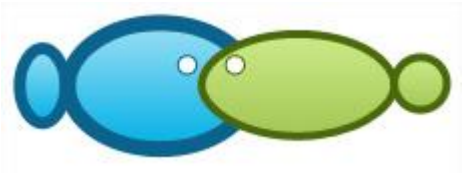

Amino acids, fatty acids and volatile compounds of *terasi udang*, an Indonesian shrimp paste, during fermentation

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Abstract. *Terasi udang* is a fermented shrimp paste and play an important role in Indonesia as condiment. The product is obtained by fermentation of shrimps (*Acetes* sp.) and has a palatable taste, caused by the chemical composition formed by endogenous microbial and hydrolytic enzymes activity. The study aims to identify the derivative compounds hydrolyzed during *terasi udang* fermentation, particularly on the amino acid, fatty acid, and volatile compounds. The *terasi udang* was purchased from the SME producer of Madura Island, Indonesia and formed into a tube-like (3x3x10 cm). Samples were fermented for 2, 4 and 6 weeks then subjected to chemical analysis employing an HPLC, GC, and GCMS to identify the amino acids, fatty acids, and the volatile compounds respectively. The essential amino acids (EAA) values are relatively higher than non-essential amino acids (NEAA) in both raw material and the product. EAA profile was dominated by lysine, valine, and leucine, while NEAA were glutamic acid, aspartic acid, and alanine. Saturated fatty acid (SFA) levels were relatively stable, while MUFA was detected in the highest concentration in the early stage of fermentation, and decreased along the fermentation period. PUFAs, especially the omega 3 and 6 groups had a significant increased after 6 weeks, particularly ALA, EPA, and DHA. Concerning the volatile compounds a total of 59 compounds had been detected, including alcohol (5) compounds, carbonyl (16), acid (8), esters (2), hydrocarbons (7), N-containing (15), S-containing (3) and phenolic (3) compounds. *Terasi udang* contains a high nutritional value, especially after 6 weeks of fermentation periods. It was contained a complete EAA and PUFA omega-3, 6 and 9 groups, as well as high of volatile compounds affected to desirable aroma of the product.

Key Words: amino acid, PUFA, volatile, fermented food, condiment.

Introduction. *Terasi udang* is the most popular shrimp-based fermented food in Indonesia. The product is daily consumed as a condiment therefore it can found in various traditional receipt and cuisine of Indonesia (Ali et al 2019b). *Terasi udang* is classified as traditional fermented food and consumed to enhance the flavor of food (Murwani et al 2016). The main raw material was *Acetes* sp., and sometimes found mixed with tiny shrimp of genus *Mesopodopsis* (Mantiri et al 2012).

Even though the processing of *terasi udang* was varied among regions in Indonesia (Kobayashi et al 2003), but according to Ali et al (2019b), the processing includes steps through the combination of fermentation, salting and sun drying. The shrimp is then grounded following by the addition of 10% solar salt and fermented for 2-7 days.

The fermentation occurred as a spontaneous fermentation by employed several hydrolytic enzymes and endogenous microbes. Both of them degrading the complex compounds from the raw material into the simpler ones that believed not only to enhance the desirable taste of *terasi udang* but also to increase of functional properties of the product (Steinkraus 2002; Faithong et al 2010).

According to Anggo et al (2014), fermentation periods and salt concentration affected and plays a crucial role in the enzymatic and microbial activities during *terasi udang* fermentation. The hydrolytic enzymes engaged in the *terasi udang* production

process are especially proteases (Duan et al 2016), fibrinases (Hua et al 2008), lipases (Surono & Hosono 1994), chitinases and chitosanases (Sheu et al 2011). While bacterial fermentation was dominated by lactic acid (LAB) and halophilic bacteria.

Furthermore, the natural taste of *terasi udang*, formed by fermentation is greatly appreciated by the consumers and increases the demand for the product. The flavor may be due to the combination of volatile compounds, fatty acids, and amino acids of the *terasi udang* (Bakar 2002).

Therefore it is important to explore and recognize the diversities of derivative compounds produced during *terasi* fermentation periods. The results of this study will be helpful to characterize the derivative compounds within *terasi udang* more comprehensively and provide beneficial information for further research including the functional perspective.

Material and Method

Terasi udang sampling. *Terasi udang* was purchased from SME's located in Bangkalan District, Madura Island of East Java province, Indonesia. Krill (*udang rebon*) and 10% of solar salt were mixed and grounded. Minced shrimp and salt were sun-dried until it became fine non-sticky and then was followed by reground. The semi-dried *terasi* was fermented for a day at ambient temperature followed by forming into a tube-like (3x3x10 cm) and dried in the sun two days and then wrapped tightly in banana leaves and left for the fermentation process. Samples were subjected to chemical analysis on raw material, 2, 4, and 6 weeks fermentation.

Amino acid determination. Analysis of amino using HPLC Shimadzu (LC 20AT, RF 20-A Fluorescence Detector, λ 450, OPA, Shimadzu, Japan). The column used was C18 Shim-pack VP ODS 5 µm 150 x 4.6 mm. The sample weighed 0.1 g then 5 mL of 6 N HCl was added and drained in the oven (110^{o}C) for 22 hours. After being diluted the sample was placed on a 0.45 µm membrane filter. To the filtrate AABA and ddH_2O was added followed by addition of AccQ Fluor Borate, fluorine reagent and incubated at 55^{0}C for 10 minutes. A 100 µL sample was injected on an HPLC device and run for 30 minutes with at 450 nm wavelength and a flow rate of 1 mL min^{-1}. The amino acid mix was used as a standard.

Fatty acid determination. The fatty acid analysis was carried out with GC (Shimadzu GC-2010AF) and the column used was Restek Famewax (30 m, ID 0.25 mm df 0.1 µm). The 1 µL methylated sample (FAME) was injected into the GC apparatus. The split ratio was 1:50 and Helium (Pa 1 kg cm^{-2}) and Nitrogen (Pa 0.5 kg cm^{-2}) was used as a carrier gas. The flow rate of hydrogen was 40 mL min^{-1}, oxygen 400 mL min^{-1}, nitrogen 30.1 mL min^{-1}, and 46.4 mL min^{-1} of helium. The temperature of the injector was set to 250^{0}C and the detector of MS (FID) was 250^{0}C. The temperature of the columns was set at an initial 150^{0}C and increased to 240^{0}C at 5^{0}C min^{-1}. The fatty acids were identified by comparing the chromatogram peak with the fatty acid standard (mix).

Volatile compounds determination. The apparatus of GCMS (Shimadzu GCMS QP 2010 SE) was equipped with the column of ZB - AAA (10 mL x 0.25 mmL D (Phenomenex Inc). Helium gas was used as a carrier with a 0.6 mL min^{-1} flow rate. The volume of injection was 2 µL with a split ratio of 127.5 and the temperature was set for the oven column of 60^{0}C with an increase in temperature of 6^{0}C up to 220^{0}C with a constant pressure of 15 kPa. The temperature was then raised to 280^{0}C. The injection temperature was kept at 280^{0}C and the reading time of 15 minutes. Mass spectrophotometer was run in positive ion-electron mode with ionization energy of 70 eV. The cut time of the solvent was set for 0-2 minutes. Data sampling set from 0.5 to 7 min at m/z 20-1000 (3.33 u sec^{-1}). The relative percentage of each compound is known by comparing the average peak area to the total area. Following by identification of the compound, molecular weight, and structure based on data stored in the Wiley Lib. and processed using Lab Solution software.

Statistical analysis. *Terasi udang* derivative compound was assessed by a completely randomized design following by one-way ANOVA (SPSS V22). The significant differences were evaluated using the multiple-range test of Duncan to compare the mean of the variables analyzed (Steele & Torrie 1990).

Results. The observation concerning the amino acids of *terasi* showed that the product contained complete essential amino acids (EAA) which showed the nutritional value and the quality of the protein contained in the *terasi*. The results of this study (Figure 1) show that the amount of EAA (His, Arg, Thr, Lys, Met, Val, Iso, Leu, Phe, Try) is relatively higher than non-essential amino acids NEAA (Ser, Gly, Val, Leu, Asp, Glu, Ala, Pro, Cys, Tyr, Asp, Cys, Glu) both in the raw material *Acetes* sp. or in *terasi* products in the same fermentation period.

The concentration of amino acids of *terasi* was relatively lower compared to the raw material. This is possible because amino acids have hydrolyzed into simpler compounds, but uniquely in the 6 weeks of fermentation had been significantly enhanced (Figure 1).

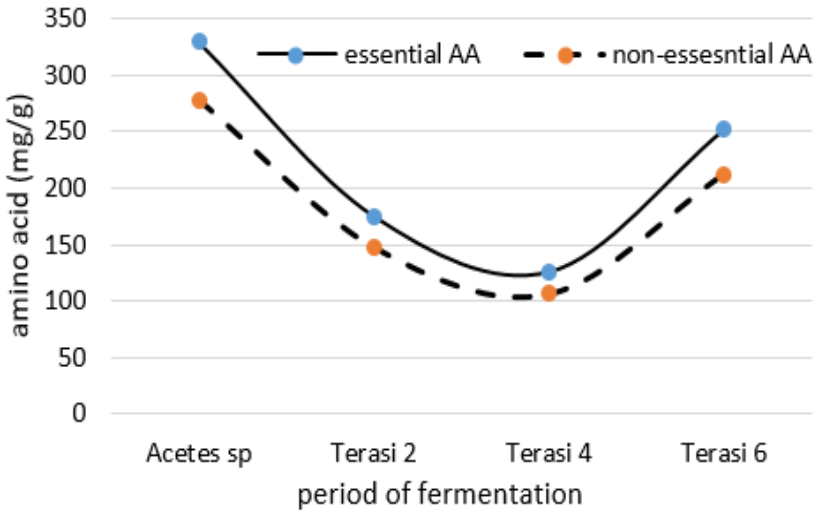

Figure 1. The comparison of essential (EAA) and non-essential amino acid (NEAA) of *terasi udang* during fermentation periods.

The EAA profile of *terasi* was dominated by Lys, followed by Val and Leu, while NEAA was dominated by Glu, Asp and Ala in raw material and fermented product (Table 1). Amino acids with the highest value were glutamic acid that contributes to the "umami" or savory taste.

Several types of fatty acids were detected on the terasi product, including long-chain fatty acid (LCFA) group which is a fatty acid with 13 to 20 carbon aliphatic s and very long-chain fatty acid (VLCFA) which has 22 carbon aliphatic or more. While short-chain fatty acids (SCFA) were not detected in the sample. The saturated fatty acids (SFA) were 11.10-13.14 g mg^{-1}, the monounsaturated fatty acids (MUFA) were 8.26-18.33 g mg^{-1} and polyunsaturated fatty acids (PUFA) were 8.11-13.19 g 100 g^{-1} of fatty acid methyl esters (Table 2). The present study detected 5 types of SFA, 6 and 10 types of MUFA and PUFA respectively.

SFA compounds, in both, raw materials and *terasi* with different fermentation periods showed a relatively stable situation. Types of SFA detected in raw materials of *rebon* shrimp (*Acetes* sp.) were myristic acid (C14: 0), palmitic acid (C16: 0), stearic acid (C18: 0) and arachidic acid (C20: 0). Uniquely, C20: 0 was no longer detected in *terasi* products and a higher fatty acid compound, namely behenic acid (C22: 0). These fatty acids were detected in all tested *terasi* samples.

Table 1

Amino acid profiles of *terasi udang*

Amino acid	*Values (mg g^{-1})*			
	Acetes sp.	*Terasi 2*	*Terasi 4*	*Terasi 6*
Essential amino acid (EAA)				
Threonine	24.57	13.09	9.41	18.83
Valine	53.67	28.56	20.56	41.11
Methionine	17.17	9.17	6.58	13.17
Isoleucine	29.41	15.61	11.25	22.51
Leucine	42.25	22.55	16.20	32.40
Tryptophan	8.26	4.46	3.18	6.36
Phenylalanine	20.75	11.03	7.94	15.89
Histidine	40.18	21.33	15.38	30.76
Lysine	55.54	29.49	21.26	42.52
Arginine	37.35	19.87	14.30	28.61
Total EAA	329.13	175.16	126.07	252.14
Non-essential amino acid (NEAA)				
Asparagine	4.81	2.56	1.84	3.68
Serine	23.35	12.50	8.96	17.92
Glutamic acid	75.61	40.14	28.94	57.88
Proline	19.59	10.30	7.47	14.95
Glycine	24.30	12.97	9.32	18.64
Alanine	30.77	16.30	11.77	23.54
Tyrosine	28.00	14.95	10.74	21.48
Aspartic acid	60.74	32.27	23.25	46.50
Glutamine	4.26	2.26	1.63	3.26
Cysteine	5.91	3.17	2.27	4.54
Total NEAA	277.35	147.42	106.19	212.38

Table 2

Fatty acid profile during *terasi udang* fermentation

Fatty acid (mg g^{-1})	*Acetes sp.*	*Terasi 2*	*Terasi 4*	*Terasi 6*
Saturated fatty acids (SFA)				
Myristic acid (C14:0)	0.63	1.42	1.52	1.38
Palmitic acid (C16:0)	6.70	9.58	7.61	9.28
Stearic acid (C18:0)	3.63	1.97	2.12	1.93
Arachidic acid (C20:0)	0.14	-	-	-
Behenic acid (C22:0)	-	0.17	0.21	0.08
Total SFA	11.10	13.14	11.45	12.67
Monounsaturated fatty acids (MUFA)				
Myristoleic acid (C14:1 n-5)	-	0.50	0.62	0.35
Palmitoleic acid (C16:1 n-7)	2.23	9.07	7.23	11.29
Vaccenic acid (C18:1 n-7)	0.88	-	-	-
Oleic acid (C18:1 n-9)	4.67	7.44	5.80	8.12
Gadoleic acid (C20:1 n-9)	0.48	0.84	0.73	1.04
Erucic acid (C22:1 n-9)	-	0.47	0.38	0.55
Total MUFA	8.26	18.33	14.76	11.18
Polyunsaturated fatty acids (PUFA)				
Hexadecatrienoic acid (C16:2 n-4)	-	0.68	0.52	0.88
Linoleic acid (C18:2 n-6)	2.35	1.68	1.44	2.05
α-Linolenic acid (C18:3 n-3)	0.45	2.46	1.95	2.97
Eicosadienoic acid (C20:2 n-6)	0.17	0.18	0.14	0.36
Eicosatrienoic acid (C20:3 n-3)	0.59	-	-	-
Arachidonic acid (C20:4 n-6)	1.55	0.66	0.58	0.83
Eicosapentaenoic acid (C20:5 n-3)	4.19	2.44	2.04	2.97
Adrenic acid (C22:4 n-6)	-	-	0.29	0.54
Sardine acid (C22:5 n-3)	-	-	0.72	1.09
Docosaheksaenoic acid (C22:6 n-3)	2.92	-	1.00	1.52
Total PUFA	12.22	8.11	8.67	13.19

MUFA was detected in the lowest concentration of raw *Acetes* sp. (8.26 mg g^{-1}), at early fermentation stage in the highest concentration (18.33 mg g^{-1}), and decreased along fermentation period to 14.76 and 11.18 mg g^{-1} of 4 and 6 weeks of fermentation respectively.

PUFA fatty acid group (omega 3 and 6) was the most detected compared to other types of fat. The PUFA on the *Acetes* sp. shrimp was detected at 12.22 mg g^{-1}, much higher than the *terasi*, especially in the early phase of 2 and 4-week fermentation were was 8.11 and 8.67 mg g^{-1} respectively. However, in the longer fermentation period (6 weeks) the PUFA increased and exceed the raw material which was 13.19 mg g^{-1} (Figure 2). Uniquely the omega 3 and 6 in *terasi* after 6-week fermentation indicated a significant increase from ALA, EPA and DHA (Table 2).

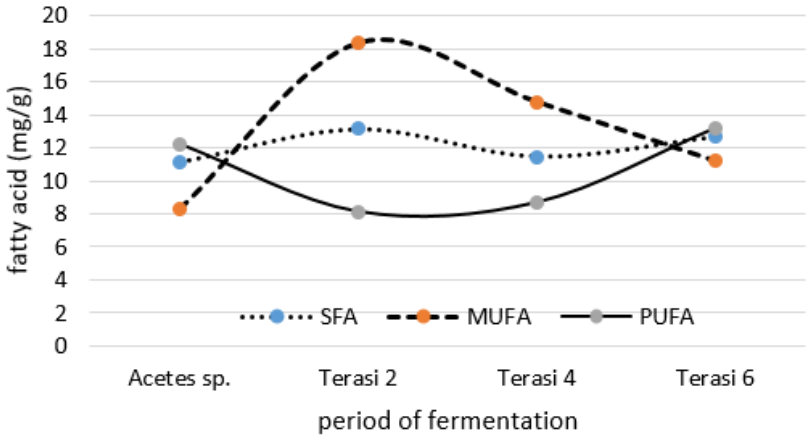

Figure 2. Profiles of total saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acid (PUFA) of *terasi udang* during fermentation periods.

In *Acetes* sp., as the raw material of *terasi*, a total of 45 volatile compounds were identified. In fermentation of *terasi* for two week were detected as many as 46 compounds and 55 and 57 volatile compounds respectively for fermented *terasi* for 4 and 6 weeks. The volatile compounds could be classified as alcohols, carbonyls, acids, esters, hydrocarbons, nitrogenous and sulfur-containing compounds, and phenolic compounds. GC analysis indicated carbonyl, N-containing compound, and organic acid was the highest volatile compound in *terasi*.

The alcoholic compounds were highest in *terasi* fermented for 2 weeks and decreased with the prolonged fermentation of 4 and 6 weeks. It was similar to carbonyl and S-containing compounds. Ester and hydrocarbon increased during the fermentation period (Figure 3).

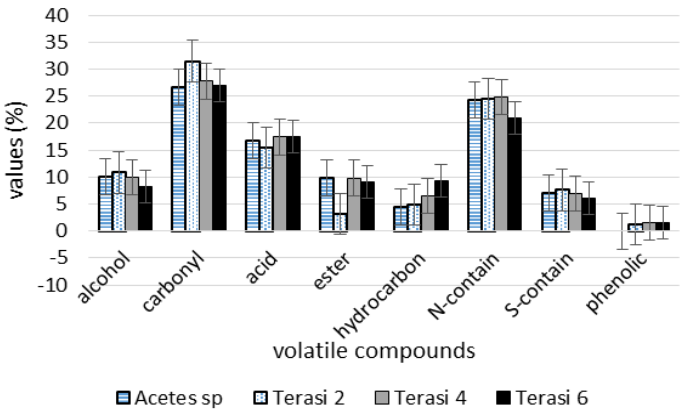

Figure 3. Volatile compounds-based on chromatogram peak area (%) of *Acetes* sp. and differences of fermentation period of *terasi udang.*

Phenolic compounds were not detected in the raw material but in all *terasi udang* products regardless the fermentation periods (Table 3). This indicates that *terasi udang* have potential functional properties such as antioxidant, antibiotic, etc.

Table 3

The volatile base of *terasi udang* during fermentation

No	*Volatile compounds*	*Relative amount (%)*			
		Acetes sp.	*Terasi 2*	*Terasi 4*	*Terasi 6*
		Alcohols			
1	1-pentanol	1.25	1.35	1.24	1.28
2	Methylthioethanol	3.31	3.60	3.29	2.40
3	1-penen-3-ol	1.67	1.81	1.66	1.71
4	Methionol	2.99	3.25	2.97	2.07
5	Benzyl alcohol	0.76	0.83	0.76	0.78
	Total alcohols	9.98	10.85	9.92	8.25
		Carbonyls			
1	Benzaldehyde	-	1.92	-	-
2	2-butanone	0.89	0.96	0.91	0.88
3	2-pentanone	0.99	1.08	1.02	0.99
4	4-methyl-4-penten-2-one	1.11	1.21	1.14	1.11
5	1-methyl-2-pyrrolidinone	3.81	4.14	3.91	3.78
6	N-methyl-2-pyridone	3.44	3.74	3.53	3.42
7	2-heptanone	1.53	1.67	1.57	1.52
8	Acetophenone	0.68	0.74	0.70	0.68
9	(3E. 5E)-3.5-octadien-2-one	3.31	3.60	3.40	3.29
10	2-octanone	1.54	1.67	1.58	1.53
11	2-nonanone	2.30	2.50	2.36	2.29
12	3-butyl-3-hexen-2-one	1.02	1.11	1.05	1.01
13	2-decanone	1.09	1.38	1.25	1.26
14	(5S)-5-pentyloxolan-2-one	1.27	1.80	1.57	1.65
15	2-undecanone	1.01	1.10	1.04	1.01
16	2-acetylpyrrole	2.66	2.89	2.73	2.64
	Total carbonyls	26.65	31.51	27.76	27.05
		Acids			
1	Butyric acid	2.76	3.00	2.75	2.84
2	Isovaleric acid	2.53	-	2.51	2.52
3	Valeric acid	2.19	2.38	2.17	2.25
4	Hexanoic acid	2.18	2.37	2.16	2.24
5	Heptanoic acid	3.34	3.64	3.31	3.43
6	Octanoic acid	2.82	3.06	2.80	2.90
7	Nonanoic acid	0.88	0.96	0.87	0.90
8	1.2-benzenedicarboxylic acid	-	0.02	0.84	0.43
	Total acids	16.69	15.42	17.42	17.49
		Esters			
1	Methylmiristate	5.10	3.12	5.06	4.43
2	Methylpalmitate	4.77	-	4.74	4.76
	Total esthers	9.87	3.12	9.80	9.18
		Hydrocarbons			
1	1.4-octadiene	-	0.88	0.80	0.84
2	1.11-dodecadiene	-	1.36	-	1.36
3	Cyclododecane	-	0.80	-	0.80
4	3-tetradecene	-	0.55	-	0.55
5	1-pentadecene	-	0.91	0.83	0.87
6	Hexadecane	-	0.40	0.37	0.38
7	Limonene	4.48	-	4.45	4.47
	Total hydrocarbons	4.48	4.90	6.45	9.27

No	Volatile compounds	Relative amount (%)			
		Acetes sp.	*Terasi 2*	*Terasi 4*	*Terasi 6*
	N-containing compounds				
1	2-methylpyrazine	2.94	3.20	3.02	2.93
2	2.5-dimethylpyrazine	-	0.83	0.79	0.75
3	2.6-dimethylpyrazine	2.38	0.70	1.24	0.64
4	2-ethylpyrazine	1.85	2.01	1.90	1.84
5	2.3-dimethylpyrazine	1.00	1.09	1.03	1.00
6	2.3.5-trymetylpyrazine	2.04	2.22	2.09	2.03
7	Tetrametylpyrazine	1.67	1.81	1.71	1.66
8	2.6-dimetyl-3-propylpyrazine	1.60	1.74	1.64	1.59
9	2-(2-hydroxyethyl) piperidine	-	1.69	1.69	-
10	Dimethylcyanamide	0.45	0.49	0.46	0.45
11	Pyridine	2.65	2.88	2.72	2.63
12	Isovaleramide	3.32	3.61	3.41	3.30
13	3.4-lutidine	3.32	0.62	1.50	0.56
14	Indole	-	0.57	0.54	0.52
15	Tetramethylurea	1.00	1.09	1.03	1.00
	Total N-cont. compounds	24.22	24.53	24.78	20.87
	S-containing compounds				
1	Dimethyl disulfide	2.52	2.74	2.50	1.59
2	Dimethyl trisulfide	2.19	2.38	2.18	2.25
3	Dimethyl sulfoxide	2.26	2.46	2.25	2.32
	Total S-cont. compound	6.97	7.58	6.93	6.16
	Phenolic compounds				
1	Phenol	-	0.52	0.48	0.50
2	2.6-bis(1.1-dimethylethyl) phenol	-	-	0.45	0.35
3	Butyl hydroxytoluene	-	0.68	0.63	0.65
	Total phenols	0	1.20	1.55	1.50
	Total volatile compounds	99.87	99.11	100	100

Discussion. Fermentation has been used for years to preserve food and provide high quality and distinctive taste (Chelule et al 2010). The derived compounds produced throughout the fermentation process not only influence the determination of flavor of shrimp paste (Gao et al 2010; Kleekayai et al 2016) but also can increase the functional value of the product. The combination of salt and microbial degradation of protein, fat, and carbohydrate may contribute to *terasi* flavor profiles.

The *terasi* is made from *Acetes* sp. processing of *terasi* includes preparation of raw materials, drying, grinding, salt addition, fermentation, drying, and packaging (Surono & Hosono 1994). The main compounds of *terasi undang* are derivatives of protein, fat, carbohydrate, chitin (carapace), pigments, and minor compounds such as minerals and vitamins. All these compounds are in the form of polymers that will be degraded during the fermentation.

Amino acids. Generally, shrimp paste products and similar products in Southeast Asia which have a total nitrogen of 1.51-2.41% (Yoshiko 1998). Meanwhile, according to Mizutani et al (1992), the total amount of amino acids in shrimp paste protein was 12.5%, therefore it is an important amino acid source (Hajeb & Jinap 2012).

The total amino acids in the 2 weeks fermentation (33.72%) was higher than of 4 weeks fermentation (21.72%), this shows that a long fermentation period can reduce amino acid levels of and break them down into other compounds (Anggo et al 2014). But uniquely, in the present study, we found that the number of amino acids increased again in the 6th week after fermentation.

Seafood is a source of high protein and has different components and sequences with proteins from terrestrial animals, especially there are high content and high diversity of essential amino acids (Wang et al 2008). The protein is converted by the action of

microorganisms or endogenous enzymes into simpler compounds such as peptides, amino acids, and other nitrogenous compounds (Deshmukh 1991; Hajeb & Jinap 2012).

The composition and concentration of amino acids in the present study are relatively complete in both essential and non-essential amino acids (EAA and NEAA). Amino acids contribute to the characteristic taste of many marine foods such as shrimp paste (Deshmukh 1991; Duan et al 2016). Kim & Rhee (1990), explained that the amino acids Arg, Asp, Iso, Lys, Pro, Ser, Thr, and Val are responsible for the good taste of a product.

Kim et al (2014) reported that in the Korean shrimp paste the short-chain peptides and amino acids were also responsible for the unique flavor of the product. According to Aryanta (2000), the deamination and decarboxylation of amino acids to form lower fatty acids and amides, producing the characteristic flavor of *terasi*. According to Jung et al (2013), the concentration of amino acids will increase dramatically in the initial fermentation phase, then it will be constant or decrease after 6-8 weeks fermentation, while according to Peralta et al (2008), the number of amino acids will increase with the increase of the fermentation period.

Mouritsen et al (2012), explained that aspartic acid beside the glutamic acid contributes to the *umami* or savory taste. Likewise in the *terasi undang* analyzed in the present study, which has high values of glutamic and aspartic acid. Our findings were in line with the *ronto*, the Southern Borneo shrimp sauce (Khairina et al 2016). Kim et al (2003) reported that shrimp sauce products showed the highest levels of glutamic acid after 3 months of fermentation, the fermented product from China had the highest glutamic acid even after fermentation for 1 year (Babu et al 2005).

Fatty acids. Fermented shrimp products have different fat content. *Terasi* fat content was 3.43-5.93% (Ali et al 2019b), and Indonesian shrimp sauce *kecalok* has 4.52-4.73% (Ali et al 2019a). The *mongong* product from Thailand has 6.83% fat (Binsan et al 2008), Korean *saeu-jeot* has 4.89% (Kim et al 2014), and only 2.9% of fat from Thailand *kapi* (Kleekayai et al 2015).

Fish fats are generally good dietary sources of essential polyunsaturated fatty acids (PUFAs) including EPA and DHA. The PUFA occupies the highest composition of *terasi* fatty acids composition due to the raw material (*Acetes* sp.) which is a tiny marine shrimp that is also rich in PUFA. During *terasi* fermentation, PUFA will be oxidized to saturated fatty acids (SFA) and monosaturated fatty acids (MSFA) (Cai et al 2017). However, PUFA is not substantially damaged during fermentation (Peralta et al 2008).

Lovern (1964), reported that short-chain saturated fatty acids were firmly bound by the fish proteins. Furthermore, SCFAs resulted in an acidic environment in the large intestine, which stimulates the proliferation of lactic microbes (Macfarlane et al 2006; Roopashri & Vardaraj 2009). Therefore the shrimp paste does not taste acidic even if BAL is detected.

The PUFAs which are the omega-3 group is α-linolenic acid (18: 3; ALA), acids (22: 6; DHA), and acids (20: 5; EPA). While linolenic acid (18: 3) is an essential fatty acid because it is needed by the body but the body cannot synthesize it.

Terasi has high PUFA content (Cai et al 2017). According to Kim et al (2014), PUFA compounds in shrimp paste include oleic, linoleic, linolenic acids, arachidonate, EPA, and DHA. The human body cannot synthesize enzymes that can produce DHA, so DHA is classified as an essential fatty acid, especially for infants and children. Fulfillment of DHA must be through food, such as shrimp paste (Hyne et al 2009).

PUFA values are relatively higher after 6 weeks of fermentation compared to 4 weeks, especially from LA, ALA, ETA, EPA, DHA, and others while MUFA tends to decrease. This is consistent with the observations of Anggo et al (2015), that SFA and MUFA were decreased while MUFA values increased. The prolonged fermentation period according to Peralta et al (2008), would improve antioxidant abilities and some nutritional values such as amino acids without loss in the PUFAs.

Volatile compounds. Fermentation processes are responsible for the development of volatile compounds and sensory properties in fermented food products (Gao et al 2010).

The characteristic taste in *terasi* products is primarily due to the existence of volatile compounds. These compounds are formed by autolytic and bacterial degradation of protein and lipid as well as due to chemical reactions through fermentation (Beddows et al 1980; Cha & Cadwallader 1995).

Volatile compounds varied depending on shrimp species, the manufacturing conditions as well as on the strains of microorganisms involved (Yan et al 2017). Proteins can also interact with flavor compounds and influences the perceptions of flavor (Pérez-Juan et al 2008).

Fats play an important role as precursors of volatile compounds and aromas in meat products (Olivares et al 2009). Fat oxidation during fermentation, derives alkanes, alkenes, and alkadienes (Karahadian & Lindsay 1989). The aroma in shrimp paste occurs due to lipolysis and the release of free fatty acids (FFA) through non-enzymatic oxidation and microbial lipase activity (Lizaso et al 1999).

Pongsetkul et al (2015), categorized the volatile compounds into alcoholic, carbonyl, organic acids, hydrocarbons, nitrogenous, sulfuric, and esters. But in the present research, the phenolic compound is separated due to the functional properties as an antioxidant promoting compound.

According to Cha & Cadwallader (1995), among the volatile compounds that play the most important role in the flavor determination of shrimp paste were N-containing compounds. Kleekayai et al (2016) reported that N-containing and S-containing compounds, aldehydes and, esters contribute primarily to the characteristic taste of the fermented shrimp paste. Alcohols, aldehydes, and ketones are typically derived from lipid oxidation and the degradation of amino acids and saccharides (Wittanalai et al 2011; Pongsetkul et al 2015).

Although alcohol was detected in *terasi* during fermentation, it was in a relatively low amount in the product. Cha & Cadwallader (1995) also found that alcohols were in low quantities in shrimp paste products. Kleekayai et al (2016) reported that alcohol has been found to correlate with aldehyde levels in Thai *kapi*. In the present research, we also recorded benzaldehyde which according to Cha & Cadwallader (1995), provide a pleasant almond, and fruity aroma. In addition, Casaburi et al (2008) clarified that aldehydes were considered to be potential odorants in many seafood products.

The change in protein content of the fermented products varies and is influenced by the proteolytic activity of the microorganisms and enzymes. The protein breakdown is particularly mediated by the lactic acid bacteria and indigenous proteases and produced nitrogenous compounds, also by the reaction of ammonia or amino acids with reducing sugars (Pongsetkul et al 2015).

N-containing compounds could be influential flavor characteristics of the shrimp paste and provide nutty, meaty, roasted odor and dried seafood like odors, which were desirable in fermented food (Cha & Cadwallader 1995). Especially pyrazines were the most abundant of N-containing compounds found in the *terasi* after the carbonyl group (Table 3).

The formation of pyrazines was stated to be associated with the Maillard reaction through the Strecker degradation from various nitrogen sources such as amino acids (Rodríguez-Bernaldo et al 2001), and metabolic activities of microorganisms throughout fermentation (Labuda 2009), such the drying step with sunlight during *kapi* production and might contribute to flavor, color as well as antioxidative activity (Rodríguez-Bernaldo et al 2001). Pyrazine derivatives were also found as the major volatile compound in *ishiru*, the Japanese fish sauce (Michihata et al 2000).

This research also identified a small amount of indole in all *terasi* samples except the raw material. The nitrogen-based compound was considered a product of tryptophan catabolism and has been used as the index for shrimp spoilage (Casaburi et al 2008).

Sulfuric compounds in shrimp paste were produced by enzymatic or heat protein degradation and proposed to associate with S-containing amino acids (cysteine and methionine) degraded by microbial enzymes or thermal degradation (Varlet & Fernandez 2010). Although the sulfuric compounds were present in the shrimp paste, their quantity was very low. However, they gave the distinctive strong aroma of the product (Choi & Han 2015). In the present study we detected three formations of S-containing

compounds including dimethyl disulfide, dimethyl trisulfide, and dimethyl sulfoxide. Kleekayai et al (2016) also detected such S-containing compounds in *kapi*.

The phenolic compounds were not detected in the raw material. But in 2 weeks fermented *terasi* phenolic and butylhydroxytoluene compounds were detected. Furthermore, after 4 and 6-week fermentation, another phenolic 2,6-bis (1,1-dimethyl ethyl) phenol appears. Phenolics were able to be produced by lipids oxidation, sugar, and protein degradation and produced amino acids and peptides which were further broken down into other components such as hydrocarbons, esters, and alcohols (Choi & Han 2015).

The phenolic compounds also acts as strong antioxidants in shrimp paste (Sobhi et al 2012). Astuti et al (2018), reported that phenolic compounds were detected in the last day of fermentation of *terasi*, in accordance with studies of Wittanalai et al (2011) that examined Thai *kapi* and found that the compounds involved in the formation of a distinctive aroma were obtained in large amounts after 30 days of fermentation. The strong antioxidant activities were also reported on *bagoong*, a Philippines fermented shrimp product (Faithong et al 2010; Kleekayai et al 2015).

Conclusions. This study has shown that *terasi udang* contained a higher EAA concentration than NEAA in all fermentation periods, where the dominant amino acid s were Lys, Val, and Leu (EAA), and Glu, Asp, and Ala (NEAA). The fatty acid composition showed various concentrations, and the highest quantity detected PUFA's omega groups were ALA, EPA, and DHA. The amino acids, fatty acids and volatile compounds affected the desirable taste of *terasi udang.* These data will provide the nutritional fact of various fermentation periods of *terasi udang* leading to the potential functional property of the product.

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