Journal of Infrastructure, Policy and Development 2024, 8(11), 7418.
https://doi.org/10.24294/jipd.v8i11.7418

Article

Environmentally utilization and chemical analysis of catfish (*Pangasianodon hypophthalmus*) industrial waste

Suwondo Suwondo[1,*], Syahrul Syahrul[2], Irwan Effendi[3], Dewita Dewita[2]

[1] Environmental Sciences Department, University of Riau, Pekanbaru 28293, Indonesia
[2] Fishery Product Technology Department, University of Riau, Pekanbaru 28293, Indonesia
[3] Marine Sciences Department, University of Riau, Pekanbaru 28293, Indonesia
*** Corresponding author:** Suwondo Suwondo, suwondo@lecturer.unri.ac.id

CITATION

Suwondo S, Syahrul S, Effendi I, Dewita D. (2024). Environmentally utilization and chemical analysis of catfish (*Pangasianodon hypophthalmus*) industrial waste. Journal of Infrastructure, Policy and Development. 8(11): 7418. https://doi.org/10.24294/jipd.v8i11.7418

ARTICLE INFO

Received: 24 June 2024
Accepted: 24 August 2024
Available online: 9 October 2024

Abstract: Catfish (*Pangasianodon hypothalamus*) are known in Asia, specifically in Southeast Asia. Currently, this fish has been exported to almost all countries in the world. This research aimed to examine the existing conditions of the solid waste produced, analyze the chemical composition of the waste, and look for alternatives for the policy and economical use of waste in the catfish processing business. Using the survey method, data were gathered through measurement at the research location and laboratory, interviews with business owners, and field observations. Proximate analysis was conducted on pink slime meat, belly fat, bones, and fish innards. Analysis of acid number, saponification number, iodine number, and fat fatty acid was carried out on stomach fat. Meanwhile, amino acid analysis was carried out for pink slime meat. Handling catfish industrial waste has yet to be carried out properly, which causes a foul smell and disturbs the environment. The catfish industry waste's chemical content (protein, fat, water content, carbohydrates, and fatty acids) (pink slime meat, belly fat, fish bones, and innards) is still relatively applicable. The study processed fish waste into products like instant porridge, analogous fish sago rice, and fish sago noodles. The proximate analysis results of these products show figures that exceed the minimum standards for similar products.

Keywords: essential amino acids; fatty acids; catfish industry waste policy; fish oil; protein concentrate

1. Introduction

Catfish (*Pangasianodon hypothalamus*) is famous for its relatively short cultivation time using affordable capital and a reasonably broad market (Artar et al., 2022; Nguyen et al., 2023a). The fish is well known in Asia, specifically in Southeast Asia, such as Vietnam, Thailand, Indonesia, Malaysia, Cambodia, Burma, and Brunei Darussalam. Catfish cultivation occurs in floating net cages, ponds, and other media in the Mekong River and along the river basin. As of 2016, the area of catfish cultivation land reached 1.1 million hectares (Nhut et al., 2017). In Indonesia, catfish cultivation centers are spread across several regions, such as Jambi, Palembang, Riau, Lampung, South Kalimantan, and Central Kalimantan. The catfish export opportunities are still very wide open to all corners of the world. Domestic market needs are also increasing (Minh et al., 2019; Mustika, 2021).

Waste from the catfish industry can be used in various environmentally responsible ways. Utilization not only adds economic value but also lessens environmental effects. Processed fish, such as fish meal and oil, which can be processed as food for human consumption, livestock, fish, and others can be made from catfish waste. This trash can have its oil removed and turned into biodiesel, an eco-friendly alternative energy source. The by-products in the form of waste can be converted into compost or other organic fertilizer. Chitin and chitosan, which have numerous uses in agriculture, water treatment, and medicine, can be made from the skin and bones of catfish. Catfish waste will be transformed into biogas, a renewable energy source, through an anaerobic process. Waste catfish can be turned into fish silage and hydrolyzate, which can be added to animal feed. Collagen and gelatin, used in the food, cosmetic, pharmaceutical, and biotechnology industries, can be extracted from the skin and bones of catfish. Catfish waste contains some enzymes that can be recovered and used in various sectors, including detergents, medicines, and food processing (Bücker et al., 2020; Masilan et al., 2021; Madende and Hayes, 2020).

Inedible fish parts, including heads, bones, skin, and internal organs, are included in the waste. If this trash is not managed appropriately, it can lead to health and environmental issues. Water pollution can result from directly disposing of fish waste into bodies of water. This organic waste can disturb aquatic life, lower dissolved oxygen levels, and raise the biological load in waterways. Ammonia and other nitrogen compounds produced by the decomposition of fish excrement can harm aquatic life. Fish waste that has rotted releases an offensive smell that may make locals uncomfortable. Improper handling of fish waste can turn it into a haven for pests like mice and flies, which can infect people and animals. The fishing business may suffer financial losses as a result of inefficient fish waste management when potentially profitable by-products may not be fully used (Jaiswal et al., 2024; Renuka et al., 2019; Rocha-Pimienta et al., 2023).

Catfish-producing countries generally process all parts of the catfish. Skin waste is used as a collagen ingredient and is widely used in cosmetics. The remaining flesh is used for fish oil or protein concentrate. Also, catfish heads and bones are used to make fish meal. By-products or catfish waste can be processed into various products with economic value, such as fertilizer, flour, and chips. With this catfish processing system, Vietnam's total fish exports reached US $6.13 billion, of which around US $1.8–2 billion came from catfish exports (Minh et al., 2019; Mustika, 2021; Sadi and Yoga, 2021).

Some researchers evaluated extraction, refinement, and characterization to produce ω-3 rich oil from catfish processing waste. The fatty acid profile of processed catfish oil, on average, presents fractions of 32%, 34%, and 28% of total saturated, monounsaturated, and polyunsaturated fatty acids industries (Igansi et al., 2021) Sugata et al., 2019). Collagen generally comes from pigs or cows. They are used for various biomedical and pharmaceutical purposes, such as pain management related to osteoarthritis, hypertension, tissue engineering, and human implants. Collagen from catfish waste was analyzed. Based on the characteristics of catfish skin collagen, this waste material has the potential to be utilized in pharmaceutical and food (Dewita et al., 2021; Hadfi and Sarbon, 2019).

Processing catfish by-products on an industrial scale causes many problems related to environmental pollution. The by-products include part of the flesh, head, innards, spines, and skin and generally are discarded. Catfish have a fairly high oil content, so catfish waste has the potential to extract fish oil, which is rich in benefits. Fish oil generally contains unsaturated fatty acids, namely eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Febrianto and Sudarno, 2020; Nguyen et al., 2023a).

Processing catfish produces solid waste in the form of pink slime meat, tail and head bones, stomach fat, and viscera, which amounts to around 20%–67% of the total processed catfish. Most solid waste is thrown into the environment around the business location without any prior processing, causing negative effects (Maghfira et al., 2023).

Clean production is an environmental management effort that needs to be implemented continuously in the production process and product life cycle to reduce risks to humans and the environment. Implementing the clean production concept is hoped to reduce waste handling costs, reduce environmental damage, and bring profits to catfish processing businesses and the surrounding community (Rossi et al., 2022; Syahrul et al., 2019). This research aimed to examine the existing conditions of the solid waste produced, analyze the chemical composition of the waste, and look for alternatives for the policy and economical use of waste in the catfish processing business at the Fish Processing Technical Service Unit (FP-TSU), Kampar Regency, Riau, Indonesia.

2. Materials and methods

2.1. Time and place

This research was conducted from 2019 to 2022 at the Fish Processing Technical Service Unit (FP-TSU), Kampar Regency, Riau, Indonesia.

2.2. Raw material

The materials used in this research solid waste from fillet and smoked fish processing of catfish (*Pangasianodon hypophthalmus*). The waste was obtained from FP-TSU. The catfish used were consumption-size fish with a body weight of around 350–560 g per fish. The solid waste obtained is in the form of abdominal (stomach) fat, pink slime meat (meat left over from fillets on the bones), bones, and innards.

2.3. Research methodology

The research method used was a survey method, namely direct observation and measurement at the research location, interviews with business stakeholders, and field observations. The stakeholders included laborers (30), business owners (5), traders (3), aquaculture business owners (5), community leaders (5), ordinary citizens (30), and government officials (5). The things observed include production facilities and infrastructure, production work systems, environmental cleanliness and sanitation systems, waste storage areas, waste disposal channels, etc. Chemical analyses of catfish processing waste were also conducted in some Riau University laboratories. In this research, industrial solid waste included pink slime meat, abdominal fat, bone, and the innards of the catfish.

2.4. Environmental assessment

The ecological condition data observed is the location of the solid waste disposal site for catfish processing. In this research, the observation was conducted at the waste disposal site and water channel at FP-TSU. It included the general condition of facilities and infrastructure, environmental sanitation systems, waste storage areas, and waste disposal channels. Literature studies related to this research carried out data collection for economic, social, technological, and institutional aspects.

2.5. Analysis of pink slime meat

Pink slime meat is flakes extracted from bones resulting from fish fillet processing. This pink slime meat is a raw food, such as catfish protein concentrate. Adding protein concentrate to fish feed is useful for increasing the nutritional content of fish so that the fish become healthy and the fish's body weight increases. Fresh catfish measuring 0.7–1.0 kg per fish were filleted skin removed and then cut into small pieces. The meat is ground using a grinder with the addition of 0.5% salt. The crushed the meat is heated for 30 min and squeezed. Then, 0.5 N solution was added until the pH was isoelectric and a paste was formed. Extraction was carried out using isopropyl alcohol (1:3) as a solvent for 10 h so that a precipitate or residue was formed. The material was dried at 40–50 °C for 15 h in a cabinet dyer; after drying, the mix was blended and then floured using a 60 mesh sieve to obtain fish protein concentrate. The proximate composition was analyzed according to Nielsen (2010) and AOAC (2016).

The water content of raw materials from processed fish solid waste and its derivative products was analyzed as follows: 1) The cup that will be used is first placed in the oven for approximately 30 min at a temperature of 100–105 °C. 2) Cooled in a desiccator to remove water vapor and weighed (until the Weight is stable) (A g). 3) The sample is weighed as much as 2 g in a cup (B g). 4) Oven at 100–105 °C for 6 h. 5) Cooled in a desiccator for approximately 30 min and weighed (C g). 6) This stage is repeated until a constant weight is obtained. Water content is calculated using the formula:

$$\%\ \text{Water Content} = B - \text{C/B} - A \times 100\%$$

where: A = Weight of empty cup (g),

B = Weight of cup with sample (g),

C = Weight of cup with sample after drying (g).

Analyzing the ash content of raw materials from processed fish solid waste and derivative products is as follows: 1) The cup that will be used is first baked in the oven for approximately 30 min at 100–105 °C. 2) Cooled in a desiccator to remove water vapor and weighed (until weight stabilizes) (A g). 3) The sample is weighed as much as 2 g in a cup (B g). 4) Burn until there is no smoke and continue ashing in the furnace at a temperature of 550–600 °C until complete ashing (occasionally, the furnace door is opened slightly to allow oxygen to enter). 5) The ashed sample is cooled in a desiccator and weighed (C g). 6) The combustion stage in the furnace is repeated until a constant weight is obtained.

Ash content is calculated using the formula:

$$\%\ \text{Ash Content} = C - A/B - A \times 100\%$$

where: A = Weight of empty porcelain ash cup (g),

B = Weight of porcelain ash cup with sample (g),

C = Weight of porcelain ash cup with sample after dried (g).

Protein analysis includes several steps: digestion, distillation, and titration

(AOAC, 2016). Protein content values were measured using the micro-Kjeldahl method. Prepare 1 g of sample in a 100 mL Kjeldahl flask and mix with 0.25 g of selenium and 3 mL of concentrated H_2SO_4. The sample was ground at a temperature of 410 °C for approximately 1 h until the solution became clear. After cooling, add another 50 mL of distilled water and 20 mL of 40% NaOH to the Kjeldahl flask and distill at a temperature of 100 °C. The distillation results were collected and put into a 125 mL Erlenmeyer flask containing 10 mL of H_3BO_3 boric acid and two drops of blue and pink methyl bioaerosol indicator. The process is stopped when the distillate reaches 40 mL and changes color to green. Then, the distillate is titrated by mixing 0.1 N HCl until the color changes to pink. The titrant volume is recorded, then the blank solution is analyzed like a sample. This method is useful for viewing total nitrogen and protein content as % crude protein = % N × protein conversion factor (6.25).

Fat content analysis based on AOAC (2016). Place 5 g (W1) of sample on filter paper with the end of the package wrapped using absorbent cotton, put the wrapped sample into a constant weight oil bottle (W2), connect the Soxhlet tube, and close tightly. The grease shoes were placed into the Soxhlet tube extraction chamber, rinsed using benzene grease solvent, and heated until refluxed for 6 h. The grease solvent in the grease bottle is distilled until all the grease solvent has evaporated. During the distillation process, the solvent is placed into the extraction chamber and removed so that it does not return to the fat tank. The grease tank is dried at 105 °C; then the tank is cooled. The desiccator was returned to constant mass (W3), and the fat content was calculated.

Amino acids were analyzed by high-performance liquid chromatography, as mentioned by AOAC (2016), Buchberger and Ferdig (2004), Kaspar et al. (2008) and Rutherfurd and Gilani (2009). HPLC equipment and injection needles should be rinsed with eluent and distilled water for 2 to 3 h before use. There are 4 stages of the analysis process: the protein hydrolyzate production stage, drying stage, derivatization stage, injection stage, and amino acid analysis. Prepared protein hydrolyzate. Weigh 30 mg of the sample and grind it. Soil samples were acid hydrolyzed with 1 mL of 6N HCl and then heated at 110 °C for 24 h. The gas or air in the sample will disappear, and the hydrolysis reaction will speed up when heated on the stove.

Drying stage. The room temperature hydrolyzed sample was transferred into a 50 mL evaporation flask, rinsed with 2 mL of 0.01 N HCl, and the washing solution was added to the evaporation flask. This process is repeated 2–3 times. The sample was dried in a freeze dryer to convert cysteine to cystine, and 10–20 mL of water was mixed into the sample and dried in a freeze dryer. This process is also repeated 2–3 times. Derivatization step. The derivatization solution was added to the dry product in 30 µL. The solution was prepared with a mixture of OPA (o-paraldehyde) stock solution and potassium borate buffer (pH 10.4) in a ratio of 1:2. OPA stock solution was prepared by mixing 50 mg of OPA crystals in 4 mL of methanol and 0.025 mL of mercaptoethanol. The mixture was shaken slowly, and 0.050 mL of Brij-30 30 solution was added, followed by 1M borate buffer until the pH reached 10.4. This OPA reagent stock solution was stored at 4 °C in a dark bottle. This process is carried out so the detector can detect compounds in the sample. Next, dilution was performed by adding 20 mL of acetonitrile 60 or 1 M sodium acetate buffer, leaving for 20 min, and filtering using Whatman filter paper.

Injection into HPLC. The resulting filter was removed and injected into HPLC as much as 5 μL. The amino acid concentration is determined by making a standard chromatogram, and the sample has undergone the same treatment. The content in 100 grams of amino acids can be calculated using the following formula: amino acids = sample surface area × C × fp × BM × 100 μg standard sample weight area. Note: C = standard concentration of amino acids (g mol^{-1}). Fp = dilution factor; BM = molecular weight of each amino acid (g mol^{-1}). During amino acid analysis, the HPLC instrument was carried out at a room temperature of 27 ℃. HPLC column type = Ultra C-18 Technology Ball Column. Eluent flow rate = 1 min. Pressure = 3000 psi; mobile phase = sodium acetate buffer and methanol 95; detector = fluorescence and wavelength = 254 nm.

2.6. Abdominal fat analysis

Fish stomach fat is part of the waste from fish fillets and smoked fish processing. The food raw material produced from catfish stomach fat is catfish oil. Processing stomach fat into fish oil starts from roasting the stomach fat in a large skillet until the fat melts into oil. Crude oil must still be purified by degumming, neutralization, and bleaching. The crude oil is stirred first, weighed, and heated to 70 ℃. After that, put it in a separator flask and add 10–20 percent of the oil volume with hot water. Then let it sit for 10 min. After that, three layers will form: oil, gum, and water. Water and gum are removed from the separating flask.

Neutralization. The oil is weighed, heated to a temperature of 80 ℃, then caustic soda is added according to the calculation and stirred with a stirrer for 2 min. After three layers are formed, namely oil, soap stock and water, the soap and water are separated from the oil. The separation is stopped until the pH of the separating water becomes neutral.

Bleaching. The neutralized oil is weighed and heated to a temperature of 80–100 ℃. Add activated charcoal as much as 1 percent of the weight of the oil and stir for 10 min. Next, the acid number, saponification number, iodine number, and fatty acid (FFA) content were analyzed according to Xu et al. (2016).

2.7. Analysis of catfish bone content

Fish bones were obtained from fish fillet byproducts, and the flesh still attached to the bone was scraped off. These fish bones can be used as raw material for fish meal. The procedure for processing fish bone meal is as follows. First, the fish bones are washed thoroughly with running water and cut into small pieces, then boiled for 30–60 min at a temperature of 80 ℃. After that, soaked in 1.5 N NaOH solution for 2–3 h, then dried in a dryer at 80–100 ℃ for 4–6 h or until the water content is <10%. Then, it is crushed with a blender until smooth and sifted with an 80 mesh sieve to produce a catfish bone meal. The proximate composition was analyzed according to AOAC (2016) and Nielsen (2010), as mentioned in session 2.5.

2.8. Analysis fish innards

Innards solid waste was obtained from processing fish fillets and smoked fish. The material was washed thoroughly with running water, boiled at 80 ℃ for 60 min, and pressed to reduce the water content. The innards were then dried in a cabinet dryer for 3–4 h at a temperature of 100 ℃ to reach a water content of <10%. The dried innards were blended and floured with an 80 mesh sieve to obtain catfish innards flour. The proximate composition was analyzed according to Nielsen (2010) and AOAC, (2016), as mentioned in session 2.5.

2.9. Utilization of catfish processing waste

This research has processed catfish waste and used it as an ingredient for nutritional enrichment in products such as instant porridge products, analog fish sago rice, and fish sago noodles. The method used was as follows.

2.9.1. Instant fish porridge

The formulation of ingredients used in making instant fish porridge fortified with catfish protein concentrate is referred to as Dewita et al. (2015). The formula used is listed in **Table 1**.

Table 1. Instant fish porridge formula.

No.	Formula ingredients	Percentage
1.	Skim milk	50
2.	Gelatinized rice flour	30
3.	Catfish protein concentrate	10
4.	Sugar flour	5
5.	Vegetable oil	5

All the constituent ingredients were mixed homogeneously, then 1 liter of boiling water (temperature 100 ℃) was added step by step to the mixture and stirred homogeneously until it formed a paste. This porridge-shaped paste is put into an aluminum plate with a thickness of ±2 cm. Next, it was dried in an oven at 50–55 ℃ for 24 h. After drying, grinding, and sieving, 80 mesh is carried out to obtain instant porridge flour, then packaged in aluminum foil. The proximate composition was analyzed according to AOAC (2016) and Nielsen (2010), as mentioned in session 2.5.

2.9.2. Analog fish sago rice

The analog fish sago rice was fortified with fish protein concentrate and catfish oil. The ingredients and procedure for preparing the rice referred to Dewita et al. (2015) as listed in **Table 2**.

Table 2. Formulation of analog fish sago rice.

No.	Formulation ingredients	Percentage
1.	Sago flour	60
2.	Cornstarch	10
3.	Brown rice flour	15
4.	Catfish protein concentrate	10
5.	Catfish oil	3
6.	Chlorella flour	2

All the ingredients that make up the analog fish sago rice above were mixed homogeneously, and then enough water was added step by step into the mixture. Then, stir into a homogeneous dough. The dough that had been formed was put into an extruder with a rice mold to produce artificial rice (analog rice). The rice was dried in an oven at 50–60 °C for 5 h, then packaged in aluminum foil. Proximate analysis of analog fish sago rice content was carried out by referring to Nielsen (2010).

2.9.3. Fish sago noodles

The materials used in making analog fish sago noodles which were fortified with fish protein concentrate and catfish oil refer to Yusmarini et al. (2013), where the materials required are listed in **Table 3**.

Table 3. Formulation of catfish sago noodles.

No.	Formulation ingredients	Amount
1.	Sago flour (g)	300
2.	Wheat flour (g)	700
3.	Water (mL)	250
4.	Chicken eggs (mL)	120
5.	Catfish protein concentrate (g)	10
6.	Salt (g)	2

Preparing fish sago noodles started by rehydrating the fish protein concentrate with water, amounting to 20%–30% of the weight of the flour. After the fish protein concentrate was hydrated, all the formula ingredients were mixed using a mixer while stirring until the dough was evenly mixed. The dough that had been formed was put into a press to produce dough sheets. This dough sheet was steamed for 20 min, then cooled and molded using an electric ampia machine to form wet fish sago noodles. To make instant fish sago noodles, dry them for 1 h at a temperature of 110 °C so that instant fish sago noodles are produced. Proximate content analysis of the fish sago noodles was carried out by Nielsen (2010).

3. Results

3.1. Catfish solid waste treatments

FP-TSU is located in Koto Mesjid village, Kampar Regency, Riau Province, with an area of 3.6 Ha. The Postharvest Processing Center began operating in 2010. Koto Mesjid Village, District XIII Koto Kampar, has been designated a national catfish cultivation development cluster by the Ministry of Maritime Affairs and Fisheries (KKP) and the local government. When this research was carried out, production of cultivated catfish, according to local community leaders, reached 4–6 tons per day. The catfish processing business is dominated by fish-smoking companies (**Figure 1**), while the others are catfish fillets (**Figure 2**) and their derivatives, such as nuggets, meatballs, crackers, and shredded meat. Most catfish processing business activities are carried out at FP-TSU. FP-TSU was built by the central and regional governments of Indonesia.

Figure 1. Smoked catfish in FP-TSU.

Figure 2. Catfish fillet in FP-TSU.

Based on observations in the field, the condition of the existing production facilities at FP-TSU is that most facilities no longer function, except for the main office building and outdoor smoking building. Fish weighing 510–600 g are processed into catfish fillets while weighing 300–400 g are processed into smoked fish. The waste from processing this fish is swallowed meat, stomach fat, tail and head bones, and stomach contents (innards). For fillet processing, solid waste is produced in the form of tail and head bones as much as 101 g (18.18%), raw meat (fillet remains), which are still attached to the bones 67.5 g (12.15%), stomach fat 49.9 g (8.98%), offal 122.9 g (22.07%). Thus, the amount of solid waste produced from fillet processing is 50%. Meanwhile, in smoked catfish processing activities, the solid waste produced consisted of 34 g (9.71%) of stomach fat and 94.7 g (10.16%) of stomach contents (innards).

Until now, this solid waste has not been widely used, especially for needs as raw material for food and feed. The solid waste produced still needs to follow standard operating procedures (SPO) because the solid waste produced has yet to be sorted and contained to accommodate the waste. This solid waste is only stored in small plastic baskets with holes, so some can spill out. The resulting solid waste is left scattered on the floor and then rinsed with water so that the solid waste is scattered on the floor, and some of it is washed into the sanitation ditch. This causes solid waste to accumulate in one place (former fish ponds and empty land). Generally, this processed waste is immediately disposed of into the fish processing environment's TSU. Until now, this solid waste has not been widely used, especially as raw material for food and feed.

The handling of solid waste in the research location still needed to have standard operational procedures. The solid waste produced needs to be sorted, and the storage containers are not standard. Generally, solid waste is collected in plastic baskets with holes so that the contents spill onto the floor, and when cleaning the floor, the washing water is channeled into the ditch (**Figure 3**). So far, solid waste has been dumped into former fish ponds and empty land at the FP-TSU location.

Figure 3. Handling of solid waste in FP-TSU.

3.2. Analysis of pink slime meat

The research showed that the protein content of catfish meal from pink slime meat was 75.31%, the water content was (8.86%), and the fat content was low, namely around 6.34% (**Table 4**). In this way, the fish protein concentrate produced can be used as raw material for food, especially snacks. Furthermore, the results of the analysis of the amino acid composition contained in catfish protein concentrate contain all types of essential amino acids (9 types) needed by the human body, such as leucine, isoleucine, lysine, valine, threonine, phenylalanine, tryptophan, methionine and threonine (**Table 5**).

Table 4. Proximate analysis of catfish protein concentrate (%).

No.	Proximate content	Sample 1	Sample 2	Sample 3	Average	STDEV
1.	Proteins	74.53	74.65	76.85	75.34	1.30
2.	Fat	6.61	6.22	6.18	6.33	0.23
3.	Ash	5.25	5.84	5.89	5.66	0.35
4.	Crude fiber	3.78	3.86	3.86	3.83	0.04
5.	Water	9.08	8.52	8.88	8.82	0.28

Table 5. Amino acid concentration (%) of catfish protein concentrate.

No.	Amino acid	Sample 1	Sample 2	Sample 3	Average	STDEV
1	Leucine	7.01	6.04	6.01	6.35	0.56
2	Valine	3.88	4.22	4.44	4.18	0.28
3	Lysine	6.93	7.12	7.32	7.12	0.19
4	Threonine	2.89	3.95	3.92	3.58	0.60
5	Methionine + Cystine	3.55	2.24	2.42	2.73	0.710
6	Tyrosine + Phenylalanine	3.19	2.92	3.45	3.18	0.265
7	Tryptophan	0.19	0.08	0.02	0.09	0.086
8	Aspartic acid	7.98	8.16	8.15	8.09	0.11
9	Glutamic acid	11.94	12.54	12.51	12.33	0.33
10	Serine	2.96	3.13	3.12	3.07	0.09
11	Histidine	2.01	1.72	2.06	1.93	0.18
12	Glycine	2.81	2.95	2.92	2.89	0.07
13	Arginine	5.17	5.16	5.18	5.17	0.01
14	Alanine	4.84	4.62	4.42	4.62	0.21
15	Phenylalanine	3.2	3.21	3.32	3.24	0.06
16	Isoleucine	3.96	4.76	4.66	4.46	0.43

3.3. Abdominal fat analysis

Stomach fat solid waste amounts to around 8%–10%. Large fish over 1 kg tend to have a relatively low belly fat percentage. This stomach fat is further processed into fish oil and analyzed (Endo, 2018; Syahrul et al., 2023). The peroxide and free fatty acid (FFA) numbers (**Table 6**) of the catfish oil produced are still low, meaning it still meets the quality standards permitted by the International Fish Oil Standards (Indah et al., 2022).

Table 6. Chemical index of catfish abdominal fat of fish oil.

No.	Chemical index	Unit	Sample 1	Sample 2	Sample 3	Average	STDEV
1.	Acid index	mgKOH/g fat	0.44	0.58	0.42	0.48	0.08
2.	Peroxide index	meq/kg	7.41	7.32	7.34	7.35	0.04
3.	Iodine index	g/100g	4.76	4.86	4.96	4.86	0.10
4.	FFA	% w/w	0.68	0.88	0.96	0.84	0.14
5.	Saponification index	mgKOH/g fat	179.88	181.22	180.22	180.44	0.69

3.4. Chemical analysis of catfish bones

Fishbone solid waste is obtained from processing catfish fillets, which leave the tail bones and fins. This waste is utilized to obtain raw material for catfish bone meal. This waste cannot be used for food products, but if further processed, it can be used as a source of raw material for gelating gelatinized rice flour catfish protein concentrate (**Table 7**).

Table 7. Proximate composition of catfish bone meal.

No.	Proximate content	Amount (%)
1.	Water	6.43
2.	Ash	66.80
3.	Fat	2.16
4.	Proteins	12.08
5.	Calcium	12.53

3.5. Chemical analysis of fish innards

Innards waste from catfish is obtained from processing fish fillets and smoking, where the most significant amount comes from smoking fish. The protein content of catfish innards meal is relatively high, namely 60.21% (**Table 8**), which means it is perfect as a raw material for fish and poultry feed.

Table 8. Proximate content of catfish innards flour (%).

No.	Proximate content	Sample 1	Sample 2	Sample 3	Average	STDEV
1.	Proteins	59.98	60.42	60.22	60.20	0.22
2.	Fat	28.82	29.52	30.11	29.48	0.64
3.	Ash	2.82	2.86	2.84	2.84	0.02
4.	Fiber	2.12	2.16	2.16	2.14	0.02
5.	Water	6.79	6.22	6.24	6.42	0.32

3.6. Instant porridge

Instant porridge fortified with fish protein concentrate in this study showed good results, with the protein content around 18.54% and the fat content around 10.34%. Ash content and grade also indicate good quality (**Table 9**).

Table 9. Proximate analysis of instant porridge fortified with catfish protein concentrate.

No.	Proximate content	Amount (%)	Standard (GRI, 2004)
1.	Water	5.91	5%–10%
2.	Fat	10.34	Minimum 10%
3.	Proteins	18.54	Minimum 15%
4.	Ash	2.41	Maximum 5%
5.	Carbohydrate	63.43	-

3.7. Analog fish sago rice

Analog fish sago rice is made from 60% sago flour, 20% corn, and 20% brown rice (**Table 10**) and is fortified with fish starch protein concentrate. This rice has a proximate composition that meets the requirements, where the fat, ash, and carbohydrate content of fish sago rice is relatively no different from paddy rice; even the water and protein content is better than paddy rice.

Table 10. Proximate fish sago rice fortified with catfish protein concentrate.

No.	Proximate content	Sago rice (%)	Paddy rice (%)
1.	Water	10.24	12.50
2.	Fat	0.35	0.92
3.	Proteins	12.75	8
4.	Ash	1.17	1.31
5.	Carbohydrate	71.41	89.86

3.8. Fish sago noodles

The proximate composition of fortified fish sago noodles and fish protein concentrate is better than regular sago noodles. The fat, ash, and carbohydrate content of fish sago noodles was relatively no different, but the water and protein content was better than regular sago noodles (**Table 11**).

Table 11. Proximate analysis (%) of wet sago and fish noodles.

No.	Proximate content	Wet SN (%)	Wet FSN (%)	Dry FSN (%)
1.	Water	29.85	24.15	9.48
2.	Proteins	0.60	3.96.	10.42
3.	Fat	0.30	0.79	1.65
4.	Ash	4.09	1.32	6.24
5.	Carbohydrates	62.56	70.26	72.21

SN = sago noodles; FSN = fish sago noodles.

4. Discussion

4.1. Catfish solid waste treatment issues

Sanitation of fishing industry waste is very important to prevent environmental pollution and maintain public health. Solid waste is collected regularly. Solid waste can be processed into value-added products. Waste that cannot be utilized must be disposed of safely and in accordance with applicable regulations. Before entering the processing system, liquid waste must be filtered to separate solid particles. Sedimentation or flotation aims to remove suspended solids and oil. Biological processes such as aerobic lagoons or anaerobic reactor systems are intended to break down organic materials. Additional processes such as filtration or disinfection can serve to remove harmful substances before they are released into the environment. Effective implementation of this will help reduce the negative impacts of the fishing industry on the environment and public health (García et al., 2005; Ibrahim et al., 2023).

Handling the negative impacts of industrial waste can also be implemented in terms of compliance with government regulations. The government can evaluate that all aspects of waste management comply with government regulations. Carry out routine monitoring of waste quality and report it to the relevant authorities. Provide training to employees on the importance of sanitation and waste management procedures. Encourage environmental awareness among employees and the surrounding community. Effective implementation of these measures will help in reducing the negative impacts of the fish industry on the environment and public health (Masilan et al., 2021; Renuka et al., 2019).

The fish waste processing policy in Indonesia aims to reduce negative environmental impacts and society and encourage the reuse of waste into value-added products. Government Regulation of Indonesia No. 82 of 2001 concerns water quality management and pollution control. This regulation sets wastewater quality standards the fish processing industry must meet before being discharged into the environment. Regulates permits for wastewater discharge and the obligation to monitor wastewater quality. This policy aims to ensure that the fish processing industry in Indonesia can operate in an environmentally friendly manner, meet quality standards, and support the sustainability of natural resources. Ministerial Decree of Ministry of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 concerns Wastewater Quality Standards for Fish Processing Businesses and Activities. This regulation sets wastewater quality standards that the fish processing industry must meet. The industry requires treating wastewater before it is discharged into water bodies (GRI, 2001; REFR, 2016).

Minister of Maritime Affairs and Fisheries Regulation No. 52/PERMEN-KP/2016 has regulated the technical requirements for processing fishery products and guaranteeing the quality and safety of fishery products. Regulates technical requirements for fishery product processing, including waste management. It requires the industry to have adequate waste processing facilities. Republic of Indonesia Law No. 32 of 2009 concerns environmental protection and management. The regulation requires all industrial activities, including fish processing, to comply with environmental protection principles. It regulates environmental impact analysis for the fish processing industry, which has the potential to pollute the environment. This regulation also encourages the fish processing industry to utilize waste for value-added products, such as animal feed, organic fertilizer, or other products. The government incentivizes industries that use environmentally friendly waste management technology (RMMAF, 2016; RIL, 2009).

4.2. Chemical analysis of catfish industrial waste

The results showed that the protein content of catfish meal made from pink slime meat was relatively high (75.31%), the water content (8.86%), and the fat content (6.34%) were low. The results of the analysis of the amino acid composition contained in catfish protein concentrate contain all types of essential amino acids (9 types) needed by the human body, such as leucine, isoleucine, lysine, valine, threonine, phenylalanine, tryptophan, methionine, and threonine. Thus, fish protein concentrate produced from pink slime meat can be used as a raw material for food, especially snacks (Kumoro et al., 2022; Sokamte et al., 2020).

According to Yaqin et al. (2021), the type of amino acids that make up protein determines the quality of the protein in a food ingredient. The human body needs amino acids, primarily essential amino acids. Because the human body cannot produce essential amino acids, they must be obtained from food.

Stomach fat waste can be further processed into fish oil. The peroxide and free fatty acid (FFA) numbers of the produced catfish oil are still low, meaning they meet the permitted quality standards. International Fish Oil Standards (Indah et al., 2022) state that oxidation parameter values that comply with the standard include a peroxide value (PV) ≤5.00 meq/kg and a free fatty acid number ≤1.50%. In this way, the fish oil produced is still good and meets the quality standards for sound quality fish oil (Amri et al., 2021; Nurilmala et al., 2018).

Fishbone waste is obtained from processing catfish fillets, which leave behind tail bones and fins. Solid fish bone waste is utilized to obtain raw material for bone meal. The parameters measured in this study were water, ash, fat, protein, and calcium content. This waste cannot be used for food products, but if further processed, it can be used as a source of raw material for gelatin (Oktaviani et al., 2022).

Innards waste is obtained from processing fish fillets and smoked fish. The protein content of catfish innards meal is relatively high, namely 60.21%, meaning it is perfect as a raw material for fish and poultry feed. The application of innards flour in making pellet feed produces pellets with a protein content of around 33.88%, fat 5.4%, water 8.13%, ash 3.07%, crude fiber 2.92%, and carbohydrates 45.19% (Truong, 2021).

4.3. Utilization of catfish industry waste

In waste management, recovery is an effort to take materials that still have high economic value from waste and then process them into products as raw materials for the food and feed industry. The recovery that can be done for fish waste is to use this waste into fish protein concentrate, innards fish meal, bone meal, and fish oil with quality that meets standards. Then, it can be used as raw material for the food and feed industry (Wiyono and Dewi, 2023).

In catfish processing businesses, fish bone waste can be reused as a bone meal and a source of gelatin. Extraction of bone meal as a source of gelatin from fish bones is an effort to utilize waste from fish processing businesses, namely from filet processing (Santoso and Atma, 2020). So far, fish bones as waste have yet to be utilized optimally. Namely, they are only used as ingredients for making feed or fertilizer, so their economic value is minimal.

In this study, instant porridge fortified with fish protein concentrate (FPC) showed promising results in protein, fat, ash, and carbohydrate levels. Porridge is a form of processed food that is easy for people to consume because porridge has a soft texture and is easy to digest. According to SNI 01-4321-1996 (ISN, 1996), instant porridge is an instant dry processed product made from meat, fish, vegetables, cereals, or a mixture with or without additional permitted food ingredients. One of the instant porridge products being developed is instant porridge fortified with catfish protein concentrate.

Based on standard (SNI 01-4321-1996), instant porridge fortified with FPC catfish meets quality standards as a complementary food for breast milk for babies (under two years), especially its protein content. High-quality protein is essential for babies for the formation of new tissue, enzymes, antibodies, and other functions in the body (Gan et al., 2017).

Analog fish sago rice made from sago flour, corn, and brown rice has a proximate composition that meets the requirements. Fish sago rice's fat, ash, and carbohydrate content is no different from paddy rice, but the water and protein content are even better than paddy rice at 6.61%–9.34% (Shi et al., 2022). Thus, analog fish sago rice fortified by FPC catfish has good nutritional value. Proximate fortified sago fish noodles and protein concentrate are relatively better quality than regular ones. Fish sago noodles' fat, ash, and carbohydrate content is similar to rice noodles or even better. Wet sago noodles without fish protein concentrate catfish have a shallow protein content (0.6%). This condition is one of the limiting factors for developing sago-based food products (Yusmarini et al., 2013). Furthermore, sago noodles that are fortified with fish protein concentrate catfish can increase the protein content to 3.96% (wet) and 10.42% (dry).

5. Conclusion

The handling of catfish industrial waste has not been carried out properly and is not environmentally friendly in FP-TSU, Kampar Regency, Riau, Indonesia. The chemical content (protein, fat, water content, carbohydrates, and fatty acids) of catfish industry waste (pink slime meat, belly fat, fish bones, and innards) is still relatively useful. The fish waste can be used as an ingredient in some products like instant porridge, analogous fish sago rice, and fish sago noodles. The results of proximate analysis of these products show figures that exceed the minimum standards for similar products, so this is a development challenge in the future.

Author contributions: Conceptualization, SS (Suwondo Suwondo) and SS (Syahrul Syahrul); methodology, SS (Syahrul Syahrul); software, IE; validation, SS (Suwondo Suwondo), SS (Syahrul Syahrul) and IE; formal analysis, SS (Suwondo Suwondo); investigation, DD; resources, SS (Suwondo Suwondo) and DD; data curation, SS (Syahrul Syahrul), IE; writing—original draft preparation, SS (Suwondo Suwondo), SS (Syahrul Syahrul), IE; writing—review and editing, SS (Suwondo Suwondo); visualization, DD; supervision, IE; project administration, DD; funding acquisition, SS (Suwondo Suwondo). All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

Amri, U., Diharmi, A., & Sukmiwati, M. (2021). Characteristics of catfish oil, red palm oil and shark liver oil as functional foods. Depik, 10(2), 151–160. https://doi.org/10.13170/depik.10.2.19131

AOAC. (2016). Guidelines for Standard Method Performance Requirements. Available online: https://www.aoac.org (accessed on 30 May 2024).

Artar, E., Olgunoglu, M. P., & Olgunoglu, İ. A. (2022). Mineral Contents and Fatty Acids Compositions of Fillets of Female and Male Pangas (Pangasıus Hypophthalmus, Sauvage 1878) Cultured in Turkey. Progress in Nutrition, 24(3), e2022056. https://doi.org/10.23751/pn.v24i3.12382

Buchberger, W., & Ferdig, M. (2004). Improved high-performance liquid chromatographic determination of guanidino compounds by pre-column dervatization with ninhydrin and fluorescence detection. Journal of Separation Science, 27(15–16), 1309–1312. https://doi.org/10.1002/jssc.200401866

Bücker, F., Marder, M., Peiter, M. R., et al. (2020). Fish waste: An efficient alternative to biogas and methane production in an anaerobic mono-digestion system. Renewable Energy, 147, 798–805. https://doi.org/10.1016/j.renene.2019.08.140

Dewita, D., Syahrul, S., Desmelati, D., Lukman, S. (2015). Innovation on street food products (instant porridge and cookies) based on fortified patin fish protein concentrate with red palm oil and encapsulated oil fish. Jurnal Pengolahan Hasil Perikanan Indonesia, 18(3), 315–320. https://doi.org/10.17844/jphpi.v18i3.11215

Dewita, D., Syahrul, S., Irasari, & Sumarto. (2021). Characteristics of Oil Mixed Red Palm Oil with Catfish Oil (Pangasius hypothalmus). IOP Conference Series: Earth and Environmental Science, 695(1), 012051. https://doi.org/10.1088/1755-1315/695/1/012051

Endo, Y. (2018). Analytical Methods to Evaluate the Quality of Edible Fats and Oils: The JOCS Standard Methods for Analysis of Fats, Oils and Related Materials (2013) and Advanced Methods. Journal of Oleo Science, 67(1), 1–10. https://doi.org/10.5650/jos.ess17130

Febrianto, R., & Sudarno, S. (2020). Fish Oil Production Process from Waste Catfish (Pangasius Pangasius) in Balai Besar Pengujian Penerapan Hasil Perikanan (BBP2HP) East Jakarta. Journal of Marine and Coastal Science, 9(2), 65. https://doi.org/10.20473/jmcs.v9i2.20251

Gan, J., Bornhorst, G. M., Henrick, B. M., et al. (2017). Protein Digestion of Baby Foods: Study Approaches and Implications for Infant Health. Molecular Nutrition & Food Research, 62(1). https://doi.org/10.1002/mnfr.201700231

García, A. J., Esteban, M. B., Márquez, M. C., et al. (2005). Biodegradable municipal solid waste: Characterization and potential use as animal feedstuffs. Waste Management, 25(8), 780–787. https://doi.org/10.1016/j.wasman.2005.01.006

Hadfi, N. H., & Sarbon, N. M. (2019). Physicochemical properties of silver catfish (Pangasius sp.) skin collagen as influenced by acetic acid concentration. Food Research, 3(6), 783–790. https://doi.org/10.26656/fr.2017.3(6).130

Ibrahim, I. D., Sadiku, E. R., Hamam, Y., et al. (2023). Recent Recycling Innovations to Facilitate Sustainable Packaging Materials: A Review. Recycling, 8(6), 88. https://doi.org/10.3390/recycling8060088

Igansi, A. V., da Silva, P. P., Engelmann, J. I., et al. (2021). Techno-Economic Analysis of Producing Oil Rich in ω-3 from Catfish Processing Wastes. Waste and Biomass Valorization, 13(1), 707–717. https://doi.org/10.1007/s12649-021-01502-1

Indah, I., Rohman, A., & Lestari, L. A. (2022). Physicochemical Characterization Patin Fish Oil (Pangasius micronema) Is Refined Using Bentonite and Activated Carbon. Journal of Food and Pharmaceutical Sciences, 626–633. https://doi.org/10.22146/jfps.4682

Jaiswal, K. K., Dutta, S., Banerjee, I., et al. (2024). Valorization of fish processing industry waste for biodiesel production: Opportunities, challenges, and technological perspectives. Renewable Energy, 220, 119601. https://doi.org/10.1016/j.renene.2023.119601

Kaspar, H., Dettmer, K., Gronwald, W., et al. (2008). Advances in amino acid analysis. Analytical and Bioanalytical Chemistry, 393(2), 445–452. https://doi.org/10.1007/s00216-008-2421-1

Kumoro, A. C., Wardhani, D. H., Kusworo, T. D., et al. (2022). Fish protein concentrate for human consumption: A review of its preparation by solvent extraction methods and potential for food applications. Annals of Agricultural Sciences, 67(1), 42–59. https://doi.org/10.1016/j.aoas.2022.04.003

Madende, M., & Hayes, M. (2020). Fish By-Product Use as Biostimulants: An Overview of the Current State of the Art, Including Relevant Legislation and Regulations within the EU and USA. Molecules, 25(5), 1122. https://doi.org/10.3390/molecules25051122

Maghfira, A. N., Patmawati, P., Pujiastuti, D. Y., et al. (2023). Characteristics of catfish (Pangasius pangasius) viscera oil purified with bentonite. Jurnal Teknologi Pangan, 16(2). https://doi.org/10.33005/jtp.v16i2.3226

Masilan, K., Neethiselvan, N., Jeya shakila, R., et al. (2021). Valorization of discarded industrial fish processing wastes for the extraction of gelatin to use as biodegradable fish bait matrix using RSM. PeerJ Materials Science, 3, e14. https://doi.org/10.7717/peerj-matsci.14

Minh, N. P., Mai, P. X., Trang, N. T. T. (2019). Effect of edible film glazing on physico-chemical, microbial, and sensory attributes of frozen Pangasius fillet. Journal of Global Pharma Technology, 11(4), 63–72.

Ministry of Maritime Affairs and Fisheries of Indonesia, Jakarta. (2016). RMMAF (Regulation of the Minister of Maritime Affairs and Fisheries) Number 52/PERMEN-KP/2016 of 2016 concerning General Guidelines for Preparing Work Plans and Budgets for the Ministry of Maritime Affairs and Fisheries. Ministry of Maritime Affairs and Fisheries of Indonesia. Jakarta.

Mustika, R. (2021). Production Management and Feasibility of Patin (Pangasius Sp.) Cultivation in Banjar Regency, South Kalimantan Province, Indonesia. Journal of Economics, Finance and Management Studies, 04(05). https://doi.org/10.47191/jefms/v4-i5-30

National Standards Agency of The Republic of Indonesia. Jakarta. (1996). INS (Indonesian National Standards). SNI 01-4321-

1996 Fish flour. National Standards Agency of The Republic of Indonesia, Jakarta.
Nguyen, L. A. D., Huynh, T. K. D., Nguyen, T. N. H., et al. (2023b). Effect of rosemary (Rosmarinus officinalis) extract on the protection of the fishballs from knife fish (Chitala chitala) and striped catfish by-product (Pangasianodon hypophthalmus) against spoilage during frozen storage. Food Research, 7(2), 85–95. https://doi.org/10.26656/fr.2017.7(2).670
Nguyen, T. A. T., Nguyen, Q. T. T., Tran, T. C., et al. (2023a). Balancing the aquatic export supply chain strategy- A case study of the Vietnam pangasius industry. Aquaculture, 566, 739139. https://doi.org/10.1016/j.aquaculture.2022.739139
Nhut, N., Hao, N., Bosma, R., et al. (2017). Quantifying sustainability indicators in striped catfish Pangasianodon hypophthalmus downstream and upstream ponds. Aquaculture Environment Interactions, 9, 293–309. https://doi.org/10.3354/aei00231
Nielsen, S. S. (2010). Food Analysis Laboratory Manual, 2nd ed. Springer Science+Business Media. p. 171. https://doi.org/10.1007/978-1-44191463-7
Nurilmala, M., Nurhayati, T., & Roskananda, R. (2018). Waste of patin filleting industry for protein hydrolysate. Jurnal Pengolahan Hasil Perikanan Indonesia, 21(2), 288. https://doi.org/10.17844/jphpi.v21i2.23083
Oktaviani, Rz, I., Uthia, R., Jannah, F., et al. (2022). Extraction of catfish bone waste (pangasius hypophtalmus) by utilizing an organic liquid of pineapple peel waste (ananas comosus) into gelatin. IOP Conference Series: Earth and Environmental Science, 1041(1), 012007. https://doi.org/10.1088/1755-1315/1041/1/012007
Renuka, V., Kumar, J. A., & Joseph, T. C. (2019). Nature and composition of fish processing industrial waste and handling protocols. In: Toms, C. J., Kumar, J. A., Renuka, V., Remya, S. (editors). FishTech-19, Fishery Waste Management: Challenges and Business Opportunities in Gujarat- Souvenir. Veraval Research Centre of ICAR-CIFT, Veraval, Gujarat. pp. 25–37.
Rocha-Pimienta, J., Navajas-Preciado, B., Barraso-Gil, C., et al. (2023). Optimization of the Extraction of Chitosan and Fish Gelatin from Fishery Waste and Their Antimicrobial Potential as Active Biopolymers. Gels, 9(3), 254. https://doi.org/10.3390/gels9030254
Rossi, E., Efendi, R., Rahmayuni, et al. (2022). Utilization of Waste Mixed Pangasius Fish Fillet and Pineapple Core to Produce Peptone for Lactic Acid Bacteria Growth Media. Volume, 11, 272–279. https://doi.org/10.47278/journal.ijvs/2021.126
Rutherfurd, S. M., & Gilani, G. S. (2009). Amino Acid Analysis. Current Protocols in Protein Science, 58(1). https://doi.org/10.1002/0471140864.ps1109s58
Sadi, N. H., & Yoga, G. P. (2021). Skin characteristic of Pangasius Catfish in Indonesia. IOP Conference Series: Earth and Environmental Science, 789(1), 012026. https://doi.org/10.1088/1755-1315/789/1/012026
Santoso, R. A., & Atma, Y. (2020). Physical Properties of Edible Films from Pangasius catfish Bone Gelatin-Breadfruits Strach with Different Formulations. Indonesian Food Science & Technology Journal, 3(2), 42–47. https://doi.org/10.22437/ifstj.v3i2.9498
Shi, S., Wang, E., Li, C., et al. (2022). Use of Protein Content, Amylose Content, and RVA Parameters to Evaluate the Taste Quality of Rice. Frontiers in Nutrition, 8. https://doi.org/10.3389/fnut.2021.758547
Sokamte, T. A., Mbougueng, P. D., Mohammadou, B. A., et al. (2020). Proximal composition and fatty acid profile of fresh and smoked fillets of Pangasius hypophthalmus. Scientific African, 9, e00534. https://doi.org/10.1016/j.sciaf.2020.e00534
Sugata, M., Wiriadi, P. F., Lucy, J., et al. (2019). Total lipid and omega-3 content in Pangasius catfish (Pangasius pangasius) and milkfish (Chanos chanos) from Indonesia. Malaysian Journal of Nutrition, 25(1), 163–169. https://doi.org/10.31246/mjn-2018–0137.
Syahrul, Dewita, Isyandi B., et al. (2019). Healthy environmental management strategy in the industrial processing of patin fish. International Journal of Oceans and Oceanography, 13(1), 73–80.
Syahrul, S., Dewita, D., Effendi, I., et al. (2023). The use of striped catfish (Pangasianodon hypophthalmus) abdominal fat as a raw material for highly nutritional fish oil. AACL Bioflux, 16(2), 979–988.
The Government of the Republic of Indonesia, Jakarta. (2001). GRI (Government Regulation of Indonesia) Number 82 of 2001 concerning Water Quality Management and Water Pollution Control. The Government of the Republic of Indonesia, Jakarta.
The Government of the Republic of Indonesia, Jakarta. (2004). GRI (Government Regulation of Indonesia) Number 28 of 2004 concerning Food Safety, Quality and Nutrition. The Government of the Republic of Indonesia. Jakarta.
The Government of the Republic of Indonesia, Jakarta. (2009). RIL (Republic of Indonesia Law) Number 32 of 2009 Concerning Environmental Protection and Management. The Government of the Republic of Indonesia, Jakarta.
The Ministry of Environment and Forestry of Indonesia, Jakarta. (2016). RMEFR (Regulation of Minister of Environment and Forestry Regulation) No. P.68/Menlhk-Setjen/2016 concerns Wastewater Quality Standards for Fish Processing Businesses

and/or Activities. The Ministry of Environment and Forestry of Indonesia, Jakarta.

Truong, V. T. (2021). Research on formula establishment to produce nutritional seasoning powder from pangasius by-product hydrolyzed protein. Ministry of Science and Technology, Vietnam, 63(6), 50–56. https://doi.org/10.31276/VJST.63(6).50–56

Wiyono, T., & Dewi, K. (2023). Integrated Waste Treatment: Solutions and Utilization of Waste with Economic Value. Jurnal PKM Manajemen Bisnis, 3(1), 39–48. https://doi.org/10.37481/pkmb.v3i1.587

Xu, L. Z., Gao, F., Yang, Z. L., et al. (2016). Discriminant analysis of terrestrial animal fat and oil adulteration in fish oil by infrared spectroscopy. International Journal of Agricultural and Biological Engineering, 9(3), 179–185. https://doi.org/10.3965/j.ijabe.20160903.2239

Yaqin, M. A., Agustono, & Lokapimasari, W. (2021). The Effect of Essential Amino Acid (Lysine) in Commercial Feed of Patin Catfish (Pangasius sp.). World's Veterinary Journal, 11(2), 263–266. https://doi.org/10.54203/scil.2021.wvj34

Yusmarini, Y., Pato, U., Anirwan, S., et al. (2013). Instant noodles from sago starch and catfish (Pangasius sp.) and their shelf life estimation using an accelerated method. Jurnal Teknologi Dan Industri Pertanian Indonesia, 5(2). https://doi.org/10.17969/jtipi.v5i2.1005