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FULL PAPER

The effects of extrusion conditions on the properties of *Amplang*, a traditional fish snack in Borneo

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Abstract

The effects of extrusion process parameters on *Amplang* fish snack production are investigated in this study using a single-screw extrusion machine. The extrusion parameters are based on two factors, namely the barrel temperature (100 - 140^{o}C) and screw speed (146 - 208 rpm). The central composite design (CCD) is used to produce thirteen experimental combinations and the effects of the extrusion parameters on the physical and functional characteristics (hardness, bulk density, expansion ratio, and water absorption and solubility indexes) of the *Amplang* fish extrudate were assessed as responses. The fish extrudates investigated in this study varied between 45.57 - 246.33 N (hardness), 0.09 - 0.21 g/cm^3 (bulk density), 1.00 - 2.67 (expansion ratio), 2.58 - 4.01 g/g (water absorption index), and 19.25 - 29.8% (water solubility index). The bulk density, expansion ratio, water absorption index, and water solubility index were shown to be significantly (P < 0.05) affected by the barrel temperature and screw speed. In conclusion, barrel temperature and screw speed can influence the physical and functional properties of extruded fish snacks and the extrusion technique demonstrated in this study can be utilised to produce *Amplang* fish snacks in Sabah.

1. Introduction

Snack foods have become an integral part of the diet worldwide, with fish crackers being the most popular snack food in many Southeast Asian countries (Taewee, 2011). Fish crackers are prepared by blending the flesh of the fish with starch and water, followed by shaping the mixture into round, oblique, stick or longitudinal forms that are subsequently boiled or steamed for gelatinisation (Chng and Kuang, 1991). The product is then cooled, sliced into different shapes, and dried. In Malaysia, a small, round-shaped fish snack known as *Amplang* is a popular snack among the local people, particularly in certain parts of Borneo (Sabah). Hence, there is potential for this fish snack cottage industry to be transformed into a bigger industry in Sabah due to its popularity. According to the State Development Department of Sabah (2016), the production of fish snacks is approximately 600-700 kilograms per month and the production is expected to increase based on the market demand.

Extrusion cooking is one of the major processes involved in producing expanded snack foods. It is a continuous process of cooking and shaping (forming), in which various conditions such as extruder type, screw configuration, feed moisture, the temperature profile in the barrel, screw speed, feed rate, and die geometry are essential to produce the unique physical and chemical properties of the product. In the extruder, raw materials are thermo-mechanically cooked at high temperature, pressure, and shear stress conditions generated in the screw-barrel assembly (Moscicki, 2011). The cooked dough is subsequently texturised and shaped in the die. The use of extruder machines to replace the traditional methods in food processing is energy-efficient and cheaper, thereby resulting in the reduction of raw materials (19%), labour (14%), and capital investment (44%) (Deshpande and Poshadri, 2011). High-quality products can be produced as extrusion is a high-temperature process that helps to reduce nutrient loss and improve the digestion of protein and starch.

Furthermore, single- and twin-screw extruders have been used to develop dry expanded snack food products from fish mince and starchy ingredients. For instance, Noorakmar *et al.* (2012) and Tumuluru and Sokhansanj (2013) successfully developed snack foods using the extrusion of fish and different types of starch flour. In another study, Singh *et al.* (2014) optimised the

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extruder conditions for fish-rice-corn blends in food snacks with satisfactory customer acceptance. The production of *Amplang* as a popular traditional food snack in Sabah has always been performed conventionally and the scale of production is only sufficient for the local market. Hence, to increase the production of *Amplang* and satisfy the market demand outside of Sabah as well as for export to other countries, other methods that are non-labour intensive should be utilised for the efficient production of this snack food. At present, the conventional method that is performed manually by experienced workers limits the production of *Amplang*. It is envisaged that the use of the extrusion method can increase the production of *Amplang* and at the same time, retain the same formulation and properties of the snack, thus boosting the economy of entrepreneurs in Borneo, especially in Tawau, Sabah.

Response surface methodology (RSM) is a technique that could determine the relationship between the response and the chosen independent variables. It is used to improve a process or product by mapping a response surface over a specific region of interest, optimising the response, or for selecting operating conditions to achieve target specifications or customer requirements (Singh *et al.*, 2014). Hence, this study aims to determine the effects of barrel temperature and screw speed on the production of *Amplang* based on their physical and functional characteristics (hardness, bulk density, expansion ratio, and water absorption and solubility indexes) using RSM.

2. Materials and methods

2.1 Sample preparation

White fish fillets were manually cut into small pieces, washed with tap water, and dried using a drying cabinet (M-412294, Sanyo Electric, Japan) at 65°C for 5 hrs to achieve a final moisture content of 12%. The fish fillets were blended for 30 s, molded, and cut into 1 cm^2 per piece. The cut fillets were dried again using a drying cabinet (M-412294, Sanyo Electric, Japan) at 65°C for 5 hrs. Approximately 500 g of dried fish fillets were blended using a blender (Waring Laboratory Blender, Model 7011OH, United States) for 2 mins with a moderate speed to form fish powder with particle sizes of not more than 25 µm. The fish powder was mixed with other ingredients as shown in Table 1 until a dough was formed. The moisture content of the mixed dough was maintained at 13% or below. The dough was kept in a plastic container coated with aluminum and stored overnight in the refrigerator at 4°C.

2.2 Amplang formulations

The formulation of the *Amplang* fish snack using the extrusion process was based on a method used by a local commercial producer, Muhibbah Raya, Tawau, Sabah with some modifications. Table 1 shows the formulation of *Amplang*.

Table 1. Fish snack formulations (*Amplang*) for extruder application

Materials	Quantity (%)
Fish powder	17
Cassava flour	43.84
Cornflour	29.23
Salt	2.39
Sugar	6.1
Baking powder	0.85
Soda powder	0.36
MSG	0.23

Source: Muhibbah Raya, Tawau, Sabah with some modifications

2.3 Fish snack production using extrusion techniques

A total of 4 kg of dough mix was required for thirteen experimental runs, with approximately 300 g of dough mix used for each run. The dough was inserted into the extruder's feeder after setting the parameters for the extrusion process. The extrudate was pushed out through a 10 mm diameter screw and cut using cutters at the ends of the die. The extruded products were left to cool at room temperature for 5 h and stored in an airtight container prior to analysis.

2.4 Extruder conditions

A Brabender® single-screw extruder (20 DN) with a diameter of 1.90 cm (Model 823500, OHG Duisburg, Germany) equipped with a feeding device (AEV 330) was used to produce the *Amplang* fish crackers. The length to diameter ratio of the barrel was 20:1 and the extruder was powered by a 2.2 kWh motor with screw speeds ranging from 0 – 250 rpm. The compression ratio and die nozzle diameter used were 3:1 and 10.0 mm, respectively, and the screw speeds were set at 146 rpm, 177 rpm, and 208 rpm, respectively. The dough mixture was fed into the gravity feeder funnel and the barrel was equipped with a cold compressed electric air heater controlled by a thermostat to adjust the temperature. The temperatures of the extruder barrel were set as follows: a) first zone (80°C), b) second zone (100°C), and c) third zone (100°C, 120°C, and 140°C) for each experimental run. The extruder was conditioned prior to sample processing and the extrudate was cut into small round shapes by the cutter located at the end of the screw.

2.5 Determination of moisture content

The moisture content was determined using the oven -drying method described previously (AOAC, 2000). Approximately 2 g of samples were placed in the oven at 103°C for 24 hrs. The samples were cooled in a desiccator and weighed prior to analysis.

2.6 Determination of response

In this study, the physical (hardness and bulk density) and functional (expansion ratio, water absorption analysis, and water solubility analysis) characteristics of the *Amplang* fish crackers were identified as the observed responses. Table 2 shows the central composite design (CCD) of the extraction parameters for all the responses investigated in this study.

The fitted model was assessed based on the R^2 value and the variation in the dependent variables was evaluated according to the response surface graphs and factor parameters. The response surface equation of the second-order polynomial model used in the surface response methodology is as follows:

$$\eta = \beta o + \sum_{i=1}^{k} \beta ixi + \sum_{i=1}^{k} \beta iixi + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta ijxixj$$

2.7 Physical properties

2.7.1 Hardness

The texture of *Amplang* was measured using a texture analyser (TA.XT Plus Analyzer, Texture Technologies, Scarsdale, New York). Approximately 15 mm-sized (in length) *Amplang* fish crackers were used for the measurement of texture. A cylinder probe (10 mm) was used to press the samples based on the following settings: (1) 1 mms^{-1} pretest speed, (2) 0.5 mms^{-1} speed during testing, (3) 1 mms^{-1} speed after testing, (4) 10 mm distance, (5) 5 g triggering power, and (6) 70% sample suspension (Maskus and Arntfield, 2015). Three replicate runs were performed for each formulation.

2.7.2 Bulk density

The bulk density of *Amplang* was assessed by calculating the actual dimensions of the extrudate (Thymi *et al.*, 2005). The diameter and length of the samples were measured using a Vernier caliper. Five samples were randomly selected, and the bulk density was calculated using the following equation:

$$\text{Bulk density (g/cm}^3) = M / (1/4 \times d^2 \times L)$$

Where m = extruded product weight, d = diameter of extrusion product, and L = length of extrusion product

2.8 Functional properties

2.8.1 Expansion ratio

The expansion ratio of the samples was measured using the equation formula developed by Rayas-Duarte*et al.* (1998) as shown below:

Expansion ratio = Extruded diameter/mold diameter

2.8.2 Water absorption index

Water absorption was measured according to the method developed by Anderson *et al.* (1970) with some modifications. Approximately 4.5 g of extruded sample was blended and mixed with 30 mL of water in a centrifuge tube at room temperature for 30 mins. The sample was stirred slowly using a glass rod for 1 min. The sample was centrifuged for 10 mins at 3000 rpm and evaporated to dryness at 110°C overnight. The water absorption index was calculated based on the following equation:

Water absorption index = wet sediment weight/dry sample weight

2.8.3 Water solubility index

The water solubility index was measured using the same method described for the water absorption index. The water solubility index was calculated based on the following equation:

Water solubility index = dry supernatant weight/dry sample weight x 100

2.9 Statistical analysis

The Design Expert version 7.0 software was used for the regression analysis of the experimental data and the generation of surface and contour response plots based on the parameters established for this study. Additionally, the analysis of variance (ANOVA) was

Table 2. Design of composite center for extruder parameter response

Type of Response	Unit	Experiment	Minimum value	Maximum value	Average	Standard deviation	Ratio
Bulk density	g/cm^3	13	0.09	0.21	0.13	0.04	2.33
Hardness	N	13	4557	29750	15404	7258	6.53
Expansion Ratio	-	13	0.5	1.7	1.1	0.41	3.4
Water Absorption Index	g/g	13	2.58	4.01	3.24	0.34	1.55
Water Solubility Index	%	13	19.8	29.8	24.09	2.52	1.55

Source: Design Expert Software version 7.0

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used to identify the significant differences between the tested parameters.

3. Results and discussion

3.1 Experimental results

The central composite design and responses for the dependent variables (hardness, bulk density, expansion ratio, water absorption, and water solubility) are shown in Tables 2 and 3. The regression analysis was employed to check the fit of the full response surface model for every response investigated in this study including all linear (A, B), interaction (AB), and quadratic (A^2, B^2) terms.

The examination of the fitted model was necessary to ensure that an adequate representation of the true system was developed in this study. To develop the fitted model, all insignificant terms were eliminated, and the fitted model is shown in Table 4. A small R^2 value indicates a low relevance of the dependent variables analysed in the model. The model is shown to fit well with the actual data when the R^2 value approaches unity (Myers and Montgomery 2002).

The analysis of variance (ANOVA) was used to evaluate the significance of the quadratic polynomial model equation. In this analysis, the terms in the model that have a large F-value and a small P-value indicate a more significant effect on the response of the variable investigated.

The estimated response function and the effects of the independent variables (A: barrel temperature and B: screw speed) on the dependent variables (hardness, bulk density, expansion ratio, water absorption, and water solubility) are shown in Figure 1.

3.2 Hardness

The hardness of the *Amplang* products investigated in this study ranged from 45.57 N to 246.33 N. It was revealed that the coefficients and their corresponding interaction effects of both the barrel temperature and screw speed were shown to be significant ($P \leq 0.01$). A moderate coefficient of determination (R^2) value of 0.7149 was obtained for hardness, thereby indicating that only 71.48% of the fitted model can be explained in this study. Based on Figure 1 (a), increases in the barrel temperature and screw speed were shown to increase the hardness of the *Amplang* fish extrudate. High temperatures can cause the fibre structures on the outside of the product to become hard and a high moisture content of feed materials can result in the products becoming less porous.

In most cases, high barrel temperatures and die temperatures may increase the crispiness of the extrudate due to the low moisture content and increased porosity of the structure (Verma, 2010). However, the moisture content of 13% obtained in this study may not have been low enough to reduce the hardness of the extrudate. Generally, fish extrudates produced with a low expansion rate have a hard texture. Low expansion rates contribute to high bulk density and subsequently, increases the hardness of the product (Wani *et al*., 2015).

3.3 Bulk density

The bulk density of the *Amplang* products formed in this study ranged from 0.09 to 0.21 g/cm^3. The barrel temperature and screw speed coefficients were significant ($P \leq 0.01$) and their corresponding interaction effects on bulk density were also shown to be significant. A high coefficient of determination (R^2) value of 0.9595 for bulk density was obtained in this study, thereby indicating that the model was suitable to represent the true relationships among the selected parameters. Bulk density is an index that measures the extent of puffing as well as the expansion in all directions. As shown in Table 2 and Figure 1 (b), the bulk density of the fish extrudate decreased as the barrel temperature and expansion ratio increased. However, the bulk density increased when the barrel temperature exceeded a temperature of 140°C. The minimum bulk density was achieved at a barrel temperature of 120°C and an expansion ratio of 177 rpm. This observation was consistent with the findings by Singh *et al*. (2014) who reported that bulk density reduced with the decrease in expansion ratio and the increase in barrel temperature.

Some of the factors that can influence bulk density are barrel temperature, gelatinisation process, and moisture content of the dough. Gelatinisation and moisture content were shown to be positively correlated with bulk density, whereas screw speed had an inverse association with bulk density (Rayas-Duarte *et al*., 1998; Shankar and Bandyopadhyay, 2005; Singh *et al.,* 2014). High barrel temperatures and low moisture content were also shown to increase the porosity of the dough when the products exit the extruder, thus resulting in the reduction of bulk density (Tumuluru and Sokhansanj, 2013). However, the increase in bulk density at higher barrel temperatures is due to starch degradation at high temperatures.

3.4 Expansion ratio

The expansion ratio of the *Amplang* products ranged from 1.00 to 2.67 for all the barrel temperatures and screw speeds investigated in this study. The coefficient values for the barrel temperatures and screw speeds as well as their corresponding interaction effects were not

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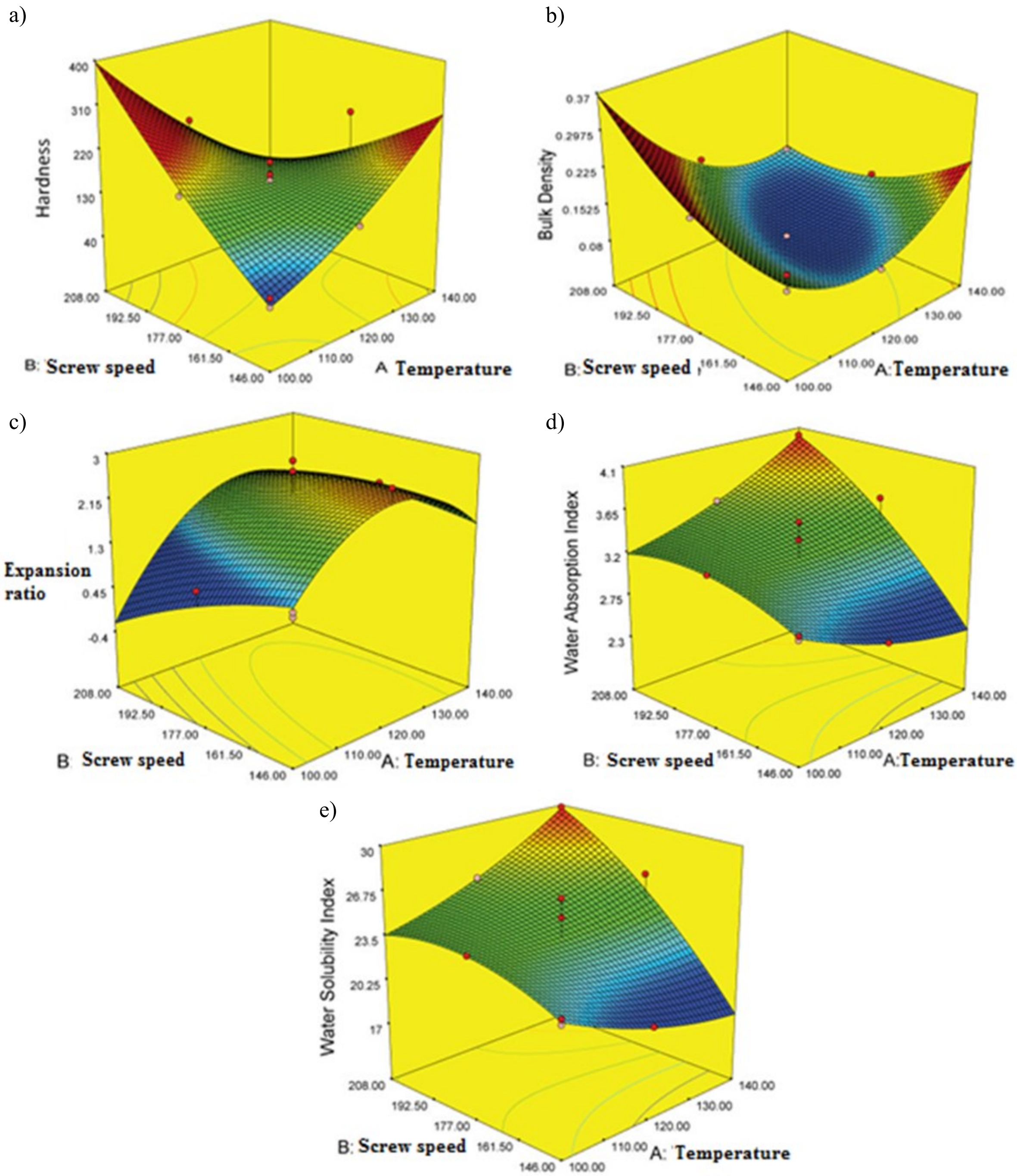

Figure 1. Response surface plots showing the effects of expansion ratio and barrel temperature on 2 (a) hardness, (b) bulk density, (c) expansion ratio, (d) water absorption and (e) water solubility

Table 3. Central composite design for optimizing the extrusion condition for all responses according to the 2nd order response surface models

Combination	Factor		Response				
	Temp (°C)	Screw speed (rpm)	Bulk Density	Hardness	Expansion Ratio	Water Absorption Index	Water Solubility Index
1	120	177	0.09	195.76	2.16	3.34	24.87
2	140	177	0.14	246.33	2	3.53	26.24
3	100	146	0.16	45.57	1.16	2.96	21.93
4	140	177	0.14	105.35	1.5	3.21	23.89
5	100	177	0.21	189.02	1	3.27	24.24
6	120	177	0.09	169.5	2	2.99	22.22
7	120	177	0.09	157.13	2.16	3.13	23.18
8	120	146	0.11	129.92	2	2.58	19.25
9	120	177	0.09	137.63	2.67	3.53	26.27
10	120	177	0.09	140.17	2.67	3.1	23.04
11	120	208	0.17	227.76	1.5	3.5	25.94
12	140	208	0.12	67.64	2	4.01	29.8
13	100	146	0.19	62.74	1.25	3	22.32

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Table 4. Response surface model for all responses of fish extrudates

Response	Quadratic polynomial model	R^2	P-value
Hardness	$160.04 - 17.27A + 34.68B - 140.33AB + 25.95A^2 - 18.80B^2$	0.7149	$P \leq 0.01$
Bulk density	$0.090 - 0.042A + 0.021B - 0.077AB + 0.087A^2 + 0.050B^2$	0.9595	$P \leq 0.01$
Expansion ratio	$2.33 + 0.47A - 0.18B + 0.75AB - 0.99A^2 + 0.52B^2$	0.7902	$P > 0.05$
Water absorption index	$3.22 + 0.051A + 0.46B + 0.35AB + 0.10A^2 - 0.18B^2$	0.8421	$P \leq 0.05$
Water solubility index	$23.85 + 0.44A + 3.38B + 2.63AB + 0.73A^2 - 1.32B^2$	0.8371	$P \leq 0.05$

found to be significant ($P > 0.05$). A moderate coefficient of determination (R^2) value of 0.7902 for bulk density was obtained in this study, thereby indicating that only 79.02% of the model can be explained by the regression model for the selected parameters (Table 4). Based on Figure 1 (c), the highest expansion ratio was achieved at a barrel temperature of 140°C and a screw speed of 208 rpm. Additionally, the expansion ratio was shown to increase when the barrel temperature increased [Figure 1 (c)]. However, the expansion ratio decreased when it reached a certain temperature. The optimal expansion ratio obtained in this study was at barrel temperatures ranging between 120 and 130°C and at screw speeds which did not exceed 177 rpm. The increase in the screw speeds reduced the viscosity of the starch due to the increase in shear rate, thus reducing the rate of expansion ratio. Moreover, high screw speeds resulted in shorter dwell time and reduced the degree of starch gelatinisation due to incomplete cooking (Hashimoto and Grossmann, 2003).

The expansion ratio observed in this study was shown to decrease when the barrel temperature exceeded 130°C. A similar range of expansion rates for barrel temperatures between 150 - 170°C was also reported by Ilo *et al*. (2014) and Raleng *et al.* (2016) using maize grit and pineapple pomace powder, respectively, thereby indicating that the expansion ratio was closely associated with the type of raw materials used. The decrease in expansion ratio was due to excessive structural damage and starch degradation at high temperatures that caused the structures to become fragile. The reduction of expansion ratios at high temperatures was also a result of increased axial and longitude expansion. A similar finding by Dileep *et al.* (2010) using fish and rice flour blends showed that a higher moisture content influenced the starch gelatinisation process and affected the extrudate properties such as the expansion ratio.

3.5 Water absorption index

The water absorption index of the *Amplang* products ranged from 2.58 to 4.01 (Table 3). The barrel temperature coefficient was observed to be significant ($P \leq 0.05$), while the screw speed coefficient was not significant ($P > 0.05$). The corresponding interaction effect of barrel temperature and screw speed on the water absorption index was not shown to be significant as well. A high coefficient of determination (R^2) value of 0.8421 for bulk density was achieved in this study, thereby indicating that the model was suitable to represent the true relationships among the selected parameters (Table 4). Based on Figure 1 (d), the highest water absorption index at 4.01 was obtained at a barrel temperature of 140°C and a screw speed of 208 rpm, whereas the lowest absorption index was obtained at a barrel temperature of 100°C and a screw speed of 148 rpm. The 3-dimensional surface plot shows that the water absorption index was at the highest when the barrel temperature and screw speed were at 120°C and 177 rpm, respectively. The water absorption index was shown to decrease when the screw speed increased to more than 177 rpm. Similar findings were reported by Pardhi *et al.* (2019), in which the authors noted that higher screw speeds resulted in a shorter time frame for the starch to remain in the barrel and thus, led to lower rates of water absorption for starch -based products. The increase in the rate of water absorption index was also shown to be proportionate to the barrel temperature due to the increase in starch degradation and starch shortening (Pelembe *et al.,* 2002; Pardhi *et al.*, 2019). Additionally, the water absorption index was also reduced when the duration of the extrusion process overlapped with the gelatinisation process (Altan *et al.,* 2009; Pardhi *et al.*, 2019). However, the water absorption index is dependent on the existence of intact starch molecules that do not lose their ability to bind water molecules after the extrusion process (Salata *et al.*, 2014).

3.6 Water solubility index

The water solubility index is generally used as an indicator of the degradation of molecular components that are dependent on the state and type of reaction involved in the extrusion process. The water solubility index of the *Amplang* products ranged between 19.25 to 29.80 (Table 3). Based on the regression analysis, the barrel temperature coefficient was found to be highly significant ($P \leq 0.01$), while the screw speed coefficient was not significant ($P > 0.05$). The corresponding interaction effects of the barrel temperature and screw speed were not found to be significant ($P > 0.05$). A high coefficient of determination (R^2) value of 0.8371 was obtained, thereby indicating that 83.71% of the variability in the water solubility index could be explained by the model and hence, represented the true relationships among the selected process parameters (Table 4).

Similarly, the water solubility response was shown to fit the quadratic model with a high coefficient determination (R^2) of 0.8731 and thus, represented the true relationships among the selected parameters. The water solubility index ranged between 19.25 to 29.80 at barrel temperatures of 100, 120, and 140°C and screw speeds of 146, 177, and 208 rpm, respectively. Additionally, the barrel temperature coefficient was shown to be significant ($P \leq 0.01$), while the coefficient of the screw speed was not found to be significant ($P > 0.05$).

Based on Figure 1 (e), the highest water solubility index was achieved at a barrel temperature and screw speed of 140°C and 208 rpm, respectively. The water solubility index remained low although the barrel temperature increased. Similar to the water absorption index, the water solubility index increases proportionally with the increase in screw speed. In addition, the starch gelatinization process and other reactions that produce low molecular-weight compounds cause the release of amylose and amylopectin. Nevertheless, the increase in screw speed is thought to increase the shear rate and subsequently, increase water solubility. For instance, although higher screw speeds shorten the dwell time of the starch in the extruder, the amount of starch or fibres that have undergone the degradation processes is sufficient to increase water solubility (Arun Kumar *et al.,* 2015). The authors also stated that water absorption and water solubility indexes are important parameters used to evaluate how the materials interact, particularly in applications that require the use of extrusion processes.

Apart from the screw speed, screw configuration and feed composition can also affect the extruder-induced water solubility index. Additionally, the increase in shear energy and dwell time in the barrel leads to degradation and polymerization of the starch molecular structure. It was previously noted that the high shear strength may cause the breakdown of starch and proteins, thus leading to degraded products with smaller and more soluble molecules (Arun Kumar *et al*., 2015; Pardhi *et al*., 2019).

Significant changes in the physical and functional properties were observed, in which bulk density, expansion ratio, water absorption index, and water solubility index of the extruded fish snacks were all shown to be significantly affected by the variation in barrel temperatures and screw speeds. In this study, *Amplang* was successfully developed using extrusion technology that has the potential to be applied in the production of local *Amplang* in Borneo. Specifically, a barrel temperature of 120°C and screw speed at 146 rpm produced *Amplang* fish crackers that had a higher expansion rate and low bulk density, although it was slightly harder as compared to the commercially produced *Amplang*. More studies should be performed to improve the formulation and moisture content of the fish extrude to reduce its hardness. It is envisaged that this pilot study has the potential to be further improvised and used for the commercial production of *Amplang* in Borneo particularly in Sabah.

Conflict of interest

The authors declare no conflict of interest.

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