

# Characterisation of fish protein concentrate from underutilised red-toothed triggerfish *Odonus niger* (Ruppell, 1836)

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## Abstract

*Odonus niger*, despite being nutritionally comparable to many commercially important species, continues to remain underutilised in the food sector. Owing to its high content of quality protein, it represents a promising raw material for developing fish protein concentrate (FPC). FPC prepared using a combination method (alkaline sodium bicarbonate washing followed by acetic acid precipitation) was characterised for yield, bulk density (untapped UTBD and tapped TBD), water holding capacity (WHC), oil absorption capacity (OAC), water activity ( $a_w$ ), colour ( $L^*$ ,  $a^*$ ,  $b^*$ ), proximate composition, and amino acid profile. The developed FPC exhibited a proximate composition meeting the requirements mentioned in IS:9808 standards for FPC, containing  $89 \pm 0.20\%$  crude protein,  $9.54 \pm 0.10\%$  moisture,  $0.36 \pm 0.04\%$  crude fat, and  $0.31 \pm 0.03\%$  ash. A total of 21 amino acids were identified, with essential amino acids including lysine (12.79%), leucine (15.07%) and methionine (13.29%) constituting the major fraction of the total amino acid profile. The FPC demonstrated good physicochemical quality with a yield of  $13.56 \pm 0.38\%$ , UTBD and TBD of  $0.65 \pm 0.03$  and  $0.75 \pm 0.01$  g ml<sup>-1</sup>, respectively, OAC of  $0.79 \pm 0.03$  g g<sup>-1</sup>, WHC of  $7.96 \pm 0.63$  ml g<sup>-1</sup>,  $a_w$  of  $0.40 \pm 0.02$  and  $L^*$ ,  $a^*$ ,  $b^*$  values of  $76.88 \pm 0.36$ ,  $3.33 \pm 0.53$ , and  $24.43 \pm 0.78$ , respectively. The results demonstrated that the characteristics of the developed FPC were in agreement with those reported in earlier studies. Therefore converting *O. niger* into a stable protein preparation represents an effective approach for its optimal utilisation, with potential incorporation into suitable value added food products.

## Introduction

Red-toothed triggerfish *Odonus niger* (Ruppell, 1836) is a commercially important but non-conventional species (Ramachandran and Philip, 2010) of the Balistidae family in the Tetraodontiformes order. Widely distributed in the Indo-Pacific (Smith, 1986), including Indian reefs (Matsuura, 2015), they inhabit coral habitats at depths up to 130 m (Ramachandran and Philip, 2010). Initially, despite being frequently caught as trawl bycatch, they were typically discarded at sea due to low market demand, and to free up storage space for more lucrative species (Balasubramanian *et al.*, 1995). Heavy landings of the species have been reported along various coasts of India (Ambarish *et al.*, 2018; Mahesh *et al.*, 2019; Tank *et al.*, 2019). With 2.74 lakh t, this species was the most landed marine resource in 2019 in India (CMFRI, 2019). It has since

reemerged in Kerala's marine fisheries with landings reaching 7132 t and ranked as the second most landed species in Tamil Nadu in 2023. A further 2% increase in 2024 to 38,400 t allowed it to remain among the top five species in the state (CMFRI, 2024; 2025). Many authors have reported the use of *O. niger*, as a suitable raw material for fish meal production (Abdussamad *et al.*, 2009; Dineshababu *et al.*, 2011; Mahesh *et al.*, 2019). The landings in Kerala were primarily driven by demand from the surimi industries from Mangalore and by their use as a principal component in poultry feed produced at fish meal plants in Kerala (Dineshababu *et al.*, 2011; CMFRI, 2020). Although several authors have reported instances of direct human consumption (Abdussamad *et al.*, 2009; Sethi *et al.*, 2011; Ambarish *et al.*, 2018), the species is only sparingly taken for domestic consumption and is not commercially utilised for value added food production either. Whereas



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studies on the protein quality and fatty acid profile of the species by Suyani *et al.* (2023, 2024) suggest the species has a nutrient profile comparable to other commercially valued food fishes. Species was found to be rich in essential amino acids (EAA), with most EAA having chemical scores exceeding FAO standards, highlighting the suitability of the species in nutrition-supplement programmes. Therefore, this potential yet underutilised resource could become a suitable source of raw material for fish protein concentrate preparation (FPC).

FPC is a stable protein product derived from fish prepared through process such as solvent extraction, enzymatic treatment, pH shift methods, biological fermentation using microorganisms or chemical processing, and is intended for human consumption (Kumoro *et al.*, 2022). Incorporated in foods as a supplement or fortifying agent, FPC facilitate the formulation of novel food products with enhanced nutrition, to support human health (Shaviklo *et al.*, 2011; Cercel *et al.*, 2016; Phadtare *et al.*, 2021). Producing FPC is a promising way to increase consumer acceptance of a fish (Kumoro *et al.*, 2022). FPCs have been prepared from many commercially important fishes (Akhade *et al.*, 2016; Phadtare *et al.*, 2021; Rieuwpassa *et al.*, 2022; Asfar *et al.*, 2025). Although Sarika *et al.* (2020) reported the feasibility of producing FPC from *O. niger*, their study was limited to a few selected compositional and functional attributes. Comprehensive evaluation of physicochemical quality, purification efficacy, detailed amino acid profiling and standard compliance remains unexplored for this species.

Understanding the nutritional and functional properties of FPC is essential for its effective use in food applications. The physicochemical characteristics influence their general behaviour in food systems during every stage of processing up to consumption. Systematic evaluation of such properties helps to assess how new protein sources will perform and whether they can replace existing conventional protein sources (Kinsella and Melachouris, 1976; Akhade *et al.*, 2016; Rieuwpassa *et al.*, 2022). Therefore, the present study focused on the development of FPC from *O. niger* using a combined washing-acid precipitation method and provides a comprehensive physicochemical and nutritional characterisation to establish its quality and application potential.

## Materials and methods

### Raw material

*O. niger* procured from Munambam Fisheries Harbour, Ernakulam, Kerala, was brought in iced condition to the laboratory in insulated containers, maintaining an ice to fish ratio of 1:1. It was then thoroughly washed with potable water, gutted, de-skinned, and filleted. The fillets packed in LDPE pouches were stored at -18°C.

### FPC preparation

FPC was prepared following the combination method given by Ikasari and Wijaya (2021), including the use of 2% NaHCO<sub>3</sub> and 1% acetic acid, with minor modifications to suit the laboratory conditions. Food-grade sodium bicarbonate and acetic acid were used for the preparation of FPC.

Fish fillets were cooked at 80°C for 30 min in a water bath. The cooked meat was ground and mixed with distilled water (1:3 w/v) and stirred continuously for 15 min. The mixture was filtered using a cheese cloth and the residue was treated with 2% NaHCO<sub>3</sub> and stirred continuously for 15 min. The mixture was filtered, and the residue was again mixed with cold distilled water (10°C) (1:3 w/v) and stirred continuously for 15 min. The mixture was filtered, and the residue was homogenised with added distilled water (1:2 w/v). The homogenate was treated with 1% acetic acid (v/w) (15-20 min) and then filtered, and the residue was dried in a hot air oven at 45°C for 15 h. The dried powder (FPC) was ground and sieved through a 150 micron sieve to achieve a final particle size <150 µm. FPC was then stored in opaque containers to prevent the action of light in an airtight condition at room temperature for further biochemical and physicochemical analyses.

## Physicochemical properties

FPC yield was determined as the percentage ratio of the developed FPC weight to the total weight of fish meat utilised. Bulk density of FPC, represented as g ml<sup>-1</sup>, was assessed in both tapped (tapped bulk density, TBD) and untapped conditions (untapped bulk density, UTBD), according to the methodology explained by Wang and Kinsella (1976). Water holding capacity (WHC) recorded in terms of milligrams of water absorbed per gram of FPC was analysed according to the method given by Diniz and Martin (1997). Oil absorption capacity (OAC) was analysed as per the method by Ahmedna *et al.* (1999). The results were represented as grams of oil absorbed per gram of FPC. Water activity recorded as a<sub>w</sub> was measured using a water activity meter (AQUALAB 4TE, Addium/METER Group Inc., USA). Colour of FPC was recorded using the colourimeter (ColorFlex EZ Spectrophotometer, Hunter Associates Laboratory, Inc., USA) and was expressed using CIELAB spaces. The colour attributes of the sample were evaluated using the CIELAB colour system, and the L\* (lightness), a\* (redness) and b\* (yellowness) values were recorded.

## Proximate composition

The FPC prepared was analysed for proximate composition, including moisture, crude protein, crude fat, and total ash, based on AOAC (2000), and acid insoluble ash was assessed according to BIS (1981).

## Amino acid profiling

LC-MS/MS was used to profile free and bound amino acids employing a modified Nimbalkar *et al.* (2012) technique. To determine free amino acids, a known quantity of sample was homogenised with 5 ml of 0.1% formic acid in 20% methanol, and centrifuged (10,000 g for 15 min). The supernatant was diluted, filtered (0.2 µm nylon membrane), and injected into a Waters Acquity UPLC H-Class system with a TQD MS/MS detector (USA). Bound amino acids were released through acid hydrolysis using 6M HCl at 110°C for 6 h under vacuum. This was followed by centrifugation, drying, reconstitution in 0.1% formic acid in 20% methanol, and filtration before injection. At 25°C and 0.1 ml min<sup>-1</sup> flow rate, separation was achieved on a BEH-C18 column (2.1×50 mm, 1.7µ) with a gradient

of solvent A (0.1% formic acid in water) and solvent B (methanol: water, 50:50, with 0.1% formic acid). TDQ-MS/MS tailored for amino acid identification was used to evaluate eluted amino acids after they were identified by Photodiode array (PDA) detector.

## Statistical analysis

All analyses were performed in triplicate and the results are expressed as mean±standard deviation. As the study involved a single treatment condition, only descriptive statistics were applied. Data analysis was done employing Statistical Package for Social Sciences (IBM SPSS Statistics 25), and graphical representations were generated using MS Excel 2021.

## Results and discussion

### Physicochemical properties

#### Yield

The FPC yield, represented as a percentage of the raw material, indicates the quantity of product that can be obtained from a given quantity of raw material and extraction process (Ikasari and Wijaya, 2021). The yield of FPC developed was  $13.56\pm 0.38\%$  (Table 1). A slightly lower but comparable readings were observed in tilapia (12.11%) and silver carp (12.69%) FPC (Kabir *et al.*, 2022). Conversely, the yield was considerably higher than the reported 7.1% yield percentage in arrowtooth flounder fish protein powder developed by a similar extraction process (Sathivel *et al.*, 2004). The current yield was, however, lower compared to the yield percentage of snakehead FPC ( $27\pm 0.01\%$ ) produced via the same extraction process (Ikasari and Wijaya, 2021).

#### Bulk density

Bulk density is expressed in terms of the amount of powder (g) that could be packed in a specific volume (ml). According to Huda *et al.* (2012) and Shaviklo *et al.* (2012), the particle size, initial moisture (Kabir *et al.*, 2022), ingredients and the temperature of drying directly affect the density properties of the fish protein powders. While bulk density demonstrates a product's porosity, it also helps in determining the volume, density and type of packaging material required for a particular product (Iwe *et al.*, 2016). Bulk density of the FPC sample recorded was  $0.65\pm 0.03$  g ml<sup>-1</sup> (untapped) and  $0.75\pm 0.01$  g ml<sup>-1</sup> (tapped) (Table 1). The observed results were comparable with the densities reported by Sarika *et al.* (2020), for *O. niger* in hot extracted samples. While comparing with the FPC developed from tilapia ( $0.52\pm 0.01$  g ml<sup>-1</sup>) (Rieuwpassa *et al.*, 2022) and barbus fish ( $0.54$  g ml<sup>-1</sup>) (Asefa, 2021), higher density values were reported in the present study. A higher bulk density of FPC indicates its appropriateness for general food preparation (Abbasi *et al.*, 2021). Also, higher values will be advantageous in terms of cost-effectiveness related to packaging and transportation (Caballero *et al.*, 2003).

#### Oil absorption capacity

Oil absorption capacity is the ability of a substance to physically entrap oil, a property that is largely independent of its nitrogen solubility (Sathivel *et al.*, 2006). The presence of hydrophobic amino acids in the

protein powder is responsible for their fat absorption capacities (Holm and Walther, 1988). OAC is brought about by the hydrocarbon chains of lipids forming hydrophobic interactions with the non-polar side chains of the protein (Jitngarmkusol *et al.*, 2008). This protein's ability is influenced by several factors, including the degree of hydrolysis (Kristinsson and Rasco, 2000), hydrolysing enzymes (Haque, 1993), and bulk density (Kinsella and Melachouris, 1976). Oil absorption capacity of the developed *O. niger* FPC was  $0.79\pm 0.03$  g g<sup>-1</sup> (Table 1). Compared with the current study, solvent-cold-extracted *O. niger* protein powder exhibited higher oil absorption capacity (Sarika *et al.*, 2020). Literature shows a modestly higher value of OAC than the current study; for tilapia FPC ( $1.03\pm 0.24$  ml g<sup>-1</sup>) (Rieuwpassa *et al.*, 2022) and snakehead FPC ( $1.17\pm 0.17$  ml g<sup>-1</sup>) (Ikasari and Wijaya, 2021). A higher oil absorption may be linked with a low-fat content (Lin and Zayas, 1987) and higher bulk density (Kinsella and Melachouris, 1976). Though a higher OAC can result in improved food texture, flavour retention and enhanced shelflife (Chandra *et al.*, 2015), they can also result in an increased fat content in the final product (Kurek and Scetar, 2017), reducing the nutritional value, making them incompatible with a healthy diet, as it could be linked to cardiovascular diseases, obesity and diabetes (Cahill *et al.*, 2014; Sayon-Orea *et al.*, 2014; Frakolaki *et al.*, 2023).

#### Water holding capacity

The texture and structural integrity of dry food products are largely determined by the protein's water holding capacity. It is driven by the protein-water molecule interactions brought about by polar amino acids in the product that draw water into the protein matrix and hold it in, ultimately affecting the structure (Putra *et al.*, 2018). WHC is influenced by various factors such as extraction process parameters like technique and temperature, and species (Huda *et al.*, 2000; Yu *et al.*, 2007). *O. niger* FPC recorded a water holding capacity of  $7.96\pm 0.63$  ml g<sup>-1</sup> (Table 1). The water holding capacity observed in the study was higher than that reported for tilapia FPC ( $2.40\pm 0.14$  ml g<sup>-1</sup>) (Rieuwpassa *et al.*, 2022), snakehead FPC ( $2.98\pm 0.23$ ) (Ikasari and Wijaya, 2021) and solvent extracted ribbonfish FPC ( $2.78\pm 0.27$  ml g<sup>-1</sup> to  $4.27\pm 0.16$  ml g<sup>-1</sup>) (Akhade *et al.*, 2016). This high WHC is beneficial in food formulations, as it is an important protein functionality contributing notably to the texture development of baked goods and reconstituted meat products (Acquah *et al.*, 2021). The study also found that the developed FPC has a greater WHC than OAC, indicating a higher concentration of hydrophilic amino acids in the powder (Holm and Walther, 1988). This functionality further suggests the suitability for bread and bread-based products, where enhanced hydration may contribute to protein network formation and structural stability. This may support carbon dioxide retention and expansion and ultimately improve loaf volume and crumb structure during baking (Cappelli *et al.*, 2021; Venturi *et al.*, 2022).

#### Water activity

The ratio of vapour pressure of the food in equilibrium with its ambient air to that of pure distilled water under the same circumstances is the water activity ( $a_w$ ) for that particular food product (USDA n.d.). A  $a_w$  of less than 0.6 does not support the growth of microorganisms (Fontana, 1998). Despite their inability to grow, they may survive at low  $a_w$  and resume growth when transferred to a suitable medium (Barbosa-Cánovas *et al.*, 2020). In the current study, the water activity measurement of the FPC developed, gave a value of

0.40±0.02 (Table 1). While the water activity of FPC developed via solvent extraction from the same species by Sarika *et al.* (2020), gave a comparatively higher  $a_w$  of 0.53. Published information on the water activity of other fish protein concentrates is scant. Maintaining a water activity below 0.3 in foods provides an environment where lipid oxidation, enzyme reactions and non-enzymic browning are largely inhibited (Shaviklo, 2015).

## Colour

Colour is a vital sensory parameter which greatly influences the consumer acceptance of the product (Kabir *et al.*, 2022). The fish utilised, the extraction process, and particle size affect the colour of the developed fish protein powder, ranging from light grey to cream or pinkish (Shaviklo, 2015). Water and oil content also have a significant influence on the colour of solvent-extracted fish protein (Shaviklo, 2015).

The lightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ) values of the developed FPC are given in Table 1. The FPC exhibited a greater lightness index (76.88±0.36) compared with the cold and hot extracted *O. niger* protein powder (71.71–75.45) (Sarika *et al.*, 2020), solvent-extracted tilapia FPC (65.84±0.10) (Rieuwpassa *et al.*, 2022), freeze dried protein powders from pink (70.6±5.4) and red salmon (53.9±0.8) (Sathivel *et al.*, 2006), and edible fish powders from tilapia (70.38±0.15) and silver carp (75.07±1.98) (Kabir *et al.*, 2022). Rieuwpassa *et al.* (2013) associate a greater whiteness or lightness value with the least amount of fat in the powder, while according to Rawdkuen *et al.* (2009), preservation of native proteins in the final product could be linked with its increased brightness. However, a decrease in  $L^*$  is indicative of a higher degree of protein denaturation and lipid oxidation (Rawdkuen *et al.*, 2009).

Observed redness ( $a^*$ ) in the developed FPC (3.33±0.53) was slightly higher than pink salmon powder, 1.3±0.2 (Sathivel *et al.*, 2006) and snakehead FPC, 1.45±0.01 (Ikasari and Wijaya, 2021). The redness was analogous with that of whole herring protein powder (3.5±0.3, Sathivel *et al.*, 2004), whereas much lower than the

redness observed in tilapia and silver carp edible powder (14.10±0.8 and 11.53±0.14, respectively) (Kabir *et al.*, 2022). Colour changes in fish protein powders could be associated with hemoproteins and the oxidation process. A modest increase in redness value ( $a^*$ ) could be attributed to the residual hemoproteins even after washing (Tadpitchayangkoon *et al.*, 2010; Foh *et al.*, 2012). Considerably greater yellowness (24.43±0.78) was recorded in the developed FPC than in hake protein powder (10.89±0.205) (Pires *et al.*, 2012) and whole herring protein powder (12.5±0.5) (Sathivel *et al.*, 2004). Exposure to extreme pH levels during the production process and thereafter may hasten the myoglobin oxidation, causing an increase in yellowness ( $b^*$ ) (Kristinsson *et al.*, 2007; Rawdkuen *et al.*, 2009). Relatively similar readings were observed in freeze-dried protein powders from pink (21.1±1.1) and red salmon (20.1±0.5) (Sathivel *et al.*, 2006) and snakehead (21.76±0.01) (Ikasari and Wijaya, 2021).

## Proximate composition

Proximate composition of the FPC developed from *O. niger* is illustrated in the pie-chart (Fig. 1). The UN Systems Protein-Calorie Advisory Group (PAG) graded and classified protein concentrates based on their protein and fat content as Type A (≥67% protein and ≤0.75% fat; white or colourless), Type B (~3% fat; grayish brown, strong fishy odour) and Type C (>3% fat; crude fish meal manufactured under acceptable hygienic standards) (Kumoro *et al.*, 2022). The quality of FPC is thus directly linked to its lipid content, with a lower value generally pointing to a high-quality product (Alfio *et al.*, 2021). In this context, FPC developed from *O. niger* in the current study, with an outstanding protein content (89±0.20%) and minimal fat content (0.36±0.04%), is a Type A high-quality FPC. Compared with the protein powder developed from *O. niger* by Sarika *et al.* (2020), which had around 75-80% protein and 0.8-1.78% fat, the current study demonstrated better proximate values. The moisture content of the developed FPC showed similar values to tilapia FPC developed by the solvent extraction method (Rieuwpassa *et al.*, 2022). While a comparatively higher protein and lower lipid content were observed in the developed FPC, the results also show the efficiency of the extraction process in the development of a standard FPC.

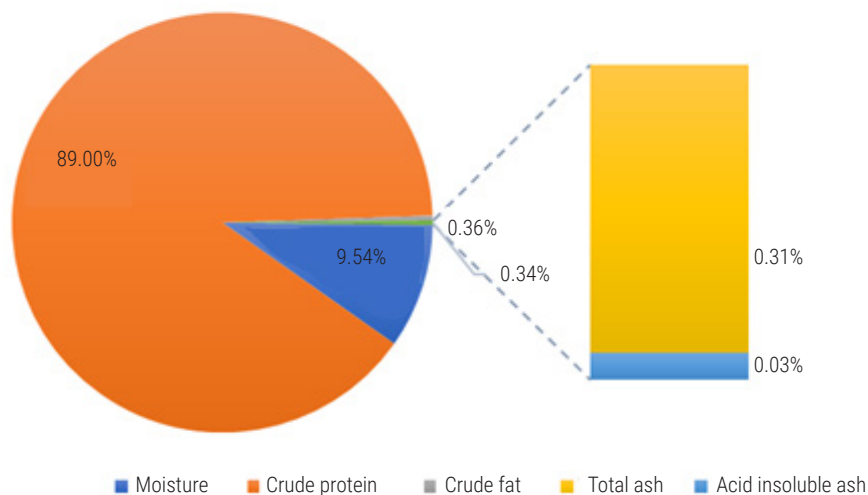


Fig. 1. Proximate composition (%) of the developed fish protein concentrate

Table 1. Physicochemical and functional properties of *O. niger* FPC, (Mean±sSD).

Functional attribute	Value
Yield (%)	13.56±0.38
Untapped bulk density (g ml <sup>-1</sup> )	0.65±0.03
Tapped bulk density (g ml <sup>-1</sup> )	0.75±0.01
Oil absorption capacity (g g <sup>-1</sup> )	0.79±0.03
Water holding capacity (ml g <sup>-1</sup> )	7.96±0.63
Water activity	0.40±0.02
L*	76.88±0.36
a*	3.33±0.53
b*	24.43±0.78

All the proximate composition parameters met the Indian Standards specifications, with ash and acid-insoluble ash values falling below the maximum limits, and the remaining parameters also conforming to the standards BIS, 1981. As indicated by the comparative assessment (Table 2), the overall composition of the final product satisfied the IS: 9808, Indian Standards for fish protein concentrate (BIS, 1981)

Table 2. Comparison between the proximate composition of the FPC developed from *O. niger* and the standard requirements of FPC according to BIS IS:9808 specification for FPC

Characteristic	FPC	IS: 9808 Requirement*
Moisture (%)	9.54±0.10	<10.00
Crude protein (N×6.25) (%)	89.00±0.20	>70.00
Crude fat (%)	0.36±0.04	<0.75
Ash (%)	0.31±0.03	<20.00
Acid insoluble ash (%)	0.03±0.004	<0.50
Available lysine (g 100 g <sup>-1</sup> of protein)	6.69±0.07 (66.92±0.71 mg g <sup>-1</sup> )	>6.50

Source: IS: 9808 Requirements\* - BIS. (1981). IS 9808: Specification for fish protein concentrate. New Delhi

## Amino acid profile

Amino acid analysis of the protein concentrate from *O. niger* revealed a profile of 18 amino acids, consisting of both 8 essential and 10 non-essential amino acids (Table 3). Essential amino acids (EAA) constituted a substantial proportion of the total amino acid profile, with lysine (12.79%), leucine (15.07%), and methionine (13.29%) as the major contributors. Importantly, lysine and methionine are considered to be limiting amino acids in plant-based proteins, where their concentrations are inadequate to support optimal growth (Galili and Amir, 2013). Comparing the amino acid profile of FPC with the values reported for unprocessed *O. niger* by Suyani *et al.* (2023), all amino acids were present at markedly higher concentrations, except for glycine and cysteine. Pires *et al.* (2012) reported methionine and leucine concentrations of 79.3 mg g<sup>-1</sup> and 35.71 mg g<sup>-1</sup>, respectively, in hake protein powder. In contrast, the present study exhibited a higher methionine level and comparable leucine content. Likewise, the limiting amino acids lysine and methionine in the developed FPC exceeded those in pink salmon powder (54.9 mg g<sup>-1</sup> and 25.6 mg g<sup>-1</sup>, respectively) (Sathivel *et al.*, 2006), and it also possessed a higher concentration of leucine than whole herring protein powder (72.0

mg g<sup>-1</sup>) (Sathivel *et al.*, 2004). The available lysine requirement mentioned in the IS standards (>6.5 g 100 g<sup>-1</sup> of protein) was met by the developed FPC (66.92±0.71 mg g<sup>-1</sup>, viz. 6.69 ±0.07 g 100 g<sup>-1</sup>) (Table 2).

Comparing the observed results with the dietary amino acid requirements in adults established by Food and Agriculture Organization, World Health Organization, and United Nations University (FAO/WHO/UNU, 2007), most of the amino acids in the FPC developed met the recommended levels, including lysine (45 mg g<sup>-1</sup>), histidine (15 mg g<sup>-1</sup>), leucine (59 mg g<sup>-1</sup>), and sulphur amino acids (methionine+cystine) (22 mg g<sup>-1</sup>). The aromatic amino acids (phenylalanine+tyrosine) also showed a comparable value (38 mg g<sup>-1</sup>).

The present study shows that the FPC developed from *O. niger* using the combination method meets the IS: 9808 standard requirements, yielding a product with a higher protein concentration, minimal moisture and fat concentration and a good amino acid profile. The functional attributes of the FPC developed were also comparable to the available literature, with an appreciable yield, higher bulk density and water holding capacity, acceptable level of oil absorption capacity, greater lightness index and an appropriate level of water activity. These characteristics suggest its potential suitability for incorporation as a dry ingredient in shelf-stable products such as cereal bars, cakes, breads and confectionery formulations. Developing fish protein concentrates is an effective way to utilise the maximum potential of *O. niger* sustainably, as well as to improve the consumer acceptance of this unfamiliar species. FPC offers several advantages, including versatility in raw materials and production processes, cost-effectiveness, enhanced nutritional composition, broad applicability, extended shelf life and ambient storage conditions. It is a valuable dietary supplement with great potential to address malnutrition economically on a global scale due to its low cost of production and high quality final

Table 3 Amino acid profile of *O. niger* FPC in mg g<sup>-1</sup> and percentage of total amino acid (Mean±sSD)

Amino acid classification	Amino acids	Content (mg g <sup>-1</sup> )	% of Total amino acid
Essential amino acids (EAA)	Lysine	66.92±0.71	12.79
	Leucine	78.86±1.05	15.07
	Phenyl alanine	31.55±0.05	6.03
	Methionine	69.55±1.12	13.29
	Valine	22.71±0.47	4.34
	Histidine	16.29±0.07	3.11
	Threonine	17.04±0.32	3.26
	Tryptophan	0.002±0.00	0.0004
	ΣTEAA	302.91	57.88
	Non-essential amino acids (NEAA)	Arginine	43.25±0.05
Glycine		0.08±0.002	0.02
Tyrosine		5.92±0.17	1.13
Proline		17.90±0.03	3.42
Cysteine		0.04±0.003	0.01
Alanine		20.86±0.04	3.99
Serine		23.17±0.05	4.43
Asparagine		0.83±0.07	0.16
Aspartic acid		34.96±0.32	6.68
Glutamic acid		73.45±3.02	14.03
ΣTNEAA	220.473	42.12	
ΣTAA (mg amino acid g sample <sup>-1</sup> )	523.385	100	

product. It can be successfully incorporated into food products as a supplement/additive and can also serve as a functional ingredient for the development of novel food products.

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