FISH SIDE-STREAM AS A POTENTIAL PEPTONE PRODUCTION: TOWARDS ZERO WASTE FISH PROCESSING

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Abstract

Fish processing plants generated significant side-streams composing of heads, skins, trimmings, frames, and guts, which estimated for 70-85% of raw-fish materials during fillet and surimi production. These pose a serious impact to terrestrial and aquatic environments due to the abundance of organic content. Treating side-streams, on the other hand, would impact on financial burden of the fish processing industries. Therefore, an attempt is necessary to convert fish side-streams into value-added products. This is not only to reduce financial burden but also in accordance with the 12th Sustainable Development Goal (SDG) which support zero-waste processing concept. One of the promising products from fish side-streams is peptone. Peptone, a protein hydrolysate characterized as non heat-coagulable and water-soluble product, extensively used in microbiological media. As microbial growth accelerating media, fish peptone could be a precursor for beneficial metabolic products, such as antimicrobial peptides and other bioactive compounds. This review highlights the isolation of peptone from fish processing side-streams specifically the extraction and characterization. In addition, the metabolite productions from lactic acid bacteria with fish peptone-supplemented media are also covered.

Keywords: characteristics, fish side-stream, metabolite production, peptone

INTRODUCTION

The global fish production has been rising over recent year. According to [1], total production of fish was around 20 million tons (MT) in 1950, and rising up to around 178 MT in 2018 with represents 96.4 MT and 82.1 MT for capture and aquaculture production, respectively; in line with that, per capita consumption also increased to 20.5 kg in 2018 from 9.0 kg in 1961. Fish processing plant generated large quantity of fish side-streams, including head, skin, trimming, bone, fin, scale, viscera, and blood. Kim and Park [2] revealed the fish side-streams from industrial fish processing were about 70-85% of fish harvests. These constitute a serious concern due to the abundance of organic waste being disposed to the environment. On the other hand, treating side-streams as requirement from the regulating agency would result on financial burden to fish processors. Therefore, converting fish side-streams into value-added products is gaining considerable attentions from processors and researchers. Prior works have demonstrated that the side-streams from fish processing were able to be utilized as fertilizers, animal feeds, fish snacks, and biofuels. However, these products were considered as low valued-products [3].

There are other valuable products that could be generated from fish side-streams such as collagen, gelatin, and peptone. Peptone, a protein hydrolysate characterized as non heat-coagulable and water-soluble product, extensively used in microbiological media. Traditionally, peptone is produced from terrestrial animals and plants, due to essential reasons related to religious concerns, infectious diseases and genetically modified organism-based plant, as well as high commercial value. Hence, peptone from fish side-streams is an alternative for existing peptone products. Jaziri et al. [4] reported protein-rich peptones derived from parrotfish (*Scarus javanicus*) and grouper (*Epinephelus* *fuscoguttatus*) with good solubility and greater bacterial growth for Staphylococcus aureus and Escherichia coli compared to commercial peptone. Setijawati et al. [5] reported peptones isolated from head portion of river catfish *(Pangasius pangasius*) and catfish (*Clarias gariepinus*) which support higher bacterial growth and biomass than that of commercial peptone. Similarly Shirahigue et al. [6] reported peptones from cobia (*Rachycentron canadum*) and tilapia (*Oreochromis niloticus*) with combinations of different acid which increase the biomass production and bacterial growth of E. coli and S. aureus. e. Furthermore, Poernomo and Buckle [7] reported that peptone obtained from viscera of cowtail ray (*Trygon sephen*) supported E. coli, S. aureus, Bacillus subtilis, and Saccharomyces cerevisiae growth. Srikandace et al. [8] informed that crescent grunter (*Terapon jarbua*) peptone hydrolyzed by protease (papain) had a higher cell yield in E. coli than observed in gold standard peptone. Also, Husin et al. [9] showed that peptones from heads and viscera of sardine (*Sardina pilchardus*) and mackerel (*Rastrelliger kanagurta*) isolated by using protease (Alcalase and Protemax), and alkaline supported B. subtilis and S. cerevisiae. On the other hand, fish peptone could also support the growth rate of fastidious bacteria and interestingly produce various advantages of metabolic products production. For example, Vazquez et al. [10] found that hyaluronic acid could be produced from Streptococcus zooepidemicus in media supplemented with peptones from mussel and tuna. Another study by Vazquez et al. [11] exhibited that peptones from viscera of rainbow trout (*Oncorhynchus mykiss*), yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*) and squid (*Loligo vulgaris*), supplemented in media for lactic acid bacteria could also yield nisin and pediocin bacteriocins. Additionally, the anti-oxidative compound from Atlantic salmon viscera-based hydrolysate hydrolyzed using lactic acid bacteria (LAB) possessed [12].

Peptone is a commercially important protein-rich product for microbial media. As reported in the Report of Global Peptone Market (2019), the value of global peptone production in 2014 was approximately USD 262.0 million (M) and rose up to around USD 271.0 M in 2019. In the domestic market, as imported product, Indonesia spent around USD 12.15 M in 2012 for peptone and increases to USD 20.76 M in a year later 2013 from [13]. To fill this increasing demand, fish side-streams are potential raw materials for domestic peptone production. Besides the issue of great and increasing demand, they are also concern on the halal issue of commercial peptones [14] especially among the Muslim as stated in the halal assurance system on halal critical point in fermentation product. Fish peptone could be produced using enzyme-, alkaline- and acid-aided processes. In enzyme-assisted procedure, fish proteins will be cleaved into amino acids, which typically contain 2-20 amino acids. Meanwhile, alkaline- and acid-assisted extraction process possesses several advantages, including short extraction time, low cost, and applicable to industrial view point [15]. This paper presents the production of peptones from fish side streams and discusses the effect of enzyme-, alkaline- and acid-assisted extraction process for fish peptone production. The characterizations, including microbial test and metabolite productions from lactic acid bacteria with fish peptone-supplemented media are also covered.

EXTRACTION OF FISH PEPTONE AND PHYSICOCHEMICAL ATTRIBUTES

Peptone from fish side-streams can be isolated by using acid-, alkaline-, and protease-aided extraction process as summarized in Table 1. In principle, protein obtained from fish residues would be cleaved at the peptide bonds by applying specific cleavage substances (protease enzymes) or unspecific cleavage cutting (chemical solutions). For acid-assisted extraction method, several types of acid were used as hydrolysis agent for peptone production, including propionic, formic, lactic, citric, phosphoric, acetic, sulphuric,hydrochloric, either singly or in a combination of acids. But, among those substances, propionic and formic acids were widely applied in fish peptone production. For example, Jaziri et al. [4] studied the effect of propionic and formic acids (at ratios of 1:2, 1:3, and 1:4, v/v) on peptone derived from parrotfish (*S. javanicus*) and grouper (*E. fuscoguttatus*). In line with this, Setijawati et al. [5] used the same extraction methods for production of peptones from pangas catfish (*P. pangasius*) and catfish (C. *gariepinus*). Another acid combination has been used in peptone obtained from from viscera of cowtail ray (*T. sephen*) [7]. Meanwhile, a single acid solution was also applied in fish peptone production, as reported by Gildberg et al. [16] in the extraction of peptone from Atlantic cod (*Gadus morhua*) stomach by using formic and phosphoric acids. In addition to this, Pratomo et al. [17] Investigated the side-stream from threadfin beam head could be extracted by using single acid solution *viz*. propionic, formic, and citric acids for peptone production. Also, hydrochloric acid was added in the peptone extraction from head part of mackerel (*Scomber japonicus*) [14]. In the alkaline-aided extraction process, Najim et al. [18] Implemented sodium hydroxide in the solution containing marine fish viscera to produce peptone for bacterial growth. From these studies, the mixture of propionic and formic acids mostly give higher yield, protein content, and solubility value compared with single acid-assisted treatments (as showed in Table 1). These findings were recommended by many scientists by using the combination of propionic and formic acids; however, the ratio of acid mixture were in the range of 1:1 to 1:3 (v/v) with variation of concentration, pH, temperature, and time extraction were 1.5-35 (v/w), 4.2-7.0, 25-40ºC, and 6-10 days, respectively [4-7]. These organic acids used during peptone production process due to the fact that these organic acids are good preservative agent, support efficient autolysis, and provide good separation between aqueous soluble and oil rich fractions [16].

Besides chemical-assisted extraction, fish peptone can be hydrolyzed by adding protease enzymes. As reported by Kristinsson and Rasco [19], a viscera from Atlantic salmon (Salmo salar) was successfully hydrolyzed by alkaline protease. Another study used papain as protease-aided extraction applied in the by-products of yellowstripe sead (*Selaroides leptolepis*), skipjack tuna (*Katsuwonus pelamis*), and swamp eel (*Monopterus albus*) [20] [21] [22]. Furthermore, Tanuja et al. [23] hydrolyzed striped catfish (*Pangasianodon hypophthalmus*) frame meat by using alcalase and subsecuently peptone was produced. Last, Ovissipour et al. [24] used Protamex for pepton production obtaine from persian sturgeon (*Acipenser persicus*) viscera. Overall, fish side-streams could be utilized as valuable peptone through both chemical- and enzyme-assisted extraction methods. Through protease-aided extraction, the yield of end-products could be recovered and the results showed higher than those observed in the peptones extracted by using chemical-assisted procedure. It might be due to the action of protease enzymes, and as know that proteases play an important role during hydrolysis process with cleaving the peptide bonds of fish protein into a number of amino acids. But, to optimize yield of fish peptone, the optimal extraction condition should be selected by means of adjusting enzyme/substrate ratio, pH, temperature, and extraction time [25].

In term of solubility, as aforementioned that peptone is defined as a water soluble protein hydrolysate. Solubility is an important parameter of fish peptone and to meet this requirement, many researchers have been tested that fish peptones hydrolyzed by using both protease- and chemical-aided procedures possessed high solubility attribute. From example, Jaziri et al. [4] revealed the solubility values of fish peptones were 96.42 and 99.67% for grouper and parrotfish heads. Additionally, Tajuna et al. [23] reported that peptone from striped catfish (frame meat portion) exhibited solubility of more than 98%. Also, Nurhayati et al. [20] informed the peptone isolated from skipjack tune viscera showed high solubility (98.20%). The percentage of solubility depends on extraction process, storage time, and lipid content. Tatterson and Windsor [34] reveal that changes in protein solubility of fish peptone indicate the breakdown of protein to low molecular-weight peptides and free amino acids. The level of change decreases after 30 days of storage when 75 to 85% of the total nitrogen content has been solubilised. Additionally, protein solubilisation may be reduced with increasing lipid content of the fish, due to a reduction in enzyme diffusion, especially at temperatures below the melting point of the fat present [34].

Other important parameters for peptones are protein content and amino acid composition. The compositions of protein and amino acids of fish peptones are presented in Table 1-2. For instance, Jaziri et al. [4] reported peptones from head portion of grouper and parrotfish had respectively 86.64 and 86.67% of protein content. Another study from Setijawati et al. [5] found the protein contents of catfish and pangasius were 89.41 and 72.06%, respectively. In addition, Atlantic salmon viscera hydrolyzed by alkaline protease, the resulting peptone possessed approximately 88.39% of protein content [19]. A greater amount of protein contained in fish peptones, higher nitrogen source found in fish peptones. As a result, these fish peptones can be promising supplemented media for microbial culture. For amino acids composition, many scientists documented that amino acids contained in the fish peptones varied [4] [5] [6] [7] [25] and comparable to reference peptone (Oxoid). The variation of amino acids composition generally depends on several factors such as raw material, enzyme source, and hydrolysis condition [21]. Also, a number of amino acids contained in fish peptones contribute to microbial growth rate and biomass production [7].

Table 1. Procedure used, yield, protein content and solubility of fish peptone

Fish species	**Portion**	**Extraction used**	**Yield (%)**	**Protein content (%)**	**Solubility (%)**	**Reference**
Grouper (*E. fuscoguttatus*)	Head	Propionic & formic acids	3.45	86.64	96.42	[4]
Parrotfish (***S.** javanicus*)	Head	Propionic & formic acids	5.70	86.67	99.67	[4]
Threadfin bream (*Nemipterus* sp.)	Head	Propionic, formic & citric acids	1.70-3.87	6.27-8.12	-	[17]
Catfish (*C. gariepinus*)	Head	Propionic and formic acids	5.66	89.41	98.37	[5]
Mackerel (***S.** japonicus*)	Head	Hydrochloric acid	-	72.06	97.07	[14]
Atlantic cod (*G. morhua*)	Stomach	Phosphoric & formic acids	1.05-1.06	75.4-84.4	-	[16]
Marine fish	Viscera	Acid & alkaline	-	60.63-67.5	-	[18]
Atlantic salmon (***S.** salar*)	viscera	Alkaline protease	-	88.39	98.73	[19]
Skipjack tuna (*K. pelamis*)	Viscera	Papain	3.92-5.54	50.18	98.20	[20]
Yellowstripe scad (*S. leptolepis*)	By-products	Papain	-	74.19	96.74	[21]
Swamp eel (***M.** albus*)	fillet	papain	14.72	62.56	-	[22]
Striped catfish (*P. hypophthalmus*)	Frame meat	Alcalase	7.03-9.85	-	>98	[23]
Persian sturgeon (*A. persicus*)	viscera	Protamex	-	71.67	-	[24]

Table 2. Amino acid composition from fish peptone and commercial peptone (Oxoid)

Amino acid	**Grouper[1]**	**Parrotfish[1]**	**Catfish[2]**	**Pangasius[2]**	**Cobia[3]**	**Cowtail ray[4]**	**Rainbow trout[5]**	**Commercial peptone[4]**
Alanine	9.70	8.12	4.72	5.79	7.70	5.60	7.19	7.00
Arginine	7.59	5.86	5.32	5.86	7.30	6.30	5.97	6.20
Aspartic acid	6.39	7.21	7.97	5.47	9.60	7.40	9.78	7.50
Glutamic acid	9.97	9.11	12.83	10.05	15.60	14.50	13.89	11.60
Glycine	18.67	21.34	18.17	19.05	10.0	6.90	9.93	5.60
Histidine	2.24	1.90	1.58	1.30	2.60	2.90	2.20	1.50
Isoleucine	4.07	3.49	4.77	4.91	4.50	2.90	3.22	2.40
Leucine	7.32	6.54	8.45	8.57	7.60	5.40	7.09	5.00
Lysine	3.73	2.68	5.69	5.46	9.80	4.50	7.78	5.80
Phenylalanine	6.96	6.73	4.87	4.73	4.40	3.80	4.38	2.30
Proline	7.64	8.70	9.37	10.29	7.00	-	5.30	-
Serine	4.20	6.30	3.94	4.77	5.10	3.80	5.00	2.90
Threonine	4.86	5.68	4.78	5.91	4.20	4.30	4.38	2.60
Tyrosine	1.40	1.39	1.04	1.01	2.10	2.50	3.36	1.80
Valine	5.26	4.95	6.54	6.84	6.50	4.50	4.35	3.60

[1] [4]; [2] [5]; [3] [6]; [4] [7], [4][26]

MICROBIAL GROWTH AND BIOMASS PRODUCTION

To evaluate the quality peptone products, microbial growth test and biomass production are essential parameters for fish peptone development and these parameters are showed in Table 3. As supplemented microbial growth media, test of microbial growth rate both unfastidious and fastidious bacteria is most important in developing new alternative sources of media cultures. Numerous studies have been conducted to meet the attribute of selected media from a large variety of microorganism's species. Setijawati et al. [5] [14] evaluated that fish peptones from catfish, pangasius, and mackerel by-products exhibited higher bacterial (*S. aureus* and *E. coli*) growth rate compared with reference peptone media. Another study from Pratomo et al. [17] presented that threadfin bream peptone formulated in Luria-Bertani (LB) broth had superior growth rate in E. coli and S. aureus culture compared with reference peptone. Moreover, other microorganism tests, including E. coli, S. aureus, Aspergillus flavus, B. subtilis, and S. cerevisiae were tested by using peptone extracted from cowtail ray viscera and the results showed all formulated fish peptones have supported the growth of microorganism. Also, Vázquez et al. [25] proved that by-products from red scorpionfish and mackerel had potential peptones formulated in the media growth of fastidious bacteria, lactic acid bacteria (Pediococcus acidilacti) and the results performed that fish peptones could support growth performance of lactic acid bacteria. Meanwhile, most selected fish peptones in this study found that fish peptones had capability to support bacteria for biomass production, as reported by Jaziri et al. [4], Setijawati et al. [5], Shirahigue et al. [6], Pratomo et al. [17], Vázquez et al. [25], and Poernomo and Buckle [7]. It can be suggested that fish peptones could accelerate microbial growth rate and support biomass production due to abundance of protein content and more specifically amino acids composition; as subsequently, a number of nitrogen substances is utilized as an essential source for microbial growth. By understanding these characteristics, all peptones hydrolyzed from fish side-streams can act as a sustainable alternative for peptone production.

Table 3. Microbial growth and biomass production from fish peptone

Fish species	**Type of side-stream**	**Microbial used**	**Biomass production (mg)**	**Microbial growth exhibited**	**Reference**
Grouper (*E. fuscoguttatus*)	Head	*E. coli* & *S. aureus*	42.37-64.63	Higher than commercial peptone (CP)	[4]
Parrotfish (*S. javanicus*)	Head	*E. coli* & *S. aureus*	30.33-55.63	Better performance compered to CP	[4]
Threadfin bream (*Nemipterus* sp.)	Head	*E. coli* & *S. aureus*	44.00-62.40	Comparable to CP used in bacterial culture	[17]
Catfish (*C. gariepinus*)	Head	*E. coli* & *S. aureus*	37.59-57.59	Greater optical density (OD) than observed in CP	[5]
Pangasius (*P. pangasius*) (***S.** japonicus*)	Head	*E. coli* and *S. aureus*	35.53-59.31	Higher than commercial peptone	[5]
Mackerel (***S.** japonicus*)	Head	*E. coli*, *S. aureus, S. thyphi, & A. hydrophila*	54.15-76.85	Faster growth rate compared with CP	[14]
Tilapia (O. *niloticus*)	Side-streams	*E. coli and S. aureus*	26.30-65.90	Higher cell yield than found in CP	[6]
Atlantic cod (*G. morhua*)	Stomach	*V. anguillarum & C. divergens*	-	Comparable to formulated CP in microbial culture	[16]
Marine fish	Viscera	*P. aeruginosa & L. acidophilus*	-	Comparable to added CP in microbial culture	[18]
Cowtail ray (*T. sephen*)	Viscera	*E. coli, S. aureus, A. flavus, B. subtilis, & S. cerevisiae*	81.0-190.0	Better growth rate that investigated in CP	[7]
Skipjack tuna (*K. pelamis*)	Viscera	*E. coli and S. aureus*	-	Higher cell yield compared to CP media	[21]
Red scorpionfish (*S. scrofa*)	Head	*P. acidilacti*	1.37 g/L	Higher growth rate than that of CP	[25]
Mackerel (*S. scombrus*)	Skin & bone	*P. acidilacti*	1.53g/L	Comparable to the CP supplemented in media	[25]

METABOLITE PRODUCTION

As a potential candidate for microbial growth media, fish processing residues can also promote lactic acid bacteria (LAB) produce beneficial metabolic products such as acetic acid (AA), lactic acid (LA), hyaluronic acid (HA), bioactive compound, and even bacteriocins. These metabolites and the specific fish side-streams-formulated media are presented in Table 4. An example observed by [27], the metabolic products (HA and LA) were successfully generated from fed-batch fermentation by using S. zooepidemicus with media supplemented from peptones of shark and thornback ray side-streams. [10] combined new carbon and protein sources derived from respectively mussel wastewater and tuna peptone in the media of S. zooepidemicus, and the results increased production of LA and HA with a molecular weight of 2500 kDa. Through this finding, more importantly, the cost production could be reduced by more than 50%. Also, a recent work conducted by [26] reported that other peptones from several fish (blue whiting, red scorpionfish, mackerel, pouting, gurnard, grenadier, megrim, hake, boardfish, and Atlantic horse mackerel) by-products formulated in different LAB were higher in LA and AA production when compared with gold standard broth media (MRS). Besides organic acids production, some LAB strains produce a wide variety of antimicrobial peptides (bacteriocins) for instances Pediocin SA-1, Nisin, Sakacin A, Helvecitin J, Paracin 1.7, Lactococcin G, Pantaricin ASM1, and so forth. Among them, Nisin and Pediocin bacteriocins obtained from respectively Lactococcus lactis and Pediococcus acidilactici were investigated. The results exhibited higher bacteriocins production in media supplemented with fish viscera peptones (squid, yellowfin tuna, swordfish, and rainbow trout) than that of commercial media (MRS and BP) [28]. In addition, [29] used the peptone from Loligo opalescens squid pen as formulated media of P. acidilactici. As a subsequence, approximately 70% of Pediocin SA-1 could be generated and showed higher percentage of bacteriocin than formulated by MRS culture media. Another bacteriocin exploration from Lactobacillus sakei Lb 706 called Sakacin A that was produced with addition of tilapia viscera-based peptone and yielded around 500% of bacteriocin [30] Furthermore, [31] used Japanese cod protein powder formulated in the growth media of B. subtilis RB14 and performed about 4450 and 5050 mg/L of iturin A yielded in submerged fermentation (5% cod protein & 12% maltose) and in biofilm fermentation (5% cod protein & 15% maltose), respectively. On the other hand, some bioactive compounds were successfully gained through microbial hydrolysis in the media formulated by fish processing residues. For example, [12] studied the anti-oxidative compound from Atlantic salmon viscera-based hydrolysate and the result revealed LAB applied in the hydrolysis process had higher glutathione protection against oxidation compared to other hydrolysis agents (Flavourzyme & formic acid). Based on those valuable investigations, the fish side-streams after processing can be developed as potential biomaterials for metabolites production that may not only minimize environmental degradation, but also highly contribute to financial generations particularly in food and pharmaceutical viewpoints.

Table 4. Metabolite production from LAB with fish peptone-supplemented media

Metabolite production	Supplemented media	Findings showed	Reference
Lactic acid (LA) and acetic acid (AA)	Fish side-streams peptones from blue whiting, red scorpionfish, mackerel, pouting, gurnard, grenadier, megrim, hake, boardfish, and Atlantic horse mackerel	Higher production of metabolites (mainly LA) from *Lactobacillus plantarum, L. brevis, L. casei,* and *Leuconostoc mesenteroides* by using substituted fish side-streams peptones (around 87%) compared with MRS commercial broth media.	[26]
Lactic acid (LA)	Peptone from redfish (*Sebastes mantilla*)	High LA production by using 1% (w/w) lactic acid bacteria, 5% (w/w) lactose at 37^{o}C	[32]
Lactic acid (LA) &hyaluronic acid (HA)	Mussel wastewater and tuna peptone	High HA and LA productions were 2.46 and 30.83 g L^{-1}, respectively. HA has a high molecular weight of 2500 kDa. Also, this finding could reduce the production cost > 50%	[10]
Lactic acid (LA) &hyaluronic acid (HA)	Peptones from shark and thornback ray side-streams	Production of HA and LA increased when supplemented with fish side-stream peptones	[27]
Lactic acid (LA), acetic acid (AA) and bacteriocins	Seafood side-streams protein hydrolysates	Production of LA and AA was >60% and activity of inhibition against Gram-positive and -negative microorganisms, especially against *Listeria monocytogenes*	[32]
Pediocin SA-1	*Loligo opalescens* squid pen peptone	Higher production of pediocin SA-1 (70%) by *Pediococcus acidilactici* than that of commercial media (MRS)	[28]
Nisin and Pediocin	Viscera peptone from squid, yellowfin tuna, swordfish, and rainbow trout	Higher bacteriocins production in media supplemented with fish viscera peptone compared to the commercial media	[11]
Bacteriocin	Peptones from herring and mackerel	High inhibition against *Listeria innocua* observed by *Pediococcus acidilactici*	[33]
Iturin A	Japanese cod protein powder	Around 4450 and 5050 mg/L of iturin A yielded in submerged fermentation (5% cod protein & 12% maltose) and in biofilm fermentation (5% cod protein & 15% maltose)	[30]
Bacteriocin Sakacin A	Peptone from *Tilapia nilotica* Viscera	Hgh quantities of bacteriocins from *Lactobacillus sakei* Lb 706 up to 500% more than the quantity obtained using commercial media	[29]
Anti-oxidative peptide	Hydrolysate from Atlantic salmon viscera	Higher glutathione protection against oxidation compared to other hydrolysis agents (Flavourzyme & formic acid)	[12]

CONCLUSION & FUTURE PERSPECTIVES

Peptone from fish side-streams not only could reduce environmental pollution, but also generate additional income. As described in the paper, fish peptone could be used as supplement in culture media to accelerate microbial growth. More importantly, this peptone has also being proven as an essential material during microbial fermentation in producing beneficial metabolite such as organic acids, bacteriocins, and bioactive compounds. These metabolic products have wide application in food and nutraceutical industry; thus, through proper utilization of industrial fish side-streams, fish and seafood processing will implement to zero waste and sustainable production as illustrated in Fig. 1. At the end, this practice contributes to attain the 12th Sustainable Development Goal (SDG).

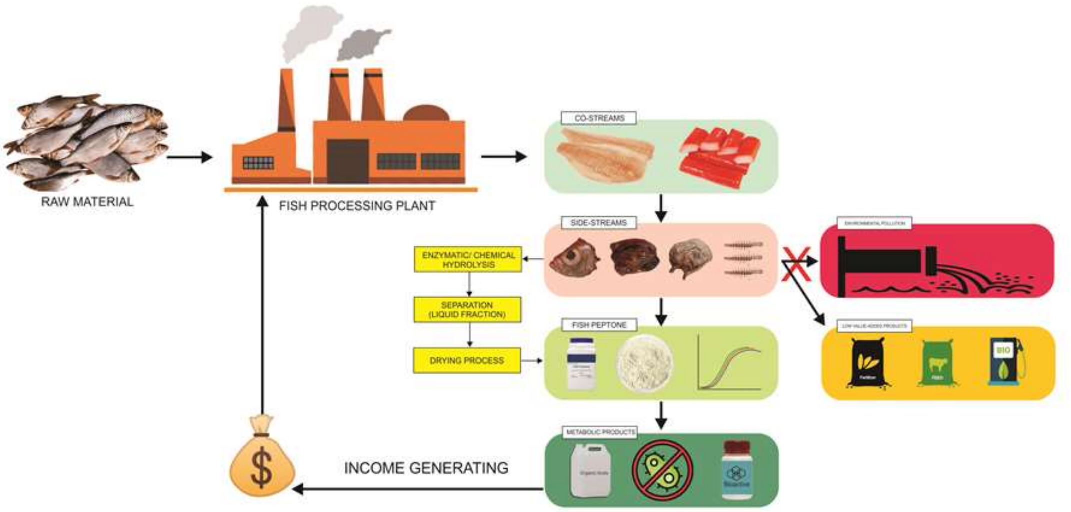

Figure 1. Zero waste concept for sustainable fish processing industry

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