Indian J. Fish., 68(4): 128-134, 2021
DOI: 10.21077/ijf.2021.68.4.109353-14

Potential for commercialisation of bioactive peptides from tuna red meat: A techno-economic analysis

U. PARVATHY, A. SURESH, P. K. BINSI, A. A. ZYNUDHEEN AND GEORGE NINAN
ICAR-Central Institute of Fisheries Technology, Willingdon Island, Kochi - 682 029, Kerala, India
e-mail: p.pillai2012@gmail.com

ABSTRACT

Seafood byproduct is upgraded as certified waste on realisation of the bio-potent compounds it possesses, which has immense nutraceutical and therapeutical applications. Among the various possibilities to recover valuable nutrients from the discarded material, a major and efficient option is the production of fish protein hydrolysate/fish peptides. Optimised protocols for deriving peptides with tailor-made properties, helps to explore its utilisation potential and paves path for its industrial production. The present study addresses the feasibility with regard to the commercial production of peptides derived from the canning discards *viz*, red meat from yellowfin tuna. The protocols previously identified for tuna protein hydrolysate (TPH) production with optimum antioxidant properties, in laboratory-scale evaluations, were used to model large-scale production in pilot facilities. The parameters *viz*, cost of raw material, equipment, labour cost and final product price were derived based on the actual conditions prevailing in the market. Study results indicated good potential with regard to its commercialisation with respect to economic indices like net present value, internal rate of return and benefit cost ratio which had values of ₹63,908,381, 50% and 1.26, respectively. The sensitivity analysis also indicated that the commercial production is economically viable even with potential risks of raw material costs as well as selling price of fish protein hydrolysates.

Keywords: Bioactive, Fish processing, Fish protein hydrolysate, Seafood, Tuna red meat

Introduction

The role played by seafood sector towards the sustainability of global economy is well established. Globally, it forms the single largest animal-based food production sector satisfying 20% of the average *per capita* intake of animal protein of more than 3.1 billion people (FAO, 2016). Among seafood, tuna represents a significant share with an annual value of 42.2 billion USD (Galland *et al*., 2016). However, exploring the application potential of this highly nutritious seafood substrate is still in its infancy, with its major share being either discarded causing huge environmental issues, or converted to commodities like animal feed and fertilisers (Hou *et al.*, 2017). Various upgradation technologies have been reported to convert this protein dominant substrate to valuable bioactive components. An effective and most promising approach is the derivation of bioactive peptides with immense scope in various foods and nutraceuticals. Protein hydrolysates are proteins fragmented down into peptides of different sizes either chemically by employing acids/bases or biologically by using enzymes (Rustad, 2003; Pasupuleti and Braun, 2010). However, enzymatic proteolysis is the most common way to synthesise desirable protein hydrolysates, based on its catalytic properties with regard to substrate specificity which derives different oligopeptides *via,* enzyme-substrate interaction. Various fish species/substrates, proteolytic enzymes and process parameters *viz*, temperature, pH, time and enzyme-substrate ratio facilitate the optimised production of fish protein hydrolysates with tailor-made molecular structures and associated bioactive properties with therapeutic or nutritional interest (Guerard *et al*., 2002; Chabeaud *et al*., 2009). However, various limiting factors restrict its upscaling possibilities *viz*, enzyme cost, high production time, low protein recovery, acceptability issues due to bitterness, unpredictability in production of desired molecular weight peptides with specific functions and lack of demonstration with regard to applications. More effective and optimised processing protocols can assist in the production of fish protein hydrolysate with better functions in an economically feasible manner. Based on these aspects, the objective of the present study was to explore the upgradation possibilities of optimised antioxidant peptides from tuna red meat, a valuable cannery discard by upscaling the laboratory outcomes and its economic feasibility analysis for further commercialisation. The bioactive peptides derived have immense potential in food and nutraceutical sectors *viz*, infant formulations, health nutrition, geriatric nutrition and sports nutrition. The characteristics of the raw material, the main steps of the technological scheme with the equipment used and fish protein hydrolysate were considered according to the prevailing market scenario.

Based on this, the major economic indices *viz*, net present value, internal rate of return and benefit cost ratio were calculated and analysed. This work applies the concept of “waste to wealth”, considering its importance that has been accorded national priority in India.

Materials and methods

Materials

Tuna red meat, a byproduct of canning, from a private processing company namely, Forstar Frozen Foods Pvt. Ltd., Mumbai, Maharashtra, India was used for deriving bioactive protein hydrolysate/peptides employing papain enzyme (Hi Media, India). All the chemicals used for the protein analysis were of laboratory grade from Merck and Hi media, India.

Optimisation of hydrolysis

The enzymatic hydrolytic conditions previously identified to produce tuna protein hydrolysate (TPH) with optimised antioxidant properties *viz*. 0.98% enzyme-substrate ratio (E/S), 240 min hydrolysis time, 60°C temperature and pH 6.5 in laboratory-scale evaluations (Parvathy *et al*., 2020), were used to model its large-scale production utilising the pilot facilities available at ICAR-Central Institute of Fisheries Technology (ICAR-CIFT), Kochi.

Economic feasibility analysis

For economic feasibility evaluation, the following factors were considered (Zugarramurdi *et al*., 1995):

- Fixed capital was estimated by evaluating the factors *viz*, cost of investments including land, building as well as the machineries involved in the operation. The equipment employed in the hydrolysis process included a raw material washing unit, grinder/mincer, chemical reactor for hydrolysation, decanter, centrifuge, filtration and sterilisation unit, spray drier, packaging machine and effluent treatment unit. The volume or capacity of equipment was chosen in relation to the production yield per batch, assuming one ton raw material per day as the plant capacity.
- The process operation mode was set up as a batch process and the annual operation time was set at 7200 h (300 working days per annum), the typical annual operation time for a batch process (He *et al*., 2015).
- Working capital included raw material cost, salary/ wages for personnel, other utilities and contingencies and was calculated on monthly basis. Prevailing market scenario was considered for major assumptions with regard to the working capital elements.
- Net present value (NPV) is the present value of all future cash flows of a project. To calculate NPV, future cash flows are discounted in order to get the present value of each cash flow and sum of present values associated with each time period is considered.

$$NPV = \sum_{t=1}^{n} \frac{Rt}{(1+i)^t}$$

where, t = Number of years; Rt = Net return in the year t; i= Discount rate

The higher the NPV, the better the project in terms of economic/ financial viability.

- Internal rate of return (IRR), a measure used for assessing the economic/ financial feasibility of potential investments, is that discount rate which equates NPV to zero. It was calculated as:

$$NPV = \sum_{t=1}^{n} \frac{Rt}{(1+IRR)^t} = 0$$

- Benefit-cost ratio (BCR), an indicator showing the relationship between the relative costs and benefits of a proposed project, was calculated as:

$$BCR = \frac{\text{Discounted benefits}}{\text{Discounted costs}}$$

$$BCR = \frac{\sum_{t=1}^{n} \frac{Bt}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Ct}{(1+r)^t}}$$

where, Bt and Ct are the gross benefit and costs, respectively in the year t, r is the discount rate.

Results and discussion

Yield and protein recovery of bioactive peptides

A major desirable outcome expected out of any product is their commercial scale production exploring its maximum utilisation. However, most of the research outcomes are limited to laboratory levels and the disadvantages encountered during confined research is seldom rectified. The main factors hindering the upscaling of a process can be solved to a great extent by optimised process protocols. Optimisation is crucial to scientific decision making when analysing the operational systems with quantitative measures to assess a system’s qualitative performance. Several methods are employed in this regard, of which response surface methodology (RSM) enables optimisation to produce hydrolysate with required characteristics and is successfully applied to optimise seafood processing operations (Saidi *et al*., 2014; Halim *et al*., 2016). Previous standardisation conditions conducted for deriving antioxidant peptides with emphasis to protein recovery (Parvathy *et al*., 2020) were applied during further upscaling operations in the present study. Based on the study, an optimised output was obtained under an enzymatic hydrolytic condition employing papain *viz*, enzyme substrate ratio of 0.98% for 240 min at 60°C and 6.5 pH, with a desirability of 0.71.

The economic viability of a process is mainly defined by the final product yield obtained during the process. On an average, the protein content of the initial raw material was about 25% and a recovery of about 56% was observed on conversion to its hydrolysate. Since protein is the major element of interest in the hydrolytic process, its maximum recovery is desirable (Chalamaiah *et al*., 2012). The optimised hydrolytic conditions followed by subsequent filtration and centrifugation promoted the concentration of desirable protein in the derived sample with removal of other undesirable components like fat and minerals. Extended hydrolysis under optimised protocols resulted in papain to act more extensively on the substrate resulting in more recovery of protein into the hydrolysate solution (Haslaniza *et al*., 2010). However, sequential hydrolysis employing single or multiple enzymes can facilitate more protein recovery into the final solution (Binsi *et al*., 2016). Simultaneously, the yield was also influenced by the amount of protein recovered into the solution which was further spray dried to powder. The results of upscaling indicated a product yield of 12.4% from the raw material. This was much higher than those values reported by other lab-scale studies (Gajanan *et al*., 2016; Parvathy *et al*., 2016, 2018). Generally, these lower yields are mainly due to the factor that only soluble fractions are dried and further associated to the solid losses occurring during spray drying operation. Drying operations carried out under batch mode generally offer a lower yield while higher volumes of operation on continuous mode can give better yields. In general, studies suggested a yield ranging between 10-15% based on the substrate used as well as hydrolytic conditions and further drying methods adopted (Quaglia and Orban, 1990). Reports suggest yield as a key factor, which affects profitability of operations in fish plants (Montaner *et al*., 1994). Based on the yield studies, TPH production per batch was set as 124 kg considering a raw material processing of one ton per batch.

Economic feasibility analysis

Fixed capital

Fixed costs, defined as the expenses to be paid out irrespective of whether production occurs or not, includes the cost involved prior to production (in setting up of land, building and machinery) and yearly fixed costs. Land and building costs (Table 1) were evaluated based on the prevailing market conditions in the locality assessed through in-depth on-site studies conducted, focused group discussion and interviews. Further, the findings from the previous studies combined with the information collected with regard to the cost and operational information from equipment manufacturers concerning the specific volume/capacity and life expectancy of capital equipment were incorporated for the economic feasibility analysis. Montaner *et al*. (1995) explained the relevance of considering the locality while estimating the machinery cost wherein location differences occur in construction costs. Reports have suggested a constant relation between the cost of a plant and its primary equipment for analysing the capital investment which is reliant on the nature of the process, particularly the type of products manufactured (Lang, 1948). In addition to cost estimation by real time data collection used in the current study, other methods like use of cost capacity factor can be opted which is the scaling factor that relates the theoretical building models to predict cost involved in commercial scale versions. It has been used to scale up cost of major process equipments in seafood processing industry (Zugarramurdi *et al*., 1995; Goldsmith *et al*., 2003).

Working capital

For profitability or sustainability of a process, various factors are influential of which an initial and major factor is the availability of the appropriate quantity and quality of raw material at an affordable rate (Zugarramurdi *et al*., 2004; He *et al*., 2013). Further, Petrova *et al*. (2018) signified the relevance of evaluating raw materials critically at technological line to provide effective recovery of protein fraction. Based on the previous laboratory studies conducted, the purchase cost of raw material *viz*, tuna red meat was proposed at ₹30 kg^{-1}, in accordance with the maximum current whole sale price of the material in the Indian seafood industry (market analysis conducted by authors as on 2019). Currently major share of this raw material is either unutilised or used for the conversion to commodities like fertilisers and animal feed. Exploiting this proteinaceous source for alternative options like bioactive peptides having high market demand can bring a new outlook for this commodity. Generally, about 80% of the total production cost is contributed by working capital (variable cost) of which raw material cost has a major share and hence it impacts the profitability of an operation (Montaner *et al*., 1994; Zugarramurdi *et al*., 1995). Similarly, the cost of enzyme *viz*, papain used was also set based on the specificity, considering the brand and the prevailing market price. Further, the information collected from the industry during the period 2019, was used to estimate cost of labour, materials, other utility and contingency expenses for representative size operations (Table 1).

Table 1. Economic feasibility analysis of optimised tuna protein hydrolysate (TPH)

Particulars	Amount (₹)
Fixed capital	
Land and building	2000000
Machinery and equipment	20000000
Total	22000000
Working capital (per month)	
Personnel	300000
Raw material including packaging (Tuna red meat: 1000 Kg @ ₹30 kg^{-1} for 25 days; Papain: 10 kg @ ₹ 2500 kg^{-1} for 25 days; other packaging and miscellaneous charges)	1400000
Utilities (Electricity, water, diesel etc.)	150000
Other contingency expenses (Repair/maintenance, transportation, publicity, postage, insurance etc.)	100000
Total	1950000
Financial analysis	
Cost of production per annum	23477500
Turnover per annum	27900000
Net present value (₹)	63908381
Internal rate of return (%)	50
Break even point (Quantity, kg)	30,556
Benefit-cost ratio	1.26

Final product cost

Product pricing is regarded as a major challenge and a key parameter determining the business viability (Nicholson and Stephenson, 2007). Durham *et al*. (2015) reported the significance of collecting necessary information to determine a reasonable retail price so as to cover the production and marketing cost of the product. Product price was fixed based on the current market prices of the same products, or similar products taken as references. The commercial fish protein hydrolysate powders reported a wholesale selling price ranging from ₹250-300 kg^{-1} for crude hydrolysate intended for fertiliser application whereas the retail selling price was as high as ₹1000 kg^{-1}. Hydrolysate for high end pharmaceutical applications reported an average international market price of ₹2000 kg^{-1}, whereas in India, the hydrolysate price in domestic market ranged from ₹500 to 1000 kg^{-1}. Based on the market survey and our intended application, meant for food and pharmaceutical sector, an average price of ₹750 kg^{-1} was set as the selling price for the end product and economic indices were derived (Table 1).

Economic indices

Economic indices are measures which assist to understand the level of potential value of a product (Durham *et al*., 2015). The major indicators *viz*, NPV, IRR and BCR of the project was observed to be ₹63,908,381/-, 50% and 1.26, respectively. IRR is the discount rate that equates the discounted net benefit of the project as zero. Generally, as far as IRR is considered independently, the project with highest IRR is the selection criteria. The positive value of IRR reveals a low risk associated with the implementation of a project and further the high value highlights the economic viability of an investment (Chinnici *et al*., 2014). An IRR, which yielded higher than the opportunity cost of capital is the viability criteria. Studies on the analysis of economic feasibility in food industries *viz*, palm oil processing reported a range of IRR *viz*, 0.32 (32%) (Ohimain *et al*., 2014) and 0.29 (29%) (Olagunju, 2008). In comparison, a higher IRR observed in the current analysis must be the influence of inputs like raw material cost which was low on account of being an industrial byproduct and is presently not priced high in the market. On the other hand, the commercial fish protein hydrolysate powders are priced higher. The production facility is not land incentive as in the case of other fish processing facilities which require elaborate pre-processing and processing facilities. Simeh (2002) suggested net return to be influenced by other factors like the equipment maintenance and depreciation of assets, being a causal factor in cost. Benefit-cost ratio, defining the profitability after accounting for the time value of money, by considering the benefits and costs using variables involved in a project (Roberts, 2018) indicated a value greater than 1.0, delivering a positive net present value to the firm and its investors. However, BCR is suggested to be used as a tool in combination with other types of analysis for a well-informed decision (Pappalardo *et al*., 2017). A higher BCR was reported elsewhere in food industry (Ohimain *et al*., 2014). Studies indicated BCR to be boosted by increased capital, improved technology employing sophisticated methodology as well as equipment and skilled labour (Olagunju, 2008).

Sensitivity analysis assists in determining the effect of variations in system inputs on its performance and helps to understand the ability of the firm to withstand various risks and uncertainties. It determines the variations in outputs of a system to various sources of uncertainty in its inputs. The output is predicted as a function of the minimum and maximum possible input values keeping other variables constant (Coker, 2007; Balaman and Balaman, 2019). In the present study, sensitivity analysis was systematically done by assuming a sequence of progressive and regressive changes in the input data *viz*, product price, capital involved and discount rate, displaying the resulting changes to the project indices *viz*, NPV, IRR and BCR (Table 2). The sensitivity analysis indicated that the project yielded positive NPV, high (higher than the present bank rate) IRR and more than unity level of BCR. Further, it was observed that product selling price had a major influence on these economic indices deciding the profitability of the venture. Overall, the project appeared to be economically viable at potential levels of market risks and indicate profitability of producing TPH on an industrial scale, set under proposed set of conditions.

The present study attempted to analyse the feasibility of upscaling the optimised bioactive hydrolysates from yellowfin tuna cannery waste *viz*, red meat. The protocols previously identified for tuna protein hydrolysate with optimum antioxidant properties, in laboratory-scale evaluations, were used to model large-scale production in pilot facilities. Return on investment of the scaled-up processes was found highly dependent on the input variables namely, raw material cost as well as selling price of the product. The low raw material (tuna red meat) cost, on account of being an industrial byproduct and the premium price that consumers recognise for the hydrolysate based on its potential could guarantee an increased turnover making hydrolysate production economically feasible. The project is economically feasible in the context of potential market risks as well. Adoption of this technology would be highly useful for tuna processing industries, as the byproduct, tuna red meat generated from the processing operations can be utilised as starting raw material for peptide production, increasing profitability of the venture. Further, nutraceutical industry is a potential user of this technology as peptides find potential application in a variety of nutraceutical products. Moreover, this outcome could be used as baseline information for future research towards other fish waste commercialisation feasibility studies.

Table 2. Sensitivity analysis chart

Product selling price	NPV (₹)	BC	IRR (%)
Actual basis	63908381	1.26	50
-10%	33069435	1.13	26
-20%	2230489	1.01	02
10%	94747326	1.39	79
20%	125586272	1.51	119
Working capital			
Actual basis	63908381	1.26	50
-10%	65215024	1.27	56
-20%	66521668	1.27	64
10%	62601737	1.25	45
20%	61295093	1.25	41
Discount rate			
4%	67355156	1.25	47
5%	65602879	1.26	48
6% (Present)	63908381	1.26	50
7%	62270886	1.27	51
8%	60689368	1.27	53

Acknowledgements

Authors wish to thank Dr. C. N. Ravishankar, Director, ICAR-CIFT, Kochi for the support rendered and permission granted in publishing this article. First author also thank all scientific, technical and supporting staff of Mumbai Research Centre and Fish Processing Division of ICAR-CIFT for the assistance given in carrying out this work. Financial support from ICAR, New Delhi is also greatly acknowledged.

References

Balaman, S. Y. and Balaman, S. Y. 2019. Uncertainty issues in biomass-based production chains. In: Sebnem Yilmaz Balaman (Ed.), *Decision-making for biomass-based production chains: The basic concepts and methodologies*, Academic Press, Massachusetts, USA, p. 113-142.

Bierman Jr., H. and Smidt, S. 2012. *The capital budgeting decision: Economic analysis of investment projects,* 9th edn. Routledge, Taylor and Francis Group, UK.

Binsi, P. K., Viji, P., Panda, S. K., Mathew, S., Zynudheen, A. A. and Ravishankar, C. N. 2016. Characterisation of hydrolysates prepared from engraved catfish (*Nemapteryx caelata*) roe by serial hydrolysis. *J. Food Sci. Technol*., 53(1): 158-170.

Chabeaud, A., Dutournié, P., Guerard, F., Vandanjon, L. and Bourseau, P. 2009. Application of response surface methodology to optimise the antioxidant activity of a saithe (*Pollachius virens*) hydrolysate. *Mar. Biotechnol.*, 11(4): 445-455. DOI:10.1007/s10126-008-9158-x.

Chalamaiah, M., Hemalatha, R. and Jyothirmayi, T. 2012. Fish protein hydrolysates - Proximate composition, amino acid composition, antioxidant activities and applications: A review. *Food Chem.*, 135(4): 3020-3038. doi: 10.1016/j.foodchem.2012.06.100.

Cheremisinoff, P. N. 1995. *Waste minimisation and cost reduction for the process industries*. Noyes Publications, USA.

Chinnici, G., Pappalardo, G. and Pecorino, B. 2014. Economic evaluation of innovative solutions for food safety in cereal sector in Sicily. *Calitatea*, 15(S1): 41.

Coker, A. K. 2007. Cost estimation and economic evaluation. In: Kayode Coker, A. (Ed.), *Ludwig's applied process design for chemical and petrochemical plants*. Gulf Professional Publishing, Burlington, USA, p. 69-102.

Durham, C. A., Bouma, A. and Meunier-Goddik, L. 2015. A decision-making tool to determine economic feasibility and break-even prices for artisan cheese operations. *J. Dairy Sci.*, 98(12): 8319-8332. DOI:10.3168/jds.2014-9252.

FAO 2016. *The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all*. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Gajanan, P. G., Elavarasan, K. and Shamasundar, B. A. 2016. Bioactive and functional properties of protein hydrolysates from fish frame processing waste using plant proteases. *Env. Sci. Pollut. Res.*, 23(24): 24901-24911. doi: 10.1007/s11356-016-7618-9.

Galland, G., Rogers, A. and Nickson, A. 2016. *Netting billions: A global valuation of tuna*. The Pew Charitable Trust, Washington, DC, USA.

Goldsmith, P., Amankwah, F., Gunjal, K. and Smith, J. 2003. Financial feasibility of producing value-added seafood from shrimp waste in Quebec. *J. Aquat. Food Prod. Technol.*, 12(4): 39-61.

Guerard, F., Guimas, L. and Binet, A. 2002. Production of tuna waste hydrolysates by a commercial neutral protease preparation. *J. Mol. Catal. B: Enzym.*, 19: 489-498. DOI:10.1016/S1381-1177(02)00203-5.

Halim, N. R. A., Yusof, H. M. and Sarbon, N. M. 2016. Functional and bioactive properties of fish protein hydolysates and peptides: A comprehensive review. *Trends Food Sci. Technol.*, 51: 24-33. https://doi.org/10.1016/j.tifs.2016.02.007.

Haslaniza, H., Maskat, M. Y., Wan Aida, W. M. and Mamot, S. 2010. The effects of enzyme concentration, temperature and incubation time on nitrogen content and degree of hydrolysis of protein precipitate from cockle (*Anadara granosa*) meat wash water. *Int. Food Res. J.*, 17(1): 147-152.

He, S., Franco, C. and Zhang, W. 2013. Functions, applications and production of protein hydrolysates from fish processing co-products (FPCP). *Food Res. Int.*, 50(1): 289-297. DOI:10.1016/j.foodres.2012.10.031.

He, S., Franco, C. M. and Zhang, W. 2015. Economic feasibility analysis of the industrial production of fish protein hydrolysates using conceptual process simulation software. *J. Bioprocess Biotechnol.*, 5(1): 1.

Hou, Y., Wu, Z., Dai, Z., Wang, G. and Wu, G. 2017. Protein hydrolysates in animal nutrition: Industrial production, bioactive peptides, and functional significance. *J. Anim. Sci. Biotechnol.*, 8(1): 24. DOI:10.1186/s40104-017-0153-9.

Lang, H. J. 1948. Simplified approach to preliminary cost estimates. *Chem. Eng.*, 55: 112-113.

Montaner, M. I., Parin, M. A., Zugarramurdi, A. and Lupin, H. M. 1994. Inputs requirement in the fish industry, II: labor. *Alimentaria (Espana)*, 254: 81-85.

Montaner, M. I., Gadaleta, L., Parin, M. A. and Zugarramurdi, A. 1995. Estimation of investment costs in fish processing plants. *Int. J. Prod. Econ.*, 40(2-3): 153-161.

Nicholson, C. and Stephenson, M. 2007. *Financial performance value-added dairy operations in New York, Vermont and Wisconsin*. American Agricultural Economics Association Annual Meeting, 29 July - 1 August 2007, Portland, Oregon, USA.

Ohimain, E. I., Emeti, C. I., Izah, S. C. and Eretinghe, D. A. 2014. Small-scale palm oil processing business in Nigeria: A feasibility study. *Greener J. Bus. Manag. Stud.*, 4(3): 070-082.

Olagunju, F. I. 2008. Economics of palm oil processing in South-western Nigeria. *Int. J. Agric. Econ. Rural Dev.*, 1(2): 69-77.

Pappalardo, G., Chinnici, G. and Pecorino, B. 2017. Assessing the economic feasibility of high heat treatment, using evidence obtained from pasta factories in Sicily (Italy). *J. Clean. Prod.*, 142: 2435-2445.

Parvathy, U., Zynudheen, A. A., Panda, S. K., Jeyakumari, A. and Anandan, R. 2016. Extraction of protein from yellowfin tuna (*Thunnus albacares*) waste by enzymatic hydrolysis and its characterisation. *Fish. Technol.*, 53: 115-124.

Parvathy, U., Binsi, P. K., Zynudheen, A. A., Ninan, G. and Murthy, L. N. 2018. Peptides from white and red meat of yellowfin tuna (*Thunnus albacares*): A comparative evaluation. *Indian J. Fish.*, 65(3): 74-83. DOI: 10.21077/ijf.2018.65.3.78269-10.

Parvathy, U., Binsi, P. K., Joshy, C. G., Zynudheen, A. A., George, N. and Ravishankar, C. N. 2020. Antioxidant peptides from dark meat of yellowfin tuna (*Thunnus albacares*): Process optimisation and characterisation. *Waste Biomass Valori.*, 1-16.

Pasupuleti, V. K. and Braun, S. 2010. *State of the art manufacturing of protein hydrolysates*. In: Pasupuleti, V. K. and Demain A. L. (Eds.), *Protein hydrolysates in biotechnology*. Springer, New York, USA, p. 11-32.

Petrova, I., Tolstorebrov, I. and Eikevik, T. M. 2018. Production of fish protein hydrolysates step by step: Technological aspects, equipment used, major energy costs and methods of their minimizing. *Int. Aquat. Res.*, 10(3): 223-241.

Quaglia, G. B. and Orban, E. 1990. Influence of enzymatic hydrolysis on structure and emulsifying properties of sardine (*Sardina pilchardus*) protein hydrolysates. *J. Food Sci.*, 55(6): 1571-1573. DOI:10.1111/j.1365-2621.1990.tb03571.x.

Roberts, T. 2018. Benefit/cost analysis in public and private decision-making in the meat and poultry supply chain. In: Roberts, T. (Ed.), *Food microbiology and food safety - Practical approaches: Food safety economics - Incentives for a safer food supply*. Springer, Cham, Switzerland.

Rustad, T. 2003. Utilisation of marine by-products. *Electron. J. Env. Agric. Food Chem.*, 2(4): 458-463.

Saidi, S., Deratani, A., Belleville, M. P. and Amar, R. B. 2014. Antioxidant properties of peptide fractions from tuna dark muscle protein by-product hydrolysate produced by membrane fractionation process. *Food Res. Int.*, 65: 329-336.

Simeh, M. A. 2002. Factors affecting fluctuations in net returns from the processing of oil palm fruit bunches. *Oil Palm Ind. Econ. J.*, 2(1): 28-33.

Zugarramurdi, A., Parin, M. and Lupin, H. M. 1995. Economic engineering applied to the fishery industry. *FAO Fisheries Technical Paper 351*, Food and Agriculture Organisation of the United Nations, Rome, Italy.

Zugarramurdi, A., Parin, M. A., Gadaleta, L., Carrizo, G. and Lupin, H. M. 2004. The effect of improving raw material quality on product quality and operating costs: A comparative study for lean and fatty fish. *Food Control*, 15(7): 503-509. DOI:10.1016/j.foodcont.2003.08.001.

Date of Receipt : 07.01.2021

Date of Acceptance : 02.12.2021