

# Effect of Incorporating Fish Protein Hydrolysate into Pasta: Impact on Protein Digestibility, Starch Digestibility, Amino Acid, and Fatty Acid Profiles

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## ABSTRACT

The incorporation of fish protein hydrolysate (FPH) with the concentration of 5, 10, 15 and 20% prepared from fish waste using 1% pepsin enzyme was found beneficial in semolina-based pasta. The *In-vitro* protein and starch digestibility of the FPH incorporated pasta were studied. Besides, amino acid and fatty acid composition of the pasta were also evaluated. The protein digestibility of the pasta was in the range of 80.32% to 83.76% and digestibility curve was generated by plotting the pH and time. The value of sugar released at 20 min, 60 min and 120 min was recorded and a graph was developed showing readily digestible starch (RDS) and slowly digestible starch (SDS). The pasta's diverse amino acid profile, including 8 essentials and 9 non-essentials, alongside saturated fats at 39.93%-44.65% and PUFA at 12.49%-16.27%, collectively define its nutritional quality.

*Keywords: Fish protein hydrolysate, Pasta, In-vitro protein and starch digestibility, Amino acid, Fatty acid*

## 1. INTRODUCTION

The quest for developing pasta products with improved nutrition has directed to explore an alternative protein source into conventional food matrices. Pasta has long shelf life (Ribeiro *et al.*, 2021), high glycaemic index (Brennan *et al.*, 2004), deficient in the essential amino acids such as lysine and threonine (Gopalakrishnan *et al.*, 2011) and fatty acids (Ainsa *et al.*, 2021). Amino and fatty acids support body tissue growth and maintenance (Laleg *et al.*, 2019). Pasta, fortified with various animal and plant protein sources such as eggs, fava bean flour, meat, barley flour, shrimp powder, amaranth seed flour, almond flour, quinoa and salmon powder (Desai *et al.*, 2019). Every year, 7.3 million

tons of fish processing waste rich in amino acids and fatty acids (including viscera, heads, frames, cut-offs, bone, and skin) are discarded (Pierre [et al.](#), 2012). Enzymatic hydrolysis of fish proteins has been employed for converting fish waste into valuable products for the pharmaceutical and food industries. Fish protein hydrolysate (FPH), high in protein, essential amino acids, fatty acids and bioactive peptides offers a way to reduce the nutritionally dense fish waste. FPH contain reduced di- and tri-peptides, improves protein digestibility and functional properties of food product (Kristinsson and Rasco 2000). The addition of different protein sources, pangas protein isolates (PPI) (Singh [et al.](#), 2021), soy protein isolate with egg white protein (Rachman [et al.](#), 2020), and cod (*Pseudophycis bachus*) protein (Desai [et al.](#), 2021) to pasta alter the protein digestibility and starch digestibility as compared to control. Protein digestibility, a critical factor, influence the bioavailability and utilization of dietary proteins. Cereal-based pasta contains less protein and digestibility compared to animal protein-based pasta; also, the absence of amino acids (threonine, methionine, and lysine) and specific fatty acids makes them comparatively less nutritious (Carbonaro [et al.](#), 2012). Fish protein hydrolysate are known to have bioactive peptides that can offer additional health benefits, such as antioxidant, anti-inflammatory, and immunomodulatory effects. The hydrolysis process also makes the protein more digestible, meaning the body can more efficiently absorb and use the amino acids. The addition of fish protein hydrolysate may alter the texture of pasta. Proteins can influence the water absorption capacity, elasticity, and firmness of pasta. Therefore, enriching food products with a high nutritional profile extends the means to enhance protein digestibility while reducing starch digestibility (Li [et al.](#), 2014), and additionally, FPH contains beneficial fatty acids (omega-3 polyunsaturated fatty acids - PUFAs) provides nutritional advantage to consumers. PUFAs provide various health benefits, such as cardiovascular health and anti-inflammatory properties. Pasta enriched with sea-bass byproduct (Ainsa [et al.](#), 2021) and salmon protein (Desai [et al.](#), 2020) showed high level of mono- and poly-unsaturated fatty acids profile. Bread prepared with 5%, 10% and 15% cod protein powder enhanced protein digestibility and reduced predictive glycaemic index (Desai [et al.](#), 2021). Modifying carbohydrate and protein content in cereal food impacts glycaemic index and digestibility, enhancing product quality, as seen with pasta fortified with cod (*Pseudophycis bachus*) & salmon (*Oncorhynchus tshawytscha*) powder (Desai [et al.](#), 2021; Desai [et al.](#), 2018a) and bread fortified with cobia (*Rachycentron canadum*) powder (Fagundes [et al.](#), 2018). Incorporating FPH into pasta presents an opportunity to enhance protein digestibility, starch digestibility, and improve the amino acid and fatty acid profiles of the final product. Therefore, the aim of present study was to prepare a pasta from fish protein hydrolysate and evaluate for its nutritional characteristics such as protein digestibility, starch digestibility, amino acid and fatty acid profile.

## 2. MATERIAL AND METHODS

### 2.1 Raw materials

Semolina (Semola di grano duro, durum wheat semolina, Corato (BA) – Italy), purchased from Amazon.in (online), was used for the preparation of pasta. The fish waste was collected from Mirkarwada Fish Landing Centre and transported in chilled condition to the laboratory of Department of Fish Processing Technology and Microbiology, College of Fisheries, Ratnagiri, Maharashtra, India.

### 2.2 FPH preparation from fish waste

FPH was prepared with 1% pepsin (10,000 U/mg, Himedia, Maharashtra, India) enzyme in a substrate made from homogenization of fish waste and distilled water in a 1:2 ratio (Tejpal *et al.*, 2021). The homogenate was adjusted to pH 2.5 using 2M HCl prior to the addition of enzyme and incubated for 5 min at 37°C to reach equilibrium temperature. The hydrolysis was performed at 37°C for 3 hours and terminated by heating in boiling water for 15 minutes (Bio Techno Lab, Mumbai, India). Then, the mixture was cooled to room temperature, adjusted to pH 7 with 2 M NaOH, filtered through muslin cloth, and filtrate was centrifuged (Hettich Zentrifugen, D-78532, Germany) for 15 min at 10,000 rpm. The supernatant obtained was dried using a tray in cabinet dryer (Fourtech, Techno industries, 1000 rpm, 230 volt, India) at 55°C for 6 h. The obtained hydrolysate was packed airtight and stored at -20°C for further process.

### 2.3 Pasta preparation

Pasta was freshly prepared by incorporating FPH in five different concentrations with semolina in the ratio of 0:100; 5:95; 10:90; 15:85 and 20:80 (Desai *et al.*, 2018a) using pasta making machine (Kent, RO systems Ltd., U.P., India) with 50 holes die measuring 2.25 mm diameter. Ingredients were added to the machine and mixed for 20 minutes before water was incorporated. Then, the machine was switched to the extrusion function. The long strands of uniform thickness (approximately 3.5 mm) were collected on a tray and cut at around 10 cm length using a stainless-steel knife. For each batch of pasta preparation, 500 g of dry ingredients and 190 ml of RO water (room temperature) were added. The pasta samples were packed in zip lock bags, stored at -18°C, and thawed for 10 minutes at room temperature before analysis.

### 2.4 *In-vitro* protein digestibility of the pasta

Each FPH-enriched pasta sample was analysed for *in vitro* protein digestibility using different enzymes (Himedia, Maharashtra, India) and optimal pH conditions (Hsu *et al.*, 1977). A 50 ml protein suspension (6.25 mg of protein/ml) was prepared in distilled water, adjusted to pH 8 with 0.1 N HCl/0.1 N NaOH, and placed on a magnetic heating stirring block at 37°C. An enzyme solution containing 1.6 mg/ml trypsin (2000 U/g), 3.1 mg/ml chymotrypsin (2500 U/mg), and 1.3 mg/ml peptidase (Pepsin - 10,000 U/mg) was maintained in an ice bath and adjusted to pH 8.0 using 0.1 N HCl/0.1 N NaOH. 5 ml of the enzyme solution was added to the protein suspension maintained at 37°C. The decrease in pH was recorded after adding the enzymatic solution for every 10 minutes using a digital pH meter. The protein digestibility percent (Y) was calculated using the following equation:

$$Y = 210.46 - 18.10 X$$

Where: X = change in pH after 10 min

### 2.5 *In-vitro* starch digestibility of the pasta

The *In-vitro* carbohydrate digestibility of the pasta samples was performed (Desai *et al.*, 2019), measuring the amount of free reducing sugars released during the enzymatic hydrolysis. The pasta was initially cooked in 600 ml of boiling tap water for the optimum time, then cut into 2-5 mm pieces with a knife. 2.5 g of samples were suspended in 30 ml RO water and placed on a pre-heated 15 place magnetic heated stirring block and maintained at 37°C with constant stirring. The *in-vitro* stomach digestion began with the addition of 0.8 ml 1 M HCl and 1 ml of 10% pepsin solution in 0.5 M HCl, followed by incubation for 30 min at 37°C with stirring. At time 0, 1 ml aliquots of each sample were taken and mixed with 4 ml ethanol. To prevent end product inhibition of pancreatic  $\alpha$ -amylase, 0.1 ml amyloglucosidase (Sigma Aldrich, St Louis USA) was added to the digestion flask. Small intestine digestion commenced with the addition of 5 ml of 2.5% pancreatin (Sigma Aldrich, St Louis USA) in 0.1 M sodium maleate buffer pH 6, stirred constantly at 37°C for 120 min, with aliquots withdrawn after 20, 60, and 120 min and mixed with 4 ml ethanol. The samples were stored for reducing sugar analysis at 4°C using 3,5-dinitrosalicylic acid (DNS). For reducing sugar estimation, sample aliquots were centrifuged for 10 min at 1000 g. Then, 0.05 ml of each sample aliquot from each replicate, along with appropriate controls, were transferred to clean, dry test tubes. A 0.25 ml enzyme solution comprising 1% invertase and 1% amyloglucosidase was added to each tube, followed by incubation for 20 min at room temperature. Subsequently, 0.75 ml DNS reagent was added to each tube, which were then covered, heated for 10 min in a boiling water bath, cooled, and mixed with 4 ml RO water. The absorbance was measured at 530 nm after adjusting the spectrophotometer to zero with RO water as the blank. Reducing sugar content was calculated as mg/g sample and plotted

against time, with area under the curve (AUC) calculated by dividing the graph into trapezoids.

## 2.6 Quantification of total amino acids of the FPH enriched pasta

The total amino acid content of FPH (80.55% protein) (obtained from pepsin treated fish waste) was analysed using high performance liquid chromatography (HPLC) (Agilent Technologies, Palo Alto, California, USA), RP-HPLC (HP-Agilent 1,100 model, Agilent Technologies) technique of Islam *et al.* (2021). To analyse total tryptophan, 100 mg of protein hydrolysate was combined with 8 ml of 5 mol/L NaOH and heated at 120°C for 22 hours under nitrogen gas. Subsequently, it was neutralized with 6.67 ml of 6 M HCl. Additionally, other amino acids were determined using the same sample amount, which was hydrolysed with 8 ml of 6 mol/L HCl under nitrogen gas, incubated in an oven under identical time and temperature conditions, and neutralized with 4.8 ml of 10M NaOH. For free amino acids evaluation, 1,000 mg protein hydrolysate was taken and diluted with 25 ml of 5% TCA and stranded for 1-2 h and centrifuged for 10 min at 10,000 g. Finally, 1 µl of solutions were injected into HPLC analytical column of 250 × 4.6 mm I.D, 5 µm particle size. The study was made by reverse-phase HPLC assembly system at 338 nm detection, 1.0 ml/min flow rate at 40°C column temperature. Mobile phase A was 7.35 mM/L C<sub>2</sub>H<sub>3</sub>NaO<sub>2</sub>/triethylamine/tetrahydrofuran (500:0.12:2.5, v/v/v) and adjusted to pH 7.20 ± 0.05 with CH<sub>3</sub>COOH while mobile phase B (pH 7.20 ± 0.05) was 7.35 mM/L C<sub>2</sub>H<sub>3</sub>NaO<sub>2</sub>/CH<sub>3</sub>OH/acetonitrile (1:2:2, v/v/v). the results were expressed as g/100g.

## 2.7 Fatty acids profiling of the FPH enriched pasta

Lipids from fish protein hydrolysate and pasta samples were detected with heptane solvent and analysed in gas chromatography coupled with a flame ionisation detector (FID) (Perkin Elmer, Waltham, MA, USA). A VARIAN gas chromatograph model CP 7420 equipped with CP-Sil (100 m long, 0.25 mm internal diameter and 0.2 µm film thickness) fused silica capillary column and FID was used to separate fatty acid methyl esters. The sample (1 µl) was injected and the temperature injector and detector were set 250°C. The ramp rate of the column temperature was 13°C/min and 4°C/min until 175°C and 215°C respectively which were held at 27 and 35 min respectively. The column temperature was started at 45°C. After the oven temperature attained 250°C, it was kept for 5 min. The total fatty acid content was detected and expressed in percentage. To establish the correction factors of the fatty acids, a standard solution (68 D) was used to transform the percentage peaks by weight (mg/g of total fatty acids). In this process, helium gas used as the carrier gas with a flow rate of 16.7

cm/s. The methyl ester was quantified using star 6.0 software through the integration of the peak area (Palmquist and Jenkins, 2003).

## 2.8 Statistical analysis

All experiments were conducted in triplicate (n=3) and the data are presented as mean  $\pm$  SD unless specified otherwise. The results were analysed using one-way ANOVA, and significant differences ( $P < 0.05$ ) were determined using Tukey's comparison test (Snedecor and Cochran, 1967).

## 3. RESULTS AND DISCUSSION

### 3.1 Protein content and *In-vitro* protein digestibility of the pasta

The protein digestibility of control and enriched pasta with different FPH concentration showed in the range of  $80.32 \pm 0.1\%$  to  $83.76 \pm 0.1\%$  (Table 1, digestibility curve shown in Fig. 1). Protein quality relies on chemical composition, digestibility, and compounds affecting amino acid utilization, determining the nutritional characteristics of food (Lorusso *et al.*, 2017). Protein digestibility is crucial for protein intake. Key factors affecting digestion and absorption include phenolic compounds, anti-nutritional factors, protein inhibitors, and processing methods (Gilani *et al.*, 2012). A study found fish protein to be more digestible than plant protein. The author explains that food protein digestibility involves enzymatic hydrolysis into amino acids or smaller peptides for intestinal absorption (Greco *et al.*, 2017). In the present study, the protein digestibility was found decreasing ( $P > 0.05$ ) with increased level of FPH incorporation in pasta as compared to control pasta. The control pasta was shown 83.76% protein digestibility and 82.43%, 81.58%, 81.16%, 80.32% for 5%, 10%, 15% and 20% FPH level respectively (Table1). Similarly, Ramya *et al.* (2015) observed a decreasing trend in protein digestibility with the influence of freeze-dried shrimp powder in pasta processing using Indian durum wheat, where protein digestibility was 93% for control pasta, and 72%, 90%, and 96% for pasta fortified with 2.5%, 5%, and 10% dried shrimp powder, respectively. Also, De Marco *et al.* (2014) found decreasing trend in protein digestibility (80.88 to 55.45%) of spirulina fortified pasta with the increased level (5 to 20%) of spirulina in the pasta which was due to the presence of phenolic compounds in the spirulina. Polysaccharides and phenolic compounds are the factors responsible for protein digestion in the food matrix where the interaction between protein and phenolic compounds results to the decrease in the digestibility. Proteins and oxidized phenolic compounds create insoluble complexes, disrupting proteolytic activity and interfering protein utilization

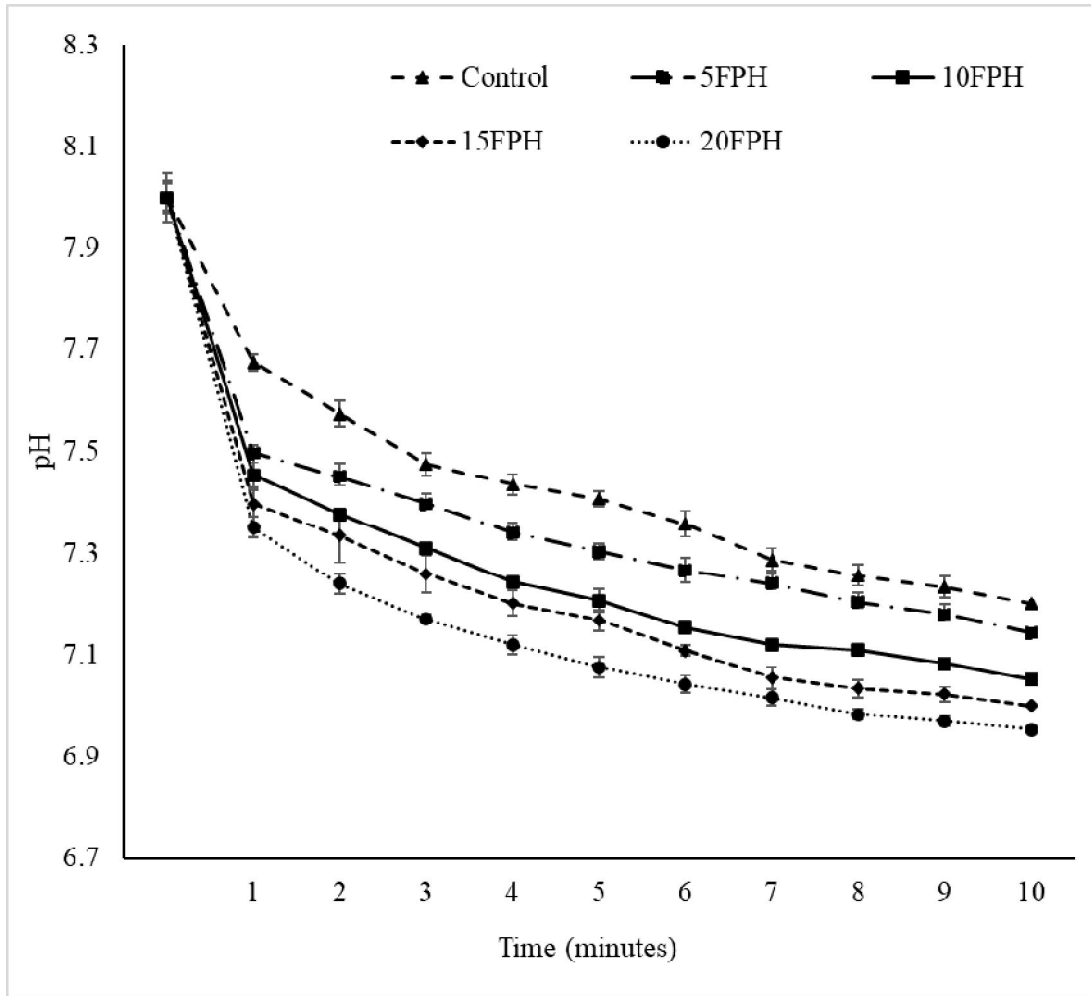
(Labuckas *et al.*, 2008). FPH in the pasta, increase the protein content. However, there was no significant difference between the uncooked and cooked pasta. This indicates no protein loss during the cooking process. A similar result was observed by Desai *et al.* (2018) in pasta enriched with red cod fish powder and De Marco *et al.* (2014) in pasta fortified with spirulina.

In the protein digestibility curve, the pH of the FPH enriched pasta using enzymes (trypsin, chymotrypsin, protease) decreased significantly ( $P < 0.05$ ) (Fig.1). Protein digestion releases amino acid and peptides, lowering the pH of surrounding medium. Enzyme addition to the protein solution releases carbonyl (-COO-) and amino (-NH<sub>3</sub><sup>+</sup>) groups. Protons (H<sup>+</sup>) are liberated at neutral pH by deionizing the free amino groups in water and resulted decreased pH of the solution. Additionally, phenolic compounds in the pasta can oxidize with peptide amino groups, forming quinone complexes and protein cross-links. Further, the amino and sulfhydryl groups of proteins react with quinines lowered the protein digestibility (Prodpran *et al.*, 2012).

**Table 1: Protein content, In-vitro protein digestibility and protein availability of pasta fortified with fish protein hydrolysate (FPH)**

Sample	PC in dry raw pasta (%)	PC in dry cooked pasta (%)	PD (%)	Significance between PC of uncooked and cooked pasta	PA dry pasta (%)
CO	14.02 ± 0.01 <sup>a</sup>	14.18 ± 0.02 <sup>a</sup>	83.76 ± 0.1 <sup>a</sup>	* P < 0.05	12.93 ± 0.005 <sup>a</sup>
5FPH	18.95 ± 0.02 <sup>b</sup>	18.85 ± 0.05 <sup>b</sup>	82.43 ± 0.1 <sup>b</sup>	* P < 0.05	17.14 ± 0.03 <sup>b</sup>
10FPH	22.08 ± 0.06 <sup>c</sup>	22.64 ± 0.04 <sup>c</sup>	81.58 ± 0.3 <sup>c</sup>	* P < 0.05	20.57 ± 0.005 <sup>c</sup>
15FPH	26.72 ± 0.03 <sup>d</sup>	26.92 ± 0.01 <sup>d</sup>	81.16 ± 0.2 <sup>c</sup>	* P < 0.05	25.13 ± 0.005 <sup>d</sup>
20FPH	32.23 ± 0.04 <sup>e</sup>	31.33 ± 0.05 <sup>e</sup>	80.32 ± 0.1 <sup>d</sup>	* P < 0.05	29.28 ± 0.02 <sup>e</sup>

PC- protein content, PD - *In-vitro* protein digestibility, PA- protein availability. CO- control pasta, 5FPH, 10FPH, 15FPH and 20FPH: pasta prepared with 5, 10, 15 and 20g of fish protein hydrolysate /10g of semolina flour respectively. Results in the table represent the mean of triplicate measurements. Mean ± standard deviation (n = 3). Values within a group column followed by the same superscript letter are significantly different from each other ( $P < 0.05$ ) and \* indicate not significant ( $P < 0.05$ ). according to Tukey's test



**Fig. 1: The pH vs time curves obtained by different concentration of FPH incorporated pasta incubated with multi-enzymes (trypsin, chymotrypsin and protease)**

### **3.2 In-vitro starch digestibility of the FPH enriched pasta**

The FPH enriched pasta was examined for starch digestibility, recording reducing sugar levels at 20 min, 60 min, and 120 min. A graph depicting the relationship between released reducing sugar and time is presented (Fig. 2). The different amount of sugar comprises of readily digestible starch (RDS) and slowly digestible starch (SDS) are given in Fig. 3. Additionally, Fig. 4 compares starch hydrolysis values (control vs. FPH-enriched pasta) as area under the curve (AUC).

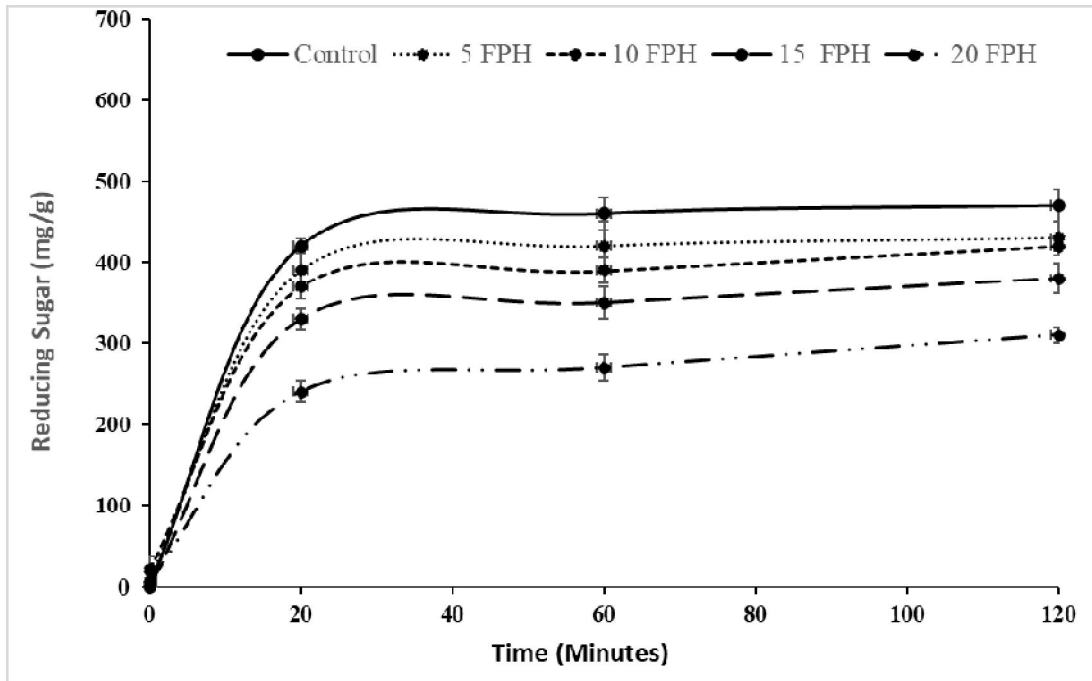
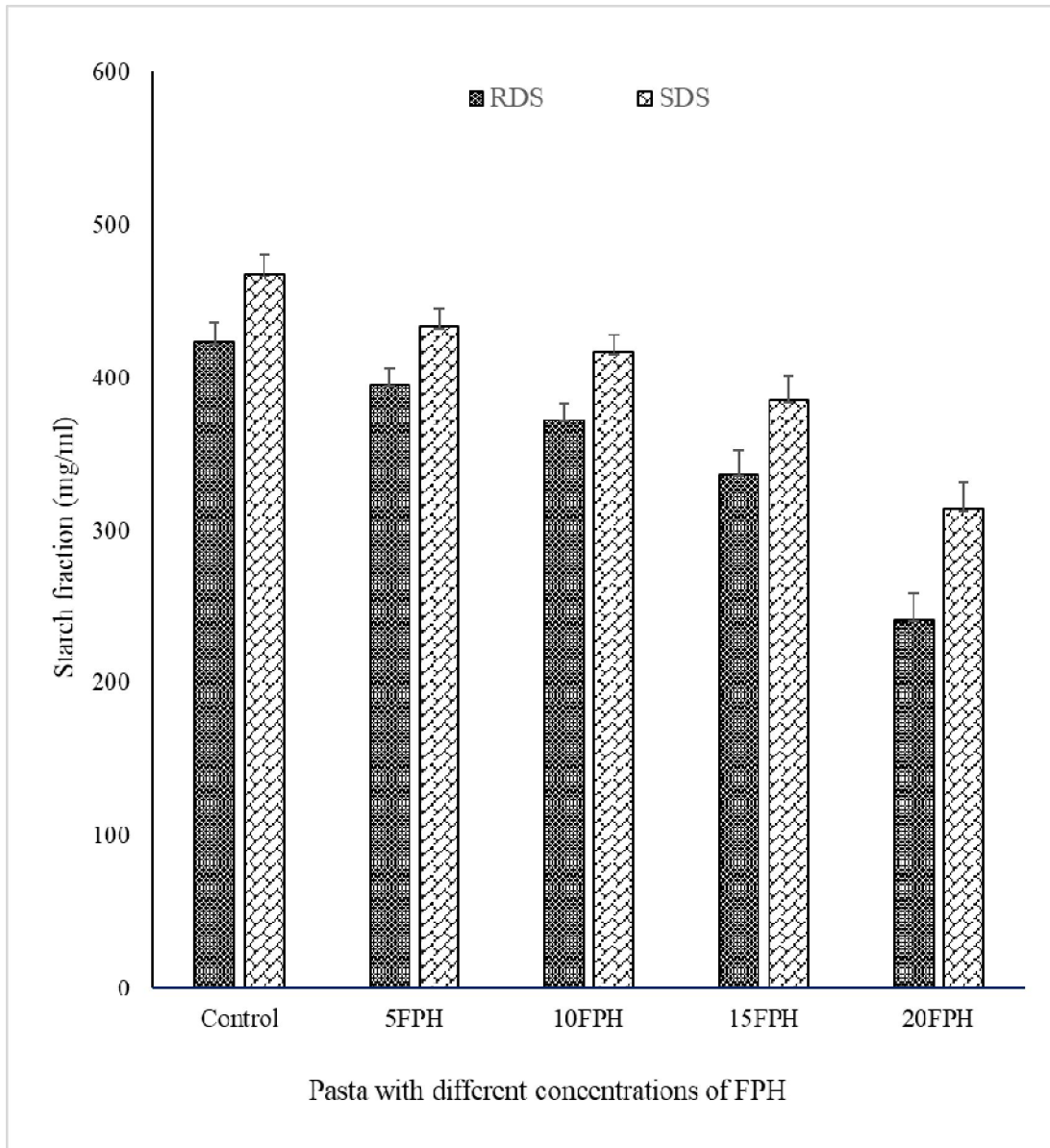
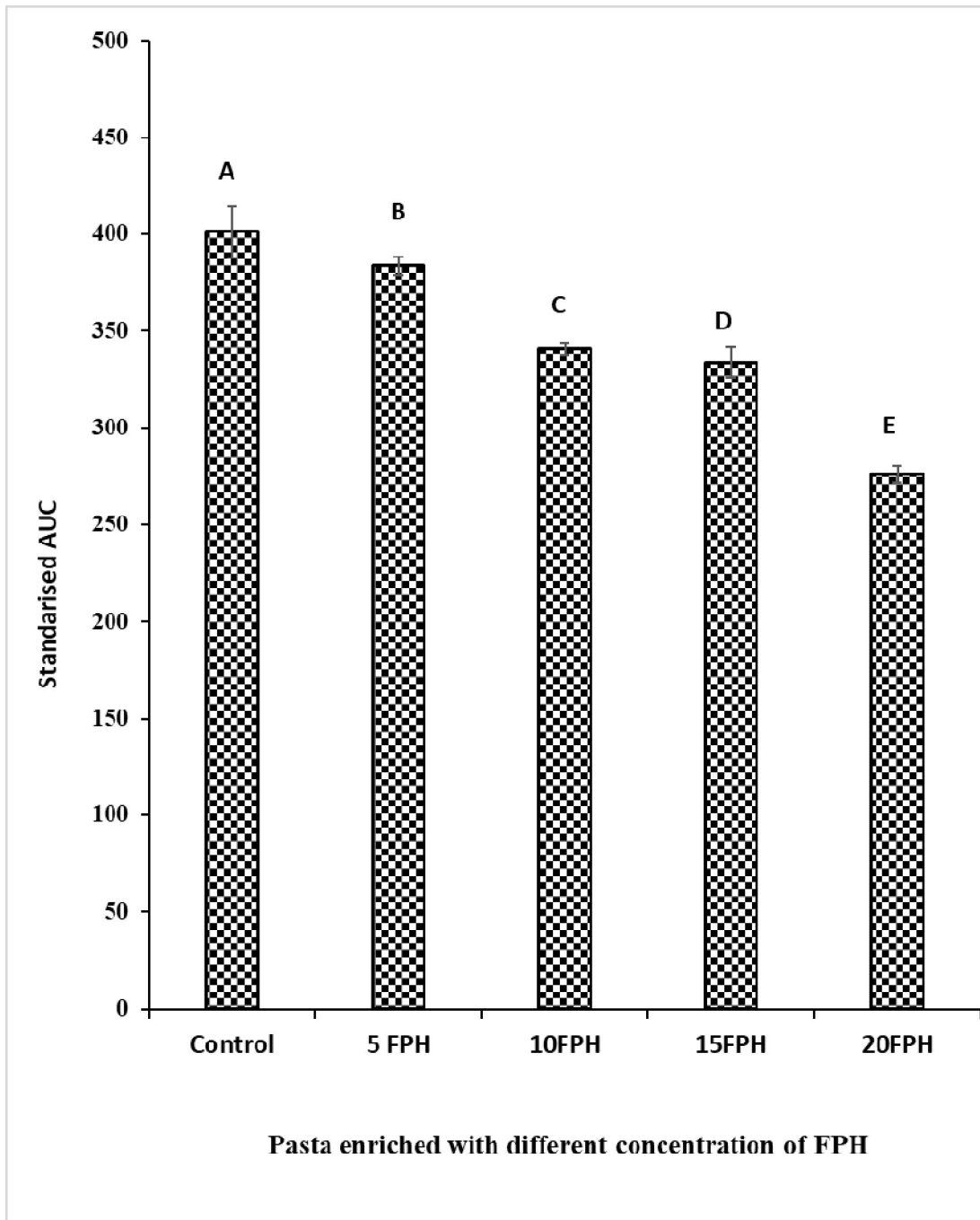


Fig. 2: Amount of reducing sugar released during *in-vitro* digestion of the control and FPH enriched pasta - 5FPH, 10FPH, 15FPH and 20FPH: pasta prepared with 5, 10, 15 and 20 g of fish protein hydrolysate /100 g of semolina flour respectively, CO: control sample.

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**Fig. 3: Readily digestible starch (RDS) and slowly digestible starch (SDS) – starch content hydrolysed within 20 min and 120 min respectively of control and FPH enriched pasta - 5FPH, 10FPH, 15FPH and 20FPH: pasta prepared with 5, 10, 15 and 20 g of fish protein hydrolysate /100 g of semolina flour respectively. The values are expressed as mean  $\pm$  SD (n=3). The values are significantly different from each other ( $P < 0.05$ ), according to Tukey's test.**



**Fig. 4:** Values for area under the curve (AUC) comparing control and FPH enriched pasta- 5FPH, 10FPH, 15FPH and 20FPH: pasta prepared with 5, 10, 15 and 20 g of fish protein hydrolysate /100 g of semolina flour respectively. The values are expressed as mean  $\pm$  SD (n=3). The values are significantly different from each other ( $P < 0.05$ ), according to Tukey's test.

Pasta starch digestibility is crucial for human nutrition, primarily determined by interactions among protein, lipid, and starch in the small intestine, influencing glycaemic

response (Ren *et al.*, 2016). The study evaluates the *in-vitro* starch digestibility of FPH enriched pasta by calculating the amount of reducing sugar released over 120 min *in-vitro* digestion. The amount of sugar released in 120 min by the FPH enriched pasta is lower ( $P < 0.05$ ) than the control pasta (Fig. 2). The enriched pasta samples had significantly ( $P < 0.05$ ) lower levels of readily digestible starch (RDS) than slowly digestible starch. It may be due to the complexes formed by lipids with amylose and forms a barrier on the enzyme absorption sites of starch granules by protein (Chen *et al.*, 2017). Similarly, enrichment of semolina spaghetti with protein rich bean flour lowers the RDS and SDS fraction (Giuberti *et al.*, 2015), primarily due to partial gelatinisation of starch granules. The fat content in the pasta sample was 0.48% (control), 0.51% (5% FPH), 0.53% (10% FPH), 0.56% (15% FPH) and 0.58% (20% FPH) respectively. The decrease in starch digestibility may be due to the formation of amylose-lipid complexes (ALC) which is supported by the statement given by Ren *et al.* (2016) that ALC is resistant to enzyme and the resistant capacity increases with increasing lipid chain length. Also, hydration and swelling of starch granules interrupted by lipid-amylose interaction, forming a single helical structure that obstructs the enzymatic hydrolysis of the starch granules. Lau *et al.* (2016) found the addition of fats in baked bread and performed starch digestibility test where a significant reduction in the digestibility was found with formation of amylose-lipid complex. The incorporation of stearic acid and linoleic acid in bambara starch reduced starch digestibility with the formation of single helical structure of amylose-lipid complex (Oyeyinka *et al.*, 2017). Similarly, the *in-vitro* starch digestibility and glycaemic index of millets comprises of oleic, palmitic and linoleic acids (Annor *et al.*, 2015). Moreover, in high protein sample reduction of starch granule surface accessibility area occurs that affects the enzyme susceptibility. The present study was carried out with protein rich FPH enriched pasta. Therefore, there could be formation of strong protein network that can entrap  $\alpha$ -amylase (Singh *et al.*, 2010). Protein and lipid content in cereal products reduce starch digestibility by forming starch-lipid and starch-lipid-protein complexes (Kadam and Prabhasankar, 2012). A study investigated the effect of freeze-dried shrimp meat on pasta starch digestibility, revealing a significant decrease compared to durum wheat semolina pasta. Pasta containing freeze-dried shrimp meat (2.5%, 5%, and 10%) showed digestibilities of 60%, 50%, and 38%, respectively, compared to 72% for control pasta. The reduced digestibility is attributed to shrimp protein entrapping starch granules in the gluten network and inhibiting  $\alpha$ -amylase activity (Ramya *et al.*, 2015). The protein creates a strong network in the food matrix thereby reducing the surface area of the starch granule for enzyme activity (Rosa-Sibakov *et al.*, 2016).

The effect of substituting semolina flour with FPH on standardised area under the curve (AUC) values with the control (100% durum wheat semolina) sample was illustrated in

the result (Fig. 4). The AUC values in the graph were significantly declined ( $p < 0.05$ ) with increasing percentage of FPH in the pasta. A similar pattern was also found in the development of spaghetti by replacing semolina with soya bean flour which shows the impact of decreasing carbohydrate intake on lowering the glycaemic response (Chillo *et al.*, 2010). Hence, control pasta was more digestible than FPH enriched pasta. For lowering the glycaemic index, addition of FPH in carbohydrate rich product like pasta is a wise choice.

### 3.3 Amino acid composition of FPH treated pasta

The amino acid profiling was carried out for different level of FPH treated pasta sample. The amino acid present are listed in Table 2.

**Table 2: Amino acid content (mg/g) of control pasta and pasta enriched with different concentration of FPH**

Amino acid	CO	5FPH	10FPH	15FPH	20FPH
<b>Essential amino acid</b>					
Methionine	2.17 ± 0.07 <sup>a</sup>	2.65 ± 0.1 <sup>b</sup>	3.46 ± 0.4 <sup>c</sup>	3.45 ± 0.2 <sup>c</sup>	4.08 ± 0.2 <sup>d</sup>
Isoleucine	1.84 ± 0.01 <sup>a</sup>	3.79 ± 0.5 <sup>b</sup>	3.66 ± 0.2 <sup>c</sup>	3.68 ± 0.07 <sup>c</sup>	4.15 ± 0.1 <sup>d</sup>
Leucine	1.27 ± 0.05 <sup>a</sup>	1.69 ± 0.2 <sup>b</sup>	1.66 ± 0.2 <sup>b</sup>	1.9 ± 0.1 <sup>c</sup>	5.55 ± 0.1 <sup>d</sup>
Lysine	7.65 ± 0.19 <sup>b</sup>	7.43 ± 0.4 <sup>a</sup>	7.55 ± 0.2 <sup>b</sup>	8.53 ± 0.1 <sup>c</sup>	9.02 ± 0.2 <sup>d</sup>
Threonine	1.76 ± 0.09 <sup>b</sup>	1.63 ± 0.2 <sup>a</sup>	1.68 ± 0.1 <sup>a</sup>	2.52 ± 0.2 <sup>c</sup>	2.58 ± 0.09 <sup>c</sup>
Tryptophan	1.03 ± 0.15 <sup>a</sup>	1.65 ± 0.2 <sup>c</sup>	1.51 ± 0.2 <sup>b</sup>	2.12 ± 0.03 <sup>d</sup>	2.38 ± 0.1 <sup>d</sup>
Histidine	0.99 ± 0.02 <sup>a</sup>	1.57 ± 0.2 <sup>b</sup>	2.22 ± 0.1 <sup>c</sup>	2.48 ± 0.1 <sup>d</sup>	2.64 ± 0.07 <sup>e</sup>
Valine	0.37 ± 0.04 <sup>a</sup>	1.56 ± 0.2 <sup>c</sup>	1.44 ± 0.07 <sup>b</sup>	2.05 ± 0.5 <sup>d</sup>	2.15 ± 0.1 <sup>e</sup>
Total	17.08 ± 1.34 <sup>a</sup>	21.97 ± 2.34 <sup>b</sup>	23.18 ± 1.83 <sup>c</sup>	26.73 ± 1.74 <sup>d</sup>	32.55 ± 1.14 <sup>e</sup>
<b>Non-essential amino acids</b>					
Aspartic acid	4.81 ± 0.13 <sup>a</sup>	9.43 ± 0.2 <sup>b</sup>	10.4 ± 0.2 <sup>c</sup>	16.8 ± 0.4 <sup>d</sup>	25.7 ± 0.3 <sup>e</sup>
Glutamic acid	22.21 ± 0.28 <sup>a</sup>	29.11 ± 0.4 <sup>b</sup>	33.75 ± 0.1 <sup>c</sup>	47.2 ± 0.8 <sup>d</sup>	59.41 ± 1.04 <sup>e</sup>
Cysteine	1.38 ± 0.18 <sup>a</sup>	2.46 ± 0.3 <sup>b</sup>	3.7 ± 0.1 <sup>c</sup>	6.47 ± 0.3 <sup>d</sup>	8.84 ± 0.1 <sup>e</sup>
Serine	0.27 ± 0.06 <sup>a</sup>	0.32 ± 0.09 <sup>b</sup>	0.63 ± 0.1 <sup>c</sup>	4.65 ± 0.1 <sup>d</sup>	9.59 ± 0.2 <sup>e</sup>
Glutamine	0.80 ± 0.08 <sup>a</sup>	0.87 ± 0.07 <sup>a</sup>	1.19 ± 0.09 <sup>b</sup>	2.37 ± 0.1 <sup>c</sup>	4.7 ± 0.3 <sup>d</sup>
Glycine	19.11 ± 0.14 <sup>a</sup>	21.29 ± 0.4 <sup>b</sup>	24.58 ± 0.1 <sup>c</sup>	35.29 ± 0.8 <sup>d</sup>	65.34 ± 0.5 <sup>e</sup>
Arginine	0.85 ± 0.02 <sup>a</sup>	1.48 ± 0.2 <sup>b</sup>	6.6 ± 0.06 <sup>c</sup>	6.83 ± 0.2 <sup>d</sup>	13.86 ± 0.6 <sup>e</sup>
Alanine	6.23 ± 0.19 <sup>a</sup>	7.41 ± 0.1 <sup>b</sup>	7.81 ± 0.1 <sup>b</sup>	8.88 ± 0.1 <sup>c</sup>	17.54 ± 0.3 <sup>d</sup>
Tyrosine	6.16 ± 0.29 <sup>a</sup>	8.78 ± 0.2 <sup>b</sup>	10.71 ± 0.04 <sup>c</sup>	12.76 ± 0.3 <sup>d</sup>	25.79 ± 0.3 <sup>e</sup>
Total	61.82 ± 3.12 <sup>a</sup>	81.15 ± 2.67 <sup>b</sup>	99.37 ± 3.96 <sup>c</sup>	141.25 ± 4.12 <sup>d</sup>	230.77 ± 2.45 <sup>e</sup>

5FPH, 10FPH, 15FPH and 20FPH: pasta prepared with 5, 10, 15 and 20 g of fish proteinhydrolysate /100 g of semolina flour respectively. CO: control sample. Mean ± SD<sup>a,b,c,d,e</sup> (n = 3) within a raw followed by the same superscript letter are not significantly different from each other (P < 0.05), according to Tukey's test.

Addition of fish protein hydrolysate to pasta product increased (P < 0.05) the levels of essential amino acids (EAA) such as methionine, lysine, tryptophan, threonine, isoleucine, leucine, valine, histidine, and some non-essential amino acids (NEAA) including aspartic

acid, glutamic, cysteine, serine, glutamine, glycine, arginine, alanine, and tyrosine. In the EAA, methionine, isoleucine, leucine, and lysine were increased ( $P < 0.05$ ) in the pasta incorporated with FPH (5 to 20 g/kg) as compared to control pasta. While, content of tryptophane, histidine and valine were higher ( $P < 0.05$ ) in the fortification containing 45%, 37% and 17% of control pasta respectively. No difference ( $P > 0.05$ ) was observed in the threonine contents. Amongst the NEAA, aspartic acid, glutamic acid, glycine, arginine, alanine and tyrosine levels were increased ( $P < 0.05$ ) in a level- dependent manner of FPH addition to pasta. While, cystine, serine and glutamic content was found higher ( $P < 0.05$ ) in 5FPH, 10FPH, 15FPH and 20FPH than control pasta sample (without FPH). With the enrichment of FPH, the content of essential and non-essential amino acid in the pasta were found improving with the increase in the amount of FPH added. In agreement with our results, Monteiro *et al.* (2016) and Seda (2014) reported similar pattern for total EEA and NEAA levels in tilapia (*Oreochromis niloticus*) flour fortified pasta and Tinca tinca mince incorporated bread, respectively. However, the results indicated a decrease in tryptophan, histidine, and methionine contents due to the fortification of tilapia flour and T. tinca mince, contrary to current findings. Desai *et al.* (2018) reported a higher level of amino acids in pasta made from cod fish powder compared to semolina-made pasta. Similarly, the powder of whole herring, herring by-products and arrowtooth flounder fillet has also shown increasing the pattern of amino acid (Sathivel *et al.*, 2004).

### Fatty acid profile of FPH enriched pasta

The fatty acid profile of pasta enriched with different levels of FPH and control pasta (without FPH) were depicted in Table 3.

**Table 3: Fatty acid profile (g of individual fatty acids/100g of total fatty acids) of pasta enriched with different levels of fish protein hydrolysate (FPH)**

Fatty acid	Control	5FPH	10 FPH	15FPH	20FPH
<b>Saturated Fatty Acids (SFA)</b>					
C12:0	2.51 ± 0.01 <sup>d</sup>	2.59 ± 0.02 <sup>d</sup>	2.06 ± 0.01 <sup>c</sup>	1.82 ± 0.00 <sup>b</sup>	1.68 ± 0.00 <sup>a</sup>
C14:0	7.62 ± 0.06 <sup>e</sup>	5.61 ± 0.07 <sup>d</sup>	5.14 ± 0.04 <sup>c</sup>	4.56 ± 0.01 <sup>b</sup>	4.16 ± 0.01 <sup>a</sup>
C15:0	1.75 ± 0.01 <sup>e</sup>	1.35 ± 0.01 <sup>d</sup>	1.10 ± 0.01 <sup>c</sup>	0.93 ± 0.01 <sup>b</sup>	0.82 ± 0.01 <sup>a</sup>
C16:0	24.46 ± 1.44 <sup>a</sup>	30.77 ± 0.08 <sup>e</sup>	28.32 ± 0.05 <sup>d</sup>	27.12 ± 0.03 <sup>c</sup>	26.23 ± 0.03 <sup>b</sup>
C17:0	0.85 ± 0.08 <sup>e</sup>	0.74 ± 0.08 <sup>d</sup>	0.61 ± 0.04 <sup>c</sup>	0.55 ± 0.04 <sup>b</sup>	0.44 ± 0.04 <sup>a</sup>
C18:0	7.16 ± 0.11 <sup>c</sup>	7.24 ± 0.10 <sup>d</sup>	6.48 ± 0.01 <sup>c</sup>	6.18 ± 0.01 <sup>b</sup>	6.04 ± 0.01 <sup>a</sup>
C19:0	0.18 ± 0.01 <sup>b</sup>	0.21 ± 0.01 <sup>c</sup>	0.14 ± 0.02 <sup>a</sup>	0.18 ± 0.02 <sup>b</sup>	0.17 ± 0.01 <sup>b</sup>
C20:0	0.12 ± 0.01 <sup>b</sup>	0.11 ± 0.03 <sup>a</sup>	0.12 ± 0.02 <sup>b</sup>	0.11 ± 0.02 <sup>a</sup>	0.10 ± 0.01 <sup>a</sup>

C22:0	-	0.06 ± 0.00 <sup>a</sup>	0.11 ± 0.01 <sup>b</sup>	0.15 ± 0.01 <sup>c</sup>	0.16 ± 0.01 <sup>c</sup>
C24:0	-	0.07 ± 0.01 <sup>a</sup>	0.09 ± 0.02 <sup>a</sup>	0.11 ± 0.01 <sup>c</sup>	0.13 ± 0.01 <sup>b</sup>
<b>Monounsaturated Fatty Acids (MUFA)</b>					
C14:1	0.80 ± 0.04 <sup>e</sup>	0.61 ± 0.03 <sup>d</sup>	0.48 ± 0.02 <sup>c</sup>	0.42 ± 0.03 <sup>b</sup>	0.38 ± 0.01 <sup>a</sup>
C16:1 ω-7	1.27 ± 0.02 <sup>a</sup>	2.43 ± 0.01 <sup>b</sup>	3.59 ± 0.01 <sup>c</sup>	3.84 ± 0.00 <sup>c</sup>	3.94 ± 0.01 <sup>c</sup>
C17:1	0.13 ± 0.01 <sup>a</sup>	0.16 ± 0.01 <sup>b</sup>	0.17 ± 0.01 <sup>b</sup>	0.16 ± 0.02 <sup>b</sup>	0.17 ± 0.01 <sup>b</sup>
C18:1 ω-9	16.17 ± 0.08 <sup>d</sup>	21.35 ± 0.12 <sup>b</sup>	26.11 ± 0.01 <sup>c</sup>	33.13 ± 0.05 <sup>d</sup>	36.09 ± 0.04 <sup>e</sup>
C20:1	0.03 ± 0.04 <sup>a</sup>	0.35 ± 0.03 <sup>b</sup>	0.78 ± 0.02 <sup>c</sup>	1.01 ± 0.02 <sup>d</sup>	1.21 ± 0.03 <sup>e</sup>
C22:1 ω-9	-	0.11 ± 0.00 <sup>a</sup>	0.14 ± 0.01 <sup>b</sup>	0.16 ± 0.02 <sup>c</sup>	0.17 ± 0.04 <sup>c</sup>
C24:1 ω-9	-	-	0.07 ± 0.01 <sup>a</sup>	0.08 ± 0.02 <sup>a</sup>	0.08 ± 0.02 <sup>a</sup>
<b>Polyunsaturated fatty acids (PUFA)</b>					
C18:2 ω-6	11.07 ± 0.09 <sup>a</sup>	11.57 ± 0.06 <sup>b</sup>	11.77 ± 0.04 <sup>c</sup>	11.71 ± 0.01 <sup>c</sup>	11.76 ± 0.01 <sup>c</sup>
C18:3 ω-3	1.34 ± 0.00 <sup>a</sup>	1.38 ± 0.01 <sup>b</sup>	1.48 ± 0.01 <sup>e</sup>	1.43 ± 0.00 <sup>d</sup>	1.40 ± 0.00 <sup>c</sup>
C20:2 ω-6	-	0.11 ± 0.01 <sup>a</sup>	0.14 ± 0.00 <sup>b</sup>	0.16 ± 0.00 <sup>c</sup>	0.17 ± 0.00 <sup>d</sup>
C20:3 ω-6	-	0.08 ± 0.01 <sup>a</sup>	0.13 ± 0.00 <sup>b</sup>	0.15 ± 0.00 <sup>c</sup>	0.17 ± 0.00 <sup>d</sup>
C20:4 ω-6	-	0.13 ± 0.01 <sup>a</sup>	0.21 ± 0.02 <sup>b</sup>	0.24 ± 0.04 <sup>c</sup>	0.25 ± 0.06 <sup>d</sup>
C20:5 ω-3	-	0.28 ± 0.01 <sup>a</sup>	0.45 ± 0.05 <sup>b</sup>	0.57 ± 0.07 <sup>c</sup>	0.63 ± 0.03 <sup>d</sup>
C22:5 ω-3	0.08 ± 0.04 <sup>a</sup>	0.17 ± 0.01 <sup>b</sup>	0.24 ± 0.00 <sup>c</sup>	0.27 ± 0.00 <sup>d</sup>	0.30 ± 0.00 <sup>e</sup>
C22:6 ω-3	-	0.76 ± 0.03 <sup>a</sup>	1.29 ± 0.01 <sup>b</sup>	1.53 ± 0.01 <sup>c</sup>	1.59 ± 0.01 <sup>d</sup>
ΣSFA	44.65 ± 0.45 <sup>c</sup>	48.75 ± 0.41 <sup>d</sup>	44.17 ± 0.27 <sup>c</sup>	41.71 ± 0.12 <sup>b</sup>	39.93 ± 0.11 <sup>a</sup>
ΣMUFA	18.40 ± 0.17 <sup>a</sup>	25.01 ± 0.18 <sup>b</sup>	31.34 ± 0.12 <sup>c</sup>	38.72 ± 0.06 <sup>d</sup>	41.96 ± 0.06 <sup>e</sup>
ΣPUFA	12.49 ± 0.14 <sup>c</sup>	14.48 ± 0.13 <sup>c</sup>	15.71 ± 0.08 <sup>c</sup>	16.06 ± 0.04 <sup>c</sup>	16.27 ± 0.04 <sup>c</sup>
Σ ω-6	11.07 ± 0.01 <sup>a</sup>	11.89 ± 0.02 <sup>b</sup>	12.25 ± 0.05 <sup>c</sup>	12.26 ± 0.07 <sup>c</sup>	12.35 ± 0.08 <sup>d</sup>
Σ ω-3	1.42 ± 0.01 <sup>a</sup>	2.59 ± 0.04 <sup>b</sup>	3.43 ± 0.03 <sup>c</sup>	3.80 ± 0.02 <sup>d</sup>	3.92 ± 0.02 <sup>d</sup>
PUFA/S FA	0.27	0.29	0.35	0.38	0.40
ω-6/ ω-3	7.79	4.45	3.57	3.22	3.15

5FPH,10FPH,15FPH and 20FPH: Pasta prepared with 5, 10, 15 and 20 g of FPH /100 g of semolina. Control pasta sample. Mean ± SD (n = 3). 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.

In this study, elevating the FPH concentration in pasta led to a decline in saturated fatty acid (SFA) levels (P > 0.05), while increased level (P < 0.05) of mono-unsaturated fatty

acid (MUFA) and polyunsaturated fatty acid (PUFA) was found. This reflects a positive impact of addition of FPH on pasta quality which will ultimately improves health of consumer. FPH fortification in pasta increased the content of palmitoleic acid (C16:1), and vaccenic acid (C18:1) than the control pasta and resulting on increased ( $P < 0.05$ ) of total MUFA content. The major PUFA present in control pasta was linoleic acid (C18:2). The major PUFA present in control pasta was linoleic acid (18:2) and omega-3 fatty acids were low in content with the ratio of  $\omega$ -6:  $\omega$ -3 being 7.79. The higher  $\omega$ -6:  $\omega$ -3 ratio in control pasta could be due to the prevalence of linoleic acid in pasta made with semolina (Fradique *et al.*, 2013). The pasta prepared with different proportion of FPH showed the ratio of  $\omega$ -3:  $\omega$ -6 fatty acids increased ( $P < 0.05$ ) from 4.45 to 3.15. The recommended ratio on  $\omega$ -6:  $\omega$ -3 is 1 - 5 as specified by food agencies, scientific societies and national and international organisations (Agostoni *et al.*, 2010) and also added that from human nutrition standpoint and prevention of cardiovascular disease, a food with ratio of  $\omega$ -6:  $\omega$ -3 is 1 - 5 is recommended. Researchers also proved that  $\omega$ -6:  $\omega$ -3 ratio of cereal based enriched product can also enhance with the inclusion of Japanese seaweed (*Undaria pinnatifida*) (El-beltagi *et al.*, 2017), shrimp meat (*Penaeus monodon*) (Prabhasankar *et al.*, 2009) and carp fish powder (*Cyprinus carpio*) (Ramya *et al.*, 2015). The consumption of FPH enriched pasta can also meet the daily requirement of EPA and DHA. The intake of  $\omega$ -3 LC-PUFA rich food helps in the prevention of colon cancer and improves insulin sensitivity (Shahidi and Ambigaipalan, 2018). Future studies about the effects of drying and cooking processes of the pasta on EPA and DHA content are necessary. Our findings can be attributed to the difference between fatty acid composition of semolina and FPH. Pasta products contain mostly carbohydrates and exhibit low fatty acid content while FPH presents elevated levels of MUFA and PUFA (Monterio et al., 2016).

#### 4. CONCLUSION

The amino acid and fatty acid content of the pasta was found increased with the incorporation of FPH consists of PUFAs with better protein and starch digestibility. Therefore, fish waste can be utilized for the development of food hydrocolloids, fish protein hydrolysate with rich in nutrient source instead of discarding it in the environment that leads to environmental pollution which in turn effects human health. There is significant potential and demand for the development of cereal-based products, such as pasta, enriched with protein-rich fish protein hydrolysate, amino acids, and unsaturated fatty acids, including omega-3 fatty acids. This approach aims to reduce starch digestibility while increasing protein digestibility, thereby creating a product with low carbohydrate content and high protein content. High carbohydrate products are linked to various chronic diseases.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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