb.1401.01009.
18. AOAC. Official method of analysis. 19th ed. Maryland: AOAC; 2012.
19. Fisher RB, Peters DG. Quantitative chemical analysis. 3rd ed. Philadelphia: W. B. Saunders Co.; 1968.
20. Lioe HN, Takara K, Yasuda M. Evaluation of peptide contribution to the intense umami taste of Japanese soy sauces. J Food Sci. 2006;71(3):S277–83. https://doi.org/10.1111/j.1365-2621.2006.tb15654.x.
21. Wolfe BE, Dutton RJ. Fermented foods as experimentally tractable microbial ecosystems. Cell. 2015;161(1):49–55. https://doi.org/10.1016/j.cell.2015.02.034.
22. Park SY, Kim S, Hong SP, Lim SD. Analysis of quality characteristics of regional traditional and commercial soybean pastes (*Doenjang*). Korean J Food Cook Sci. 2016;32(6):686–95. https://doi.org/10.9724/kfcs.2016.32.6.686.
23. Abiose SH, Allan MC, Wood BJB. Microbiology and biochemistry of miso (soy paste) fermentation. Adv Appl Microbiol. 1982;28:239–65. https://doi.org/10.1016/S0065-2164(08)70237-5.
24. Wiriyawattana P, Suwonsichon S, Suwonsichon T. Effects of aging on taste thresholds: a case of Asian people. J Sens Stud. 2018;33(4):e12436. https://doi.org/10.1111/joss.12436.
25. Ojokoh AO, Fayemi OE, Ocloo FC, Alakija O. Proximate composition, antinutritional contents and physicochemical properties of breadfruit (*Treculia africana*) and cowpea (*Vigna unguiculata*) flour blends fermented with *Lactobacillus plantarum*. Afr J Microbiol Res. 2014;8(12):1352–9. https://doi.org/10.5897/AJMR2013.6469.
26. Amankwah EA, Barimah J, Acheampong R, Addai LO, Nnaji CO. Effect of fermentation and malting on the viscosity of maize-soyabean weaning blends. Pak J Nutr. 2009;8(10):1671–5.
27. Ojokoh AO, Fayemi OE, Ocloo FC, Nwokolo FI. Effect of fermentation on proximate composition, physicochemical and microbial characteristics of pearl millet (*Pennisetum glaucum* (L.) R. Br.) and Acha (*Digitaria exilis* (Kippist) Stapf) flour blends. J Agric Biotech Sustain Dev. 2015;7(1):1–8. https://doi.org/10.5897/JABSD2014.0236.
28. Babalola RO, Giwa OE. Effect of fermentation on nutritional and anti-nutritional properties of fermenting Soy beans and the antagonistic effect of the fermenting organism on selected pathogens. Int Res J Microbiol. 2012;3(10):333–8.
29. Kim G-Y, Moon H-K, Lee S-W, Moon J-N, Yoon W-J. Effect of mixed soybeans materials on quality characteristics of traditional soybean paste (doenjang) during aging. Korean J Food Cook Sci. 2010;26(3):314–22.
30. Afify AE-MMR, Rashed MM, Mahmoud EA, El-Beltagi HS. Effect of gamma radiation on protein profile, protein fraction and solubility's of three oil seeds: soybean, peanut and sesame. Not Bot Horti Agrobot Cluj-Napoca. 2011;39(2):90–8. https://doi.org/10.15835/nbha3926252.
31. Shukla S, Choi TB, Park H-K, Kim M, Lee IK, Kim J-K. Determination of non-volatile and volatile organic acids in Korean traditional fermented soybean paste (Doenjang). Food Chem Toxicol. 2010;48:2005–10. https://doi.org/10.1016/j.fct.2010.04.034.
32. Han B-Z, Rombouts FM, Nout MJR. Amino acid profiles of sufu, a Chinese fermented soybean food. J Food Compos Anal. 2004;17(6):689–98. https://doi.org/10.1016/j.jfca.2003.09.012.
33. Han B-Z, Rombouts FM, Nout MJR. A Chinese fermented soybean food. Int J Food Microbiol. 2001;65:1–10. https://doi.org/10.1016/S0168-1605(00)00523-7.
34. Lioe HN, Apriyantono A, Takara K, Wada K, Naoki H, Yasuda M. Low molecular weight compounds responsible for savory taste of Indonesian soy sauce. J Agric Food Chem. 2004;52(19):5950–6. https://doi.org/10.1021/jf049230d.
35. Lioe HN, Wada K, Aoki T, Yasuda M. Chemical and sensory characteristics of low molecular weight fractions obtained from three types of Japanese soy sauce (shoyu)—Koikuchi, tamari and shiro shoyu. Food Chem. 2007;100(4):1669–77. https://doi.org/10.1016/j.foodchem.2005.12.047.
36. Drake SL, Carunchia Whetstine ME, Drake MA, Courtney P, Fligner K, Jenkins J, Pruitt C. Sources of umami taste in Cheddar and Swiss cheeses. J Food Sci. 2007;72(6):S360–6. https://doi.org/10.1111/j.1750-3841.2007.00402.x.
37. Lioe HN, Kinjo A, Yasuda S, Kuba-Miyara M, Tachibana S, Yasuda M. Taste and chemical characteristics of low molecular weight fractions from tofuyo—Japanese fermented soybean curd. Food Chem. 2018;252:265–70. https://doi.org/10.1016/j.foodchem.2018.01.117.
38. Frias J, Song YS, Martínez-Villaluenga C, De Mejia EG, Vidal-Valverde C. Immunoreactivity and amino acid content of fermented soybean products. J Agric Food Chem. 2008;56(1):99–105. https://doi.org/10.1021/jf072177j.
39. Hong K-J, Lee C-H, Kim SW. *Aspergillus oryzae* GB-107 fermentation improves nutritional quality of food soybeans and feed soybean meals. J Med Food. 2004;7(4):430–5. https://doi.org/10.1089/jmf.2004.7.430.
40. Saeed AH, Salam AI. Current limitations and challenges with lactic acid bacteria: a review. Food Nutr Sci. 2013;49(11A):73–87. https://doi.org/10.4236/fns.2013.411A010.
41. Barrangou R, Lahtinen SJ, Ibrahim F, Salminen S, Ouweheand AC. Genus *Lactobacillus*. In: Lahtinen SJ, Salminen S, Wright AV, Ouwehan A, editors. Genetics of lactic acid bacteria. London: CRC Press; 2011. p. 77–92.
42. Jiranek V, Langridge P, Henschke PA. Amino acid and ammonium utilization by *Saccharomyces cerevisiae* wine yeasts from a chemically defined medium. Am J Enol Vitic. 1995;46(1):75–83.
43. Savijoki K, Ingmer H, Varmanen P. Proteolytic systems of lactic acid bacteria. Appl Microbiol Biotechnol. 2006;71(4):394–406. https://doi.org/10.1007/s00253-006-0427-1.
44. Williams AG, Noble J, Banks JM. Catabolism of amino acids by lactic acid bacteria isolated from Cheddar cheese. Int Dairy J. 2001;11:203–15. https://doi.org/10.1016/S0958-6946(01)00050-4.
45. van Kranenburg R, Kleerebezem M, van Hylckama VJ, Ursing BM, Boekhorst J, Smit BA, Ayad EHE, Smit G, Siezen RJ. Flavour formation from amino acids by lactic acid bacteria: predictions from genome sequence analysis. Int Dairy J. 2002;12:111–21. https://doi.org/10.1016/S0958-6946(01)00132-7.
46. Qin L, Ding X. Formation of taste and odor compounds during preparation of douchiba, a chinese traditional soy-fermented appetizer. J Food Biochem. 2007;31(2):230–51. https://doi.org/10.1111/j.1745-4514.2007.00105.x.
47. Tseng Y-H, Lee Y-L, Li R-C, Mau J-L. Non-volatile flavour components of *Ganoderma tsugae*. Food Chem. 2005;90(3):409–15. https://doi.org/10.1016/j.foodchem.2004.03.054.
48. Dang Y, Hao L, Cao J, Sun Y, Zeng X, Wu Z, Pan D. Molecular docking and simulation of the synergistic effect between umami peptides, monosodium glutamate and taste receptor T1R1/T1R3. Food Chem. 2019;271:697–706. https://doi.org/10.1016/j.foodchem.2018.08.001.

49. Zhang J, Sun-Waterhouse D, Su G, Zhao M. New insight into umami receptor, umami/umami-enhancing peptides and their derivatives: a review. Trends Food Sci Technol. 2019;88:429–38. https://doi.org/10.1016/j.tifs.2019.04.008.
50. Zhao Y, Zhang M, Devahastin S, Liu Y. Progresses on processing methods of umami substances: a review. Trends Food Sci Technol. 2019;93:125–35. https://doi.org/10.1016/j.tifs.2019.09.012.
51. Shiyan R, Liping S, Xiaodong S, Jinlun H, Yongliang Z. Novel umami peptides from tilapia lower jaw and molecular docking to the taste receptor T1R1/T1R3. Food Chem. 2021;362:130249. https://doi.org/10.1016/j.foodchem.2021.130249.
52. Zhang Y, Gao X, Pan D, Zhang Z, Zhou T, Dang Y. Isolation, characterization and molecular docking of novel umami and umami-enhancing peptides from *Ruditapes philippinarum*. Food Chem. 2021;343:128522. https://doi.org/10.1016/j.foodchem.2020.128522.
53. Chen M, Pan D, Zhou T, Gao X, Dang Y. Novel umami peptide IPIPATKT with dual dipeptidyl peptidase-IV and angiotensin I-converting enzyme inhibitory activities. J Agric Food Chem. 2021;69(19):5463–70. https://doi.org/10.1021/acs.jafc.0c07138.
54. Shen D-Y, Begum N, Song H-L, Zhang Y, Wang L-J, Zhao Y-J, Zhang L, Liu P. In vitro and in vivo antioxidant activity and umami taste of peptides (<1 kDa) from porcine bone protein extract. Food Biosci. 2021;40: 100901. https://doi.org/10.1016/j.fbio.2021.100901.
55. Hui W, Hou Q, Cao C, Xu H, Zhen Y, Kwok L-Y, Sun T, Zhang H, Zhang W. Identification of microbial profile of *koji* using single molecule, real-time sequencing technology. J Food Sci. 2017;82(5):1193–9. https://doi.org/10.1111/1750-3841.13699.
56. Kim TW, Lee J-H, Park M-H, Kim H-Y. Analysis of bacterial and fungal communities in Japanese- and chinese-fermented soybean pastes using nested PCR–DGGE. Curr Microbiol. 2010;60(5):315–20. https://doi.org/10.1007/s00284-009-9542-4.
57. Chun BH, Kim KH, Jeong SE, Jeon CO. The effect of salt concentrations on the fermentation of doenjang, a traditional Korean fermented soybean paste. Food Microbiol. 2020;86:103329. https://doi.org/10.1016/j.fm.2019.103329.
58. Jung JY, Lee SH, Jeon CO. Microbial community dynamics during fermentation of doenjang-meju, traditional Korean fermented soybean. Int J Food Microbiol. 2014;185:112–20. https://doi.org/10.1016/j.ijfoodmicro.2014.06.003.
59. Wu J, Tian T, Liu Y, Shi Y, Tao D, Wu R, Yue X. The dynamic changes of chemical components and microbiota during the natural fermentation process in Da-Jiang, a Chinese popular traditional fermented condiment. Food Res Int. 2018;112:457–67. https://doi.org/10.1016/j.foodres.2018.06.021.
60. Zhang P, Wu R, Zhang P, Liu Y, Tao D, Yue X, Zhang Y, Jiang J, Wu J. Structure and diversity of bacterial communities in the fermentation of da-jiang. Ann Microbiol. 2018;68(8):505–12. https://doi.org/10.1007/s13213-018-1355-x.
61. Xie M, Wu J, An F, Yue X, Tao D, Wu R, Lee Y. An integrated metagenomic/metaproteomic investigation of microbiota in dajiang-meju, a traditional fermented soybean product in Northeast China. Food Res Int. 2019;115:414–24. https://doi.org/10.1016/j.foodres.2018.10.076.
62. Baroroh S. Microorganism Community Profile in the Cianjur Tauco Fermentation Process. Bandung. Bandung Institute of Technology; 2012. https://digilib.itb.ac.id/index.php/gdl/view/48189.

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