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The effect of semolina replacement with protein powder from fish *(Pseudophycis bachus)* on the physicochemical characteristics of pasta

Ajay Desai [a], Margaret A Brennan [a] & Charles S Brennan [a,b]

[a] Department of Wine, Food and Molecular Biosciences, Lincoln University, P.O. Box 85084, Lincoln 7647 Christchurch, New Zealand.
[a] Riddet Research Institute, Palmerston North, New Zealand

Corresponding author: Tel.: +6434230637; E-mail address: Charles.brennan@lincoln.ac.nz

Abstract

This study replaced semolina with red cod *(Pseudophycis bachus)* fish powder in pasta at 5, 10, 15 and 20 g/100 g levels. The effects on the chemical composition, physical properties (optimal cooking time, cooking loss, water absorption index, swelling index and colour) and textural properties (firmness and extensibility) of the supplemented pasta samples were evaluated compared with a control sample. Fortification with fish powder increased protein, lipid and ash contents significantly (P < 0.05). Cooking loss increased (P < 0.05) with increasing levels of fish powder. However, all pasta samples were in the acceptable range (8 g/100g) for cooking loss. Fish powder incorporation decreased optimal cooking time, swelling index and water absorption significantly (P < 0.05), whilst increasing firmness and resistance to uniaxial extension of pasta. The addition of fish powder increased yellowness (b*) of the pasta significantly (P < 0.05) compared to control sample. Thus, pasta fortified with fish powder has the potential to be a technological alternative for the food industry to provide nutritional enriched pasta.

Keywords Pasta; semolina; fish powder; cooking quality; protein supplementation.

1. Introduction

Pasta is the second most consumed food item in the world, and consumption of pasta increased by 2 million tonne in 2014 in relation to 2013 (International Pasta Organisation Survey, 2015). Pasta is a popular food product because of its' versatility, low cost, ease of preparation and nutritional quality (Foschia, Peressini, Sensidoni, Brennan, & Brennan, 2015). Pasta is a healthy food which contains protein, vitamins and is an important source of carbohydrates with virtually no fat (Malcolmson, 2003; Krishnan, Menon, Padmaja, Sajeev, & Moorthy, 2012; Foschia et al., 2015). Cooking quality is the most important consumer attribute of pasta, including parameters such as cooking time, cooking loss, water absorption index, swelling index, texture (Gelencser, Gal, Hodsagi, & Salgo, 2008; Sobota, Rzedzicki, Zarzycki, & Kuzawiriska, 2015; Ficco, De Simone, & De Leonardis, 2016). The quality of pasta, and cooking characteristics, are dependent upon the protein-starch network of the pasta product (El-Khayat, Samaan, Manthey, Fuller, & Brennan, 2006). Pasta firmness, elasticity and cooking loss can be related to protein content as well as the starch composition (Samaan, El-Khayat, Manthey, Fuller, & Brennan, 2006). Raw material composition used for the preparation of pasta product affects the physical, chemical and textural properties of pasta (Brennan, Derbyshire, Tiwari, & Brennan, 2013; Lu, Brennan, Serventi, Mason, & Brennan, 2016). Currently, there are many studies focused on increasing nutritional value in terms of the protein content of pasta products (Fuad & Prabhasankar, 2012; Padalino, Mastromatteo, De Vita, Ficco, & Del Nobile, 2013; Pena & Manthey, 2014). Over the past few decades, wheat pasta has been prepared incorporating different ingredients including, bean flour (Gallegos-Infante et al., 2010), pea flour (Wojtowicz & Moscicki, 2014), shrimp meat (Ramya, Prabhasankar, Gowda, Modi, & Bhaskar, 2015), shrimp mince (Kadam & Prabhasankar, 2012), beef meat (Liu et al., 2016) and green mussel (Vijaykrishnaraj, Kumar, & Prabhasankar, 2015).

Fish powder is a by-product of fish processing and represents a cheap source of high quality nutrients that can be utilised in the human diet, this is mainly due to high levels of essential amino acids and polyunsaturated fatty acids especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Oliveira, Lourengo, Sousa, Joele, & Ribeiro, 2015; Stevanato et al., 2010). Fish protein has the potential to have beneficial health effects such as manipulation of obesity, hypertension and cardiovascular disease in human beings (Kadam & Prabhasankar, 2010). Fish powder is also a good source of various vitamins (A, D, B6 and B12) and minerals (iron, zinc, iodine, selenium, potassium and sodium) (Anbudhasan, Asvini, Surendraraj, Ramasamy, & Sivakumar, 2014). Previous studies evaluated the nutritional and physicochemical characteristics of pasta manufactured with fish powder of *Peneus monodon* (Kadam & prabhasankar, 2012), *Nemipterus Japonicus* (Chin, Huda, & Yang, 2012), green mussel *(Perna canaliculus)* powder (Vijaykrishnaraj et al., 2015), *Oreochromis niloticus* (Monteiro et al., 2016) and pasta enriched with mince of *Catala Catla* mince (Devi, Aparana, & Kalpana, 2013). However, as nutritional composition and chemical stability varies depend on the fish species that is utilised and the processing parameters subsequently employed (Schneedorferova, Tomcala, & Valterova, 2015), the physiochemical properties of pasta enriched with partial replacement of semolina wheat flour by red cod powder *(Pseudophycis bachus)* are still unknown. Therefore, the aim of this project was to develop pasta with improved nutrition by substituting semolina flour with cod powder at various concentrations and study the changes in nutritional, cooking, colour and textural characteristics of the pasta.

2. Materials and methods

2.1 Raw materials

Semolina (Sun Valley Foods, New Zealand) was obtained from local New World supermarket (Foodstuffs, New Zealand), and red cod *(Pseudophycis bachus)* fish were bought in ice condition from Christchurch Wholesale Seafood (Christchurch, New Zealand).

2.2 Fish powder preparation

The fish was de-scaled, beheaded, eviscerated and washed with potable water. The dressed fish material was cooked by boiling in water for 10 min. The cooked fish was deskinned and deboned manually before drying in a cabinet dryer (Moffat, E32M, Christchurch, New Zealand) at 45 °C for 16 h. The dried fish muscle was used to produce a powder in a domestic mixer (Fig.1) and sieved to pass through the appropriate 0.5 mm mesh screen (Majumdar & Ratankumar Singh, 2014). Dried powder was put in a sealed polythene bag and stored at (-20 °C) temperature until required.

Raw material

⇩

Washing

⇩

Fish dressing (descaling, beheading, eviscerating)

⇩

Washing

⇩

Cooking in boiling water for 10 min.

⇩

Separation of cooked meat from bones

⇩

Drying of boiled meat (45 °C, 16 h)

⇩

Pulverising in grinder

2.3 Pasta production

Fresh pasta was prepared using a machine with 2.25 mm diameter die with 20 holes (Model: MPF15N235M; Firmer, Ravenna, Italy). Tap water was used for the experiment at 32.5 g/100 g water (41 °C), mixed for 20 min according to the manufacturer’s guidelines. Extruded fresh pasta samples (20 g) were put into a resealable polythene bag and frozen at -18 °C until required. Prior to analysis, the pasta was defrosted for 10 min at room temperature.

Five pasta formulations were prepared in the ratios (semolina/ fish powder) of 100:0; 90:5: 90:10; 85:15 and 80:20.

2.4 Proximate chemical composition analysis of pasta and constituents

Crude protein was demined using the Micro-Kjeldahl method according to AACC method 976.05 (2000) and using a nitrogen to protein conversion factor of 6.25. Total fat content of raw and cooked pasta was assessed using the Soxhlet extraction method AACC (2000). The ash content of raw and cooked pasta samples was measured according to AACC (2000). The proximate carbohydrate content was estimated by subtracting the total fat content, protein content, ash and moisture content from 100 %.

The energy valve was calculated using the formula described by Merrill & Watt (1973).

Energy value (kcal/100 g) = 4x protein (%) + 9 x lipid (%) + 4 x carbohydrate (%)

2.5 Physical properties

2.5.1 Optimal cooking time

Pasta strands (20 g) were cut into equal lengths of 40 mm and cooked in 300 mL of boiling water. During cooking the optimal cooking time was evaluated by taking a sample strand of pasta every 30 s and observing the time of disappearance of the core of pasta, by squeezing it between two transparent glass side, according to the AACC approved method 66-50 AACC (2000). The time at which the core completely disappeared was taken as the optimal cooking time.

Additionally, 10 g of pasta were cooked in 600mL of boiling water at optimal cooking time, rinsed with 100 mL of cold water, strained for 30 s to determine the cooking loss and swelling index of the pasta samples. The samples were made in triplicate (Foschia, Peressini, Sensidoni, Brennan, & Brennan, 2014)

2.5.2 Cooking loss

The amount of solid substance lost in the cooking water, was evaluated by Approved Methods 66-50 AACC (2000). An aluminium vessel was used to collect the cooking water. The vessel placed in an air oven at 105 °C and evaporated until a constant weight was reached. The residue was weighed and reported as a percentage of starting material.

2.5.3 Swelling index and water absorption index

The swelling index (SI) of cooked pasta (g water/ g dry pasta) was determined according to the procedure described by Cleary & Brennan (2006). Pasta (100 g) was weighed after cooking and dried at 105 °C until constant weight was reached.

Swelling index (SI) =$(Weight\ of cooked\ pasta\ (g))/(Weight\ of\ pasta\ after\ drying\ (g)\ )$

The water absorption index was determined as

Water absorption index (WAI) = $\frac{Weight\ of\ cooked\ pasta - weight\ of\ uncooked\ pasta}{weight\ of\ uncooked\ pasta} x 100$

2.5.4 Moisture content

The moisture content of the cooked pasta was determined by the oven-drying method, and the general operation procedures for this method described by Lu et al. (2016). Samples were weighed using an analytical balance (ARCI20; OHAUS Corp., Parsippany, NJ, USA) into a pre-weighed dish. The dish was placed in an oven at 105 ± 2 °C overnight. The dish was placed in the desiccator for 1 h to cool to room temperature before reweighing.

Moisture (%) = $\frac{weightof\ fresh\ sample - weight\ of\ dried\ sample}{Sample\ of\ weight} x\ 100$

2.5.5 Colour measurements

Colour readings were taken from nine separate points on the surface of the cooked (after pasta was cooked to optimal cooking time, drained and allowed to stand for 5 min at room temperature) and uncooked pasta using a tristimulus colour analyser (Minolta Chroma Meter CR 210, Minolta Camera Co., Japan). The illuminant C (CIF, standard, 6774 K) was used. Results were expressed as L* (brightness), a* (redness) and b* (yellowness). The instrument was calibrated using a standard white tile (L*=98.03, a*=-0.23, b*=0.25). The change in colour due to fish powder addition was determined by calculating the colour differential index (ΔE) using following equation

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Where, ΔL: $L*_{sample} - L*_{control}$; Δa: $a*_{sample} - a*_{control}$; and Δb: $b*_{sample} - b*_{control}$

2.6 Textural characteristics

The firmness and tensile strength of pasta were evaluated by Texture Analyser (TA.XT2; Stable Micro Systems, Godalming, UK) equipped with a 5 kg load cell. Prior to the testing of firmness and tensile strength pasta samples were cooked for the optimum cooking time and kept at room temperature for 10 min. Firmness and resistance to uniaxial extension of the cooked pasta were determined according to the method described by Foschia et al. (2015). Data are mean of twelve measurements from three different cooking replications.

2.7 Statistical analysis

All experiments were performed in triplicate unless otherwise stated. Data obtained during the study were subjected to one way analysis of variance (ANOVA) and significance difference in the response and sample were evaluated by Tukey's comparison test ($P < 0.05$). Statistical software version 16 (Minitab, Australia) was used to perform the statistical analysis of the data.

3. Results and discussion

3.1 Chemical composition

The proximate composition of the fish powder enriched cooked and uncooked pasta is presented in Table 1. The fish powder incorporation decreased ($P < 0.05$) carbohydrate and moisture content whereas increased ($P < 0.05$) the lipid, protein, and ash; potentially due to the fish powder composition. The decrease in the moisture content can be attributed to a greater protein-polysaccharides interaction when compared to control (Gomez-Guillen, Borderias, & Montera, 1997; Zhang, Li, Wang, Xue, & Xue, 2016). Previous research has also shown an increase in protein, ash and lipid contents when *Catla catla* mince, *Sardinella longiceps* mince and oil, tilapia protein concentrate and tilapia flour were added to pasta formulations, respectively (Devi et al., 2013; Anbudhasan et al., 2014; Goes et al., 2016; Monteiro et al., 2016). Pasta incorporation with 20 g/100g of fish powder showed the greatest ($P < 0.05$) energy value, however no difference ($p > 0.05$) was observed between FP 5 g/100g, FP10 g/100g and FP 15 g/100g in the energy value. The lowest energy ($P < 0.05$) value was observed in the control sample as compared to the enriched pasta with fish powder. This increase in energy value in pasta enriched with fish powder could be due to the inclusion of nutrients such as polyunsaturated fatty acids and essential amino acids present in the fish powder (Oliveira et al., 2015) but absent from the durum wheat semolina (Zhang et al., 2016).

3.2 Effect of fish powder inclusion on cooking loss, swelling index and water absorption index of pasta

The cooking quality of pasta is an important feature and is assessed using optimal cooking time, cooking loss (solid material leaching during cooking), water absorption index, and swelling index which represents the uptake of water content during cooking. Several authors have reported that the quality and content of protein used in food processing as well as protein interaction in the continuous network, are very important to form the optimum carbohydrates - protein network in order to obtain pasta of good cooking quality (Cleary & Brennan, 2006; De Noni & Pagani, 2010; Chillo, Monro, Mishra, & Henry, 2010). Table 2 shows that increasing levels of fish powder in pasta resulted in increased cooking loss compared with the control pasta. The cooking loss of the samples ranged from 3.99 to 5.85 g/100 g. The highest cooking loss values were for the 20 g/100g enriched pasta samples (5.85 g/100 g), while the sample with no fish powder had significantly ($P < 0.05$) lower cooking loss (3.99 g/100 g). However, all pasta samples presented cooking losses below 8 g/100 g, the value above which pasta quality is considered unacceptable according to industry guidelines (Foschia et al., 2015; Dick & Young, 1988). The higher cooking loss in pasta enriched with fish powder might be attributed to a weakening and disruption of the protein gluten network. Similar results have been observed by Ramya et al. (2015) who studied the effect of shrimp meat powder on the leaching of solids from pasta and reported that the solids that leached into the cooking water increased as the inclusion level of shrimp meat powder was increased. Also, Chin, et al. (2012) who worked on the effect of inclusion of threadfin bream (*Nemipterus sp*.) powder on leaching of solids, found that as the inclusion levels increased in pasta (5-20 g/100g), the cooking loss increased from 13.51-19.45 %. These results were in agreement with those from Vijaykrishnaraj et al. (2015) and Kadam & Prabhasankar (2012), who reported an increase in cooking loss of pasta containing 2.5-10 g/100g green mussel powder and 10-30 g/100g shrimp meat.

The optimum cooking time decreased with the addition of fish powder to pasta samples (Table 2). The reduction in cooking time was due to a lower water absorption (98.91 % for control and 87.84 % to 74.11 % for pasta enriched fish powder) and higher cooking loss (3.99 % for control vs 3.54 % to 5.85 % for enriched pasta). These results are in agreement with Petitot et al., (2010) and Pena & Manthey (2014) who also reported that pasta fortified with bean flour and soybean flour had a shorter cooking time than control pasta. In contrast to this study, other authors have reported that pasta containing shrimp meat had minimal or longer cooking time than the control pasta (Ramya et al., 2015; Kadam & Prabhasankar, 2012; Devi et al., 2013).

The swelling index of pasta samples are reported in Table 2. Pasta prepared with 5–20 g/100g fish powder showed significantly lower swelling index (1.91-1.81 g water/g dry pasta respectively) than the control pasta (2.95 g water/g dry pasta). The reduced swelling index could be due to the formation of a protein network in the pasta enriched with fish powder resulting in the limited supply of water for starch granule for swelling and gelatinisation. Similar results were observed by Liu, et al (2016) who reported that swelling index decreased significantly ($P < 0.05$) as the levels of beef (15-45 g/100 g) increased in fortified pasta. However, some research has shown a significant increase in the swelling index at increasing concentration of dietary fiber and legumes in pasta (Brennan et al., 2004; Cleary & Brennan, 2006; Brennan & Tudorica, 2007; Arvind, Sissons, Egan, & Fellows, 2012; Wojtowicz & Moscicki, 2014; Foschia, et al, 2015) The difference in optimal cooking time and swelling index results obtained in the present study and reported in literature could be due to different type and content of ingredient used and different processes used (Brennan et al., 2013; De Noni & Pagani, 2010).

Water absorption index is a measure of the amount of water absorbed by the pasta (Oikonomou & Krokida, 2011). Table 2 illustrates that the substitution of semolina flour with fish powder caused a significant decrease in water absorption index. Water absorption value ranged from 87.84 g/100g -74.11 g/100 g for pasta containing 5-20 g/100g fish powder respectively and was 98.91 g/100g for control. This may be due to the substitution of semolina flour with fish powder in pasta samples, which reduces starch swelling and pasta water absorption by competing with the starch for water during pasta formation. The decrease in water absorption index could be partly explained by a decrease in swelling index. During pasta formation, fish powder is competing with the starch and this would reduce starch swelling and consequently water absorption of pasta. Similarly, Ramya et al. (2015) and Vijaykrishnaraj et al. (2015) reported addition shrimp meat and green mussel powder in pasta significantly (P < 0.05) decreased water absorption index as the level of shrimp meat and green mussel powder increased in the blend respectively. More recently, found that pasta water absorption was affected by inclusion with 2.5 -10 g/100g of green mussel powder. In contrast to this study, Devi et al. (2013) reported an increase in water absorption value of pasta containing 15 g/100g fish mince. The higher water absorption index values obtained for pasta containing fish mince may be explained by the higher capacity of the fish mince to absorb and retain water within a very well developed starch-protein network. Recently, Foschia et al. (2015) reported that inclusion of different dietary fiber into pasta cause a significant increase in water absorption index than control semolina sample. Brennan et al. (2004) reported that the water absorption index of pasta increased due to the increased degree of starch gelatinisation and disruption of the protein-starch matrix within the product. In this study, the results of the water absorption indicated that starch in the pasta enriched with fish powder may be less gelatinised during pasta cooking compare to the control sample.

The colour parameter of pasta is an important factor responsible for consumer acceptance (Petitot et al., 2010). Table 3 shows the L^*, a^* and b^* values for all pasta samples before and after cooking. Raw and cooked pasta samples enriched with fish powder showed lower lightness (L^*) value than control pasta. The lightness of pasta samples decreased as the amount of fish powder in the recipe increased. This observation was more evident for cooked pasta with addition of 15 and 20 g/100g fish powder (P < 0.05). Similarly, Kadam & Prabhasankar (2012) studied the effect of shrimp meat on the colour characteristics of pasta and reported that the addition of 10-30 g/100g shrimp meat into pasta decreased the lightness (L^*) value compared to control samples. In addition, Vijaykrishnaraj et al. (2015) and Liu et al. (2016) found that increased levels of green mussel powder and beef meat in pasta showed decreased lightness parameters. The increase redness parameter (a^*) in pasta enriched with fish powder showed a significant increase (P < 0.05) compared to control samples while in cooked pasta samples redness (a^*) is not affected by the treatments. These results were in agreement with those from Kadam and Prabhasankar (2012) and Vijaykrishnaraj et al. (2015), who reported an increase in the red colour of pasta associated with the inclusion level of shrimp meat and green mussel powder. The yellowness b value was compared to understand the acceptability of product; the b^* values for uncooked and cooked pasta samples were 29 to 31 and 26 to 29, respectively. Changes in colour among different pasta samples were due to various incorporation levels. The results obtained by Ramya et al. (2015) supports the above mentioned observation of low L^* and b^* values. They reported that yellowness value of pasta samples increased as the level of shrimp meat (2.5 to 10 g/100g) powder increased in pasta. Also, Santana, Huda, & Yang (2015) demonstrated that incorporation of 50 and 100 g/100g surimi powder in sausages were significantly different yellowness (b^*) characteristics to those of control. This difference may be due to the higher concentration of surimi powder used.

The ΔE values was also determined to evaluate the colour differences between the control and the fish powder containing formulations. The ΔE values of fish powder containing pasta increased with increasing levels of fish powder in both cooked and uncooked forms. In addition, cooked pasta exhibited higher ΔE compared to the uncooked pasta, indicative of the colour compounds released after cooking of pasta. The ΔE values were more than 3.0 for cooked pasta, and below 3.0 for uncooked pasta. According to handbook of colour science (Yamauchi, 1989) these values fall in the “appreciable, detectable by ordinary people” and “noticeable, detectable by trained people” respectively. Imran, Yousif, Johnson, & Gamath (2014) reported that sorghum flour enriched pasta showed higher ΔE with increasing level20 % to 40 %.

3.3 Texture measurements

For pasta cooking, quality texture parameters are important characteristics. From the consumer point of view, the development of texture parameters is a critical point to ensure the acceptance of products. The textural properties of pasta are mainly controlled by a gluten network, which is a structural network of starches, protein additions, and other ingredients

(Chang & Wu, 2008). Firmness is a reflection of the bond strength and the integrity of the protein matrix present in the pasta after the cooking process (Dexter & Matsuo, 1979). The firmness and tension properties of the pasta enriched with fish powder and control sample are shown in Table 4. There was a significant increase in firmness when the amount of fish powder was increased ($P < 0.05$). The firmness increased from 2.79 N in control sample to 3.81- 4.51 N in the 5-20 % fish powder sample respectively. The above results appeared to be related to values obtained for cooking losses, indicating that high cooking loss in 20 g/100g fish powder (5.85 %) had the highest firmness value (4.51 N). This could be due to the incorporation of fish powder in pasta, with low swelling index and water absorption index value being related to hardness. In the present study, fish protein interacts with the insoluble network of pasta, forming a matrix structure, and leading to the high firmness and extensibility as observed from results. The textural properties of pasta in the present study correspond to results from studies carried out on the addition of shrimp meat powder and green mussel powder into pasta (Ramya et al., 2015; Vijaykrishnaraj et al., 2015), and the incorporation of fish meat, shrimp meat and beef meat into pasta (Devi et al., 2013 ; Kadam & Prabhasankar, 2012; Liu et al., 2016). Foschia et al. (2015) reported that higher moisture content and swelling index are responsible for lower firmness value of pasta like products. Extensibility was examined as maximum force applied before breaking pasta (Chang & Wu, 2008). The extensibility of pasta increased significantly ($P < 0.05$) as the levels of fish powder increased (Table 4). This may be attributed to the higher amount of polypeptide chain associated with higher protein content, which increases the ability of proteins to form an insoluble network. This insoluble protein network can entrap swollen and gelatinised starch granules, which prevents pasta from disruption (Chillo et al., 2010). The extensibility value in the present study ranged from 0.42 N to 0.56 N.

4. Conclusions

The results illustrated that the fish powder can be incorporated into pasta to enhance the product with high protein and other bioactive ingredients. The addition of fish powder affected cooking, textural and colour parameters. The fortification of pasta with fish powder improved the protein, fat and ash contents. The cooking loss increased and cooking time decreased with the addition of fish powder to pasta. In addition, increased firmness and extensibility were observed in a higher fish powder containing pasta.

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Table 1.

Chemical composition (%) and energy value (kcal/100g) of cooked and uncooked pasta fortified with different fish powder levels.

Sample	Parameters Protein (g/100g)	Fat (g/100g)	Ash (g/100g)	Moisture (g/100g)	Carbohydrate (g/100g)	Energy (kcal/100g)
Fish powder	88.75 ± 0.00	1.37 ± 0.02	5.94 ± 0.08	7.92 ± 0.07	-	367 ± 1
Semolina	12.70± 0.05	1.0 ± 0.01	1.1 ± 0.02	10 0 ± 0.10	72.8 ± 0.24	351 ± 2
Cooked pasta						
CO	12.63 ± 0.17^{a}	nd	0.46 ± 0.02^{a}	67.90 ± 0.91^{a}	19.01 ± 1.06^{a}	127 ± 3^{a}
FP5	16.52 ± 0.29^{b}	nd	0.65 ± 0.01^{b}	65.70 ± 0.98^{ab}	17.13 ± 1.24^{a}	135 ± 4^{ab}
FP10	20.69 ± 0.11^{c}	nd	0.76 ± 0.00^{c}	65.91+ 0.62^{ab}	12.64 ± 0.52^{b}	133 ± 2^{ab}
FP15	25.15 ± 0.25^{d}	nd	0.89 ± 0.04^{d}	65.74 ± 0.74^{ab}	8.22 ± 0.83^{c}	133 ± 3^{ab}
FP20	29.82 ± 0.29^{e}	nd	1.09 ± 0.04^{e}	64.46 ± 1.61^{b}	4.64 ± 1.62^{d}	138 ± 6^{b}
Uncooked pasta						
CO	12.21 ± 0.20^{a}	0.24 ± 0.02^{c}	0.76 ± 0.1^{a}	32.23 ± 0.16^{ab}	54.48 ± 0.24^{a}	269 ± 1^{a}
FP5	16.67 ± 0.25^{b}	0.36 ± 0.01^{b}	1.04 ± 0.07^{b}	32.74 ± 0.11^{ab}	49.08 ± 0.31^{b}	267 ± 1^{ab}
FP10	20.08 ± 0.26^{c}	0.39 ± 0.02^{b}	1.28 ± 0.06^{c}	33.02 ± 0.16^{a}	45.13 ± 0.35^{c}	265 ± 1^{ab}
FP15	25.29 ± 0.14^{d}	0.53 ± 0.04^{a}	1.53 ± 0.00^{d}	33.24 ± 0.44^{a}	39.32 ± 0.43^{d}	264 ± 2^{ab}
FP20	30.12 ± 0.06^{e}	0.55 ± 0.01^{a}	1.69 ± 0.05^{e}	31.98 ± 1.04^{b}	35.63 ± 0.99^{e}	268 ± 4^{b}

FP5, FP10, FP15, and FP20: pasta prepared with 5, 10, 15, and 20 g of fish powder /100 g of semolina flour.
CO: control sample.
Results in the table represent the mean of triplicate measurements. Mean ± standard deviation.
Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$), according to Tukey's test.
nd: not detected

Table 2

Physical properties of cooked pasta products enriched with fish powder.

Sample	Optimal Cooking Time (min)	Cooking Loss (g/100g)	Swelling Index (g water/ g dry pasta)	Water absorption Index (g/100g)
CO	6.30	3.99 ± 0.27^{bc}	2.95 ± 0.09^{a}	98.9 ± 6.2^{a}
FP5	5.30	3.54 ± 0.12^{c}	1.91 ± 0.09^{b}	87.8 ± 4.2^{ab}
FP10	5.30	3.97 ± 0.11^{bc}	1.93 ± 0.05^{b}	85.4 ± 3.2^{b}
FP15	5.00	4.55 ± 0.42^{b}	1.92 ± 0.06^{b}	83.9 ± 3.0^{b}
FP20	5.00	5.85 ± 0.40^{a}	1.81 ± 0.14^{b}	74.1 ± 6.2^{c}

FP5, FP10, FP15, and FP20: pasta prepared with 5, 10, 15, and 20 g of fish powder /100 g of semolina flour.
CO: control sample.
Results in the table represent the mean of triplicate measurements. Mean ± standard deviation.
Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$), according to Tukey's test.

Table 3.
Colour characteristics of cooked and uncooked pasta enriched with fish powder.

Sample	Measurements			
	L^*	a^*	b^*	ΔE
Uncooked pasta				
CO	90.24 ± 0.76^{a}	-8.08 ± 0.24^{a}	29.35 ± 0.35^{b}	
FP5	89.97 ± 0.92^{a}	-9.48 ± 0.72^{b}	31.02 ± 0.61^{ab}	2.55 ± 0.66^{a}
FP10	89.88 ± 0.97^{a}	-9.17 ± 0.20^{b}	31.24 ± 0.30^{a}	2.50 ± 0.47^{a}
FP15	90.75 ± 0.51^{a}	-9.50 ± 0.05^{b}	31.31 ± 0.02^{a}	2.66 ± 0.48^{a}
FP20	89.94 ± 1.76^{a}	-9.54 ± 0.15^{b}	30.26 ± 1.21^{ab}	2.93 ± 0.69^{a}
Cooked pasta				
CO	91.24 ± 0.23^{a}	-9.59 ± 0.09^{a}	26.81 ± 0.77^{b}	
FP5	90.52 ± 0.61^{ab}	-10.79 ± 0.56^{a}	28.81 ± 0.28^{a}	2.49 ± 1.01^{a}
FP10	89.49 ± 1.52^{abc}	-10.26 ± 0.42^{a}	29.01 ± 0.87^{a}	2.99 ± 1.63^{a}
FP15	87.84 ± 0.51^{c}	-10.06 ± 0.15^{a}	28.08 ± 0.47^{ab}	3.82 ± 0.40^{a}
FP20	88.63 ± 1.15^{bc}	-10.13 ± 0.85^{a}	27.86 ± 0.68^{ab}	3.29 ± 0.63^{a}

FP5, FP10, FP15, and FP20: pasta prepared with 5, 10, 15, and 20 g of fish powder /100 g of semolina flour.
CO: control sample.
Results in the table represent the mean of triplicate measurements. Mean ± standard deviation.
Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$), according to Tukey's test.

Table 4.
Textural properties of enriched pasta with fish powder.

Sample	Measurements	
	Firmness Peak force (N)	Maximum breaking strength (N)
CO	2.79 ± 0.05^{c}	0.42 ± 0.01^{c}
FP5	3.81 ± 0.02^{b}	0.46 ± 0.01^{b}
FP10	4.45 ± 0.05^{a}	0.54 ± 0.01^{a}
FP15	4.39 ± 0.05^{a}	0.53 ± 0.01^{a}
FP20	4.51 ± 0.13^{a}	0.56 ± 0.02^{a}

FP5, FP10, FP15, and FP20: pasta prepared with 5, 10, 15, and 20 g of fish powder /100 g of semolina flour.
CO: control sample.
Results in the table represent the mean of triplicate measurements. Mean ± standard deviation.
Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$), according to Tukey's test.

- Nutricious pasta was produced by adding fish powder to semolina.
- Replacing semolina with fish powder showed high protein contents of pasta.
- Optimal cooking time, swelling index and water absorption index were affected by inclusion of fish powder.
- Addition of fish powder increases firmness and tensile strength of pasta.