

3-29-2025

Thermochemical Characterization and Pyrolysis of Fish Processing Waste to Bioenergy, including the synthesis of biohydrogen

Sumon Reza

Institute of Physical and Technical Sciences, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

Masadina Binti Sambong

Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong, BE 1410, Brunei Darussalam

Shammya Afroze

Institute of Physical and Technical Sciences, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

Parassat Omirzak

Institute of Physical and Technical Sciences, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

Nursultan Aidarbekov

Institute of Physical and Technical Sciences, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

Follow this and additional works at: <https://www.ephys.kz/journal>

Recommended Citation

See next page for additional authors

Reza, Sumon; Sambong, Masadina Binti; Afroze, Shammya; Omirzak, Parassat; Aidarbekov, Nursultan; Baratova, Aliya; Shorman, Aslan; Kuterbekov, Kairat; Kabimulla, Alisher; and Azad, Abul K. (2025) "Thermochemical Characterization and Pyrolysis of Fish Processing Waste to Bioenergy, including the synthesis of biohydrogen," *Eurasian Journal of Physics and Functional Materials*: Vol. 9: No. 1, Article 4. DOI: <https://doi.org/10.69912/2616-8537.1239>

This Original Study is brought to you for free and open access by Eurasian Journal of Physics and Functional Materials. It has been accepted for inclusion in Eurasian Journal of Physics and Functional Materials by an authorized editor of Eurasian Journal of Physics and Functional Materials.

Thermochemical Characterization and Pyrolysis of Fish Processing Waste to Bioenergy, including the synthesis of biohydrogen

Authors

Sumon Reza, Masadina Binti Sambong, Shammya Afroze, Parassat Omirzak, Nursultan Aidarbekov, Aliya Baratova, Aslan Shorman, Kairat Kuterbekov, Alisher Kabimulla, and Abul K. Azad

ORIGINAL STUDY

Thermochemical Characterization and Pyrolysis of Fish Processing Waste to Bioenergy, Including the Synthesis of Biohydrogen

Sumon Reza ^{a,b}, Masadina B. Sambong ^b, Shammya Afroze ^a, Parassat Omirzak ^a, Nursultan Aidarbekov ^{a,c}, Aliya Baratova ^{a,*}, Aslan Shorman ^a, Kairat Kuterbekov ^a, Alisher Kabimulla ^c, Abul K. Azad ^b

^a Institute of Physical and Technical Sciences, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

^b Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong, BE 1410, Brunei Darussalam

^c Faculty of Transport and Energy, L.N. Gumilyov Eurasian National University, Astana 010008, Kazakhstan

Abstract

The fish processing produces a large amount of fish waste, which is hazardous for landfill disposal and environmental sustainability. In this research, the fish waste from *Caranx ignobilis* (locally known as Putih) was characterized and pyrolyzed to manage the waste and convert it into valuable products for bioenergy. Analysis of the fish oil and the pyrolysis biochar were done including GC/MS analysis, SEM analysis, moisture content, and calorific value. The lower moisture content (6.54 %) and the higher calorific value (20.79 MJ/kg) of this fish waste is an effective indication for biofuel production. The pyrolysis yield of bio-oil, biochar, and syngas are in the range of 33.80–46.12 %, 20.40–43.76 %, and 17.76–44.05 % respectively. The production of molecular hydrogen from synthesis gas is achieved by converting carbon monoxide with water vapor (water shift reaction), which produces hydrogen and carbon dioxide. The pH of the bio-oil obtained at temperature 400 °C, 500 °C, and 600 °C are 9.3, 9.0 and 9.3 respectively. The higher number of aromatic compounds was achieved for the bio-oil in 500 °C temperature. SEM analysis shows that the biochar obtained from fish waste pyrolysis could also be effective for various environmental applications.

Keywords: Fish processing waste, Pyrolysis, HHV, Biochar, Bio-oil

1. Introduction

To reduce environmental problems, renewable energy sources have been put into use as an alternative to fossil-based fuels. Due to its flexibility such as its ability to be converted to liquid, gaseous, and solid fuels, useable for heat, transport, and power production, biomass has received more attention compared to other renewable energy sources [1]. Biomass is a contemporaneous (non-fossil) and complex biogenic organic–inorganic solid product produced by natural and anthropogenic (technogenic) processes. It comprises two forms: (1) natural constituents originated from growing land and water-based vegetation via photosynthesis or generated

through animal and human food digestion; and (2) technogenic products derived through processing of the above natural constituents [2]. Biomass can be classified into several groups and sub-groups based on their distinct biological diversity and similar source and origin.

The conceivable feedstock for deriving biofuels are such as plant matter, animal waste, rural crops and buildups, rubbish, and mechanical sewages [3–6]. Bio-oil can be obtained from biomass based on triglycerides such as palm, soybean, castor and canola, along with animal fats, poultry fat, lard, and fish oil capsules. The major products includes ketones, alkenes, alkanes, aldehyde, carboxylic acids and aromatics [7]. Fish wastes obtained from the fish processing industry are

Received 13 February 2025; revised 17 February 2025; accepted 17 February 2025.
Available online 29 March 2025

* Corresponding author.
E-mail address: baratova_aa@enu.kz (A. Baratova).

<https://doi.org/10.69912/2616-8537.1239>

2616-8537/© 2025 L.N. Gumilyov Eurasian National University. This is an open access article under the CC BY 4.0 DEED Attribution 4.0 International (<https://creativecommons.org/licenses/by/4.0/>).

made into fishmeal and oil as a side-product, or to remediate soil. The content of oil in the fish waste depends on the species and tissue types and ranges between 1.4 and 40.1 % [8].

The Food and Agriculture Organization (FAO) claimed that in 2020, the estimated world fish production was around 214 million tons worth about USD 424 billion [9]. About 75 % of this production is said to be utilized directly for human consumption and the remaining is subjected to for non-food products, specifically in the manufacturing of oil and fishmeal [7]. Waste generated from fish-filleting units is used in the production of fish meal or directly used in animal feeds but more frequently it is simply discarded [10]. The discarded parts like viscera, fins, eyes, tails, etc., of marine fish can bring little economic value since it can be made into fishmeal to provide food for pets, livestock, or aquaculture. However, the crude fish oil extracted from these discarded parts may provide an abundant, cheap, and stable source of raw oil to allow maritime countries to produce biodiesel and thus help to reduce pollutant emissions [11]. Treated fish waste has found various and important applications including animal feed, biodiesel/biogas, dietetic products (chitosan), natural pigments (after extraction) and cosmetics as collagen [12]. Commercial fish production and seafood processing produces large amounts of fish waste, which create troublesome disposal problems and environmental concerns [13].

Research shows that processing wastes can be used in fertilizers and animal feed production as low-cost feedstock. However, the main bulk is regarded as litter and discarded into the water or dumping area, creating both disposal and pollution problems. Furthermore, the unorganized and improper handling of the waste in most inland fisheries sectors causes major marketing centers having difficulties in disposing the waste generated after processing salt-water fishes for domestic consumption [14,15]. The ASEAN region is surrounded by sea with abundant fish, making fish one of the food sources in the region. It is recorded that the ASEAN region has one of the highest annual fish consumption per capita, ranging between 40 and 47 kg per person [16]. Brunei is a country surrounded by seawater and has abundant number of fish. It has been reported that the country imports approximately 63 % of its domestic fish consumption largely in the form of fresh marine fin-fishes, and prawns, and shrimps [17].

Thermochemical and biochemical conversion processes are normally used to produce biofuel from animal waste, where thermochemical procedures have higher efficiencies for reactivity, quantity, quality, and time consumption [18]. Also, complicated substances cannot be converted completely in the biochemical

process, but they can be quickly degraded in the thermochemical process. Pyrolysis is one of the most common thermochemical processes (along with gasification, combustion, and hydrothermal) that produces three different biofuels (biochar, bio-oil, and bio-syngas) [19]. Solid biochar is used to improve soil quality, absorb CO₂, heat generation, water and air purification [20]. Liquid bio-oils are dark brown in color and include complicated combinations of oxygenated hydrocarbons and water. They can be used as a substitute liquid fuel after refining or as a source of synthetic chemicals [21]. Pyrolytic gases are refined and utilized for hydrogen gas production to be used in gas generators and fuel cells [22,23].

The aims and objective of this research project is to extract fish oil from fish waste available in Brunei. This is due to the abundant number of fish found in Brunei, as it can be obtained from any fish market in the country. The aim of this study is the thermochemical characterization and pyrolysis of *Caranx ignobilis* (Putih) fish waste to be an alternative source of renewable bioenergy.

2. Materials and methods

2.1. Sample collection and preparation

The fish waste sample used in the project were obtained from the Pasarneka & Tamu Tutong located in the Tutong district in Brunei Darussalam and is only consisted of one type of fish. The fish waste used is from the local fish known as “Putih” that appears in large amount in Brunei sea water and its scientific name is *Caranx ignobilis*. The obtained fish waste was fresh. The samples were packed in a plastic bag and kept in refrigerator to avoid decaying and bad odors. After collecting, the sample was naturally dried under the sun for a period of two weeks to remove free water. After that, it is grinded into smaller pieces by using the crusher and packed into a zip bag to avoid the sample from absorbing moisture from the surroundings. The process is described in Fig. 1.

2.2. Properties of the biomass sample

Before proceeding with the pyrolysis process, a series of processes is carried out in order to identify whether the sample is appropriate for the pyrolysis process. The calorific value and the moisture content of the fish waste sample is identified. The calorific value of the fish waste sample is determined by using the bomb calorimeter experiment by following the ASTM (American Society of Testing Materials) method practice D5468–02 procedure. The moisture content in the sample was determined using ASTM D3173-87. The



Fig. 1. (Left) Putih fish waste, (Middle) biomass after drying, (Right) biomass after grinding.

test was carried out twice, and the final value is taken from the average. Formula used for the moisture content calculation is shown below Eq. (1):

$$\text{Moisture content (\%)} = \frac{w_{s,i} - w_{s,f}}{w_{s,i}} \times 100 \quad (1)$$

Where,

$w_{s,i}$ is the weight of sample before heating in gram,
 $w_{s,f}$ is the weight of sample after heating in gram.

2.3. Pyrolysis

The pyrolysis used in this project is the intermediate type. The reactor used for the pyrolysis process is a stainless-steel fixed bed reactor. The reactor is connected to a gas cylinder to supply a constant flow of nitrogen gas for making the reactor system inert. 20–25 g of samples were fed into the reactor. The pyrolysis is conducted at three different temperatures: 400 °C, 500 °C and 600 °C. The heating rate and nitrogen flow rate were kept constant throughout the process at 25 °C/min and 0.5 L/min respectively. The bio-oils were collected from the flask and connector and were poured in separate vials for all three pyrolysis conditions. The bio-chars were found inside the reactor and were kept in transparent plastic containers. The amount of biogas was determined by subtracting the weight of biochar and bio-oil from the weight of the sample used.

2.4. Characterization of pyrolysis products

Characterization of pyrolysis bio-oil are done using GC/MS analysis. The composition of the fish oil was determined. Characterization of bio-chars obtained from the pyrolysis of fish waste were done by Scanning Electron Microscope (SEM). There were different four magnifications executed to the sample images: 25 × , 100 × , 1000 × and 5000 × .

3. Results and discussions

3.1. Properties of biomass sample

Two analyses (moisture content and calorific value) are conducted to determine the properties of the feedstock biomass used for the pyrolysis. Moisture content of a biomass is very important in pyrolysis process. The amount of moisture content in a feedstock biomass for a proper pyrolysis process must be below 5 wt% to 15 wt% [24]. If the percentage of moisture content is high in a feedstock biomass, it will lower down the heating value and eventually reduces the quality of the products particularly the pyrolysis biofuel. In this research project, the moisture content was 6.54 %. The moisture content for this fish waste are lower than the values for other fish waste (7.83 %) [25] and de-oiled fish waste (7.55 %) [1]. Therefore, as this value is in the proper range, the chosen fish waste feedstock biomass is suitable for producing bio-oil, biochar, and biogas using the pyrolysis process.

Calorific value is defined as the total amount of energy released when a biomass is completely burned in air. The calorific value is also affected by moisture content in the feedstock biomass. Higher moisture content will reduces the calorific value of the pyrolysis bio-oil [24]. In this research project, the calorific value of the fish waste biomass is 20.79 MJ/kg. The calorific value this fish waste is highly comparable with the values of salmon fish (16.01–23.14 MJ/kg) [26], deoiled fish waste (20.99 MJ/kg) [1], and *Tilapia nilotica* (21.72 MJ/kg) [27], and *Pelates octolineatus* (12.83 kJ/g) [28].

3.2. Product yield

The products yield obtained from the pyrolysis process depends on the pyrolysis type (slow, intermediate or fast pyrolysis), type of reactor used, operating conditions, and, type of feedstock biomass used [29]. In

this research, only the bio-oil and biochar are collected, while the biogas is vented out. The composition of the bio-oil and biochar are calculated using the Eq. (2) below:

$$\text{Product yield (\%)} = \frac{w_p}{w_i} \times 100 \quad (2)$$

Were,

w_p , is the weight of the product obtained from a run,

w_i , is the initial weight of the feedstock used during a run.

The yields of the bio-oil, biochar and syngas were different for the different pyrolysis temperatures of 400 °C, 500 °C and 600 °C. For this work, the pyrolysis products for bio-oil, biochar and biogas are in the range of 33.80–46.12 %, 20.40–43.76 %, and 17.76–44.05 % respectively. The variations in yield of the products obtained in this research might also result from the temperatures, heating rate, size of particles used for the feedstock biomass as in this research the feedstock particle size is not constant. At the lowest temperature. The time required for the vapor bio-oil to change into liquid bio-oil is short compared to high temperature hence more vapor can be condensed into bio-oils The change of particle size affected the rate of heating of the feedstock biomass, resulting in changing of the behavior of pyrolysis of biomass [1].

3.3. Production of biohydrogen from bio-synthesis gas

The process of producing biohydrogen from bio-syngas derived from fish industry waste (bone and muscle mass, scales, organs, fat, and other organic remnants) involves several key stages and operations. First, the waste is shredded and dried as necessary to reduce its moisture content to around 10–15 %, since excess moisture lowers gasification efficiency and increases heat consumption. The prepared feedstock is then fed into a gasifier, where, at temperatures ranging from 800 to 1200 °C and under restricted oxygen supply or with the use of steam, a thermochemical decomposition of organic substances occurs, resulting in the formation of biosyngas. Typical operating temperatures vary from about 800 to 900 °C for steam gasification to 900–1200 °C for high-temperature processes, and the pressure may be atmospheric or higher. The typical volumetric composition of the resulting biosyngas is as follows: hydrogen 15–25 %, carbon monoxide 15–30 %, carbon dioxide 10–20 %, methane and other hydrocarbons 2–10 %, along with small amounts of N₂, H₂S, HCl, and other compounds that depend on the original feedstock. Next, to increase the hydrogen content, the water-gas shift reaction (Water-

Gas Shift Reaction) is applied to the gas at temperatures of around 200–450 °C; as a result, CO reacts with steam, producing additional hydrogen and CO₂, and the final gas mixture may contain 40–60 % by volume of H₂. The following stage is hydrogen purification and separation, during which CO₂, sulfur-containing compounds (H₂S and others), acidic gases (e.g., HCl), and residual hydrocarbons must be removed. Membrane technologies, which selectively allow hydrogen to pass through semipermeable barriers, are used for this purpose, as well as PSA (Pressure Swing Adsorption), where hydrogen is dried and separated from other impurities, and chemical absorption methods (e.g., amine-based) to remove CO₂. The end product is a high-concentration (90–99 %) hydrogen stream suitable for use in fuel cells, various hydrogen technologies, and chemical production (ammonia synthesis, methanol, and other compounds). Utilizing fish industry waste as a feedstock addresses the challenge of disposing of biological remnants, reduces greenhouse gas emissions, and lessens anthropogenic impact on the environment, all while producing renewable hydrogen with a low carbon footprint.

3.4. Characterization of bio-oil

The bio-oil obtained in this research is brown in color and has a strong burned fish smell. The properties of pyrolysis bio-oil rely on several factors including the type of pyrolysis, properties of feedstock biomass, and the operating conditions controlled during the bio-oil production [29]. Characterization of the bio-oil was done using GC/MS (Table 1). The main pyrolysis products were grouped into acids, alkanes, amide, amine, aromatic compound, ester, ketone, lactam, miscellaneous compound, nitriles, and phenols. Table 2 and Fig. 2 shows the comparison of the different compound groups present in the pyrolysis bio-oil. Ketones, alcohols and hydrocarbons are present in a high amount in the fish oil obtained from this research and similar chemical groups are also stated in literature reviews [30,31]. The pH of the fish oil obtained at temperature 400 °C, 500 °C, and 600 °C are 9.3, 9.0 and 9.3 respectively.

3.5. Characterization of biochar

Biochar produced from the pyrolysis process is charcoal which is used as a soil amendment for both carbon sequestration and soil health benefits. Biochar is a stable solid, rich in carbon, and can endure in soil for thousands of years [32,33]. Properties such as the elemental composition and surface morphology of the biochar produced from this research are done using SEM. Fig. 3 shows the 1000 × magnified SEM images of

Table 1. Component found in the fish waste pyrolysis GC/MS at different temperature 400 °C, 500 °C and 600 °C.

Compounds Name	Peak Area (%)			Formula	MW	CAS#	Group
	400 °C	500 °C	600 °C				
Acetic acid, ethoxy-	0.55	1.5		C ₄ H ₈ O ₃	104	627-03-2	Acid
Butanoic acid, 3-methyl-	1.01	0.2		C ₅ H ₁₀ O ₂	102	503-74-2	Acid
Phenol	0.35	0.39	0.48	C ₆ H ₆ O	94	108-95-2	Phenol
Hexanamide	0.66	1.1	0.47	C ₆ H ₁₃ NO	115	628-02-4	Amide
Glycerin	0.68	0.14		C ₃ H ₈ O ₃	92	56-81-5	Miscellaneous compound
2-Pyrrolidinone	0.89	2.22	0.79	C ₄ H ₇ NO	85	616-45-5	Lactam
2-Pyridinamine, 6-methyl-	0.66	0.54	0.77	C ₆ H ₈ N ₂	108	1824-81-3	Amine
2-Ethylpiperidine		0.86	0.31	C ₇ H ₁₅ N	113	1484-80-6	Piperidine
Hexanamide	0.51	0.67	0.38	C ₆ H ₁₃ NO	115	628-02-4	Amide
Propanenitrile, 2,2-dimethyl-		0.58	0.3	C ₅ H ₉ N	83	630-18-2	Aliphatic nitrile
2,5-Pyrrolidinedione	1.37	1.82	0.39	C ₄ H ₅ NO ₂	99	123-56-8	Ketone
1,2,4-Triazine-3,5(2H,4H)-dione	1.29	2.3	0.84	C ₃ H ₃ N ₃ O ₂	113	461-89-2	Miscellaneous compound
2-Piperidinone	3.47	4.67	0.87	C ₅ H ₉ NO	99	675-20-7	Organic - Piperidine
1,4-Benzenediol, 2-methyl-	0.4	0.98		C ₇ H ₈ O ₂	124	95-71-6	Aromatic compound
1-Piperidineacetone nitrile	0.3	0.42		C ₇ H ₁₂ N ₂	124	05/03/3010	Organic
Benzenepropanenitrile		0.6	0.48	C ₉ H ₉ N	131	645-59-0	Nitriles
3,7-Dimethyl-1-octyl methylphosphonofluoridate	1.15	0.8		C ₁₁ H ₂₄ FO ² P	238	345260-82-4	Miscellaneous compound
Caprolactam	1.42	1.56	0.32	C ₆ H ₁₁ NO	113	105-60-2	Lactam
Piperidine, 1, 1'-methylenebis-	2.57	0.92		C ₁₁ H ₂₂ N ₂	182	880-09-1	Amine
2-Amino-3-hydroxypyridine	2.28	1.88	0.83	C ₅ H ₆ N ₂ O	110	16867-03-1	Amine
2,4-Imidazolidinedione, 5,5-dimethyl-	5.02	3.33		C ₅ H ₈ N ₂ O ₂	128	77-71-4	Ketone
Phenol, 3-methoxy-	1.03	1.84		C ₇ H ₈ O ₂	124	150-19-6	Phenol
1,4-Cyclohexanedione	0.79		0.3	C ₆ H ₈ O ₂	112	637-88-7	Ketone
Phenol, 3-(dimethylamino)-	0.31	5.38	0.8	C ₈ H ₁₁ NO	137	99-07-0	Phenol
Tetradecane	0.85		0.51	C ₁₄ H ₃₀	198	629-59-4	Alkanes
1H-Indole, 3-methyl-	2.65		0.44	C ₉ H ₉ N	131	83-34-1	Aromatic compound
2-Imidazolidinone, 1,3-dimethyl-	0.91	1.56	0.51	C ₅ H ₁₀ N ₂ O	114	80-73-9	Amide
2,4-Imidazolidinedione, 5-methyl-5-(2-methylpropyl)-	1.35	4.66	0.39	C ₈ H ₁₄ N ₂ O ₂	170	27886-67-5	Amide
1-(3-Aminopropyl)-2-pipecoline	0.91		0.3	C ₉ H ₂₀ N ₂	156	25560-00-3	Miscellaneous compound
Pentadecane	1.13	1.96	0.5	C ₁₅ H ₃₂	212	629-62-9	Alkanes
Pyrazine, 2-methoxy-3-(1-methylpropyl)-	0.41		0.3	C ₉ H ₁₄ N ₂ O	166	24168-70-5	Aromatic compound
6-Aminoindazole	0.54		0.35	C ₇ H ₇ N ₃	133	6967-12-0	Miscellaneous compound
Tenuate	0.43	4.75		C ₁₃ H ₁₉ NO	205	90-84-6	Amine
2-(Diethylamino)acetone nitrile	0.91		0.46	C ₆ H ₁₂ N ₂	112	04/02/3010	Nitriles
Cyclohexanamine, N-cyclohexyl-	0.89		0.32	C ₁₂ H ₂₃ N	181	101-83-7	Amine
Benzoic acid, 2,6-dihydroxy-	2.47		0.3	C ₇ H ₆ O ₄	154	303-07-1	Acid
Pyrazine, ethyl-	0.45		0.51	C ₆ H ₈ N ₂	108	13925-00-3	Aromatic compound
Lumazine	0.37		0.44	C ₆ H ₄ N ₄ O ₂	164	487-21-8	Miscellaneous compound
Tetradecanenitrile	1.02	3.58	0.68	C ₁₄ H ₂₇ N	209	629-63-0	Nitriles
1-Pentanamine, N-pentyl-	0.74	3.1	0.43	C ₁₀ H ₂₃ N	157	2050-92-2	Amine
Heptadecanenitrile	0.74		0.83	C ₁₇ H ₃₃ N	251	5399-02-0	Nitriles
Adipamide	3.47	5.1	0.69	C ₆ H ₁₂ N ₂ O ₂	144	628-94-4	Amide

(continued on next page)

Table 1. (continued)

Compounds Name	Peak Area (%)			Formula	MW	CAS#	Group
	400 °C	500 °C	600 °C				
Uric acid	2.4	4.36	2.19	C ₅ H ₄ N ₄ O ₃	168	69-93-2	Aromatic compound
1,3-Dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone	1.1	3.98	0.9	C ₆ H ₁₂ N ₂ O	128	7226-23-5	Miscellaneous compound
Pyrrolo[1,2-a]pyrazine-1,4-dione, hexahydro-	6.14	12.39	0.94	C ₇ H ₁₀ N ₂ O ₂	154	19179-12-5	Aromatic compound
Oleic acid	1.82		1.41	C ₁₈ H ₃₄ O ₂	282	112-80-1	Acid
Heptadecanenitrile	0.83	2.56	2.59	C ₁₇ H ₃₃ N	251	5399-02-0	Nitriles
Hexadecanoic acid, methyl ester	0.44	0.7	0.74	C ₁₇ H ₃₄ O ₂	270	112-39-0	Ester
Oleic acid	1.07		0.32	C ₁₈ H ₃₄ O ₂	282	112-80-1	Acid
Hexadecanenitrile	2.02	4.42	6.57	C ₁₆ H ₃₁ N	237	629-79-8	Nitriles
n-Hexadecanoic acid	5.69	0.59	7.02	C ₁₆ H ₃₂ O ₂	256	57-10-3	Acid
17-Pentatriacontene		1.83	1.1	C ₃₅ H ₇₀	490	6971-40-0	Miscellaneous compound
Oleic acid	0.89		2.28	C ₁₈ H ₃₄ O ₂	282	112-80-1	Acid
Heptadecanenitrile	0.58	0.8	1.79	C ₁₇ H ₃₃ N	251	5399-02-0	Nitriles
Oleic acid	2.19	1.58	0.85	C ₁₈ H ₃₄ O ₂	282	112-80-1	Faty acid
Octadecanoic acid	1.32	0.92	14.2	C ₁₈ H ₃₆ O ₂	284	57-11-4	Acid
2-Propenoic acid, 2-ethylhexyl ester	1.19	1.57	1.53	C ₁₁ H ₂₀ O ₂	184	103-11-7	Ester
Cyclopentylcarboxylic acid	0.69	0.38	1.21	C ₆ H ₁₀ O ₂	114	3400-45-1	Acid
9-Octadecenamide, (Z)-	0.53	0.46	1.75	C ₁₈ H ₃₅ NO	281	301-02-0	Amide
Hexadecanamide		0.11	2.01	C ₁₆ H ₃₃ NO	255	629-54-9	Amide
Cyclohexanecarboxamide, N,N-dimethyl-		0.04	1.06	C ₉ H ₁₇ NO	155	17566-51-7	Amide
Octanamide, N,N-dimethyl-		0.05	0.38	C ₁₀ H ₂₁ NO	171	1118-92-9	Amide
Octadecanoic acid, 2,3-dihydroxypropyl ester		0.02	1.98	C ₂₁ H ₄₂ O ₄	358	123-94-4	Ester
Pyrrolidine, 1-(1-oxooctadecyl)-		0.03	1.14	C ₂₂ H ₄₃ NO	337	33707-76-5	Amine
9-Octadecenoic acid (Z)-, 9-octadecenyl ester, (Z)-		0.03	1.79	C ₃₄ H ₆₄ O ₂	504	22393-99-3	Ester
13-Docosenamide, (Z)-		0.03	2.55	C ₂₂ H ₄₃ NO	337	112-84-5	Amide
Cholest-5-ene		0.01	0.67	C ₂₇ H ₄₆	370	570-74-1	Miscellaneous compound
Cholesta-3,5-diene		0.02	0.53	C ₂₇ H ₄₄	368	747-90-0	Miscellaneous compound
Cholest-5-en-3-ol (3.beta.)-, 3-phenyl-2-propenoate		0.07	1.35	C ₃₆ H ₅₂ O ₂	516	1990-11-0	Miscellaneous compound
Cholesterol		0.03	0.49	C ₂₇ H ₄₆ O	386	57-88-5	Ester

Table 2. Group of compounds in pyrolysis oil and average peak area.

Group	Peak area (%)		
	400 °C	500 °C	600 °C
Organic acid	1.77	0.86	3.45
Alkane	0.99	1.96	0.51
Amide	1.24	1.38	1.02
Amine	1.26	1.73	0.63
Aromatic compound	2.08	5.91	0.88
Ester	0.82	0.47	1.31
Ketone	2.66	3.27	0.52
Lactam	1.16	1.89	0.56
Miscellaneous compound	0.86	1.14	0.72
Nitriles	0.91	1.85	1.71
Phenol	0.56	2.54	0.64

the biochar at temperature 400 °C, 500 °C, and 600 °C respectively.

The EDX graphs of the biochar are shown in Fig. 4. The SEM images show a regular shape, and it suggest that the biochars produced at temperature 500 °C and 600 °C has a smooth surface. From the EDX graphs, the element present in the bio-chars are Carbon, Oxygen, Iron, Silicon, Calcium, Phosphorus, and Bromine. This proves that the biochar is suitable to be used as soil amendment to improve fertility of soil particularly for agricultural purposes [19].

The oxygen content of the biochar can easily be detected from the EDX analysis rather than any other

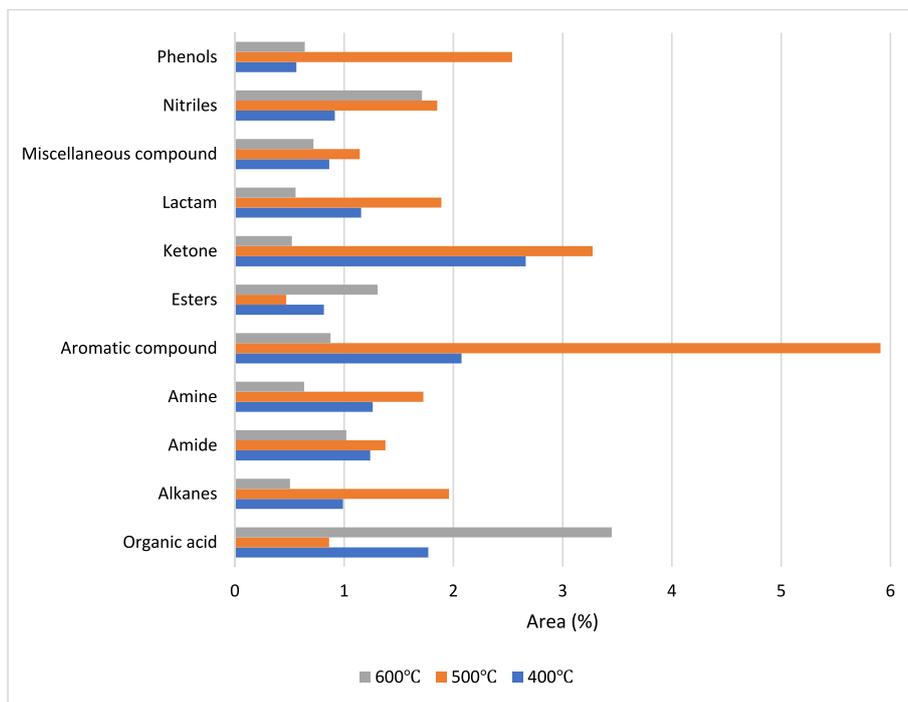


Fig. 2. Comparison of different compound groups present in the fish oil.

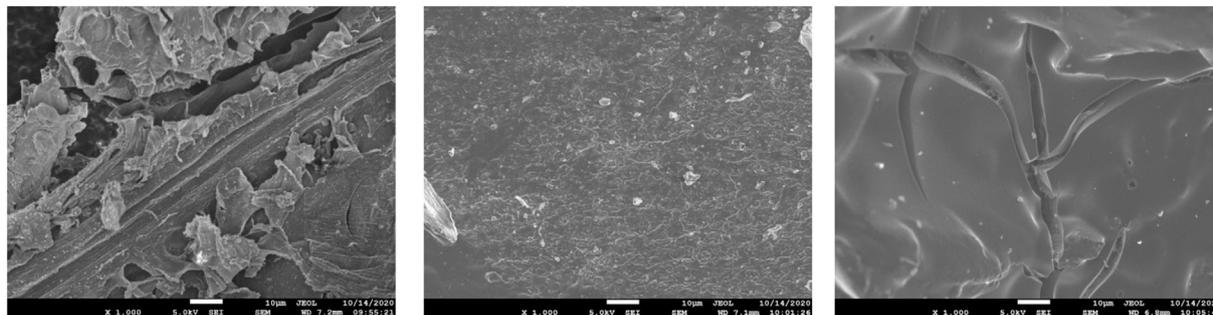


Fig. 3. SEM image of biochar at (Left) 400 °C, (Middle) 500 °C, and (Right) 600 °C.

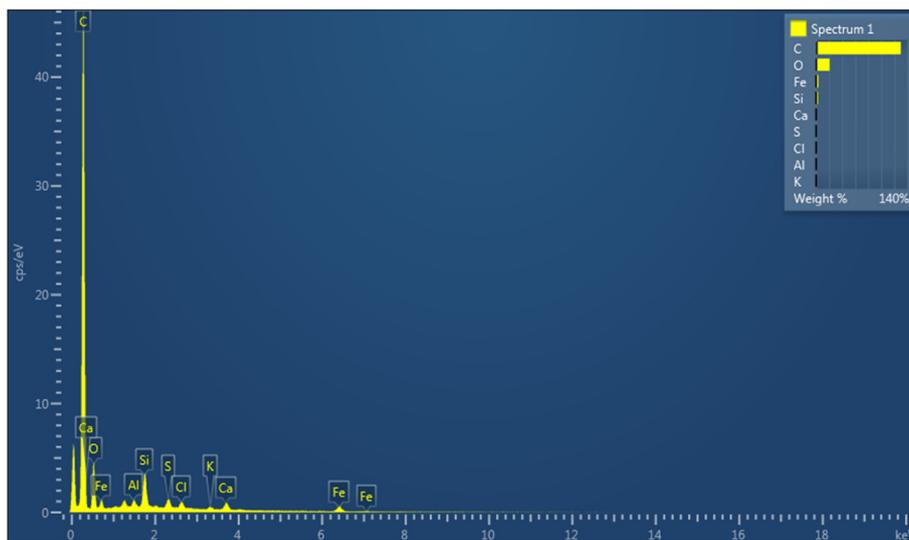


Fig. 4. EDX graph of biochar.

elemental analysis [34]. From the EDX result, the ration of the O/C is the indicator of the aromaticity and polarity of the solid carbon. If the O/C ratio is less the surface of the biochar becomes less hydrophilic [35].

4. Conclusions

To conclude, biomass has the potential to replace fossil-based fuels soon due to its flexibility and properties. In addition, biomass-based fuels have shown reduction in greenhouse gases emissions and other harmful substances. Furthermore, utilizing fish waste as the feedstock for bioenergy solves the problem associated with foul smells and pollution. Characterization of bio-oil and biochar were done in this research using GC/MS and SEM analysis respectively. Producing biohydrogen from fish industry waste involves thermochemically converting the waste into biosyngas, increasing the hydrogen content via the water-gas shift reaction, and then purifying it to obtain high-purity hydrogen, all while providing an eco-friendly solution for waste disposal and reducing carbon emissions. The yield of pyrolysis products for bio-oil, biochar and biogas are in the range of 33.80–46.12 %, 20.40–43.76 %, and 17.76–44.05 % respectively. The highest yield of bio-oil was obtained from pyrolysis at 400 °C. Highest yield of biochar was obtained at 600 °C, and at 500 °C for biogas which is vented out. GC/MS analysis of pyrolysis bio-oil shows that the groups present in the bio-oil are acids, alkanes, amide, amine, aromatic compound, ester, ketone, lactam, miscellaneous compound, nitriles, and phenols. SEM analysis shows that the biochar obtained from fish waste pyrolysis is suitable for soil amendments to improve soil fertility.

Funding

This research was funded by the grant with reference number BR21882359, provided by the Ministry of Science and Higher Education of Kazakhstan.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

The authors are profoundly thankful to the Universiti Brunei Darussalam and L.N. Gumilyov Eurasian National University for supporting this research.

References

[1] A.B. Fadhil, A.I. Ahmed, H.A. Salih, Production of liquid fuels and activated carbons from fish waste, *Fuel* 187 (2017) 435–445, <https://doi.org/10.1016/j.fuel.2016.09.064>.

[2] S.V. Vassilev, D. Baxter, L.K. Andersen, C.G. Vassileva, An overview of the chemical composition of biomass, *Fuel* 89 (2010) 913–933, <https://doi.org/10.1016/j.fuel.2009.10.022>.

[3] M.F.F. Demirbas, M. Balat, Recent advances on the production and utilization trends of bio-fuels: A global perspective, *Energy Convers. Manag.* 47 (2006) 2371–2381, <https://doi.org/10.1016/j.enconman.2005.11.014>.

[4] M. Balat, Global trends on the processing of bio-fuels, *Int. J. Green Energy* 5 (2008) 212–238, <https://doi.org/10.1080/15435070802107322>.

[5] M. Boyd, A. Murray-hill, K. Schaddelee, M. Boyd, A. Murray-Hill, K. Schaddelee, M. Boyd, A. Murray-hill, K. Schaddelee, Biodiesel in British Columbia Feasibility Study Report, Eco-Literacy Canada, 2004.

[6] K.S. Tyson, J. Bozell, R. Wallace, E. Petersen, L. Moens, Biomass oil analysis: research needs and recommendations, 2004.

[7] A. Wisniewski, V.R. Wiggers, E.L. Simionato, H.F. Meier, A.A.C. Barros, L.A.S. Madureira, Biofuels from waste fish oil pyrolysis: chemical composition, *Fuel* 89 (2010) 563–568, <https://doi.org/10.1016/j.fuel.2009.07.017>.

[8] C.P. Zuta, B.K. Simpson, H.M. Chan, L. Phillips, Concentrating PUFA from mackerel processing waste, *J. Am. Oil Chem. Soc.* 80 (2003) 933–936, <https://doi.org/10.1007/s11746-003-0799-5>.

[9] T.H.E.S. Of, In Brief to the State of World Fisheries and Aquaculture 2022, 2022. ISBN 9789251363645.

[10] O. Paper, I. Batista, Recovery of proteins from fish waste products by alkaline extraction, *Eur. Food Res. Technol.* 210 (1999) 84–89, <https://doi.org/10.1007/s002170050539>.

[11] C.-Y. Lin, R.-J. Li, Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish, *Fuel Process. Technol.* 90 (2009) 883–888, <https://doi.org/10.1016/j.fuproc.2009.04.009>.

[12] K. Jayathilakan, K. Sultana, K. Radhakrishna, A.S. Bawa, Utilization of byproducts and waste materials from meat, poultry and fish processing industries: A review, *J. Food Sci. Technol.* 49 (2012) 278–293, <https://doi.org/10.1007/s13197-011-0290-7>.

[13] A. Bougatef, Trypsins from fish processing waste: characteristics and biotechnological applications - comprehensive review, *J. Clean. Prod.* 57 (2013) 257–265, <https://doi.org/10.1016/j.jclepro.2013.06.005>.

[14] A.E. Ghaly, V.V. Ramakrishnan, M.S. Brooks, S.M. Budge, D. Dave, Fish processing wastes as a potential source of proteins, amino acids and oils: A critical review, *J. Microb. Biochem. Technol.* 5 (2013) 107–129, <https://doi.org/10.4172/1948-5948.1000110>.

[15] D. Dave, Marine oils as potential feedstock for biodiesel production: physicochemical characterization, *J. Bioprocess. Biotech.* 04 (2014) 1000168, <https://doi.org/10.4172/2155-9821.1000168>.

[16] E.A. Cinco, L.C.L. Teh, K. Zyllich, D. Pauly, Reconstructing the Marine and Estuarine Fisheries of Brunei Darussalam, 1950 to 2010; Vancouver, BC, V6T 1Z4, Canada, 2015.

[17] 1. Consumption of fish and shellfish in the region.

[18] M. Baniyadi, A. Tugnoli, R. Conti, C. Torri, D. Fabbri, V. Cozzani, Waste to energy valorization of poultry litter by slow pyrolysis, *Renew. Energy* 90 (2016) 458–468.

[19] M.S. Reza, A.K. Azad, M.S.A. Bakar, M.R. Karim, M. Sharifpur, J. Taweekun, Evaluation of thermochemical characteristics and pyrolysis of fish processing waste for renewable energy feedstock, *Sustainability* 14 (2022) 1203, <https://doi.org/10.3390/SU14031203>.

[20] M.S. Reza, S. Afroze, M.S.A.A. Bakar, R. Saidur, N. Aslfattahi, J. Taweekun, A.K. Azad, Biochar characterization of invasive pennisetum purpureum grass: Effect of pyrolysis temperature, *Biochar* 2 (2020) 239–251, <https://doi.org/10.1007/s42773-020-00048-0>.

[21] E.G. Varuvel, N. Mrad, M. Tazerout, F. Aloui, Assessment of liquid fuel (Bio-Oil) production from waste fish fat and utilization in diesel engine, *Appl. Energy* 100 (2012) 249–257.

[22] G. Kwon, D.W. Cho, H. Jang, S. Shiung Lam, H. Song, Synergistic effects of blending seafood wastes as Co-pyrolysis feedstock on syngas production and biochar properties, *Chem. Eng. J.* 429 (2022) 132487, <https://doi.org/10.1016/j.cej.2021.132487>.

- [23] S. Afroze, M.S. Reza, M.R.R. Somalu, A.K.K. Azad, Super-protonic conductors for solid acid fuel cells (SAFCs): A review, *Eurasian J. Phys. Funct. Mater.* 7 (2023) 6–37, <https://doi.org/10.32523/EJPFM.2023070101>.
- [24] M.I. Jahirul, M.G. Rasul, A.A. Chowdhury, N. Ashwath, Biofuels production through biomass pyrolysis- A technological review, *Energies* 5 (2012) 4952–5001, <https://doi.org/10.3390/en5124952>.
- [25] S.K. Kamarudin, N.S. Shamsul, J.A. Ghani, S.K. Chia, H.S. Liew, A.S. Samsudin, Production of methanol from biomass waste via pyrolysis, *Bioresour. Technol.* 129 (2013) 463–468, <https://doi.org/10.1016/j.biortech.2012.11.016>.
- [26] S. Rowland, C.K. Bowerk, R.N. Patil, C.A.M. DEWITT, Updraft gasification of salmon processing waste, *J. Food Sci.* 74 (2009) 426–431, <https://doi.org/10.1111/j.1750-3841.2009.01312.x>.
- [27] R.H. Meakins, Variations in the energy content of freshwater fish, *J. Fish. Biol.* 8 (1976) 221–224, <https://doi.org/10.1111/j.1095-8649.1976.tb03945.x>.
- [28] S.M. McCluskey, L. Bejder, N.R. Loneragan, Dolphin prey availability and calorific value in an estuarine and coastal environment, *Front. Mar. Sci.* 3 (2016) 1–23, <https://doi.org/10.3389/fmars.2016.00030>.
- [29] A. Ahmed, M.S. Abu Bakar, A.K. Azad, R.S. Sukri, N. Phusunti, Intermediate pyrolysis of *Acacia cincinnata* and *Acacia holosericea* species for bio-oil and biochar production, *Energy Convers. Manag.* 176 (2018) 393–408, <https://doi.org/10.1016/j.ENCONMAN.2018.09.041>.
- [30] W.W. Christie, X. Han, *Lipid Analysis Isolation, Separation, Identification and Lipidomic Analysis*, fourth ed., Woodhead Publishing Limited: Woodhead Publishing, 1518 Walnut Street, Suite 1100, Philadelphia, PA, USA, 2010, p. 448, 19102–23406, ISBN 9780955251245.
- [31] C.C. Parrish, Determination of total lipid, lipid classes, and fatty acids in aquatic samples, in: *Lipids in Freshwater Ecosystems*, Springer New York, New York, NY, 1999, pp. 4–20.
- [32] O. Singh, S. Singh, V.K. Singh, A. Singh, Biochar: An organic amendment for sustainable soil health, *Encycl. Green Mater* (2023) 1–10, https://doi.org/10.1007/978-981-16-4921-9_265-1.
- [33] J. Layek, R. Narzari, S. Hazarika, A. Das, K. Rangappa, S. Devi, A. Balusamy, S. Saha, S. Mandal, R.G. Idapuganti, et al., Prospects of biochar for sustainable agriculture and carbon sequestration: An overview for Eastern Himalayas, *Sustain. Times* 14 (2022) 6684, <https://doi.org/10.3390/SU14116684>. Page 6684 2022, 14.
- [34] A. Budai, L. Wang, M. Gronli, L.T. Strand, M.J.J. Antal, S. Abiven, A. Dieguez-Alonso, A. Anca-Couce, D.P. Rasse, Surface properties and chemical composition of corncob and miscanthus biochars : effects of production temperature and method, *J. Agric. Food Chem.* 62 (2014) 3791–3799, <https://doi.org/10.1021/jf501139f>.
- [35] F. Hao, X. Zhao, W. Ouyang, C. Lin, S. Chen, Y. Shan, X. Lai, Molecular structure of corncob-derived biochars and the mechanism of atrazine sorption, *Agron. J.* 105 (2013) 773–782, <https://doi.org/10.2134/agronj2012.0311>.