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Effects of different starches on the physicochemical and sensory characteristics of extruded fish snacks

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Abstract

The market for snack foods is currently heading for healthier choices. Extrusion-based snacks made of starch are widespread but less nutrient-dense. Therefore, an effort to produce expanded snacks with higher protein was attempted. However, the physical properties of high protein extrudates are less desirable. Hence, different kind of starches were used in attempt to improve the physical properties of extrudates with high protein from scad fish. The objective of this study was to determine the effect of types and percentages of three starches, namely tapioca, sago and corn (50, 67, 75% db); on the physicochemical properties of extrudates from round scad fish powder (*Decaptus madruasi*). The formulations were extruded using a single screw extruder with a 3 mm circular die. The feeder and screw speed were maintained at 150 and 50 rpm, respectively. The barrel temperatures for each zone were 80°C (zone 1), 120°C (zone 2), 140°C (zone 3) and 160°C (zone 4). The results of the study revealed that all starch types at 75% increased the expansion ratio of extrudates to 47-56% compared with the inclusion of starches at 50%. All starch types at 75% also decreased the bulk density to 21-24% and hardness to 23-50% as compared to extrudates with the lowest amount of starch. The improvements in the physical properties were more prominent in the addition of tapioca starch. The highest amount of protein was found in extrudates with tapioca starch (20.8 to 30.4%). The sensory analysis and colour indicated similar results for all extrudates. The best formulation for the production of fish snacks was extrudates with 75% tapioca starch and 25% fish powder. The finding of this study is relevant and applicable in the production of high protein extrudates for children or health-conscious consumers, with the usage of tapioca starch to assist better expansion that improves the physical properties.

1. Introduction

Nowadays, people prefer easy-to-access snacks instead of qualified meals (Pechey and Marteau, 2018; Sogari *et al.,* 2018). Snack foods are created to be less perishable, more robust and more attractive than natural foods (Njike *et al.*, 2016). Snacks have a lot of high calories, salt and fat but lack other essential nutrients such as protein and dietary fibre (Stojceska *et al.,* 2010; Hirth *et al.,* 2014; Korkerd *et al.,* 2016; Arribas *et al.,* 2019). Among many snack production, extrusion is one of the most common processing methods. Extrusion is a high-temperature, short time technology which involves continuous mixing, kneading and shaping process that uses both thermal and mechanical forces. It is a flexible cooking method that is used to create a variety of foods, including cereals, meat substitutes, and ready-to-eat foods and can be extremely flexible in providing customer satisfaction for desirable products (Alam *et al.*, 2016; Kanojia *et al.*, 2016; Offiah *et al.*, 2018; Ascheri *et al.*, 2019; Mazlan *et al.*, 2020). Unfortunately, snacks produced using extrusion are high in calories and lack essential nutrients especially protein that are beneficial for health (Obradović *et al.*, 2018). Due to the low protein content in extruded snacks, protein sources are crucial to enhance the snacks' nutrition. Several studies reported on the addition of protein in extruded snacks to improve nutrient density and health-promoting properties. Among them is enriching the extruded snacks with legume proteins (Devi *et al.*, 2013; Yu *et al.,* 2013;

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Costantini *et al.*, 2021) which resulted in significant final changes in the final extrudate physical characteristics (particularly expansion and hardness) and nutrient content. Other researchers produced nutritious extrudates by incorporating whey protein that increased the protein content (Salunke, 2015; Teba *et al.,* 2017).

Besides incorporating legumes and dairy products to enhance protein content in extrudates, there is a growing body of literature that recognizes the usage of fish in extruded products. Extruded snacks incorporated with fish flesh or powder were accepted by sensory panellists for their textural and nutritional benefits (Kuna *et al.,* 2013; Shahmohammadi, Bakar, Rahman *et al.,* 2014; Singh *et al.,* 2014). Fish flesh or powder is an excellent source of high nutritional value and easily digestible animal proteins with a balanced profile of essential amino acids that contains omega-3 fatty acids, especially essential fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Beveridge *et al.,* 2013; Elavarasan, 2018). A small quantity of fish can significantly improve the quality of dietary protein by complementing the essential amino acids compared to most terrestrial meats (Abraha *et al.,* 2018). However, previous research heavily focused on extrudate's physical attributes with less focus on the nutritional and sensory properties of the extrudates (Kuna *et al.,* 2013; Paula *et al*., 2014; Goes *et al*., 2015).

In Malaysia, round scad fish (*Decapterus madruasi*) is one of the most consumed fish by adults in Peninsular Malaysia (Ahmad *et al.,* 2016). The price is cheaper compared to other species of fish (LKIM, 2017). The protein content of scad flesh is 17-19% and the fat content varies significantly between individual fish caught in the same haul, ranging from 2 to 20%. Although the addition of fish will improve the nutritional properties of extruded snacks, the higher protein content will cause less expansion of extruded snacks (Majumdar *et al.,* 2011; Noorakmar *et al.,* 2012; Shahmohammadi, Bakar, Rahman *et al.,* 2014), due to protein molecules limiting the starch swelling and thus, affecting the gelatinization and gelling (Bravo-Núñez *et al.,* 2019). However, different kinds of starch will contribute to varying physical properties of extrudates, especially the expansion ratio.

Starch contributes to the expansion of final extruded products (Kuna *et al.,* 2013; Patel *et al.,* 2016; Fang *et al.,* 2019) due to significant structural changes such as gelatinization, melting, and fragmentation during the extrusion process while other ingredients such as proteins, sugars, fats, and fibre act as diluents (Moraru and Kokini, 2003; Kannadhason and Muthukumarappan, 2010). These molecular changes mainly affect the rheological properties of starch, which influences the expansion properties of starch during extrusion (Singha *et al.,* 2018). The primary role of these changes is to give structure, texture, mouthfeel, bulk, and many other characteristics desired for specific finished products (Chinnaswamy and Hanna, 1990). The amylose-amylopectin ratio in starch also influences the expansion, where higher amylopectin content causes higher expansion of the extrudate (Kannadhason and Muthukumarappan, 2010).

Many types of starches are used in extrusion processing including tapioca, corn and sago starches, which have different amylose-amylopectin ratios. Tapioca starch ideally contains about 11-17% amylose and is most often used in third-generation snack formulations (Riaz, 2016). Native corn starch consists of ~25% amylose and ~75% branched amylopectin (Sandhu and Singh, 2007), whereas, for sago starch, the amylose contents ranged from 21.4 to 30.0% (Uthumporn *et al.,* 2014; Cornejo-Ramírez *et al.,* 2018). During extrusion, water-plasticized starch is exposed to specific mechanical and thermal processing (Kannadhason and Muthukumarappan, 2010). Thus, the addition of protein with the right amount of starch in formulated extruded product extrusion processing will help to enhance the expansion and texture of the extrudate (Cortez-Vega *et al.,* 2013; Kuna *et al.,* 2013; Goes *et al.,* 2015)

Although several researchers studied the incorporation of fish as a source of protein in extrudates, they incorporated only one type of starch with a fixed or optimized amount in the formulation (Kuna *et al.,* 2013; Cortez *et al*., 2014; Goes *et al*., 2015). Additionally, previous research heavily focused on extrudate's physical attributes with less focus on the nutritional and sensory properties of the extrudates. Therefore, it is important to identify the most suitable starch and to determine the optimal amount of fish powder/starch ratio for a desirable and nutritious end product. Hence, this study aimed to determine the effect of different types and percentages of starch (tapioca, sago, and corn) on the physicochemical properties of extrudates from round scad fish powder (*Decaptus madruasi*). It was expected that the addition of fish with precise type and percentage of starch could improve the extrudate's nutritional value with satisfactory physicochemical properties.

2. Materials and methods

2.1 Raw materials

Round scad fish (*Decaptus madruasi*) with a length of 10-15 cm was purchased from the local market in Selangor, Malaysia. The tapioca starch (TS), corn starch (CS) and sago starch (SS) were obtained from a local store in Selangor, Malaysia.

2.2 Preparation of fish powder

The head, fins, tail and viscera of the fish were discarded, and the fish was cleaned with tap water (Noorakmar *et al*., 2012). After that, the fish was deboned by using a fish deboner (World Foodtech, Batu Caves, Malaysia) and the minced fish was collected, washed with cold water three times then dried in a cabinet dryer (Richentek, Henan, China) at 60°C. The dried minced fish was then ground by a kitchen blender (Philips, HR2221, Malaysia) and sieved using a 500 µm mesh siever (Majumder *et al*., 2017). The fish powder (FP) was vacuum packed in nylon plastic and stored in a chiller (4°C) (Cool-300, Protech, Malaysia) until further use.

2.3 Experimental design

The formulations for fish snacks were developed according to the Malaysian Fisheries Department (2014), as indicated in Table 1. The moisture content of the mixture was determined following the AOAC method 925.10 (2005) to calculate the required amount of water to achieve a moisture content of 18% according to Equation 1 (Sadik, 2015). The material was mixed for 10 mins in a mixer (Alfa KB- 502 Cake Mixer, Taiwan) and then kept in a chiller (4°C) overnight for moisture equilibrium.

$$Wa = Ms \times \frac{mf - mi}{100 - mf} \tag{1}$$

Where Wa is the weight of water added (g), Ms is the mass of the sample (g), mi is the initial moisture content (%, d.b) and mf is the final moisture content (%, d.b).

Table 1. Formulation of extruded snacks.

Sample	Fish powder (%)	Starch (%)
Tapioca (50%)	50	50
Tapioca (67%)	33	67
Tapioca (75%)	25	75
Corn (50%)	50	50
Corn (67%)	33	67
Corn (75%)	25	75
Sago (50%)	50	50
Sago (67%)	33	67
Sago (75%)	25	75

2.4 Extrusion condition

Extrusion cooking of the formulations was carried out by using a single screw extruder (KE-19/25 D, Brabender, Germany). The screw used in the extrusion process was a spiral screw with a compression ratio of 3:1 and, a round die diameter of 3 mm (Lobato *et al*., 2011). The extrudates were cut manually with a knife into 3 cm long strips. During the extrusion process, the screw speed was set to 150 rpm and the feeder speed to 50 rpm. The barrel temperature profile was set according to zones, namely zone 1: 80°C, zone 2: 120°C, zone 3: 140°C and zone 4: 160°C (Lobato *et al*., 2011; Shaviklo *et al.,* 2011). The collected extrudates were dried in a hot air drier at 50°C for 3 hrs (Singh *et al.,* 2014), cooled to room temperature for 5 mins, placed in plastic bags, sealed and stored at room temperature until analysed.

$$\mathrm{MFR}\ (\mathrm{g/s}) = \frac{\text{Weight of collected sample (g)}}{\text{Time taken to collect sample (s)}} \tag{2}$$

2.5 Mass flow rate

The mass flow rate was determined by weighing the collected extrudates as soon as they exited the die for a particular period (Foley and Rosentrater, 2013).

$$\mathrm{SME} = \frac{\text{loading power (kJ/s)} - \text{empty power (kJ/s)}}{\text{feed rate (kg/s)}} \tag{3}$$

2.6 Specific mechanical energy

Specific mechanical energy (SME) was calculated by following the method of Feng and Lee (2014) where the power consumption was measured directly by the power logger by a Three-Phase Power Logger (Model 2017, Kyoritsu, Japan) instead of calculating from the % torque, rated power and screw speed. The SME for each treatment was calculated using Equation (3). In this equation, empty power was measured by the power logger when running the extruder without feeding the sample. Loading power was measured during the feed run. Power consumptions were recorded every 2 s for 2 mins and the average values during the extrusion were used to calculate SME.

2.7 Analysis of extrudates

2.7.1 Chemical composition analysis

The chemical composition, including the moisture, ash, protein and fat contents of the raw and extruded samples were determined according to AOAC method 925.10, AOAC method 942.05, AOAC method 960.52 and AOAC method 948.22, respectively (AOAC, 2005). The moisture content was determined by oven-drying the sample at 105°C to constant weight. For crude protein content, the determination of crude nitrogen content of the sample by the Kjeldahl method (N×6.25) was used. The ash content was calculated from the permanent weight remaining after heating the sample at 550°C until no black particle was present. The fat content was determined by following the Soxhlet extraction method. All analyses were done in triplicates.

2.7.2 Expansion ratio and specific length

Sectional expansion, the ratio of the diameter of the extrudates and the diameter of the die (3 mm), was used to express the expansion of the extrudate (Ding *et al.*, 2006). The expansion ratio and specific length values were obtained from 10 samples for each treatment.

$$\text{Expansion ratio} = \frac{\text{Diameter of extruded (mm)}}{\text{Diameter of die (mm)}} \qquad (4)$$

The specific length was calculated with Eq. 5:

$$\text{Specific length}(\text{mkg}^{-1}) = \frac{\text{Le}}{\text{me}} \qquad (5)$$

where Le is the length of the extrudate sample (in meters) and me is the mass of the sample (in kg).

2.7.3 Bulk density and piece density

Extrudates with a length of 3 cm were used to determine the bulk density (BD) and piece density (PD). The seed displacement method was used to measure the BD in this study by following the method of Byars and Singh (2015). A 250 mL measuring cylinder was used to measure the volume of the extrudates by mustard millet seed displacement and gently tapped five times. The volume of 20 g randomized samples was measured for each test and the measurements were repeated four times. BD was calculated as the ratio of sample weight and the replaced volume in the cylinder (Eq. 6).

$$\text{Bulk density}\left(\frac{\text{g}}{\text{mL}}\right) = \frac{\text{Mass of extrudate (g)}}{\text{Volume of mustard seed decrease (mL)}} \qquad (6)$$

Piece density was calculated using Eq. 7:

$$\text{Piece density}(\text{kgm}^{-3}) = \frac{4 \times m_e}{\pi \times (D_e)^2 \times L_e} \qquad (7)$$

where m_e is the mass of the sample (in kg), D_e is the average diameter measured at three different points of the extrudate sample (in m) and L_e is the length of the extrudate sample (in m). Five extrudates for each treatment were analysed.

2.7.4 Water absorption index and water sorption index

Water absorption index (WAI) and water solubility index (WSI) were determined by following the method of Ding *et al.* (2005) with some modifications to the sample weight and amount of water. Sample (1 g) was suspended in 12 mL water at 25°C in a 15 mL centrifuge tube, which was then mixed well by vigorous manual shaking. During the 10 mins holding time, the tubes were shaken every 5 mins interval. Then, the samples were centrifuged for 15 mins at 3000 rpm in a Hettich centrifuge (Kubota, Model EBA 20, Germany). The supernatant was decanted into an evaporating dish and dried overnight in a universal oven (UF110, Memmert, Germany) at 105°C to obtain the data for WSI calculation. The remaining sediments in the centrifugal tube were weighed and the data obtained were calculated for WAI. Each treatment was analysed in triplicates. The WAI and WSI were calculated in Equation 8 and Equation 9, respectively.

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Weight of Dry Sample}} \qquad (8)$$

$$\text{WSI (\%)} = \frac{\text{Weight of Dried Supernatant}}{\text{Weight of Dry Sample}} \times 100 \qquad (9)$$

2.7.5 Colour analysis

The colour of the extrudates was determined using a Minolta Chroma Meter CR-400 (Minolta Co., Ltd., Tokyo, Japan). The instrument was calibrated with a white tile, and colour was expressed in CIE-Lab parameters as L*, a*, and b*. Colour readings were displayed as L* a* and b* values where L* represents the lightness/darkness dimension. The positive and negative a* value indicates redness and greenness, respectively, and b* indicates yellowness for the positive value and blueness for the negative value. The average value of ten measurements was reported.

2.7.6 Texture analysis

The textural properties of extrudate were measured by using a TA-XT2i texture analyzer (Stable Micro Systems, Surrey, UK) with Warner-Bratzler shear attachment (Paula and Conti-Silva, 2014). A standard 50 kg load cell was fit to the instrument. The extrudate was compressed by the probe at a speed of 1.0 mm/s at a distance corresponding to approximately 30% of the height of the extrudates. A force-time curve was recorded to calculate the maximum peak force, representing the resistance of the extrudate to penetration (the hardness of the extrudate). A total of twenty randomly collected samples of each extrudate at varying formulations were measured.

2.7.7 Sensory analysis

A total of sixty untrained panellists (18 - 45 years old males and females) from the Food Technology Department, Universiti Putra Malaysia, participated in the sensory test for organoleptic properties of extruded snacks such as appearance, colour, aroma, flavour, texture (crispness) and the overall acceptability. The samples were placed on a plastic plate coded with different 3-digit numbers. Before the testing, the panellists were instructed to rinse their mouths thoroughly with potable water and were requested to taste the snacks one by one. Between each sample test, they were requested to rinse their mouths with a mouthful of water. The samples were evaluated based on a 9-point Hedonic scale with a rating of 1 (least score) = disliked extremely, to 9 (highest score) = liked extremely. The lower limit of tolerance for each sensory attribute is 5 or fewer (Nyombaire *et al.*, 2011). Equation 10 was used to evaluate the products' Acceptability Index (AI):

$$\text{AI \%} = \frac{\text{Average grade obtained from product}}{9} \times 100 \qquad (10)$$

2.8 Statistical analysis

Results obtained in this study were analysed statistically and expressed as mean ± standard deviation (SD). Differences among average values were estimated by analysis of variance (ANOVA) with the application of Turkey's tests using Minitab 18 software, 2017, USA which the average values will be considered significantly different when $p < 0.05$.

3. Results and discussion

3.1 Proximate analysis of raw material

The nutritional composition of round scad fish powder and starches are tabulated in Table 2. The proximate analysis of the raw ingredients is crucial in determining the effect of each nutritional composition on the processing parameters and the estimation of the final overall quality of extrudates. The fish powder was fairly rich in protein (72.46%) and contained 10.23% fat, 5.26% carbohydrate, 9.11% moisture and 2.96% ash content. A significantly higher amount of protein content was observed for fish powder (72.46%) when compared to other starches (below 0.5%). The protein content of fish powder was similar to fish powder made from saithe (*Pollachius virens*) as reported by Shaviklo *et al.* (2011). The tapioca starch had the highest amylopectin content (80.53±3.60%) followed by corn starch (72.03±4.40%) and sago starch (69.13±1.40%). Starches with varying amylose content are useful for food processing because they have the potential to change the texture and quality of the final products (Othman *et al.,* 2015).

3.2 Mass flow rate

The extrudate's mass flow rate (MFR) (Table 3) was consistent despite the different ratios of fish powder and starches with differing amylose content. Chakraborty *et al.* (2020) observed similar findings in fish meal concentrate-based snacks at the concentration of 0 to 10% fish meal concentrate due to constant extrusion conditions and moisture content in the feed mixtures (Deshpande and Poshadri, 2011; Siddarth, 2014).

3.3 Specific mechanical energy

Specific mechanical energy (SME) is defined as the mechanical energy transferred from the extruder to the material. Results given in Table 3 elucidated that SME ranged from 989.0±176.0 to 1487.0±179.0 kJ/kg. Regardless of starch type, increasing starch concentration in the formulation caused SME to reduce to 6-21%, but the changes were insignificant. This result indicates that additional energy and pressure were needed during the extrusion of the blends containing a higher percentage of fish powder since it was expected that a higher protein content would result in interactions of starch-protein and protein-protein that would increase the viscosity of the dough melt (Lazou and Krokida, 2011). From the perspective of starch with differing amylose and amylopectin ratios, the SME for tapioca starch was similar to corn but significantly higher than sago starch. Typically, higher SME causes higher levels of starch gelatinization (Pardhi *et al.*, 2019). A higher amount of amylopectin in tapioca starch (80%) (Table 2) may cause faster gelatinization of melt due to the branched structures having a higher affinity to water as compared with linear-chained amylose. As the amount of amylose increases in starch, such as in sago starch- the dough becomes less viscous because of the low water absorption, causing lesser energy required during extrusion.

3.4 Properties of extrudates

3.4.1 Protein of extrudates

Except for the sago starch extrudates (Table 3), the protein content of samples significantly decreased as the amount of starch increased ($p<0.05$). The results showed that the protein content of extrudates decreased from 2-10% when starch was incorporated from 50-75%. The highest protein content was in tapioca starch extrudates (20-30%) followed by corn starch (9-14%) and the lowest protein content was in sago starch extrudates (2-4%). The protein content in sago starch extrudates was lower due to lower amylopectin content in sago starch compared with other starch. Hence, it might reduce the interaction of protein-starch binding as the proteins vary concerning how tightly they interact on the surface of gelatinized granules. A similar result was reported by Fang *et al.* (2019) where crude protein content decreased

Table 2. Composition of raw material.

Raw material	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Carbohydrate (%)	Amylose (%)	Amylopectin (%)
Fish powder	72.46±0.05^{a}	10.23±0.06^{a}	9.11±0.02^{a}	2.96±0.04^{b}	5.26±0.05^{c}	N/A	N/A
Tapioca Starch	0.57±0.01^{b}	0.02±0.00^{b}	9.15±0.01^{a}	0.07±0.00^{a}	90.20±0 .47^{ab}	19.47±3.60^{b}	80.53 ± 3.60^{a}
Corn Starch	0.59±0.01^{b}	0.01±0.00^{b}	9.60±0.02^{a}	0.03±0.01^{a}	89.78±0.01^{a}	27.97±4.40^{a}	72.03 ± 4.40^{b}
Sago Starch	0.59±0.01^{b}	0.02±0.00^{b}	8.29±0.32^{b}	0.04±0.01^{a}	91.33±0.33^{b}	30.87±1.40^{a}	69.13 ± 1.40^{b}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$). N/A: Not available.

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Table 3. Mass flow rate (MFR), specific mechanical energy (SME), protein and fat content of extruded fish snacks.

Sample	MFR (g/s)	SME (kJ/kg)	Protein (%)	Fat (%)
Tapioca (50%)	0.62 ± 0.16^{a}	1487.0 ± 179.0^{a}	30.41 ± 0.52^{a}	0.60 ± 0.19^{cde}
Tapioca (67%)	0.58 ± 0.06^{a}	1284.9 ± 36.6^{ab}	26.23 ± 1.09^{b}	0.40 ± 0.03^{de}
Tapioca (75%)	0.50 ± 0.14^{a}	1173.3 ± 13.2^{ab}	20.80 ± 1.20^{c}	0.25 ± 0.01^{f}
Corn (50%)	0.48 ± 0.07^{a}	1394.0 ± 174.0^{ab}	14.17 ± 1.44^{d}	1.54 ± 0.03^{b}
Corn (67%)	0.58 ± 0.18^{a}	1226.3 ± 157.9^{ab}	11.49 ± 1.43^{de}	0.74 ± 0.06^{cd}
Corn (75%)	0.53 ± 0.04^{a}	1183.0 ± 178.0^{ab}	9.35 ± 0.46^{e}	0.28 ± 0.01^{ef}
Sago (50%)	0.54 ± 0.08^{a}	1060.0 ± 177.0^{b}	4.14 ± 0.89^{f}	2.25 ± 0.30^{a}
Sago (67%)	0.67 ± 0.16^{a}	989.0 ± 176.0^{b}	3.75 ± 1.02^{f}	0.79 ± 0.02^{c}
Sago (75%)	0.60 ± 0.28^{a}	998.1 ± 73.0^{b}	2.10 ± 0.87^{f}	0.28 ± 0.01^{ef}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$).

significantly with increased corn starch percentage from 20 to 40% in tuna meat-based extrudate formulation.

3.4.2 Fat of extrudates

The fat content of extrudates was contributed by the fish powder in the mixture. The fat content of samples significantly decreased as the percentage of starch increased in all samples (Table 3). The increment of corn and sago starches in extrudates significantly decreased the fat content ($p<0.05$), whereas the fat content for tapioca starch extrudates was less affected. The lowest fat content was in tapioca starch extrudates (0.25-0.6%), followed by corn starch extrudates (0.28-1.54%) and the highest fat content was in sago starch extrudates (0.28-2.25%). Increment of sago starch in extrudates from 50% to 75% caused the fat content to decrease 11 times. The fat content for all extrudates with 75% starch showed no significant difference. As the amount of starch is elevated, the fat content decreased because it was diluted by the lower amount of fish powder. Another possible explanation is that the lower fat content was due to starch-lipid complexes, which are impervious to lipid extraction (Camire, 2001). A similar finding was revealed by Tumuluru *et al.* (2013) that indicates fat content was minimized in the extrudates at lower fish contents of less than 15% and medium feed moisture content of 35– 45%.

3.4.3 Expansion ratio

The expansion ratio (ER) of samples increased as the percentage of starch increased (Table 4). The tapioca and sago starch extrudates had higher ER (1.7-2.5) compared with corn starch extrudates (1.45-2.26). The percentage of corn and sago starches significantly affected the ER of all samples ($p<0.05$). This finding revealed that different amounts, types and nature of starch present appeared to influence the expansion ratio. The highest value of ER was achieved by sago (75%), which is prone to have better expansion due to low protein content in the extrudates (Table 3). As protein content increased, the ER was reduced due to the protein's ability to disrupt water distribution in the feed matrix and through their macro molecular structure and conformation (Deshpande and Poshadri, 2011; Chakraborty *et al.,* 2020). These results were in agreement with Kumar *et al.* (2010), which indicated that increased rice flour proportion in feed composition resulted in an increased expansion of extrudates. Hood-Niefer and Tyler (2010) also suggested that the highest starch content exhibited satisfactory expansion characteristics of pea flour extrudates.

3.4.4 Specific length

The specific length (SL) of extrudates expresses axial expansion by correlating their length with weight (Samard *et al.,* 2017). From Table 4, the SL of samples was significantly decreased when the percentage of starch increased ($p<0.05$). The SL of all extrudates was negatively correlated with ER, indicating that higher radial expansion limits the lengthening of the extrudates. The highest SL was in corn starch extrudates (42.57-64.96), followed by sago starch extrudates (35.76-47.75) and tapioca starch extrudates (31.78-42.22). The addition of the corn starch mostly affected the SL of extrudates two times more than tapioca and sago starch. Wani and Kumar (2016) reported similar results, showing the specific length was inversely proportional to the starch percentage.

3.4.5 Bulk density and piece density

A crucial factor in the creation of expanded and formed food products is density, specifically bulk density (BD). It monitors expansion in all directions and serves as an indicator of puffing intensity (Chakraborty *et al.,* 2020). The BD and piece density (PD) of extrudates decreased when the percentage of starch increased, which was positively correlated with the ER and inversely correlated with the SL of samples (Table 4). The highest BD and PD were shown by sago starch extrudates, followed by corn starch and tapioca starch extrudates. This outcome could probably be due to the

Table 3. Mass flow rate (MFR), specific mechanical energy (SME), protein and fat content of extruded fish snacks.

Sample	MFR (g/s)	SME (kJ/kg)	Protein (%)	Fat (%)
Tapioca (50%)	0.62 ± 0.16^{a}	1487.0 ± 179.0^{a}	30.41 ± 0.52^{a}	0.60 ± 0.19^{cde}
Tapioca (67%)	0.58 ± 0.06^{a}	1284.9 ± 36.6^{ab}	26.23 ± 1.09^{b}	0.40 ± 0.03^{de}
Tapioca (75%)	0.50 ± 0.14^{a}	1173.3 ± 13.2^{ab}	20.80 ± 1.20^{c}	0.25 ± 0.01^{f}
Corn (50%)	0.48 ± 0.07^{a}	1394.0 ± 174.0^{ab}	14.17 ± 1.44^{d}	1.54 ± 0.03^{b}
Corn (67%)	0.58 ± 0.18^{a}	1226.3 ± 157.9^{ab}	11.49 ± 1.43^{de}	0.74 ± 0.06^{cd}
Corn (75%)	0.53 ± 0.04^{a}	1183.0 ± 178.0^{ab}	9.35 ± 0.46^{e}	0.28 ± 0.01^{ef}
Sago (50%)	0.54 ± 0.08^{a}	1060.0 ± 177.0^{b}	4.14 ± 0.89^{f}	2.25 ± 0.30^{a}
Sago (67%)	0.67 ± 0.16^{a}	989.0 ± 176.0^{b}	3.75 ± 1.02^{f}	0.79 ± 0.02^{c}
Sago (75%)	0.60 ± 0.28^{a}	998.1 ± 73.0^{b}	2.10 ± 0.87^{f}	0.28 ± 0.01^{ef}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$).

Table 4. Expansion ratio (ER), specific length (SL), bulk density (BD) and piece density (PD) of extruded fish snacks.

Sample	ER	SL	BD (kgm^{-3})	PD (kgm^{-3})
Tapioca (50%)	1.70 ± 0.12^{c}	42.22 ± 2.18^{d}	229.13 ± 12.50^{bc}	715.6 ± 102.9^{bc}
Tapioca (67%)	2.26 ± 0.13^{b}	38.43 ± 3.14^{e}	188.17 ± 17.19^{cd}	637.8 ± 100.7^{bcd}
Tapioca (75%)	2.50 ± 0.15^{b}	31.78 ± 1.44^{f}	221.86 ± 8.03^{bcd}	624.3 ± 82.8^{bcd}
Corn (50%)	1.45 ± 0.16^{d}	64.96 ± 2.38^{a}	204.90 ± 25.90^{bcd}	662.1 ± 86.9^{bcd}
Corn (67%)	1.73 ± 0.16^{c}	54.46 ± 3.05^{b}	190.94 ± 12.48^{cd}	601.1 ± 96.4^{cd}
Corn (75%)	2.26 ± 0.15^{b}	42.57 ± 2.21^{d}	187.39 ± 14.39^{d}	549.0 ± 63.0^{d}
Sago (50%)	1.64 ± 0.13^{c}	47.75 ± 1.12^{c}	245.88 ± 10.16^{ab}	795.3 ± 76.5^{a}
Sago (67%)	2.22 ± 0.16^{b}	41.59 ± 1.69^{d}	275.78 ± 12.49^{a}	730.2 ± 98.0^{ab}
Sago (75%)	2.55 ± 0.13^{a}	35.76 ± 1.03^{ef}	198.88 ± 7.26^{cd}	599.9 ± 75.8^{cd}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$).

lower amylopectin in sago starch (Table 2) compared to tapioca and corn starch. The linear chain of amylose is less prone to breakdown as compared to the branched structure of amylopectin during high shear and high temperature in the extrusion process (Zhang *et al.*, 2021), hence limiting the expansion of extrudates that also increased the BD and PD. However, the results of BD in this study were lower than the findings by Kuna *et al.* (2013) who used 10-20% of fish powder with a combination of rice and corn starches as the expanding agent.

3.4.6 Hardness and fracturability

Extrudates' textural features are defined by their hardness and crispiness (Kaushal *et al.,* 2019). The extrudate's instrumental hardness was expressed in terms of the peak force (N) needed for the texture analyzer's probe to break the extrudate during analysis (Pankyamma *et al.,* 2014). The hardness of samples was significantly affected by the type of starch ($p<0.05$) (Table 5), where tapioca starch and sago starch showed relatively higher hardness than corn starch when compared with the same level of concentration. As the amount of tapioca starch increased in the extrudate, the hardness was reduced by ~50%, probably owing to the increased amylopectin amount that aided better expansion (Table 4) with thinner cell walls of the extrudate. The thin cell walls required lesser energy to be crushed, hence the lower hardness (Leonard *et al.*, 2020).

However, the lowering of hardness in extrudates with corn and sago starches was less prominent but was significantly different as the concentration of starch increased. The results indicated that a higher concentration of fish powder, also increased protein content (Table 3) and gave a harder texture. The interaction of protein and starch prevents better expansion of extrudates resulting in increased hardness of the extrudate (Jeyakumai and Rathnakumar, 2006; Maurya and Said, 2014). A similar result was also found by Chakraborty *et al.* (2020) where the extrudates were prepared using rice and yellow corn flour showed increased hardness with higher concentrations of Marine lizardfish (*Harpadon nehereus*) meal concentrate.

Fracturability refers to the potential of food to break into pieces when it is compressed by a set of incisors as described by Paula and Conti-Silva (2014) and it is highly related to extrudate's hardness. All the samples showed a negative correlation between hardness and fracturability (Table 5), where fracturability increased with the lowering of hardness. Table 5 reveals a gradual increase in the fracturability of extrudates with the

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addition of starch especially in sago starch extrudates ($p<0.05$). The fracturability increased two times when the percentage of starch increased from 50% to 75% for tapioca and sago starch extrudates. Similar outcomes were discovered by Ramos-Ramos *et al.* (2019) in their study of production of a snack based from maize flour and Atlantic mackerel (*Scomber scombrus*), where fracturability increased with higher amount of maize flour.

3.4.7 Water absorption index

WAI calculates the effectiveness of starch to retain and absorb water. As the amount of starch increased to 67%, the WAI of extrudates with tapioca and sago starches increased (Table 5), but eventually decreased again when the amount of starch was increased to 75%. Nevertheless, the WAI of extrudates with corn starch increased with the increment of corn starch. Initially, as the amount of starch increased to 67%, the WAI increased due to the increased gelatinization of starch that caused it to hold more water. However, when the starch content increased to 75%, the gelatinization increased, whereas the hydrophilic/hydrophobic balance of protein was affected by the conformational and structural changes, potentially affecting the WAI (Lourenço *et al.,* 2016). In the case of extrudates with 75% tapioca and sago starches, the WAI decreased, whereas the WAI of extrudates with 75% corn starch increased. In addition, starch-protein interactions are reduced, causing starch granules to be more accessible to gelatinization and starch degradation. As a consequence, WAI may reduce as observed in 75% tapioca and sago starches.

3.4.8 Water solubility index

The water solubility index (WSI) estimates how much starch is converted to soluble polysaccharides during extrusion (Yang *et al.,* 2008). In this study, the WSI of samples increased when the amount of starch increased. The most prominent WSI increase was observed in tapioca starch extrudates, followed by sago starch extrudates and finally corn starch extrudates. This result was in accordance with the WAI results, which showed tapioca and sago starch extrudates having lesser WAI as the amount of starch increased to 75% due to higher starch degradation. Hence, it is expected that the higher severity of starch degradation causes higher WSI. The WSI was influenced by the amount of soluble molecules that were affected during extrusion, which depends on the effectiveness and type of reactions (Taverna *et al.,* 2012). These large starch molecules are broken down into smaller fragments by the intense mechanical shear produced by extruders, increasing their water solubility (Rashid *et al.,* 2015; Taverna *et al.,* 2012). The WSI value also acts as an indicator for the protein state in proteinaceous mixtures. Since there is a large proportion of protein in our blend, partial protein denaturation at higher temperatures may be the cause of the increase (Oikonomou and Krokida, 2012). The WSI of extrudates in this study was equivalent to other studies where a dramatic increase in WSI was observed when the feed-moisture contents were less than 55% and fish contents were approximately 40-42% (Shankar and Bandyopadhyay, 2005). WSI of protein-rich extrudate also decreased at 11 to 40% starch level (Singh *et al.*, 2012).

3.4.9 Colour

Colour is one of the most important elements of any food product due to consumer perception (Yu *et al.,* 2013). The lightness, redness and yellowness of extrudates were inversely related to the percentage of starch as shown in Table 6. All the colour parameters showed similar values at the same concentration of all starch types, indicating starch type does not affect the colour. This result was expected because all starches showed a similar colour of off-white. The colour change was mostly affected by the concentration of fish powder because protein denaturation occurred with high temperature and high shear during extrusion, causing a

Table 5. Hardness, fracturability, water absorption index (WAI) and water solubility index (WSI) of extruded fish snacks.

Sample	Hardness (N)	Fracturability (N)	WAI	WSI (%)
Tapioca (50%)	120.50±4.2^{a}	3.44±0.20^{e}	0.84±0.02^{cd}	6.86±1.73^{cde}
Tapioca (67%)	63.93±1.3^{c}	5.87±0.40^{bc}	1.01±0.01^{ab}	10.25±0.60^{cde}
Tapioca (75%)	62.17±3.3^{bc}	6.56±0.20^{ab}	0.91±0.04^{bc}	36.75±4.05^{a}
Corn (50%)	30.89±4.2^{d}	4.17±0.10^{e}	0.75±0.01^{d}	4.87±0.24^{e}
Corn (67%)	24.24±2.4^{d}	6.08±0.40^{bc}	0.89±0.01^{c}	5.21±0.57^{de}
Corn (75%)	23.52±9.5^{d}	6.62±0.01^{ab}	1.07±0.02^{a}	11.32±3.02^{c}
Sago (50%)	77.35±6.4^{b}	3.39±0.10^{e}	0.76±0.01^{d}	7.67±0.38^{cde}
Sago (67%)	71.46±4.7^{b}	4.60±0.10^{d}	0.89±0.10^{c}	10.41±0.48^{cd}
Sago (75%)	69.54±0.5^{bc}	6.56±0.20^{a}	0.76±0.02^{d}	22.95±1.59^{b}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$).

Table 6. Lightness (L*), redness (a*) and yellowness (b*) value of extruded fish snack.

Sample	Lightness (L)	Redness (a*)	Yellowness (*b)
Tapioca (50%)	54.12 ± 1.39^{b}	5.99 ± 0.14^{a}	14.74 ± 2.47^{ab}
Tapioca (67%)	50.85 ± 1.04^{f}	5.82 ± 0.23^{a}	11.60 ± 0.79^{cd}
Tapioca (75%)	52.97 ± 0.61^{c}	4.79 ± 0.22^{d}	12.54 ± 0.62^{c}
Corn (50%)	55.66 ± 0.82^{a}	5.79 ± 0.16^{a}	14.08 ± 0.65^{b}
Corn (67%)	51.43 ± 0.67^{ef}	5.48 ± 0.37^{b}	10.75 ± 0.62^{d}
Corn (75%)	$52.\ 84\pm0.67^{cd}$	4.59 ± 0.19^{de}	11.55 ± 0.57^{cd}
Sago (50%)	55.75 ± 0.77^{a}	5.44 ± 0.14^{bc}	15.22 ± 0.97^{a}
Sago (67%)	52.01 ± 0.50^{de}	5.25 ± 0.32^{c}	11.70 ± 1.13^{cd}
Sago (75%)	51.92 ± 0.68^{e}	4.47 ± 0.16^{e}	11.43 ± 0.75^{d}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different between the sample ($p<0.05$).

darker colour. Additionally, dark colour also develops from the Maillard reaction as sugar caramelization (Chakraborty *et al.,* 2020). The results of colour also indicate the extent of Maillard-type reactions as well as the level of pigment degradation that takes place in extruded during the extrusion process (Marengo *et al.,* 2016). A similar observation was reported by Jozinović *et al.* (2016) in the effect of spelt flour on corn grits-based extruded products.

3.4.10 Sensory analysis

Figure 1 shows the sensory characteristics of fish extrudates. The overall acceptability of samples corresponded to "neither like nor dislike" on the hedonic scale. Panellists scored the fish snacks very low, presumably due to the unexpected type of extruded fish snack that is uncommon. Regardless of the types and concentrations of starch in extrudates, all sensory characteristics of extrudates were not significant. In general, the sample of tapioca (75%), corn (50%) and sago (75%) received grades between 5 and 6 (neither like nor dislike or slightly liked) for all tested criteria. The appearance and flavour of sago (75%) were slightly preferred by the panellists. For colour attributes, the highest score was achieved by tapioca (50%), whereas for texture and overall acceptance attributes, the highest score was achieved by sample corn (50%). The acceptance index, which measures products' acceptability percentage, was highest for corn (50%) at 59.63% and the least preferred was sago (50%) at 46.86%.

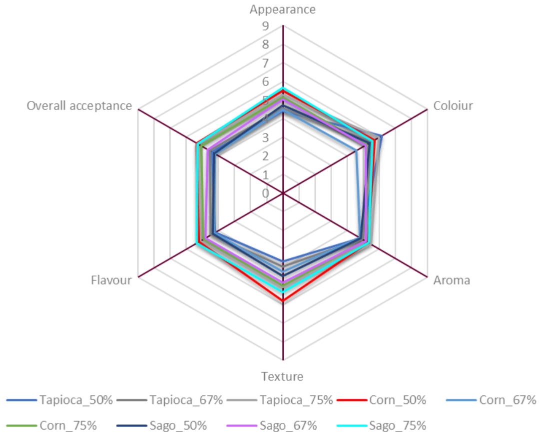

Figure 1. Sensory characteristics profile of fish snacks.

Although the physical properties of the fish extrudates were improved with the addition of the different types of starches, the concentration of starches was unable to affect the sensory preferences of the panellists, as observed by the insignificant scores in all attributes. This result may imply that the fish extrudates had lesser preferences by the panellists due to the unfamiliar taste and texture. Regardless of the insignificant results, the extrudates with lower amount of starches (50 and 67%) showed lesser preferences, particularly the texture attribute. This result validated the higher bulk density and hardness depicted in extrudates with 50 and 67% concentration for starch types, which is commonly associated with lesser preferences among sensory panellists. However, the highest concentration of starch at 75% in extrudates showed better preferences among panellists.

4. Conclusion

Starches with different amylose and amylopectin ratios affected the nutritional and physical properties of fish-based extrudate snacks. As the amount of starch increased, the physical properties of extrudates improved, particularly fish extrudates with 75% tapioca starch. The latter showed the highest protein content with a high expansion ratio, low bulk density and low hardness. At 25% fish powder and 75% tapioca starch, the extrudate shows potential in a healthy snack niche with high protein and acceptable sensory acceptance. However, the changes of the extruded fish snacks during storage are still unknown, hence, future studies should include storage studies to analyse the microbial safety and quality of the extrudates.

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Conflict of interest

The authors declare no conflict of interest.

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