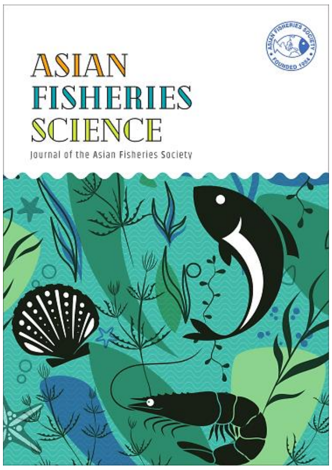

Effects of Mixing Duration and Raw Materials on the Physicochemical, Microstructural and Sensorial Properties of Sausages Prepared From Red Tilapia (*Oreochromis* sp.)

ABU BAKAR ASYRUL-IZHAR[1], NORIZAH MHD SARBON[2], MOHAMMAD RASHEDI ISMAIL-FITRY[1,*]

[1]Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia

[2]Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

*E-mail: ismailfitry@upm.edu.my | Received: 12/08/2021; Accepted: 26/12/2021

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Abstract

Tilapia can be commercialised to produce sausages. However, the use of minced tilapia or tilapia surimi as the raw material and different mixing durations of the ingredients using the bowl cutter during the sausage production could affect the quality of the products. This study determined the effects of different mixing durations (10, 15 or 20 min) on the physicochemical, microstructural and sensorial properties of sausages made from minced tilapia and tilapia surimi. The washing of the minced tilapia during the surimi production significantly increased the tilapia surimi moisture content and pH, while reducing the protein, fat and ash contents. Subsequently, the addition of other ingredients to produce the sausages influenced the moisture, fat, ash and carbohydrate contents of both types of sausages. The type of raw material and mixing duration showed significant interactions in terms of linear expansion, water holding capacity and colour properties of the sausages. Individually, the tilapia surimi sausage had a better linear expansion, cohesiveness, colour and sensory acceptability than the minced tilapia sausage. The mixing times of 15 and 20 min produced better results for the physicochemical and sensory properties of both types of sausages. However, the gel strengths of both types of sausages were better when mixed for 15 min and the microstructure images supported this. Based on the results obtained, this study concluded that tilapia surimi as the raw material with 15 min of mixing duration is recommended to produce a better-quality sausage.

Keywords: emulsion, fish processing, fish products, mechanical mixing, mixing time

Introduction

Using a bowl cutter or meat mixer is an important step in mechanical mixing to produce emulsified meat/fish products such as sausages, meatballs, and patties (Ismail et al. 2021). Generally, mixing is performed to reduce the meat/fish particle size, extract the protein, homogenise the ingredients, and improve the interaction of the protein network to produce a stable emulsion (Abdolghafour and Saghir, 2014; Murad et al., 2017). Various mixing methods have been explored to compare different mixing equipment, continuous or intermittent mixing procedures, blade speed (RPM), knife types, as well as mixing time (Gurikar et al., 2014; Krzywdzińska-Bartkowiak et al., 2014; Murad et al., 2017; Ismail et al., 2021). The appropriate mixing time is an important factor that affects the quality of products produced (Sun, 2009). For example, an adequate mixing duration to produce a homogenised mixture of ingredients such as fish meat, starch, crushed ice, and spices could result in a good expansion of the products (Cheow et al., 2004; Taewee, 2011). A shorter mixing time could lead to inadequate binding, whereas a longer mixing time could overwork the mixture resulting in undesirable product characteristics (Álvarez et al., 2007; Devine and Dikeman, 2014).

Minced fish and surimi are two different raw materials that can be used to produce fish products. Minced fish is produced by mincing the fish flesh to the desired size. At the same time, the surimi is a fish paste made from minced fish where the undesirable compounds such as water-soluble proteins (sarcoplasmic proteins), pigments, digestive enzymes and fat are removed (Choi et al., 2012; Petcharat and

Benjakul, 2018; Guo et al., 2019). Typically, minced fish produces higher yield fish products than fish surimi (Kim and Park, 2007), but taste panels find such products have undesirable eating quality (Kasapis, 2009). In addition, while fish surimi is more preferred to produce gelled seafood products, fish surimi is more expensive to produce because various processing steps are required (Amiza and Ng, 2015; Arsyad et al., 2019). Also, the use of only fish surimi results in a chewy sausage compared to the minced fish used as the raw material (Amiza and Ng, 2015).

Various species of tilapia such as Nile tilapia (*Oreochromis niloticus* (Linnaeus, 1758)), Mozambique tilapia (*Oreochromis mossambicus* (Peters, 1852)), blue tilapia (*Oreochromis aureus* (Steindachner, 1864)), and red tilapia (*Oreochromis* sp.) are a good source of proteins, lipids, vitamins, and minerals (Hernández-Sánchez and Aguilera-Morales, 2012; Bartie et al., 2020), so they have been used to produce fish products such as canned tilapia, tilapia fish balls, tilapia burgers and tilapia sausages (El-Sayed, 2019). Production of sausages from minced tilapia or tilapia surimi could result in different quality characteristics of the final products. In addition, the mixing duration could influence the functional properties of both the minced fish and surimi, which might lead to the determination of the optimised mixing process. Therefore, this research was aimed to investigate the effect of using minced tilapia or tilapia surimi as the raw material with different mixing durations (10, 15 or 20 min) on the physicochemical, microstructural, and sensorial properties of tilapia fish sausage. The findings are expected to be beneficial as a reference for fish sausage manufacturers and future research.

Materials and Methods

Minced tilapia and tilapia surimi preparation

Fresh red tilapia fish (*Oreochromis* sp.) of approximately 1 kg per fish were bought from whole-sale market, Selangor, and immediately deboned using the fish deboner machine (DH811-200, Ding-Han, Taiwan). Half of the minced tilapia was packed in plastic film and kept frozen at -18 °C, while the other half was used to produce tilapia surimi. The tilapia surimi was prepared in three steps washing by mixing the minced tilapia with cold water (4:1, water: minced fish, w/w) for 5 min. After deboning, the minced tilapia was collected for the first wash with ice slush, then decanted to separate the sediments and repeated for the second and third wash. After the third washing, the tilapia surimi paste was passed through cheesecloth to separate the water from the tilapia surimi paste and mixed with 1 % sweetener using a mixer, packed in plastic film and stored at -18 °C.

Preparation of fish sausages

The mixing was performed using a laboratory-scale silent bowl cutter (TQ-5, Fresh, Taiwan) based on the formulation as in Table 1. First, the thawed tilapia surimi or minced tilapia were chopped in the mixer for approximately 1 min before adding salt and half of the crushed ice and continuously chopped for 2 min. The remaining ingredients were placed in the silent bowl cutter and mixed for different times (10 min, 15 min or 20 min). The mixture was then placed into a hand-sausage stuffer (Zeus, Canada) and pumped into 25-mm cellulose casing (ViskoTeepak NV, Lommel, Belgium), which was tied 10–12 cm between sausages. The sausages were cooked in hot water (90 °C) for 10 min, then placed in cold water. The sausage casings were removed before they were packed in plastic film and stored at -18 °C. Three replications (n = 3) were carried out to produce sausages and analyses.

Table 1. The basic formulation for the sausages made from minced tilapia or tilapia surimi.

Ingredients	Amount (%)	Amount (g)
Fish (minced tilapia or tilapia surimi)	70.00	350.00
Sago flour	10.00	50.00
Fat (shortening)	10.00	50.00
Salt	1.25	6.25
Sugar	0.50	2.50
Black pepper	0.50	2.50
Sodium tripolyphosphate	0.25	1.25
Ice	7.50	37.50
Total	100.00	500.00

Proximate analysis

The analysis was performed according to the AOAC standard methods (AOAC, 1995). Moisture content was determined using a universal oven (Binder, Germany) and total protein (Crude protein, N = 6.25) content was determined using the Kjeldahl method. The fat content was assessed by the Soxhlet-Henkel method and the ash content was quantified by mineralisation at 550 °C. Carbohydrates were determined by calculation from the remaining percentages of moisture, fats, protein, and ash using the following equation:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture} + \text{Crude fats} + \text{Crude protein} + \text{Ash (\%)}]$$

pH analysis

Approximately 1 g of sample was homogenised (1:10 w/v) with distilled water using a homogeniser (Diax 900, Heidolph, Germany). The pH was determined with a pH meter (PB-10, Sartorius, Germany) (Alemán et al., 2016).

Linear expansion

The linear expansion (%) was determined after boiling, with the sausage length calculated as follows:

$$LE\ (\%) = (LAB - LBB) / LBB \times 100$$

where LE is the linear expansion, LAB is the length after boiled, and LBB is the length before boiling (Kyaw et al., 2001).

Cooking yield

The cooking yield was determined after boiling as follows:

$$Yield\ (\%) = WAB / WBB \times 100$$

where WAB is the weight after boiling and WBB is the weight before boiling (Ramle et al., 2021).

Water holding capacity

The sausage samples (1.5 g) were placed in centrifuge tubes with absorbent paper and centrifuged at 4000 ×*g* at 20 °C for 15 min (Kubota 3740, Japan). The water holding capacity (WHC) was expressed as the amount of retained water per 100 g of water present in the sample before centrifuging (Sánchez-Alonso et al., 2006):

$$WHC\ (\%) = WBC - WAC / OSW \times 100$$

where WHC is the water holding capacity, WBC is the weight before centrifugation, WAC is the weight after centrifugation and OSW is the original sample weight.

Gel strength

The gel strength of the sausage was measured using a texture analyser (TA-XT2, Stable Microsystem System Ltd., UK) aided with the software "Texture Expert". Sausages were cut into cylinders (25 mm height × 20 mm diameter). A spherical probe of 5 mm P/5S (test speed 1.1 mm.s^{-1}, a force of 10 g and a distance of 15 mm of the sample) were used to analyse the gel strength (g.mm) (Yamazawa, 1990).

Colour analysis

A chroma meter (CR-410, Konica Minolta, Japan) with an aperture of 50 mm and set up for illuminate D65 was used to measure the colour of the cooked sausage indicated by lightness level (L^*), redness level (a^*) and yellowness level (b^*) (Murad et al., 2017).

Texture profile analysis

Texture profile analysis (TPA) was performed using a texture analyser (TA-XT2, Stable Microsystem System Ltd., UK) with the software "Texture Expert" as described by Intarasirisawat et al. (2014) with some modifications. The determined parameters were hardness, gumminess, chewiness, and cohesiveness. Sausage samples were cut into cylinders (25 mm height × 20 mm diameter). A compression probe (P/75) was used with a 5 kg weight to calibrate the 30 kg load cell before analysis. The settings were fixed at a pre-test speed of 1.0 mm.s^{-1}, test speed of 5.0 mm.s^{-1}, and post-test speed of 5.0 mm.s^{-1}. For probe height calibration, 30 mm distance speed, 10 mm.s^{-1} return speed and 5 g contact force were set. The samples were placed on the centre of the platform and the analysis was performed with 50 % strain.

Scanning electron microscopy

Sausages were cut into small pieces and attached to an aluminium mounting stub using double-sided tape. Thin layers of the sausages were viewed and photographed using a scanning electron microscope (LEO 1455 VPSEM, Cambridge, UK) at 100× magnification.

Sensory evaluation

The hedonic scaling by Maqsood et al. (2012) with modifications was used to evaluate the sausage's sensory attributes (texture, aroma, colour, flavour, and overall acceptability). Sensory evaluation was conducted using the nine-point hedonic scales (1 = "dislike extremely", 2 = "dislike very much", 3 = "dislike moderately", 4 = "dislike slightly", 5 = "neither like nor dislike", 6 = "like slightly", 7 = "like moderately", 8 = like very much", 9 = "like extremely"). This evaluation involved 30 untrained panellists in one session in a standard sensory laboratory. Each sample consisted of 2.0 cm of sausages which was labelled with a 3-digit random code and the presentation was randomly arranged.

Statistical analysis

All experiments were performed in triplicate. The pH and proximate data were analysed by one-way ANOVA, considering the tilapia surimi or minced tilapia as the fixed effect and the replicates as the random effect. The data from the other analyses (except the pH and proximate) were submitted to the General Linear Model to observe the interaction between factors considering the treatments (tilapia mince or surimi and different mixing durations) as a fixed effect and the replicates as a random effect. The sensory data were analysed considering the minced tilapia or tilapia surimi and different mixing duration as the fixed effects and the panellists as the random effect. One-way ANOVA was conducted for an individual factor if no interaction was observed after the GLM. Means were compared by Tukey's test (P < 0.05). Data were analysed using Minitab Statistical Software version 19 (Minitab 19 Inc., USA).

Results

Proximate analysis and pH

Table 2 shows the proximate compositions and pH of the minced tilapia, tilapia surimi, minced tilapia sausage and tilapia surimi sausage. After washing, the moisture content of the tilapia surimi (82.82 %) was higher ($P < 0.05$) than the minced tilapia (77.39 %). The protein and ash contents of the minced tilapia (11.97 % and 0.84 %, respectively) were higher ($P < 0.05$) compared to the tilapia surimi (9.58 % and 0.16 %, respectively). However, the fat and carbohydrate contents between the minced tilapia (3.18 % and 6.62 %, respectively) and tilapia surimi (1.29 % and 6.15 %, respectively) were not significantly different ($P > 0.05$). The pH of the tilapia surimi was also higher ($P < 0.05$) than the minced tilapia.

The minced tilapia sausage and tilapia surimi sausage were produced using their raw materials, respectively, with the addition of other ingredients, consequently affected their proximate compositions. The moisture content of tilapia surimi sausage (65.95 %) was significantly ($P < 0.05$) higher than the minced tilapia sausage (59.94 %). Meanwhile, the fat and ash contents of the minced tilapia sausage (12.09 % and 2.09 %, respectively) were significantly higher ($P < 0.05$) compared to the tilapia surimi sausage (7.04 % and 1.31 %, respectively). However, both minced tilapia sausage's protein and carbohydrate contents (9.05 % and 16.85 %, respectively) and tilapia surimi sausage (8.97 % and 16.74 %, respectively) showed no significant differences. The sausages produced from tilapia surimi also had a higher pH ($P < 0.05$) than those made from minced tilapia.

Linear expansion, cooking yield, water holding capacity (WHC) and gel strength

The use of tilapia surimi or minced tilapia as the raw materials for the tilapia sausage and different mixing times showed an interaction effect ($P < 0.05$) towards the linear expansion of the tilapia sausage (Table 3); as the mixing time increased, the linear expansion results also increased for both sausages. However, the tilapia surimi sausages showed better linear expansion ($P < 0.05$) compared to the minced tilapia sausages except for mixing at 20 min ($P > 0.05$). The cooking yield showed no interaction ($P > 0.05$) between sausages prepared using different raw materials and with varying durations of mixing. However, in this study, the WHC of the sausages had other effects compared to the cooking yield results. There was interaction ($P < 0.05$) between the sausages prepared using different raw materials and different mixing durations towards the WHC, with a significantly higher ($P < 0.05$) WHC for the minced sausages than surimi sausages except for mixing at 15 min ($P > 0.05$).

Although there was no interaction ($P > 0.05$) for the gel strength between the sausages prepared with different raw materials and mixing times, there were differences ($P < 0.05$) for the different materials used and mixing duration individually. This is evidence in the gel strength results whereby the minced tilapia sausages had a higher value than tilapia surimi sausages at a mixing time of 20 min ($P < 0.05$). Interestingly, mixing the ingredients for 15 min resulted in higher gel strength for both the minced tilapia and tilapia surimi sausages than 10- and 20-min mixing.

Colour analysis

The sausages prepared with tilapia surimi and minced tilapia with different mixing durations showed an interaction ($P < 0.05$) towards the colour (Table 3). The L^* values of the sausages were significantly darker ($P < 0.05$) for the minced tilapia sausages (60.14) compared to tilapia surimi sausages (55.67) for the mixing duration of 15 min. In comparison, the a^* values were significantly redder ($P < 0.05$) for minced tilapia sausages compared to tilapia surimi sausages for the mixing duration of 10 min (4.72 and 3.74, respectively) and 20 min (4.38 and 3.56, respectively). No difference ($P > 0.05$) was recorded for the b^* values (yellowness) for all the treatments (13.58–13.46) except for the minced sausage mixed for 15 min (12.43).

Texture profile analysis (TPA)

No interactions ($P > 0.05$) between raw materials and mixing duration were observed for the hardness, gumminess, chewiness, and cohesiveness of the sausages (Table 4). In addition, there was no significant difference ($P > 0.05$) observed for the individual parameters against the type of raw materials and the mixing duration except for

Table 2. The proximate and pH values of minced tilapia, tilapia surimi, minced tilapia sausage and tilapia surimi sausage.

Samples	% Moisture	% Protein	% Fat	% Ash	% Carbohydrate	pH
Minced tilapia	77.39 ± 1.20[b]	11.97 ± 1.21[a]	3.18 ± 0.68[c]	0.84 ± 0.12[c]	6.62 ± 2.46[b]	6.40 ± 0.03[b]
Tilapia surimi	82.82 ± 1.11[a]	9.58 ± 0.27[b]	1.29 ± 0.36[c]	0.16 ± 0.02[d]	6.15 ± 1.24[b]	6.63 ± 0.03[a]
Minced tilapia sausage*	59.94 ± 1.22[d]	9.05 ± 0.07[b]	12.09 ± 0.90[a]	2.09 ± 0.24[a]	16.85 ± 1.05[a]	6.22 ± 0.02[c]
Tilapia surimi sausage*	65.95 ± 1.06[c]	8.97 ± 0.43[b]	7.04 ± 1.40[b]	1.31 ± 0.02[b]	16.74 ± 1.35[a]	6.44 ± 0.04[b]

Different superscripts in the same column indicate significant differences. The values represent mean ± SD. n = 3.
*The sausages used for the analyses were from the 15 min mixing.

Table 3. Linear expansion, cooking yield, water holding capacity, gel strength and colour of tilapia sausages with different raw materials and mixing duration.

	2-way ANOVA			Tilapia surimi sausage			Tilapia minced sausage		
	Types of raw materials	Mixing duration	Types of raw materials × Mixing duration	10min	15 min	20 min	10 min	15 min	20 min
Linear expansion (%)	0.001	< 0.001	< 0.001	3.89 ± 0.32^{d}	5.41 ± 0.08^{b}	6.35 ± 0.22^{a}	2.9 ± 0.18^{e}	4.62 ± 0.11^{c}	6.8 ± 0.25^{a}
Cooking yield (%)	ns	ns	ns	83.45 ± 2.63	87.09 ± 1.80	85.45 ± 1.15	88.67 ± 2.61	87.86 ± 2.15	84.10 ± 5.22
Water holding capacity (%)	< 0.001	0.004	0.007	61.18 ± 2.02^{b}	68.84 ± 0.09^{a}	63.40 ± 1.49^{b}	71.32 ± 1.09^{a}	71.96 ± 2.06^{a}	72.68 ± 2.34^{a}
Gel strength (%)	0.011	< 0.001	ns	56.40 ± 0.04^{Ca}	82.73 ± 2.23^{Aa}	70.35 ± 0.64^{Bb}	65.70 ± 5.94^{Ba}	86.55 ± 2.97^{Aa}	75.68 ± 1.59^{ABa}
Colour									
*L**	< 0.001	ns	0.011	57.55 ± 0.7^{abc}	60.14 ± 1.82^{ab}	60.29 ± 0.61^{a}	57.37 ± 0.45^{bc}	55.67 ± 1.33^{c}	57.48 ± 0.40^{abc}
*a**	< 0.001	0.004	0.050	3.74 ± 0.08^{c}	3.56 ± 0.06^{c}	3.56 ± 0.12^{c}	4.72 ± 0.03^{a}	3.93 ± 0.20^{bc}	4.38 ± 0.42^{ab}
*b**	0.008	0.014	0.009	13.58 ± 0.13^{a}	13.77 ± 0.05^{a}	13.86 ± 0.15^{a}	13.61 ± 0.26^{a}	12.43 ± 0.68^{b}	13.66 ± 0.32^{a}

If the interaction of factors is present, the post-hoc groupings are only for the interaction effects indicated by lowercase letters; different letters are significantly different at $P < 0.05$; n = 3. If no interaction is present, the post-hoc analysis is for both individual types of raw materials and mixing duration factor: means that do not share the same uppercase letter in the same row are significantly different between the different mixing duration within the same types of raw materials ($P < 0.05$); means that do not share the same lowercase letter in the same row are significantly different between the tilapia surimi sausage and tilapia minced sausage at the same mixing duration ($P < 0.05$). ns = not significant. The values represent mean ± SD.

cohesiveness ($P < 0.05$). However, the values of the hardness, gumminess and chewiness showed a unique pattern with increment at 15 min of mixing compared to 10 min, followed by reduction at 20 min of mixing. In addition, the values of gumminess and chewiness for minced tilapia sausages were lower than tilapia surimi sausages (Table 4).

No interaction ($P > 0.05$) between the sausages prepared using different raw materials with varying durations of mixing towards the cohesiveness of the sausages. However, further analysis showed differences in sausages' cohesiveness for raw materials used ($P < 0.05$) and different mixing durations ($P < 0.05$), individually. A lower ($P < 0.05$) cohesiveness was observed for the minced sausage mixed for 20 min compared to the other samples.

Scanning electron microscopy

Figure 1 showed that the protein matrix of the tilapia surimi sausage was more compact than the minced tilapia sausage. Interestingly, both tilapia surimi and minced tilapia sausages with a mixing duration of 10 min (Figs. S10 and M10) and 20 min (Figs. S20 and M20) had larger cavities than 15 min (Figs. S15 and M15), respectively.

Sensory evaluation

No interactions between the sausages prepared with tilapia surimi and minced surimi with different mixing durations were observed ($P > 0.05$) in affecting the sensory characteristics of all the tilapia sausages (Table 4). Nevertheless, significant differences ($P < 0.05$) were observed towards the sausages' colour, flavour and overall acceptability prepared with tilapia surimi and minced tilapia. The scores showed that the panellists preferred ($P < 0.05$) the tilapia surimi sausages compared to the minced tilapia sausages.

Discussion

The proximate compositions of the tilapia surimi compared to the minced tilapia are affected by the washing process during surimi production (Piotrowicz and Mellado, 2015), with the tilapia surimi having lower protein, ash, and fat contents than minced tilapia due to the loss of water-soluble proteins, leaching of

Table 4. Texture profile analysis and sensory characteristics of tilapia sausages with different raw materials and mixing duration.

	2-way ANOVA			Tilapia surimi sausage			Tilapia minced sausage		
	Types of raw materials	Mixing duration	Types of raw materials × Mixing duration	10 min	15 min	20 min	10 min	15 min	20 min
Texture									
Hardness (g)	ns	ns	ns	4750 ± 746	5797 ± 1009	5439 ± 332	4257 ± 753	4947 ± 525	4163 ± 1522
Gumminess (g)	ns	ns	ns	2356 ± 601	2994 ± 629	2589 ± 186	1723 ± 409	2315 ± 369	1485 ± 830
Chewiness (J)	ns	ns	ns	2214 ± 566	2797 ± 571	2421 ± 159	1555 ± 334	2119 ± 295	1341 ± 744
Cohesiveness	0.001	0.026	ns	0.5 ± 0.06^{Aa}	0.5 ± 0.02^{Aa}	0.5 ± 0.01^{Aa}	0.4 ± 0.04^{ABa}	0.5 ± 0.03^{Aa}	0.3 ± 0.07^{Bb}
Sensory									
Texture	ns	ns	ns	5.53 ± 1.57	5.87 ± 1.53	5.80 ± 1.63	5.27 ± 1.64	5.37 ± 1.47	5.80 ± 1.30
Aroma	ns	ns	ns	5.80 ± 1.47	5.97 ± 1.38	5.77 ± 1.17	5.53 ± 1.55	5.30 ± 1.29	5.37 ± 1.40
Colour	<0.001	ns	ns	6.53 ± 1.25^{Aa}	6.47 ± 1.11^{Aa}	6.27 ± 1.26^{Aa}	5.70 ± 1.53^{Ab}	5.53 ± 1.74^{Ab}	5.40 ± 1.69^{Ab}
Flavour	<0.001	ns	ns	5.37 ± 1.35^{Aa}	5.87 ± 1.53^{Aa}	6.03 ± 1.40^{Aa}	4.33 ± 1.90^{Ab}	4.17 ± 1.58^{Ab}	5.10 ± 1.60^{Ab}
Overall acceptability	0.010	ns	ns	5.90 ± 1.21^{Aa}	6.07 ± 1.31^{Aa}	6.03 ± 1.54^{Aa}	5.10 ± 1.56^{Ab}	4.83 ± 1.39^{Ab}	5.23 ± 1.45^{Ab}

If the interaction of factors is present, the post-hoc groupings are only for the interaction effects indicated by lowercase letters; different letters are significantly different at $P < 0.05$; n = 3. If no interaction is present, the post-hoc analysis is for both individual types of raw materials and mixing duration factor: means that do not share the same uppercase letter in the same row are significantly different between the different mixing duration within the same types of raw materials ($P < 0.05$); means that do not share the same lowercase letter in the same row are significantly different between the tilapia surimi sausage and tilapia minced sausage at the same mixing duration ($P < 0.05$). ns = not significant. The values represent mean ± SD.

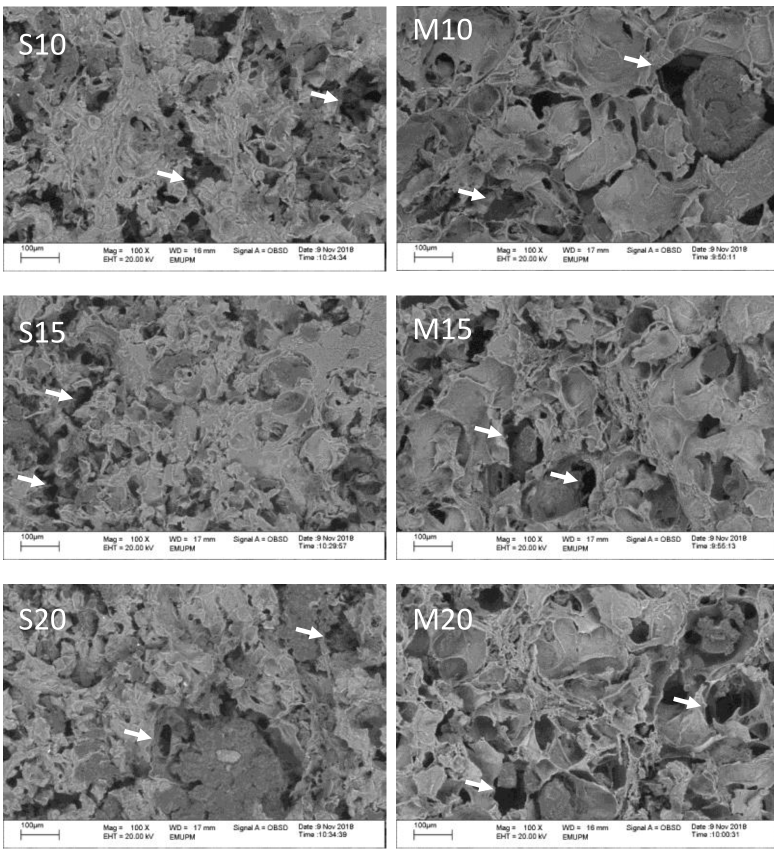

Fig. 1. Different fish sausage samples with different mixing durations were observed at 100× magnification. Tilapia surimi sausage with a mixing duration of 10 min (T10); Tilapia surimi sausage with a mixing duration of 15 min (T15); Tilapia surimi sausage with a mixing duration of 20 min (T20); Minced tilapia sausage with a mixing duration of 10 min (M10); Minced tilapia sausage with a mixing duration of 15 min (M15); Minced tilapia sausage with a mixing duration of 20 min (M20). The sizes of cavities are shown using the arrows.

minerals, and removal of lipids, respectively (Venugopal, 2005; Parvathy and George 2014; Lima et al., 2015). Subsequently, the moisture content in tilapia surimi increases as the water used for washing is trapped in the gaps left by the substances washed out. The washing process also increased the pH by removing free fatty acids, free amino acids, and other water-soluble acidic compounds (Karthikeyan et al., 2004).

Tilapia surimi used as the raw material increased the moisture content of the tilapia surimi sausage due to its high moisture content compared to tilapia minced sausage produced using minced tilapia (Cavenaghi-Altemio et al., 2013). However, ingredients such as flour added during the processing could increase the solid contents, thus lowering the moisture content of the sausages compared to their respective raw materials (Serdaroglu, 2006; Ahmed and Elhaj, 2011). Similarly, the ingredients added to the sausages could contribute to the decreased protein content based on the total composition (Ramos et al., 2012). Nevertheless, the protein contents of both types of sausages were in the range for commercial fish sausages (8.18–10.77 %) (Huda et al., 2012). The shortening added in the production of sausages increased the fat content compared to the raw materials, and since the fat content of the minced tilapia was originally higher than the surimi, the minced tilapia sausage had a higher fat content than the surimi tilapia sausage. The addition of salt during processing caused the ash content of both the minced tilapia and tilapia surimi sausages to increase, similar to starch and sugar increasing the carbohydrate content (Santana et al., 2015). Nonetheless, the sausages produced were still in the range of the commercial fish sausage for ash (1.71–2.61 %) and carbohydrate (12.30–19.59 %) contents (Huda et al., 2012). Furthermore, adding of phosphates in the sausage production significantly decreased the pH in line with the reports of Özpolat and Guran (2017) and Yapar et al. (2006). Nevertheless, the pH of the tilapia surimi sausage was still in the range of fish sausage produced from Tigris scraper (*Capoeta umbla* (Heckel, 1843)) (Özpolat and Guran, 2017).

The mixing duration and raw materials (minced tilapia or tilapia surimi) may influence the qualities of the sausages produced; for example, the linear expansion was affected by a longer mixing duration as a sufficient mixing duration contributed towards better expansion (Murad et al., 2017). The higher linear expansion for the tilapia surimi sausage was also due to its higher moisture content that provided accessible water for starch gelatinisation (Cheow et al., 1999). The cooking yield is associated with the WHC. For example, Nkrumah and Akwetey (2018) reported that a lower value WHC was related to the low cooking yield of sausages. Meanwhile, Hidayat et al. (2018) reported that cooking yield increased in the sausage as the WHC increased. However, in this study, the cooking yield was probably not affected because the sausages were boiled in the casing, preventing significant uptake or release of liquid. The WHC for the minced sausages was higher than the surimi sausages as it was affected by the washing process (Ramadhan et al., 2014). The protein matrix of the minced tilapia sausage was more stable than the tilapia surimi sausage, therefore, less water and fat were released from the minced tilapia sausages, subsequently improving the WHC. Increasing the mixing time caused the actin and myosin aggregation, which lowered the WHC. Also, the loss of the 3D protein structure during aggregation caused denaturation (Santana et al., 2015). Hui (2006) also reported that when the WHC increased, the gel strength also improved. A reduced moisture content could also improve the gelation properties (Rupsankar, 2010), which was similar to this study whereby minced tilapia sausages had a lower moisture content resulting in improved gelation properties. Similar findings were reported by Yousefi and Moosavi-Nasab (2014) on the study of Talang Queenfish sausages. However, mixing for 15 min resulted in sausages with the highest gel strength, as the shorter mixing time (10 min) was inadequate and the longer mixing time (20 min) overworked the mixture, subsequently affecting the sausage properties (Devine and Dikeman, 2014).

In general, tilapia surimi sausage had a lighter colour and lower redness than the tilapia minced sausage due to removing blood and heme pigments during washing of surimi (Ramadhan et al., 2014). In addition, a longer mixing time might also cause a more significant reduction and homogeneous dispersion of the fat particles that contribute to the whitish colour that increases the lightness values (Zhou et al., 2018; Ismail et al., 2021). In terms of the texture, the unique pattern of the hardness, gumminess and chewiness at the different mixing times could be associated with the gel strength results. As a reference, a massaging process to produce restructured meat reduced the hardness as the mixing time increased due to the decrease in the shear value of the product (Gurikar et al., 2014). Sausages with a hardness value of 4730 g and above are acceptable to consumers (Dingstad et al., 2005), which was only achieved by a mixing time of 15 min in this study.

Furthermore, minced fish from Nile tilapia filleting waste increased the softness of the sausage (de Oliveira Filho, Maria Netto, et al., 2010), possibly accounting for the lower hardness for minced tilapia sausages in the present study. The gumminess and chewiness of the minced tilapia sausages were also lower than the tilapia surimi sausages, possibly due to the high-fat content of the minced tilapia sausages, as shown with mixing for 15 min. The high fat content decreases gumminess (Banon et al., 2008), whereas a reduced fat content increases the chewiness (Huda et al., 2012). The cohesiveness of the sausage minced and mixed for 20 min, was affected by the sarcoplasmic and myofibrillar proteins (Farouk et al., 2002), as the longer mixing time caused the sausage to disintegrate, lowering the cohesiveness. The difference in the compactness of the protein matrix of the tilapia surimi sausage and the minced tilapia sausage observed by scanning electron microscopy was probably due to removing substances such as fat during the washing process. This result also correlates with the cohesiveness obtained from the TPA (Table 4), whereby the tilapia surimi sausages were more cohesive than the minced tilapia sausages. The smaller the cavities, the higher the gel strength, as evidenced by the higher gel strength value (Table 3) of the sausages mixed for 15 min. The larger sized microstructure's cavities could negatively impact gel strength (Hema et al., 2016).

The panellists could not differentiate between the texture and aroma of the tilapia surimi sausage and minced surimi sausage, similar to a study by Murphy et al. (2004) that frankfurters from surimi did not affect the consumer's preference. And there was no significant difference in the aroma of the sausages made from fish meat and surimi (Chuapoehuk et al., 2001). However, panellists found differences in the colour, flavour and overall acceptability of the sausages prepared with tilapia surimi and minced surimi, preferring the tilapia surimi sausages. The tilapia surimi sausages were different from the minced tilapia sausages due to the loss of blood pigments during the washing process resulting in a lighter colour (Uyhara et al., 2008; Yousefi and Moosavi-Nasab, 2014; Piotrowicz and Mellado, 2015) and the presence of heme pigments in the minced sausage (de Oliveira Filho, Maria Netto, et al., 2010). Also, the use of 100 % minced fish could have resulted in a very strong fish flavour (de Oliveira Filho, Fávaro-Trindade, et al., 2010), which was unacceptable to the panellists. Subsequently, higher overall acceptability by the panellists towards the tilapia surimi sausages most probably influenced by the colour and flavour of the sausages (de Oliveira Filho, Fávaro-Trindade, et al., 2010).

Conclusion

The washing process during the surimi preparation increased the moisture content and pH but reduced the protein, fat and ash contents of tilapia surimi compared to the minced tilapia. The fat, ash and carbohydrate contents of the sausages produced from tilapia surimi and minced tilapia increased compared to their respective raw materials due to the addition of ingredients such as shortening, salt and starch. Minced tilapia sausages had a higher water holding capacity, while the tilapia surimi sausages had a higher lightness (L^*), lower redness (a^*) and higher cohesiveness. The longer the mixing time, the better is the linear expansion. However, mixing for 15 min had produced better gel strength, and this was supported by the microstructure images and texture results. The sensory panellists preferred tilapia surimi sausages in terms of colour, flavour, and overall acceptability, but the preferences were not affected by mixing time neither for 15 min nor 20 min. In conclusion, sausages produced using tilapia surimi is better than minced tilapia and 15 min of mixing duration is sufficient to produce the desired quality sausages. The related industries can apply these findings to optimise the production of fish sausage or for further research.

Conflict of interest: The authors declare that they have no conflict of interest.

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