Final Report

Future Fish Waste Products

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YRKESHÖGSKOLAN NOVIA

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This report explores innovative methods to repurpose fish waste in Finland, where a significant amount is discarded. The primary goal was to transform fish waste into valuable products, including food for humans, pet food, and ingredients for cosmetics. Conducted as part of the European Project Semester (EPS), the project involved a multidisciplinary team of students from diverse educational backgrounds.

Various techniques, such as fermentation, drying, and oil and protein extraction, were utilised and evaluated for their feasibility in Finland. Experiments included extracting fish oils, producing garum through fermentation, drying fish waste, and creating soap from fish oil. These methods were tested to assess their practicality and scalability for small and large-scale fish industries. The findings indicate promising solutions for reducing waste and creating economically valuable products, contributing to more sustainable practices in Finland's fish industry.

Language: English
Key Words: Fish Waste, European Project Semester, Stabilisation methods

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4 Introduction

The "Future Fish Waste Products" project was conducted as part of the European Project Semester (EPS) at Vaasa, Finland. EPS is a multidisciplinary program designed for students from various academic backgrounds, allowing them to collaborate on real-world challenges. This initiative enhances technical skills, teamwork, cross-cultural communication, and project management capabilities. In this context, this group focused on finding sustainable solutions to the issue of fish waste in the Ostrobothnia region of Finland, which is renowned for its fishing industry but struggles with managing variable amounts of waste. The aim of this project was to develop methods to repurpose fish waste into valuable products, such as oils, food, cosmetics, and pet food, thus reducing environmental impact and creating economic opportunities for local fishermen.

Each team member brought a unique skill set to the project, ranging from mechanical engineering to product development, which was crucial for addressing the complex challenges of fish waste management. The team worked collaboratively to test various techniques, including fermentation, oil extraction, drying, and protein extraction. These findings offer practical insights for implementing these methods in the Finnish fishing industry.

4.1 European Project Semester

The European Project Semester (EPS) is an educational program designed for higher education students, particularly in engineering and technology fields. It typically involves a multidisciplinary approach, allowing students from different countries and academic backgrounds to collaborate on real-world projects.

During the EPS, students work in teams to address specific challenges or tasks set by industry partners or academic institutions. This experience not only enhances their technical skills but also promotes teamwork, cross-cultural communication, and project management abilities.

The program is often organised as part of a larger European initiative to foster collaboration and mobility among universities and students across Europe, enhancing the overall educational experience and preparing students for a global workforce.

4.2 Project Group

In the following chapter, the EPS team "Future fish waste products" introduces itself and explains the reasons and expectations for this form of study.

Kobe Halans (*Figure 1*) is 21 years old and currently studying for a master's degree in product development at the University of Antwerp in Belgium. He decided to join the European Project Semester after hearing great things about it from friends and family who recommended it. The idea of working in a team with people from different disciplines and cultures really appealed to him, as he believes it is a great way to prepare for the real challenges he'll face in the professional world. He also sees this Erasmus experience as an amazing opportunity for personal growth and self-development.

Figure 1: Kobe Halans

Lennard Hopster (*Figure 2*) is 22 years old and studies mechanical engineering at the University of Applied Sciences in Osnabrück. He is in his fifth semester and applied for the European Project Semester because he wanted to meet new people from all over the world and to see and experience a new country. He hopes to improve his English and his ability to work in a team.

Figure 2: Lennard Hopster

Johannes Kuhlmann (*Figure 3*) is 22 years old and studies Energy-, Environmental- and Process Engineering at the Osnabrück University of Applied Sciences in Germany. He is currently in his fifth semester, which he is doing as a European Project Semester in Finland (Vaasa). His expectations and goals for this semester are to work in a multicultural team, to improve his English and to solve complex problems together as a team.

Figure 3: Johannes Kuhlmann

Víctor Mendoza (*Figure 4*) is a 22 years old student and he is currently studying Mechanical engineering and Product Development engineering at the same time at the Polytechnical University of Catalonia (UPC) in Barcelona. He is doing the EPS as a final project of one of the degrees and decided to choose this program due to the extra knowledge a multidisciplinary and multicultural team can give, apart from the experience of living abroad.

Figure 4: Victor Mendoza

Julian van der Meer (*Figure 5*) is a 25 years old student from the Netherlands. He studies architectural engineering at The Hague University of Applied Sciences. He chose the EPS project to work with an international team, to develop his English skills and to grow personally. He decided to do the EPS in Finland because he was attracted by the country's natural beauty, freedom and tranquillity.

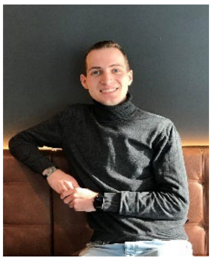

Figure 5: Julian Van der Meer

4.3 Belbin Test

Belbin's theory suggests that there are nine key team roles that individuals typically gravitate towards. These roles are grouped into three categories: action-oriented roles, people-oriented roles, and thought-oriented roles.

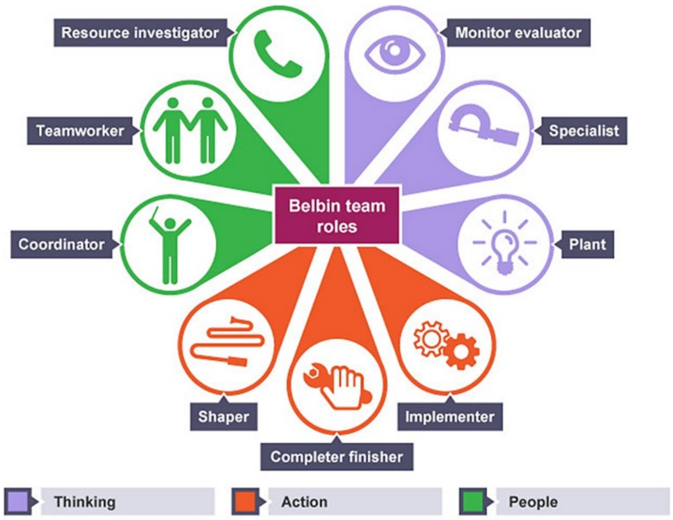

Figure 6 : Belbin team roles[1]

Figure 6 displays the Belbin team roles chart, illustrating the placement of various roles within the model. Each role is divided into three subcategories, highlighting different aspects of how individuals contribute to team dynamics. The Belbin test helps organisations and teams by improving collaboration, optimising role assignments, and enhancing overall team performance. It recognises that each role brings unique strengths, and no single role is superior to another. Teams tend to be most successful when there is a balanced mix of these diverse roles.

[1] (chegg, 2024)

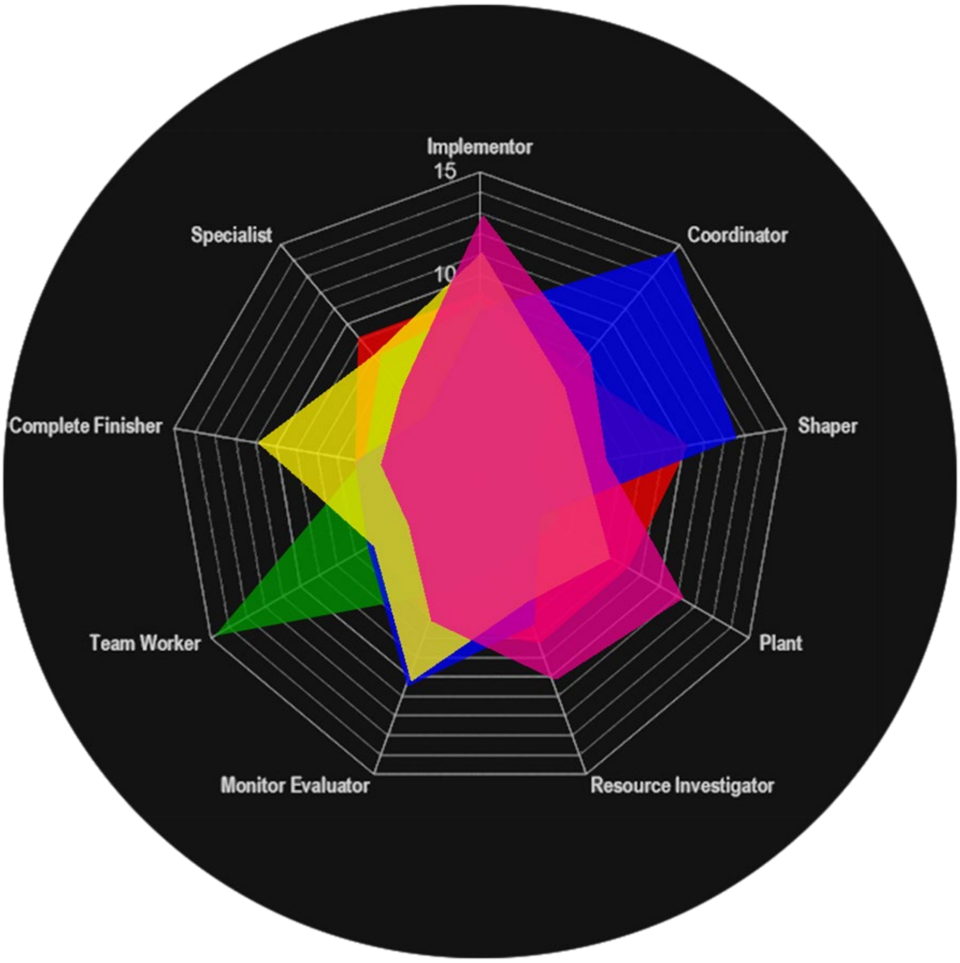

Figure 7: Belbin team chart

In *figure 7* the Belbin results for the future fish waste products team can be seen, showing that all team members are well-balanced across all roles. Notably, there is a strong emphasis on the coordinator, shaper, implementer, and team worker roles. Each team member excels in a specific aspect of their role, contributing to a balanced team dynamic. This balance, as shown in the Belbin chart, is an advantage for the success of the project.

Each colour in the Belbin team chart represents a team member from the group. The blue colour represents Johannes' result. He has strengths in the areas of coordinator, shaper and monitor evaluator. The green colour represents the result of Julian, who has a strong attitude as a team worker. The pink colour that is visible above, can be assigned to Kobe. He has a high strength in the areas of implementor, plant and resource investigator, which emphasises his educational background as a product developer. The red colour, which can be assigned to Lennard, and the yellow colour, which reflects the result of Victor's Belbin test, are balanced and show neither great strengths nor weaknesses.

4.4 Gantt–Chart

Gantt-Chart is a useful tool used on projects for planning the time in the best way possible. This diagram is special because at first sight you can understand how the time for each task is distributed. To understand how it works, you need to know that on the vertical axis the tasks are listed and on the horizonal axis the time is plotted.

See appendix for full view

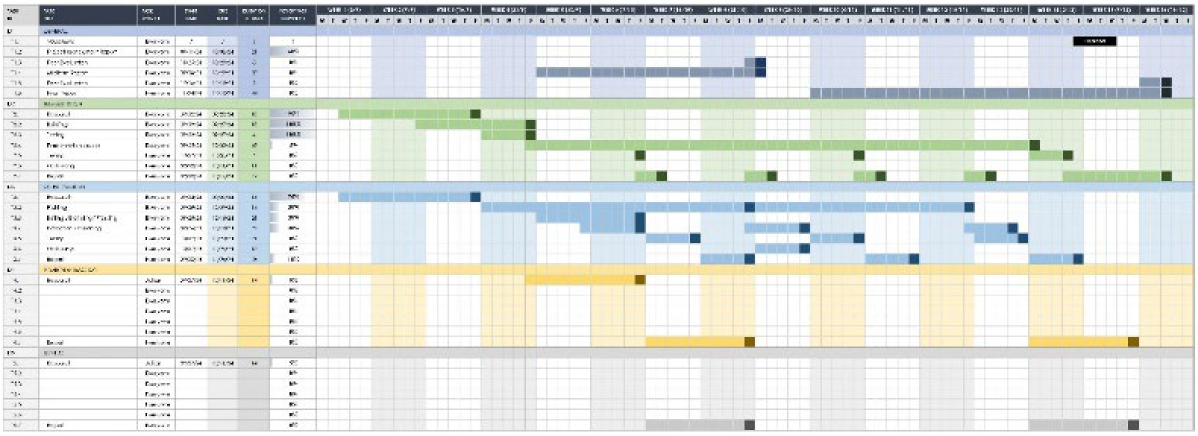

Figure 8: Gantt-Chart

As seen in the picture, the group started focussing on the research of the fermentation, because it was necessary to collect some information before something practical could be done. In addition, the team started building the bench in the second week of work, because the fermentation process should be started as soon as possible. As the team consists of five members, the work could be divided so research into oil extraction could begin at the same time.

After the fermentation process started, the focus was on testing and optimising the processes for the oil extraction. Furthermore, researching on the process of the protein extraction started. While doing this, writing the report was also an important task. Therefore, the team would not get any time trouble at the end of the semester. In the end the focus was on finishing the report and testing the results of the fermentation process.

4.5 Stakeholders

A stakeholder is an individual or a group of individuals with an interest, often financial, in the success of a business. In the following, a list of all the stakeholders that are involved in the project and their wishes.

Mikael Ehrs and Biniam Tefera are the supervisors of this project. They wish the team to behave respectfully, allowing each team member to build themselves. Regarding the project, it was expected to do lots of practical work that gives visibility to itself. In addition, some marketing for the school was requested.

Blue products is an association, which gives economic support to the project. It is formed by Kag I Österbotten, Aktion Österbotten, Österbottens Fiskarförbund, VTT Technical Research Centre of Finland, and Natural Resources Institute of Finland. Their common goal is to have practical results out of the project that gives them innovative insight into further possible development.

In addition, the parties of Blue products have their own demands as well. Kag I Österbotten is based on the project, they wish to develop their business as well as spread innovation and sustainability. The association Österbottens Fiskarförbund (Marina Nyqvist is the chief), is looking for a final product that can create a high income. Regarding the way of working, they want the project members to do publications, presentations, and communicate with the organisation

The Novia University of Applied Sciences is participating as a guest university for the students. Their aim is that the students who participate in this project, have a wonderful experience and at the same time produce impressive projects that delight the teachers. In addition, the Novia University wishes the team members to promote the university for possible newcomers by publishing a promotional video and by talking about their experience in their home university.

The wishes of the home university from team members is that the team members have a nice stay in Finland. In addition, their wish is that they learn as much as possible, especially from the industry world.

Potential customers and Fisheries often adopt a careful and traditional perspective, leading to scepticism for the potential usefulness of insights generated by this project. However, it is expected to discuss the opportunities with the ten major players in the region.

A stakeholder register is a document that provides detailed information about the stakeholders. The information is for the project management and team to identify, analyse, and manage all stakeholders involved in or affected by a project. This gives an overview to understand who is involved, their influence, interest in the project and how best to engage with the stakeholders. Down under, the Stakeholder register of this project is visualised.

See appendix for full view

ID	Role	Contact	Category	Interest	Influence	Expectations	Communication	Meeting frequence
1	Project Team	/	Internal	high	high	Reaching Deliverables	Whatsapp	3 times a week
2	Project Managers (Mikael Ehrs and Biniam Tefera)	mikael.ehrs@novia.fi biniam.tefe	Internal	high	high	Reaching Deliverables	Email	1 time a week
3	Kag I Österbotten	/	Internal	medium	low	Reaching Deliverables	Email	/
4	Aktion Österbotten	/	Internal	medium	low	Reaching Deliverables	Email	/
5	Österbottens Fiskarförbund	/	Internal	medium	low	Reaching Deliverables	Email	/
6	VTT Technical Research Centre of Finland	/	Internal	medium	low	Reaching Deliverables	Email	/
7	Natural Resources Institute of Finland (LUKE)	/	Internal	medium	low	Reaching Deliverables	Email	/
8	Marina Nyqvist	marina.nyqvist@fishpoint.net	Internal	medium	low	Reaching Deliverables	Email	1 time a month
9	Novia University	/	Internal	medium	high	Reaching Deliverables	Email	/
10	Home University from team members	/	External	low	low	Reaching Deliverables	Email	/
11	Fisheries / Potential Customers	/	External	medium	low	Reaching Deliverables	Email	2 times a month

Figure 9: Stakeholders register

The Stakeholder ID is a clear identifier for each stakeholder. The next part of the register is the stakeholder's role within the project such as sponsors, customers, teachers and more. Next to the role there is also contact information for each stakeholder. Furthermore, the category of the stakeholder is needed to categorise whether the stakeholder is internal (team members, managers) or external (customers, suppliers).

The interest level shows how a stakeholder is interested in or affected by the outcome of the project. This helps to determine how much attention or information the team should give them. The influence of the stakeholder shows how much authority the stakeholder has over the project. The stakeholder expectations show what each stakeholder will expect from the project and the communication shows the way the team should communicate with every stakeholder.[2]

4.6 Mission and Vision

The Mission for the project is given by Mikael Ehrs at the beginning of the semester. Firstly, stabilisation methods such as drying and fermentation should be researched and tested during the semester. The fermentation method will be used to produce garum, while the

[2] (Bell, 2021)

products of the drying process will be used for pet food. Two test benches will be built for fermentation, which in the best case will be able to run for three months without human intervention.

Research should also be carried out into methods specifically designed to utilise fish waste. Oil and protein extraction should be tested and researched here. Another task is to make soap from the extracted oil and find the optimum ingredients.

Another way to use fish waste is to extract and separate proteins from the fish. This could be used, for example, to produce products for food supplements. Research and testing should therefore be carried out in this area.

The vision of the project is to find sustainable and affordable ways for fishermen in Ostrobothnia to stabilise their fish waste and then convert it into valuable products. In addition, all data and findings are recorded to provide subsequent projects with important information for further work.

5 Ostrobothnia

Ostrobothnia is a region located in the western part of Finland, covering an area of 10,000 square kilometres. It features a coastal landscape with several cities and towns spread across the region. The population of Ostrobothnia is approximately 200,000 people. Ostrobothnia is known for the fishing because of its large coastline. Halfway of Ostrobothnia lies Vaasa, a key city that serves as a hub for the energy technology sector. Vaasa is known for having a high concentration of energy technology companies. This makes Vaasa and Ostrobothnia a major player in fishing and in the energy industry within the region.[3]

Figure 10: Ostrobothnia on the Finnish map[4]

5.1 The Ostrobothnia Fisheries Association

The Ostrobothnia Fisheries Association has 91 members and was founded in 1930. The members divide into 51 water owner associations, 36 fishery associations and four fishing regions. The umbrella organisation the Federation of Finnish Fisheries Associations and its main service for the members is "to promote the fishing industry in its field so that the production of fish in the fishing grounds is secured, profitable methods developed for the procurement and utilisation of fish production and the increased consumption of domestic fish." (Österbottens Fiskarförbond, 2024) The Ostrobothnia fisheries Association is an official advisory organisation and gets governmental funding.

[3] (Commerce, 2024)
[4] (Österbottens Fiskarförbond, 2024)

5.2 Fishing in Ostrobothnia

In Ostrobothnia there are several different fishing areas such as the Kristinestad-Stora fishing district, which covers Kristiinankaupunki, Bötom, Isojoki and Teuva. The Södra Kust-Osterbottens fishing district covers Kaskinen, Närpes, Korsnäs, Malax and Vaasa. The Kvarken fishing district includes Korsholm, Vora-Maxmo-Oravais and Vähäkyro. The last district is the Norra Kust-Österbottens fishing district, which covers Nykarleby Larsmo, Pedersöre, Kronoby, Jakobstad and Kokkola.[5]

The fishing industry in Ostrobothnia is small in international scales but large in a national perspective. Therefore, over 25 per cent of the fishermen in Finland can be found in the Ostrobothnia region. Just almost half of the catch of common whitefish, a third of the perch and just over a quarter of the herring is caught here. On the other hand, the number of the fisherman is decreasing in recent years. In Ostrobothnia, there are lots of tiny fishing boats under 12 meters and not much big fishing boats. This is why fishing mostly takes place near the coast. The most important fish species that are caught in the Ostrobothnia region are Baltic herring, sprat, common whitefish, perch and salmon. Also, fishing is characterised as sustainable both environmentally and in the view of the fish stocks. One of the most important landing ports for the Finish Herring fishery is in the town of Kaskinen, which is located in the Gulf of Bothnia. [6]

5.3 Fat and Proteins in Fishes Caught in Ostrobothnia

To analyse the results of the experiments done by the team during the project, the different types of fishes caught in Ostrobothnia had to be understood. In the following table the different types of fishes, that have been caught in Ostrobothnia in 2022, are presented. They are arranged chronologically by the Amount in tons that have been caught in one year. It can be seen that the fish, that has been caught the most, has a very high amount of fat and an average amount of proteins.

[5] (Gänzle, 2022)
[6] (Gänzle, 2022)

Type of fish	Amount caught in 2022 in Ostrobothnia (t)	Fat (g/100g)	Proteins (g/100g)
Herring[7]	14,715	10,70	16.3
Sprat[8]	427	11,00	18.3
Cod[9]	374	1,90	21.7
Bream[10]	232	2,90	17.5
Perch[11]	193	1,50	15.3
Whitefish[12]	119	5,90	19.1
Pike[13]	95	0,69	19.3
Roach	50	/	/
Smelt[14]	50	2,40	17.6
Burbot[15]	26	0,81	19.3
Zander[16]	18	0,70	19
Salmon[17]	16	15,00	20,4
Ide[18]	7	3,80	20.2
Trout[19]	3	3,80	19.4
Total / Average	**16,325**	**10,11%**	**16.5%**

Table 1: Nutrition of different fishes caught in Ostrobothnia

As you can see in *table 1*, there are certain types of fishes that are suitable for various processing methods based on their fat and protein content. Protein extraction aimed for human consumption, cod and zander look like ideal choices because of their high protein content (21.7g and 19g per 100g). Their profiles make them well-suited for producing concentrated protein products.

For drying and creating a powder for pet food, herring and sprat are both optimal selections. These fish have a high fat content (10.7g and 11g per 100g) and decent protein levels, which contribute to a nutrient-dense powder.

7 (Nutritional value of herring, 2024)
8 (Sprats, raw – nutrition, 1993)
9 (Roe, cod, hard, raw – nutrition, 1993)
10 (Bream, Sea, raw – nutrition, 1993)
11 (Nutrition Facts for Fish, ocean perch, Atlantic, raw, 2024)
12 (Nutrition Facts for Raw Whitefish, 2024)
13 (Nutrition Facts for Fish, pike, northern, raw, 2024)
14 (Nutrition Facts for Fish, smelt, rainbow, raw, 2024)
15 (Nutrition Facts for Fish, burbot, raw, 2024)
16 (Zander, 1993)
17 (Nutrition Facts for fish, 1993)
18 (Gardeniadream, 2024)
19 (Trout, brown, raw, 1993)

Oil extraction, for creating sustainable soap, benefits most from fish with high fat content. Salmon, with 15g of fat per 100 g, is the best candidate due to its rich omega-3 fatty acids that are valuable for skincare and soap production. Based on the average catch of fishermen in Ostrobothnia, the typical fat and oil content available for extraction is approximately 10%.

For fermentation to produce garum, herring and sprat stand out due to their balance of fat, protein, and strong flavour profiles. These fishes are widely available and have nutrient compositions that lend to typical flavours of fermented fish sauces.

Lastly, collagen extraction is best suited to fish like cod and whitefish. These types are rich in protein and low in fat, containing the connective tissues for collagen processing. Collagen extracted from these fishes can be used for supplements and skincare products for wellness and beauty industry.

5.4 The Problem of Fish Waste

Only 36% of the fish is consumed as pure meat fillets, the rest is considered fish waste even though there are some existing methods to benefit from this fish waste.[20] The only method currently used in the Ostrobothnia region to process fish waste is to produce biogas from it, even though this destroys valuable ingredients such as proteins. In addition, the Ostrobothnia fishermen work with variable amounts of fish waste and there are different fishermen companies ranging from little to national ones. That is why the aim of this project is finding ways to benefit from fish waste, even if there are variable amounts or different types of fisher companies.

[20] (Collis, 2021)

6 Stabilisation Methods

For the fishermen of Ostrobothnia, a key step in upcycling their fish waste is to find simple and cheap methods of stabilising the fish waste. As there are many small fisheries that cannot calculate exactly how much fish they will catch each day, it is important to have a reliable stabilisation method to collect more fish and start the upcycling process with larger quantities.

With this in mind, many stabilisation methods such as drying, freezing, smoking, salting, pickling, vacuum packing, canning and fermentation had to be researched. As freezing had already been researched and tested in the previous project, and due to the time limit of four months, the main aim of this project is to look at the drying, pickling and fermentation processes in relation to stabilisation methods.

The requirements for the process are that it should be as little labour intensive as possible and that it should be cost effective and easy to implement in fishermen's businesses. In addition, the stabilisation process must not degrade the proteins, collagens and fats in the fish, as these components are key to high quality end products.

6.1 Fermentation

Fermentation is a crucial biochemical process widely used in food and beverage production, biotechnology and energy generation. It plays a significant role in flavour development, preservation, and the creation of various industrial products.[21]

This biochemical process is important for this project because, by using it, a fish sauce named garum can be produced. Therefore, thanks to fermentation, a sellable product out of fish waste can be achieved. In addition, the production of garum requires a long time (between several months and a year), meaning that during the process, the fish waste will be stabilised, which is one of the main goals of this project.

To carry out fermentation with fish waste, it is necessarily need to understand what the fermentation process is all about. The "fermentation is a metabolic process in organisms that converts carbohydrates into chemical energy, without requiring oxygen". (Helmenstine, 2023) This means, that the fermentation is an anaerobic process. Fermentation is used by

[21] (Wood, 1998)

humans in many ways. Beer, wine, mead, cheese and yoghurt are only a couple of examples how products of a fermentation process could look like.

6.1.1 Different Options of Fermentation

Lacto acid fermentation is crucial for products like yoghurt, kefir, and buttermilk. Traditionally, raw milk was left to ferment naturally. Nowadays the milk must be pasteurised and injected with starter cultures due to regulations. Another similar process is lacto-fermenting vegetables, like Sauerkraut and pickles, that are produced worldwide. The process is also used in silage production for animal feed.[23]

Technical fermentation is widely used in biotechnology for producing bioethanol, amino acids, organic acids, enzymes and antibiotics. Bioethanol, especially, is a primary product with substrates like starch, sugarcane and corn used depending on the region. A future substrate for bioethanol production is Cellulose.[24]

Another way of using fermentation is biogas production. This gas is generated through anaerobic fermentation of biomass, including a mixture mainly composed of methane and carbon dioxide. The next step is to purify the gas to use it as bioenergy. Other gases like sewage gas and landfill also result from similar fermentation processes.[25]

6.1.2 Garum

The aim of using fermentation on this project is to produce garum, an ancient roman sauce. This sauce was created by letting fish and salt rest for several months in an amphora which was placed in a warm environment (30°C to 40°C) and mixing it once a day.

In this process, the bacteria inside the guts of the fish are responsible for making the fermentation. Since the original recipe was aerobic it was needed to try this method, on the other hand, it is exciting to experiment anaerobically because true fermentation is without oxygen. In the next subchapters three different fish sauces are presented.

6.1.3 Different Garum Types

Phú Quốc fish sauce is a special sauce made from anchovies that are fermented, or aged, for a long time in warm conditions. This process takes place on Phú Quốc Island in western

[23] (Gänzle, 2022)
[24] (Gänzle, 2022)
[25] (Gänzle, 2022)

Vietnam. These anchovies are stored in large wooden barrels during fermentation, which helps create a mild, pleasant smell without any strong ammonia scent.

Ishiri is a traditional Japanese fish sauce from Noto in Ishikawa Prefecture. In the western part of Noto, it is made with Japanese sardines (called iwashi), while in the eastern part, it is made with squid liver. The fish or squid is mixed with salt and left to ferment or age for seven to nine months. After fermenting, the sauce is drained from the barrels, boiled, filtered, and then cooled. It is then ready to be used.

Patis is a traditional Filipino fish sauce commonly used in Filipino cooking as a seasoning or dipping sauce. It is made by mixing fish with salt and letting it ferment or age for several months. To make patis, the fish and salt mixture is left to ferment until the fish breaks down, releasing a liquid. This liquid is then strained and bottled.[26]

6.1.4 Review of the Previous Project

The previous project tried to produce the garum with one big tank as seen in *figure 12*. Their idea of the bucket was to mix the fish waste in a filter bag with a motor inside. Because of the design of the tank, the liquid flows downwards and the fish remains on the filter, allowing the fish to be mixed and to filter the garum at the same time. Also, they had to monitor the bucket because the motor had to turn on once a day and the temperature of the bucket had to be between 30°C and 40°C, for that they used an Arduino and some sensors.

The experiment failed, because the motor was too weak to handle the amount of fish waste, that would be needed for a proper fermentation in this tank.

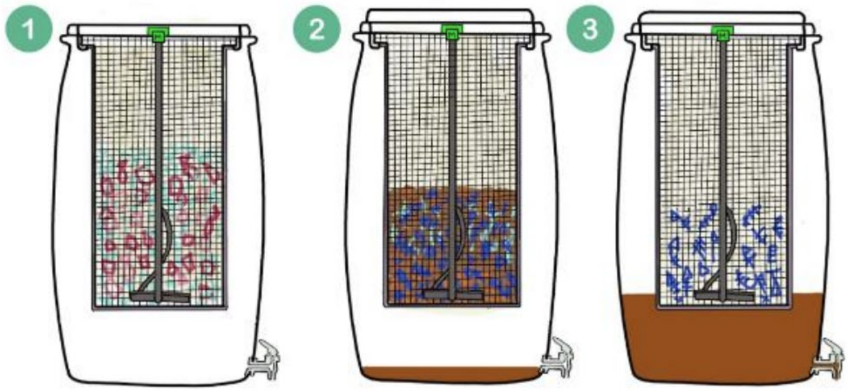

Figure 11: Sketch of last year's EPS Project

[26] (tasteatlas.com, 2024)

6.1.5 Project Teams' Idea

The idea the team decided to implement is a wooden bench where three buckets will rotate being in contact with a conveyor belt attached to a motor and these buckets will be at an angle to ease the mixing. In order to mix the buckets once a day, a socket timer needed to be connected to the motor.

To reduce friction between the buckets and the bench the team used a screw at the bottom of each bucket and added four wheels for each bucket, which also helps to stabilise the position of the buckets. Apart from the wheels a little wooden structure was installed to keep the buckets in position.

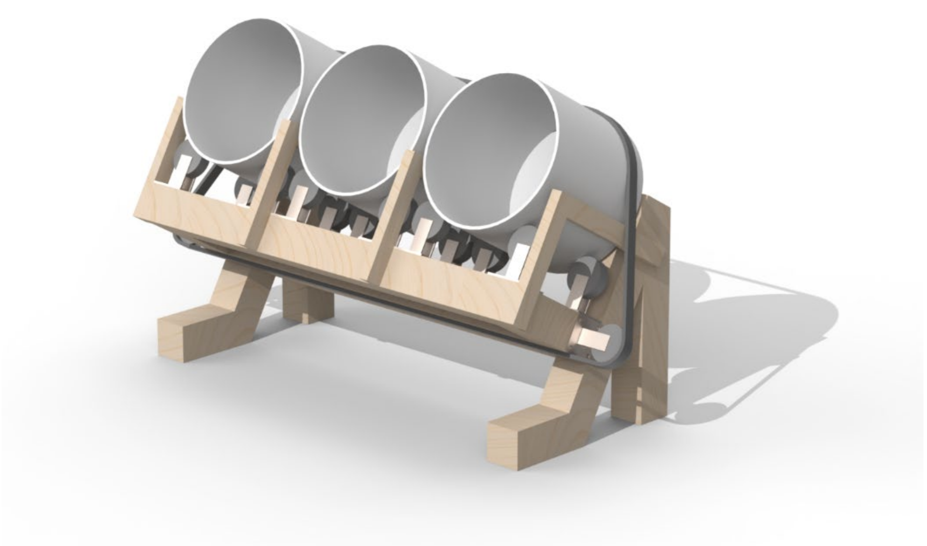

Figure 12: CAD Sketch of Fermenter

The idea was to build two benches so one can work anaerobically and the other aerobically by using three buckets on each with different ratios of salt. Also, it is worth mentioning that the buckets at the anaerobic bench will be at an angle of 30° and the aerobic one at 60° (more tilted because the top part of the buckets will have holes to make the oxygen enter).

6.1.6 Material List

The following table shows all materials and their associated functions in the construction process of the fermentation plant.

Function	Material
Framework	48 mm x 48 mm wood (5000 mm)
Framework	50 mm x 25 mm wood (1000 mm)
Turning the buckets	12 wheels
Contain the fish waste	3 litres buckets (3x)
Delivers the kinetic power	40 W wiper motor
Leading the belt, transfers the energy from the motor to the belt	Alternator Overrun Pulley (2x)
Turn the buckets	Polyurethane belt 6 x 1803 mm
Attach wheels, wood, motor	Screws

Table 2: Material list for the fermentation bench

6.1.7 Construction Process

The process the team followed for constructing each fermentation bench is explained step by step is the next one:

1. Saw the wood in the correct length.

Figure 13: Bench building process 1

2. Screw the different pieces of wood.
3. Screw the wheels in the correct position.
4. Screw the screws for reducing the friction of the buckets.
5. Make the connection between the power source and the motor.

Figure 14: Bench building process 2

6. Locate the buckets and the belt.
7. Locate the motor and the gears in the best position taking into account the tension of the belt and where you can attach them.

8. Fix the motor and the gears.

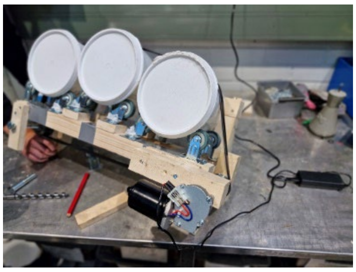

Figure 15: Bench building process 3

6.1.8 Challenges

The problems the team had in the process of building the prototypes where generated due to time. Everything had to be built as fast as possible because the fermentation needs at least three months and the project only last four months.

Because of that lack of time the team could only buy materials on close by stores or on Finnish websites with fast deliveries, which means that the project members had to choose between a scarce variety of materials. In addition, the building process had to be done aiming effectivity more than precision, as the bench did not have to do a complicated work. Some examples of problems found could be having to glue spinning wheels to make them static, or finding that the belt was too unstable, causing the buckets to fall repeatedly.

Engine

A challenge that occurred with designing the construction of the bench was buying the motor. The motor needed some requirement for example having enough Watts to drive it. Having a powerful engine is important because this was one of the flaws of previous project. The available engine was 240 volts which was too high for safety. The new engine needed to work on 12 volts. This requirement made it hard to look for a shop that sold it, was Finnish and close to Vaasa as well.

Eventually the team found an old windshield wiper engine at Motonet. For this engine a transformer was needed. This was the next challenge because the right transformer was hard to find. First the team had a car battery charger. The car battery charger was too advanced that it noticed that it was not a car battery itself. After doing research and asking an expert, the team members bought the second transformer. This was a simple yet effective transformer. With this transformer the engine finally worked.

Intern stirring paddles

Stirring the fermenting fish is a crucial part of the fermentation process. Stirring ensures that the fish waste mixes thoroughly, which facilitates fermentation. The concept for mixing the fish waste involved the use of paddles. By placing paddles along the sides of the container, the fish waste would hit the paddles as it turned, keeping the mixture continuously stirred.

When designing the fermentation station, stirring paddles were also developed. The inspiration for these paddles came from a concrete mixer, as it operates in a similar way to ensure even mixing.

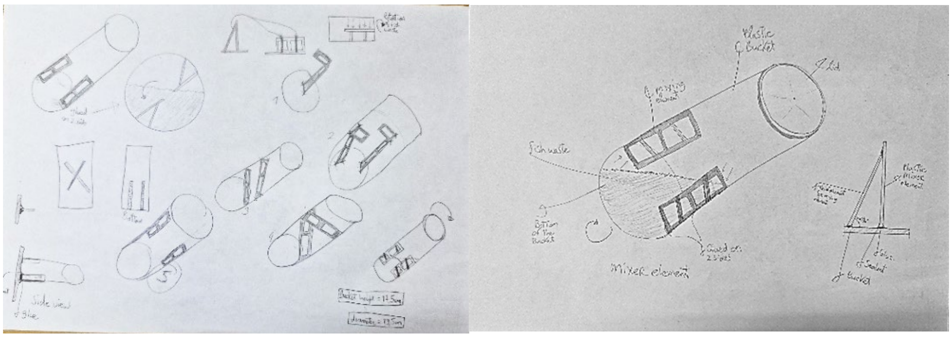

Figure 16: Sketches of the intern stirring paddles

In the design sketches, the plan was to 3D print the paddles and place them inside the buckets. However, due to time constraints, the team opted for a simpler solution. Instead, plastic was cut into the desired paddle shapes and was adhered to the bucket using silicone. The team chose silicone as an adhesive because it is non-toxic and safe for use in food production.

Figure 17: Testing the paddles

To test the stiffness of the paddles, the buckets were filled with water and shaken to observe how both the paddles and silicone would hold up and to see the water’s response. After testing, the paddles had come loose inside the buckets. Due to time constraints, the decision was made to proceed without the paddles. Now the mixing process on the fermentation bench will rely solely on the rotation of the bench itself. This choice was made with confidence that this motion will be sufficient to mix the fish waste effectively.

6.1.9 Practical Process First Bench

Once the first bench was built, the team started with the process of fermentation. Afterwards the process is described step by step and some considerations and thoughts the team had while doing it were commented:

Step 1

Cut all the fish waste (first bench was with pike) in pieces in order to make them fit into the buckets and ease the mixing and the fermentation.

Consideration: all the pieces must be cut small enough to enable the fermentation work without letting the fish rotten but without making the pieces too small because all the garum recipes are made like this.

Thoughts: some parts of the fish waste are hard to cut, like the head, and some parts are sharp enough to cut yourself, therefore, good tools and protection must be used for this process.

Step 2

Put these pieces in three buckets, always counting how many parts of each fish the team introduced depending on being head(H), body(B), fin(F) or organ(O) and weighing it:

Bucket	Weight	Head (H)	Body (B)	Fin (F)	Organ (O)	Weight of Salt	Salt-to-Fish Ratio
Bucket 1	900g	1	1	1	2	110 g	1:8
Bucket 2	998g	1	1	1	2	200 g	1:5
Bucket 3	1330g	1	1.5	1	2	440 g	1:3

Table 3: Bucket contents of the first fermentation bench

The organs are the most important part of this process because there are microorganisms in the guts, which are responsible for making the fermentation. This is why it was necessary to introduce organs from two fishes in each bucket.

Step 3

Add the salt to the fish waste in different ratios on each bucket and mix it. The salt is one of the most important ingredients of the fermentation because it avoids the fish waste to rotten and at the same time it gives a good flavour to the final product, the garum. That is why the team preferred to experiment with different ratios of salt, to find out which is the best option.

Step 4

Seal the buckets with waterproof silicon to make the process anaerobic and let it dry for 48 hours at room temperature. Making the buckets hermetic means that the team must be careful with the changes of pressure generated by the fermentation because those can break the buckets during the fermentation.

Step 5

Locate the buckets in the bench in a way that the belt position does not change over time and that the buckets are in contact with the four wheels so they can rotate properly. This part was the hardest one because due to the lack of precise machinery and the fast construction, the buckets and the belt changed their position constantly.

Step 6

Locate the bench inside the isolation tank.

Step 7

Program the temperature measuring socket so the heater does not make the temperature higher than 38ºC and lower than 32ºC. All the information that were found about the garum production says that the fermentation process must be done between 30°C and 40ºC. Also, it had to be considered that apart from the thermostat of the temperature controller socket, the heater has its own thermostat, which means that a possible interference between them could appear (solved selecting the maximum capacity of the heater).

Step 8

Program the socket timer so the motor only gets powered on between 10:00 a.m. and 10:02 a.m. every day. Mixing the fish waste two minutes a day will be enough for this process. The selected start time is good since the team is able to check the process almost every day.

Step 9

Let the fish waste ferment for at least three months.

In all the recipes were explained that at least you should let it ferment for three months, however due to the lack of time in the project it is only possible to let it run for this time with the first bench.

6.1.10 Practical Process Second Bench

For the second bench the team followed the exact same procedure as the first bench, adapting the bench because this will be aerobic instead of anaerobic.

The changes were increasing the angle of the buckets from 30 º to 60 º, so the fish waste does not fall through the holes that were made for making the process aerobic, using another type of fish (little whitefishes) and different quantities of fish waste on each bucket.

The quantity of fish waste (the fishes were small enough to put them in completely) and salt the team put inside each bucket were the following ones:

Bucket	Number of Fish (Whitefish)	Weight of Fish	Weight of Salt	Salt-to-Fish Ratio
Bucket 1	15	1kg	340g	1:3
Bucket 2	14	1kg	200g	1:5
Bucket 3	15	1kg	125g	1:8

Table 4: Bucket contents of the second fermentation bench

This second bench started working later than the first one, meaning that it will only ferment for two months and a half.

6.1.11 Results

After the aerobic samples had been fermented for exactly 42 days and the anaerobic samples for 64 days, the samples were removed from the fermenter and analysed. Pictures were taken of the flesh of the fish and the liquid. The appearance of the meat and the filtered liquids from the different samples are compared below. The pictures of the liquid in the glass test tubes represent the state after filtering with a coffee filter.

1:3 anaerobic

Figure 18: Fermentation results anaerobic, 1:3 salt ratio

The picture on the left shows the anaerobic fermented meat with a salt to meat ratio of 1:3. The fish parts had not dissolved over the fermentation period. It should be emphasised that the meat has not rotted yet after such a long time at the given temperature. In the centre picture you can see the liquid that has been separated from the fish using a sieve. On the picture on the right, you can see the liquid that could be extracted and filtered with a coffee filter. The liquid is slightly cloudy and has a yellowish to orange colour. It should be noted that the liquid has become significantly lighter in colour after it has been filtered with the coffee filters. This suggests that some solids have been filtered out.

1:5 anaerobic

Figure 19: Fermentation results anaerobic, 1:5 salt ratio

The picture on the left shows the fish parts that has been anaerobically fermented with a salt to meat ratio of 1:5. The meat in this sample has not disintegrated or rotted either. It looks similar to the meat from the sample with a salt content of 1:3, anaerobic, but it is slightly darker. The liquid of this fermentation method can be seen in the centre picture. The colour of the liquid changed slightly after filtering with a coffee filter, which could mean that only very few solids could be filtered out.

1.8 anaerobic

Figure 20: Fermentation results anaerobic, 1:8 salt ratio

The picture on the left shows the fish parts and the liquid, that had been fermented anaerobically with a salt to meat ratio of 1:8. Just the fish parts are shown in the centre picture. It can be seen that the meat has not dissolved yet. The liquid that could be extracted and filtered from this sample is darker than the sample with a salt content of 1:5, anaerobic.

1:3 aerobic

Figure 21: Fermentation results aerobic, 1:3 salt ratio

The picture on the left shows the contents of the bucket, which was fermented under aerobic conditions and with a salt content of 1:3. There is salt on the top, that has not been dissolved. In the centre picture you can see the meat from the bucket, which has now been filtered out using a sieve. You can see that the meat has neither rotted nor dissolved. The picture on the right shows the liquid that has been filtered out. It is slightly cloudy and has a yellowish to orange colour.

<u>1:5 aerobic</u>

Figure 22: Fermentation results aerobic, 1:5 salt ratio

The picture on the left shows the meat of the bucket, which was fermented under aerobic conditions and a salt content of 1:5. There is still salt visible on the top of the flesh but not as much as on the previous test result (1:3 aerobic). In the middle picture you can see the flesh of the meat that could be filtered out with a sieve. In the right picture the liquid that was filtered out with a sieve can be seen. It is slightly darker than the previous test result.

<u>1:8 aerobic</u>

Figure 23: Fermentation results aerobic, 1:8 salt ratio

In the left picture the inside of the bucket that has been fermented under aerobic conditions and a salt ratio of 1:8. In the middle picture the flesh of the fish is shown. It should be emphasised here that the meat decomposed best in this test. You can see the bones from which the meat has separated clearly. As in the other aerobic experiments, the liquid is lighter in colour than in the anaerobic experiments. Furthermore, it should be emphasised, that much less liquid could be extracted from this sample than from the others. When the sample was taken, it was found that the contents of the container were clumped together and therefore could not be mixed well. This is probably also the reason why so little liquid could be extracted

6.1.12 Conclusion

The fermentation experiments under aerobic and anaerobic conditions with different salt-to-meat ratios show that the fish meat remained preserved and did not fully dissolve in any sample, despite the fermentation period. In anaerobic conditions, the liquid was darker and cloudier, especially at higher salt ratios indicating more solids were present. The aerobic samples, on the other hand, produced lighter-colored, less cloudy liquids, with the 1:8 aerobic sample showing the most decomposition of the meat, as bones were clearly visible. In order to really know what ingredients are in the liquid, the samples are sent to a Eurofins laboratory. The results of the lab test cannot be presented in this report as the analysis takes too much time.

Salt ratio	Start-Weight	End-Weight	Percentage
1:3 anaerobic	1.770 g	222 g	12.5
1:5 anaerobic	1.198 g	186 g	15.5
1:8 anaerobic	1.010 g	235 g	23.3
1:3 aerobic	1340 g	173 g	12.9
1:5 aerobic	1.200 g	168 g	14.0
1:8 aerobic	1.250 g	45 g	3.6
Total/Average	**7.768 g**	**1.029 g**	**13.6%**

Table 5: Summary of the fermentation process

6.2 Pickling

Pickling is a method used to preserve food and extend its shelf life. This is done by fermenting the food anaerobically in brine or soaking it in vinegar. The process often changes the texture and the flavour of the food. The preserved product is called a pickle, or its name is preceded by the term "pickled." Various foods can be pickled, including vegetables, fruits, mushrooms, meat, fish, dairy products, and eggs.[27]

This process stood out the team because fish waste could be stabilised with a process that is fast, simple and doesn't need neither a lot of resources nor a lot of knowledge. Therefore, pickling is a process that can cover one of the main aims of this project, stabilisation of fish waste, while being simple enough to be done by every fisherman.

6.2.1 Experiment 1

The first series of experiments focused on pickling fish (Pike). This was initiated by using the following ingredients and ratios for the process. For this experiment, the team used a total of 4500g of fish waste, which required:

Ingredients	For 1kg	For 4.5kg
Fish Waste	1 kilogram	4.5 kilograms
Salt	150 grams	675 grams
Vinegar	1 litre	4.5 litres
Sugar	100 grams	450 grams

Table 6: Ingredients for pickling process per kilogram and per 4500 grams (1)

[27] (Davison, 2018)

Figure 24: Bucket before pickling process

All ingredients were combined and mixed thoroughly in a large container. The container was sealed airtight, with the final mixture weighing approximately 10 kg. The sealed container was stored in the rooftop lab on the 25th September 2024.

The mixture remained undisturbed for approximately two weeks. After this period, the team assessed the impact of the pickling process on the efficiency of fish oil extraction.

Figure 25: Fish waste and mix it with salt

On this attempt to process the fish waste, the team prepared a pickling mixture to extract oil. To get this mixture, the team pressed the pickled fish waste. The pickling substance came from the pike fish waste. This mixture was boiled to release the oil. The total weight of the boiled substance was 4064 g. After boiling, the mixture was poured into beakers and graduated cylinders.

Figure 26: Extracting oil from pickling

No oil has separated from the substance. In this way, it was not possible to extract the oil using a pipette. Additionally, the smell of the pickling substance was extremely unpleasant with an intensely sour fume. The fumes irritated the eyes, even when wearing safety glasses. This made it hard to work with this substance and to extract oil out of it.

6.2.2 Experiment 2

In the second experiment on pickling, the same percentage of substances were added and mixed as in experiment one. Since the fish was not rotten in the first experiment, the team considered the quantities added to be correct. For this experiment, the team used a total of 6000g of fish waste, which required:

Ingredients	For 1kg	For 6kg
Fish Waste	1 kilogram	6 kilograms
Salt	150 grams	900 grams
Vinegar	1 litre	6 litres
Sugar	100 grams	600 grams

Table 7: Ingredients for pickling process per kilogram and per 6000 grams (2)

All the ingredients were carefully measured and mixed in a large bucket. The bucket was then sealed tightly to make it airtight, with the total weight of the mixture being around 13.5 kg. The sealed bucket was stored in the rooftop lab and left undisturbed for about two weeks. After this time, the team evaluated how the pickling process affected the efficiency of extracting fish oil.

Figure 27: Crushed fish waste before pressing and boiling

As expected, the fish was not rotten in this experiment either, so the project team also tried to extract oil from the pickled fish. In comparison to experiment one, in experiment two the fish remains were shredded with a blender and boiled for 50 minutes before pressing. It is important to note that the project team was unable to use a large proportion of the fish scraps as the heads of the fish were too hard to be shredded. Furthermore, it is important to mention that the shredded part of the fish consisted almost entirely of fish skin.

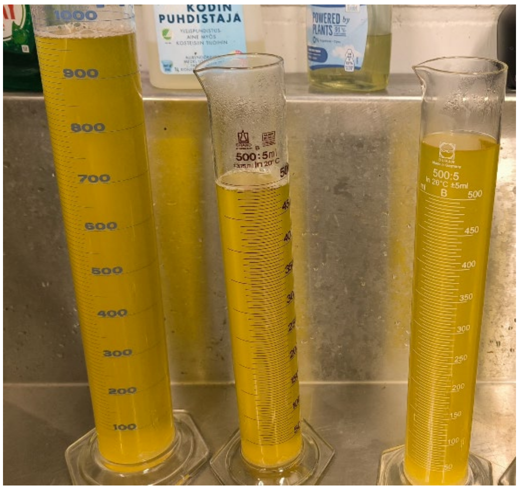

Figure 28: Separating process

As in experiment 1, the team boiled the pressed liquid, which weighed 3700 g, as can be seen in *figure 28*.

6.2.3 Conclusion

The experiments aimed to test whether oil could be extracted from pickled fish waste, using pike as the material. While the pickling process successfully preserved the fish waste and prevented it from rotting in both experiments, the attempts to extract oil were not successful.

In Experiment 1, the team pickled the fish waste with salt, vinegar, and sugar for two weeks. After boiling and trying to separate the oil from the mixture, no oil could be collected. The process also created a strong sour smell and irritating fumes, making it difficult to handle the mixture.

In Experiment 2, the team made some changes by shredding the fish waste before pickling and boiling the mixture for a longer time. Despite these adjustments, the results were the same, so no oil was extracted. It is important to note that most of the fish waste used was fish skin, which contains small amounts of oil. Additionally, vinegar may have made it harder to separate oil from water because of its ability to mix the two together.

In summary, while pickling was effective for preserving the fish waste, it did not work for extracting oil. The low oil content in the material and the effects of vinegar were the main reasons for this result.

6.3 Drying

Drying fish is a common way to preserve and process fish waste, meaning that is a process that enables its stabilisation while possibly producing valuable products, like pet food. In addition, as being used commonly in the industry, there is already a deep knowledge about it. These reasons make drying a suitable process to be studied by the team.

There are different methods like air drying, sun drying, salt drying, using a dehydrator, and smoking. Each method has its own pros and cons and affects how long the drying takes and how good the final product is. For choosing which method the team should use, it was considered that it would be studied in a small scale and DIY way.

The team focused on studying how to dry the remaining parts of fish waste left from oil extraction, in order to obtain a nutritionally reach powder that could be used as a high-quality ingredient in pet food.

6.3.1 Drying Methods

Air drying is a natural method that does not require special equipment, making it a convenient option for preserving fish. It retains the flavor and nutrients well, but its effectiveness is weather-dependent, as it is not suitable for high humidity conditions. Additionally, the drying process can take longer compared to other methods.

Sun drying, on the other hand, is energy-efficient because it uses sunlight, and it works well in dry, warm climates. However, it requires direct sun exposure, which may not always be available, and there is a risk of contamination from insects or dust.

Salt drying is an effective way to increase the shelf life of fish by inhibiting bacterial growth. It also imparts a unique flavor to the fish. However, it requires the additional step of rinsing the fish, and if not done properly, the fish can become too salty.

Using a dehydrator offers a controlled environment for drying, which results in more consistent results. It is especially useful for small batches and various types of fish. The downside is that it requires electricity and an initial investment in equipment, and it can be time-consuming when drying larger quantities of fish. However, it is the most suitable method for this project as it is easy to use in a small scale and DIY way.

Smoking fish not only provides a distinctive smoky flavor but also helps extend its shelf life. The heat involved in the smoking process kills bacteria and parasites, adding an extra layer of safety. However, it requires special equipment and some expertise, and the process can be time-consuming and requires close attention to ensure the fish is properly smoked.[28]

[28] (Robinson, 5 ways of drying fish waste to make it last, 2024)

Figure 29: Drying methods of fish

The picture above summarises the topic of drying fish. Once again, the various methods, advantages and benefits of storing fish waste are summarised.

6.3.2 Execution in Practice

After extracting oil (chapter 4) from fish waste through blending and pressing, the remaining residue undergoes a drying process. The residue is spread in thin layers within a drying machine, where it is left to dry for several hours or even days, depending on the desired outcome. The drying duration is carefully monitored and adjusted, as the team aims to determine the optimal time and temperature for consistent results in future batches. Once dried, the fish waste is reduced to small pieces. These contain all parts of the fish, such as organs, heads, and bones.

Following this, the dried material is ground into a powder. This powder holds promise as a valuable supplement for pet food, being rich in proteins, vitamins, and other essential nutrients. Currently, multiple batches of this powder are produced, each derived from different types of fish, to observe and analyse any variations between them. The goal is to develop a premium, nutrient-dense product suitable for the pet food industry.

6.3.3 First Experiment

The first experiment began on 3rd October 2024, with the drying temperature set to 70°C. The process continued for four days and was stopped on 7th October 2024. The drying machine was arranged with three layers to compare the effects of drying on different types of fish waste.

Layer one consisted of salmon waste that had been blended, boiled and pressed.

Layer two contained pike waste, also blended, boiled, and pressed following the same process as Layer one.

Layer three held unblended salmon cut into pieces, allowing for a comparison between the drying of whole fish parts and blended waste.

Figure 30: Drying process with salmon and pike

6.3.4 Result

After four days of drying at 70°C, the fish waste from Layer one and two, which had undergone blending, boiling, and pressing, was further processed by blending it into a fine powder. The blending process effectively reduced the dried material, including bones and other hard parts, into a safe and manageable form suitable for potential use in pet food.

Layer three, which contained the unblended salmon cut into pieces, remained in its dried, whole form. This layer was left unblended to observe the differences in texture and drying efficiency compared to the blended fish waste in the other two layers.

From left to right (one & two: Layer one; three & four: Layer two; five: Layer three):

Figure 31: Result after drying process

The powder produced from Layer one and two showed a uniform consistency, indicating that the drying and blending processes effectively eliminated larger, hazardous particles. The colour and texture of the powder will be further analysed to determine its suitability as a pet food supplement. The cut pieces in Layer three appeared to dry more slowly and unevenly compared to the blended layers, suggesting that blending the fish waste before drying improve drying efficiency and consistency.

Figure 32: Fish powder in the blender

Detailed images of the dried materials and the resulting powder are presented below, showcasing the differences in appearance and texture between the layers. These results will help guide adjustments in drying time and temperature for future experiments, as well as provide insight into the most effective preparation method (blended vs. unblended) for producing a high-quality fish waste powder.

Figure 33: Different fish powders and dried pieces of salmon

6.3.5 Second Experiment

The second drying process started on 16th of October and ended 48 hours later, while a temperature of 70°C was set. In this process, the dryer's maximum capacity of six layers of fish waste was utilised. As only whitefish was available in this fish delivery, each layer was the same. Each layer consisted of blended, cooked and then pressed fish scraps.

Figure 34: Drying process with the whitefish

6.3.6 Result

After 48 hours of drying, the product you can see in the picture below was created. There are no more damp patches, but the product is still sharp. In the next step the team blended the fish and received a dried fish powder, which is seen in the images below. All the hard parts, including the bones, are soft so this product could be suitable for pet food.

Figure 35: Blending procedure

6.3.7 Storing Dried Fish

As the drying of fish waste is a stabilisation method, storage options for the dried fish waste must also be considered. The easiest and way to store dried fish is to store it in a basement. A key factor in storing dried fish is to stop the fish from absorbing moisture and being exposed to oxygen. To prevent this, it is mainly recommended to wrap paper around the fish. This process is labour intensive and as a result also expensive. The temperature while storing should be at around 2°C and a humidity of 70 percents. If done wright, the fish can be stored in a basement for up to 8 months.

To decrease the labour, it is efficient to store the dried fish waste in glass jars. It is a traditional technique, which works by tightly closing the lid of the glass jar, to prevent oxygen getting in the jar. Another way of storing dried fish is to vacuum it and put it into a fridge. It might be more expensive than packing it into glass jars, but with the right process it can be less labour-intensive, because every oxygen gets pulled out.[29] By following these storage methods, dried fish can maintain its flavour and nutritional value and be safely consumed.[30]

[29] (Greg, 2024)
[30] (Robinson, 5 ways of drying fish waste to make it last, 2024)

6.3.8 Conclusions

The team managed to get powder out of fish waste which could be used for making pet food. This is nothing new because it is already done in the industry. The contribution lies on the fact that the fish waste was also used for extracting oil, so the team got two different products from the same fish waste. To know, if the powder can be used in food, the team sent the powder to a laboratory. The powder was tested on nutritional values, Microorganisms, *Listeria Monocytogenes*, *Clostridium perfringens*, *Escherichia coli, Salmonella* and Sulphite Reducing *Clostridia*. The lab results the nutritional values are shown in the table below.

Food nutrients	Values
Energy	1476 kJ/100g 351 kcal/100g
Crude fat	12,2 g/100g
Moisture	3,87 g/100g
Crude protein	55,7 g/100g
Ash	22,2 g/100g
Carbohydrates	3,23 g/100g
Fiber	2,8 g/100g

Table 8: Nutrition results dried powder

By comparing these results with pet food supplements it can be seen that the fat levels are higher than normal, which doesn't need to be bad because the fish oil is rich in Omega 3, which could be beneficial for the health of pets skin and hair. However, this high fat content can cause rancidity and therefore off-odor if the powder is stored long, which should be experimented with different storage conditions. Another consequence of high fat, together with high carbohydrate levels, is that the energy levels are high, which is normally recommended for supplements for active pets. In addition, the moisture is low enough to stop microbial growth, the protein levels are good and the dietary fiber levels are low, which is normally used in based dried pet food. Therefore, it can be concluded that the nutritional values of this dried powder concur with those of the pet food industry.

Regarding the pathogens, the concentration of *Listeria monocytogenes* was found to be under 100 cfu/g, which is considered safe for human food and indicates a low risk of contamination. The concentration of *Clostridium perfringens* was measured between 20-100 cfu/g, which falls within an acceptable range. However, it is important to monitor these levels, as excessive growth of this bacterium could lead to foodborne illness. The concentration of *Escherichia* *coli* was under 100 cfu/g, but since there is zero tolerance for *E. coli* in food products, even small amounts pose a potential safety concern and need to be addressed. No *Salmonella* was detected in a 25-gram sample, which is a positive result and indicates that the powder is free of this pathogen. Lastly, the concentration of Sulphite Reducing *Clostridia* was found to be under 100 cfu/g, which is also within an acceptable range.

In summary, the nutritional values of the dried powder are good enough comparing them with industry pet food. Regarding the pathogens, while the fish powder meets safety standards for most microorganisms tested, particular attention should be paid to ensuring that Escherichia coli is absent, as even trace amounts of this bacterium can pose a significant health risk.31 Therefore, the dried powder lab results show that further testing and field trials could be done for trying to reach the market.

7 Oil Extraction

Fish oil is derived from the tissues of oily fish and the active ingredients are omega-3 fatty acids. As preventing coronary artery disease, helping to treat rheumatoid arthritis and slowing the progression of cancer are only a couple of the benefits of fish oil, therefore it is worth to extract and use it for several products.[31] In these days, fish oil is mostly used for supplements. The supplements target different areas of the human body and are designed to promote optimum health. Alternative products and ways of using fish oil are far less widespread than supplements. That is why the team emphasise the importance of researching and testing other ways of using fish oil.

There are different ways to extract oil, and each method can affect how much oil can get extracted from the fish waste. In the past, researchers have tried processes such as freezing, pickling, and direct extraction to see which works best. The goal is to test new ways of improving oil extraction, like blending the fish and using special methods to make sure the oil is clean and has high quality.

7.1 Previous Approaches

In the previous year, another EPS-group explored three distinct methods for stabilising fish prior to oil extraction, aiming to determine the most effective approach. The first method, and the simplest, involved extracting the oil directly from the fish without implying any stabilisation processes. This served as the baseline for comparison with two additional methods. These methods were freezing the fish and pickling it in an acidic solution for a period ranging from a few weeks to a month.

Upon concluding the experiments, several insights were gained. First, freezing proved to be an ineffective method for oil extraction due to the crystallisation of fats, which impeded the process. Second, the overall yield of oil was found to be comparable between the unstabilised fish and those subjected to pickling. However, the pickling process offered a distinct advantage, which facilitated the extraction of oil compared to the unstabilised method, likely due to the softening effects of the acidic solution on the fish tissue.

[31] (Shane-McWhorter, 2024)

These findings, as reported in the *Final Report, Methods to Utilise Fish Waste*, provide valuable guidance for future optimisation of fish oil extraction methods, highlighting pickling as a potentially more practical approach.[32]

7.2 Optimising Oil Extraction

Given the limitations associated with freezing fish, the team explored two primary approaches for fish oil extraction, pickling the fish and extracting the oil without implying any stabilisation methods. To enhance the quality of the extracted oil, a fat-cleaning process was introduced between the extraction stage and the soap-making phase. Various methods and procedural sequences were tested during the oil extraction process to evaluate their impact on oil volume, quality, and saturation. These investigations aimed to identify the approach that produced the highest volume of oil with the best quality.

To further increase the percentage of oil extracted from fish waste, the team plans to expand the stabilisation techniques beyond pickling by experimenting with cooking and blending the fish into a fine paste. This paste will then be pressed and subjected to pressure to extract the maximum possible amount of oil.[33] This comprehensive approach aims to enhance both the efficiency and quality of fish oil extraction.

[32] (Brugada, Rames, Babs-Khalid, & Mous, 2024)
[33] (Bonilla & Concha, 2018)

7.3 Different Processes

Various factors influence the process of achieving optimal quality and quantity of the oil. The present study involved experimenting with the combination of optimised variables. By processing fish waste into oil, several techniques, including blending, boiling, pressing, and filtering, were implied as it can be seen in the picture below. To assess whether these factors significantly affect the outcomes, the process was repeated multiple times, both with and without the blending or boiling steps. This approach enabled observation of the differences in results attributable to these factors within the newly optimised procedure for oil production.

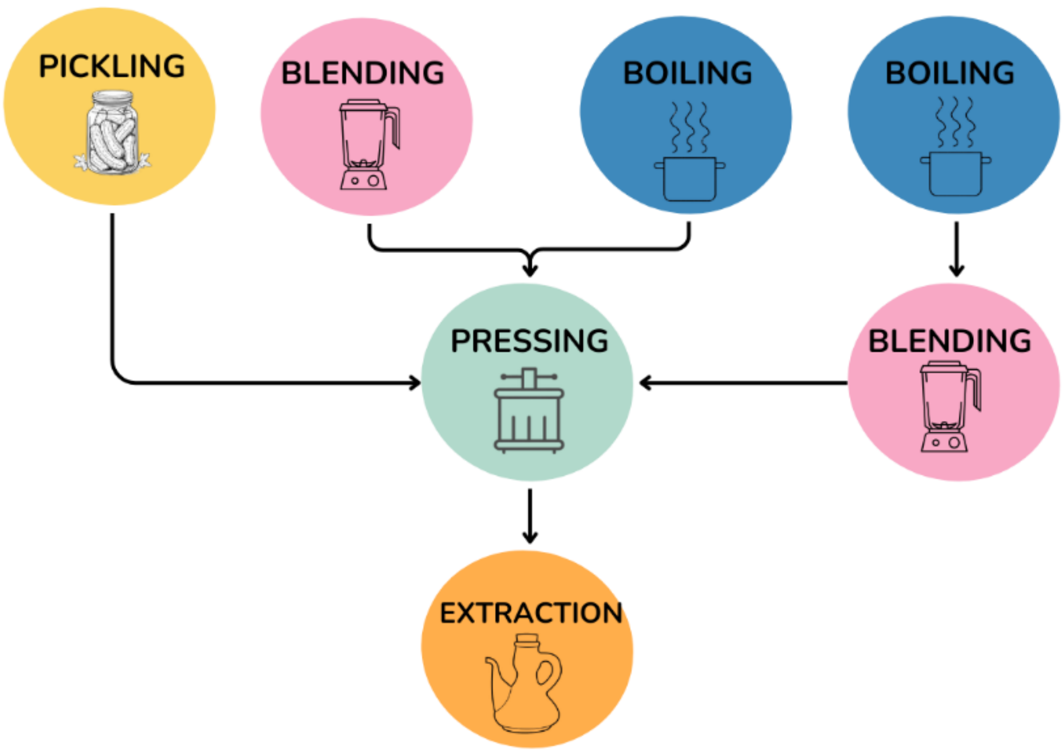

Figure 36: Brainstorming about oil extraction

7.3.1 Blending

The project team mixed 960g of fish scraps in a blender and then pressed them directly without boiling or adding water. In this process, which is seen in the images below, the group obtained 62g of liquid from the fish scraps. As the expected amount of oil will be very small and therefore difficult to extract, this step was skipped.

Figure 37: Blending process

Figure 3838: Result of blending

This method posed challenges due to the limited power of the blender. In a subsequent variation, the team attempted to blend the fish prior to cooking. This step was approached with caution, as the 400-Watt blender was barely powerful enough to process a portion of the fish into a fine paste. The engine of the blender overheated and got broken because of the stiffness from the fish waste.

After this process, a new blender was purchased, offering significantly more power than the previous one. This new blender has 1200 watts of power, allowing it to blend the fish waste smoothly and handle the workload effectively. The increased power also brings the added benefit of being able to blend dried fish waste into a fine powder.

7.3.2 Boiling

As part of the experiments without stabilisation methods, the team first boiled a portion of the fish waste for one hour, followed by pressing the oil and fats out of the waste using a pressing machine. This process was relatively straightforward and proceeded quickly. However, it was observed that a significant amount of water was required to cook the fish, which resulted in a lower oil saturation. While the oil was present, as evidenced by visible droplets floating in the container, the overall yield was diluted due to the high-water content.

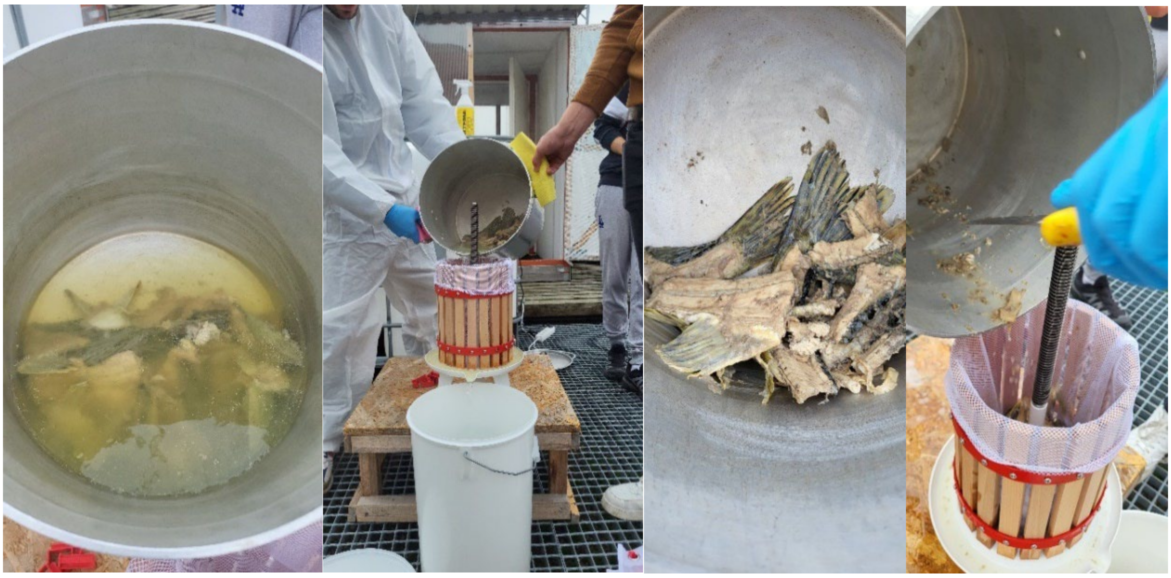

Figure 39: Boiling and pressing process

7.3.3 Blending & Boiling

A clear difference was noted between the batch where blending was used and the method without blending. The fat saturation in the blended mixture was significantly higher, as less water was required for the process.

7.4 Different Fish

In addition to examining the factors of boiling and blending, the study aimed to investigate the differences among various types of fish. To ensure consistency, identical steps were applied in the same order for each fish type, facilitating the observation of any variations. Consequently, these experiments were conducted a substantial number of times to evaluate both the differences among fish types and the influence of boiling and blending.

7.4.1 Pike

After obtaining the oil and fats, further extraction and refinement were necessary, as the initial mixture contained oil, fats, small residues, and water. The team designated the sample without blending as *Batch 1* (right bucket) and the sample with blending as *Batch 2 (left bucket)*.

Figure 40: Pressed liquids from pike

For starting the filtering process, an equal ratio of fat mixture (50%) and water (50%) was combined and brought to a boil. After boiling, the mixture was transferred into narrow chemical beakers. Subsequently, 25% cold water was added to the mixture. The solution was then allowed to cool naturally to room temperature.

It was observed that the oil layer rapidly began to rise to the surface, becoming progressively thicker over time. After several minutes, a third layer of fine residue developed between the oil and the water. The use of narrow beakers resulted in a higher oil layer, thereby facilitating more efficient extraction of the oil using a pipette.

The results were immediately noticeable: *Batch 1* (without blending) produced a minimal oil layer, where *Batch 2* (with blending) showed a significantly thicker and clearer oil layer. This led to conclude that the water content during the extraction process was already sufficiently high. To further optimise the process, the team repeated the experiment without adding water and pre-filtered *Batch 2* through a wine filter bag before boiling to remove solid particles.

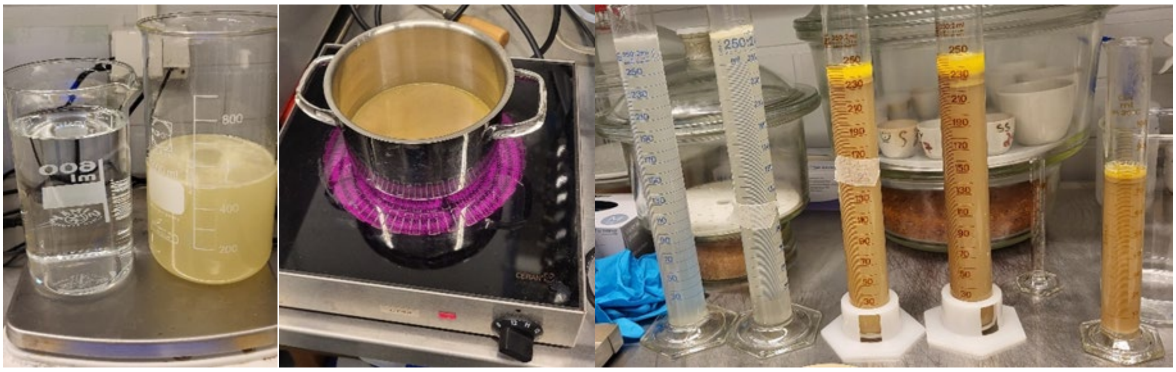

Figure 41: Separating process pike

This refinement yielded even better results, with a higher oil saturation and a thicker floating oil layer. After extracting the oil from *Batch 2*, the team filtered it through a coffee filter to remove any remaining fine residue, which could affect the oil's clarity during solidification. This filtration process took the entire weekend, but the outcome was a cleaner and clearer oil.

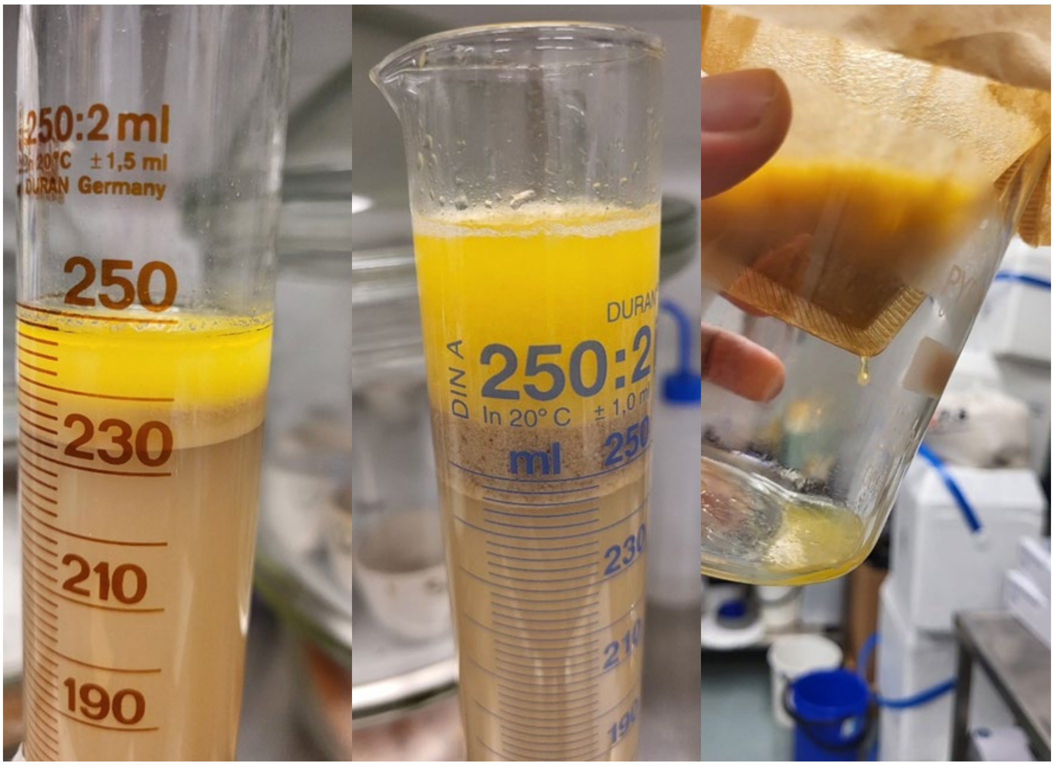

Figure 4242: Cleaning process of the extracted oil, pike

In conclusion, *Batch 1* (without blending) did not provide sufficient oil for effective extraction, and thus the team will not pursue that method further. *Batch 2* (with blending), however, proved to be successful, offering valuable insights into optimising the extraction process for obtaining clear fish oil. The team plans to use this refined oil in future experiments, particularly in soap production.

7.4.2 Salmon

The second oil extraction was done with fish waste of Salmon. At first, the fish waste was blended into smaller pieces. After the blending it was cooked in a pot. When the fish was cooked, it was placed into the presser. The cooked fish waste was pressed with using a filter. The remains in the filter were used for drying in the dehydrator machine to make powder for food out of it. After the pressing, there was a fish waste substance poured out that had water, oil and small fish particles in it. The start weight of the substance was 3,082 grams.

The substance was being cooked in the lab to separate the oil from the rest of the substance. The boiling of the substance was done for three times. When the substance was boiling, it was poured into graduated cylinder and beakers with a filter funnel to avoid spilling. In the cylinder, the amount of oil being separated of the substance was visible clearly through the glass. After the pouring, the oil was extracted from the substance using pipets and placed into a pot to let it cook once again.[34]

Figure 43: Cleaning process of the extracted oil, salmon

This time it was cooked until the substance and water was out of the mixture to have pure oil. The boiling point of the substance and the water is lower than the boiling point of oil. Therefore, when the boiling in the pot stopped, it meant that the substance and water was fully out, and the pure oil was left. After cooking in the pot, the oil was filtered to make sure there is as much pure oil as possible. With this method, the smell of the fish went away remaining only a oil scent.

What noticeable was comparing to the first oil extraction, is that this time contained much more oil. The difference is that this oil is from salmon instead of pike fish. Salmon fish contains a significant amount of fat in general. This can be useful for making other products out of it like soap for example.

The total amount of extracted oil from the salmon fish was above 600 grams. The exact amount of oil is difficult to measure because some per cent of oil was lost for example with pouring and cooking during the process.

Figure 4444: Result of the oil extraction

[34] (Brunning, 2015)

In conclusion Salmon fish waste contains a significant amount of oil. This can be useful to make other products such as soap. The oil was clear and almost pure after the oil extraction. Also, the smell of fish waste was almost gone.

During the oil extraction from the salmon waste, a small portion of pike fish waste, weighing 1,650 grams, was also processed. The pike waste underwent the same extraction method as the salmon. However, there was no oil extracted this time from the Pike.

7.4.3 Whitefish

During the third oil extraction with the blended fish waste, the team worked with waste from the whitefish, following the same procedure as the previous two extractions. At first, the fish waste was blended and then cooked in water. Second, the cooking was transferred to a press, extracting and filtering as much fish particles out of it as possible. The remaining solid residue was dried using a dehydrator machine, ensuring nothing was wasted throughout the process of cooking, pressing, and blending.

Figure 45: Separating process from the whitefish

The filtered liquid was then used for oil extraction, following the same method as before. A total of 5,142 grams of fish waste was cooked, after which the mixture was poured into beakers and graduated cylinders. In the beaker and graduated cylinders, the oil was able to be separated from the substance. The separated mixture allowed it to take out the oil using a pipette. The oil was cooked again and filtered with a coffee filter to achieve a pure result. Notably, this extraction yielded less oil than the previous oil extraction with salmon. Additionally, the oil had a darker colour compared to earlier extractions.

7.5 Conclusion

The fish waste the team got every time was a different type of fish. The first type of fish waste was Pike, the second type of fish waste was salmon, and the third type of fish waste was whitefish. After extracting the oil from all the fishes there was a difference in the amount of oil. The most extracted oil came from the salmon. The amount of oil from the salmon was a significantly higher than from the other types of fishes.

Type of fish	Fish waste weight	Amount of oil extracted	Per cent of oil extraction
Pike	1072 g	97 g	9
Salmon	4500 g	650 g	14
Whitefish	5142 g	85 g	1,6

Table 9: Comparison of oil extraction from various fishes

Among the different processes, oil was extracted after the various processes (boiling, blending + boiling and pickling). It was noticeable that the most effective one is blending + boiling. Among the different types of fish waste used, 14% of the weight of the salmon could be extracted. In contrast, only 9% could be extracted of the pike and 1,6% from the whitefish. Therefore, it can be concluded that the best type of fish for extracting oil is the salmon.

Regarding the feasibility of the process for fishermen, the results of this process are highly promising. Oil was extracted without a bad smell from fish waste with a easy process. This oil could be sold to other companies for different purposes, for example extracting omega-3 fatty acids or making soap.

8 Soap Production

As described in the previous chapter, fish oil is mostly used for supplements and other purposes hadn't been deeply studied. Therefore, the team aims to produce soap out of the oil previously extracted from fish waste, in order to demonstrate that alternative possibilities for producing valuable products from fish oil exist.

For producing soap, many different ingredients were available and it was not clear what exact quantities should be used, which led the team to experiment with different variations of the quantities of the ingredients. The aim of these experiments was to find the optimal quantities of ingredients to produce a usable hard soap with enough good properties to be sold in the market.

8.1 Ingredients

The following table shows the various input materials that were available to the group. In addition, the function and a letter are listed for each substance to simplify categorisation during the chapter.

Ingredient	Function	Letter
Fish oil	Main oil for saponification.	A
Coconut fat	Provides hardness and boosts lather.	B
Butter pallets	Adds moisturising properties, hardness.	C
Sunflower wax	Adds hardness, smoothness, and gloss	D
NaOH (Lye)	Required for saponification (calculated).	E
Water	Used to dissolve the lye.	F
Sodium lactate (60%)	Increases hardness and extends shelf life.	G
Kaolin clay	Adds silky texture and acts as an exfoliant.	H
Xanthan gum	Improves stability, texture, and consistency	I
Blue food colouring	Provides colour to the soap.	J
Fragrance	Adds scent to the soap.	K

Table 10: Available ingredients for making soap and corresponding function

In the search for the best way to make soap, the group tried out various methods. Among other things, it was played around with the quantities of ingredients, as well as which substance is used at all. The following table shows the batches that were used to produce soap.

Batch	A	B	C	D	E	F	G	H	I	J	K
1	35g (70%)	/	/	/	5g (10%)	10 g (20%)	/	2,5 g (5%)	/	1 g (2%)	1 g (2%)
2	10 g (20%)	22,5 g (45%)	/	/	6 g (12%)	11,5 g (23%)	/	/	/	1 g (2%)	1 g (2%)
3	25 g (50%)	10 g (20%)	3 g (6%)	/	3.3 g (6,6%)	8 g (16%)	1 g (2%)	1 g (2%)	/	0.5 g (1%)	0.5 g (1%)
4	30 g (60%)	7.5g (15%)	2.5 g (5%)	/	3.45 g (6,9%)	8 g (16%)	1.2 g (2,4%)	1 g (2%)	/	0.5 g (1%)	0.5 g (1%)
5	35 g (70%)	5 g (10%)	1.5 g (3%)	/	3.6 g (7,2%)	8 g (16%)	1.4 g (2,8%)	1 g (2%)	/	0.5 g (1%)	0.5 g (1%)
6	40 g (80%)	2.5 g (5%)	1 g (2%)	/	3.75g (7,5%)	8 g (16%)	1.5 g (3%)	1 g (2%)	/	0.5 g (1%)	0.5 g (1%)
7	45 g (90%)	1.5 g (3%)	0.5 g (1%)	/	3.9g (7,8%)	8 g (16%)	1.6 g (3,2%)	1 g (2%)	/	0.5 g (1%)	0.5 g (1%)
8	25 g (50%)	5 g (10%)	1 g (2%)	1 g (2%)	4 g (8%)	5 g (10%)	1 .5 g (3%)	0.5 g (1%)	0.2 g (0.4%)	1 g (2%)	1 g (2%)
9	25 g (50%)	6 g (12%)	/	/	4 g (8%)	5 g (10%)	2 g (4%)	0.5 g (1%)	/	1 g (2%)	1 g (1%)

Table 11: Different batches

The first aim was to make cleaning soap with fish oil, without caring much about the ingredients (batch one and two). After this, the aim was to make soap with as much fish oil as possible, which was tested by increasing the percentage from batch one to batch seven. Having the results of the first seven batches, the recipe with the best results was used to test two more concepts. The first was to add hardener ingredients (Sunflower wax and Xanthan Gum) to batch eight and then try not to use any hardener ingredients in batch nine. In addition, for the last two batches oil lemon fragrance was used instead of lavender fragrance to get a better smell on the final product.

8.2 Procedure

The practical process of soap production was iterative, with a recipe formulated for each batch. However, the ingredient composition varied between batches. Following the production and testing of the initial soaps, the ingredient proportions were adjusted in subsequent batches to identify the optimal formulation.

The same recipe for making soap was used for all the soap batches, which is as it follows:

1) Weigh all ingredients:

A) Fish oil	B) Coconut fat	D) NaOH (lye)	E) Water
G) Kaolin clay	F) Sodium lactate	C) Butter pallets	H & I) Fragrance & colour

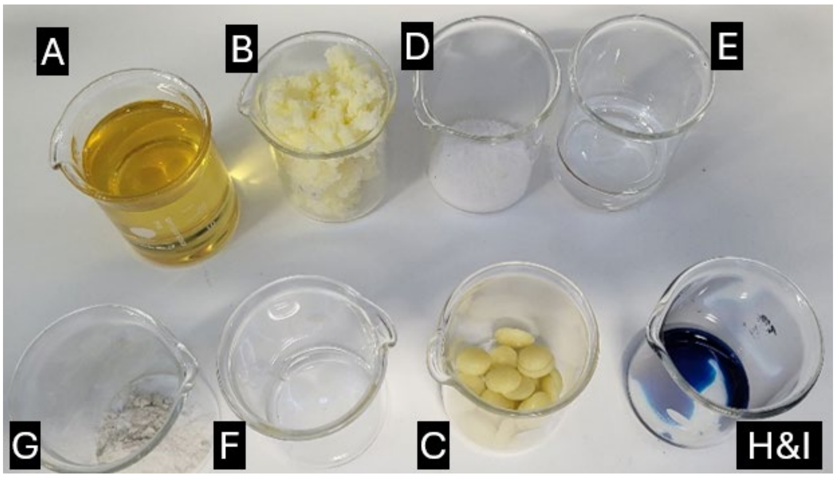

Figure 46: Ingredients for soap production scaled and listed

2) Melt oils and fats:

Melt fish oil, coconut fat, and butter pallets together in a 70°C environment. Allow them to cool to around 40-50°C.

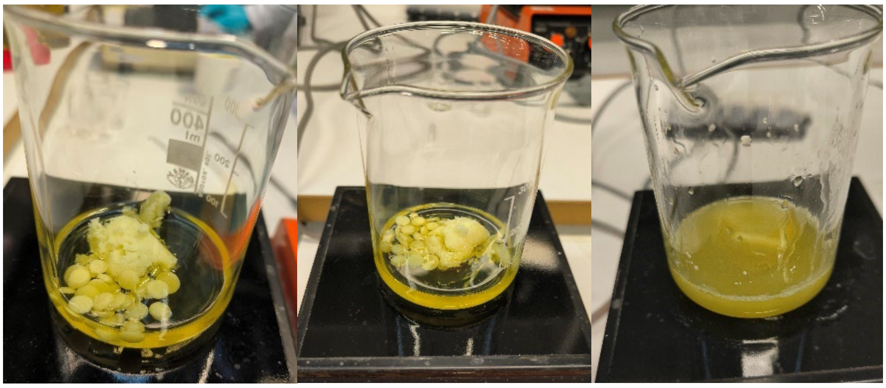

Figure 47: Melting process of oil and fat for soap production

3) Add additives:
Stir in sodium lactate and kaolin clay into the oil mixture. This helps create a harder, silkier bar.

4) Prepare the lye solution:
Carefully dissolve NaOH into water (always add lye to water, never the reverse). Let it cool to around 40-50°C.

Figure 48: Preparing the lye solution

5) Combine lye and oils:
Slowly pour the cooled lye solution into the oils. Blend with a stick blender until it reaches a light to medium "trace" (thickening).

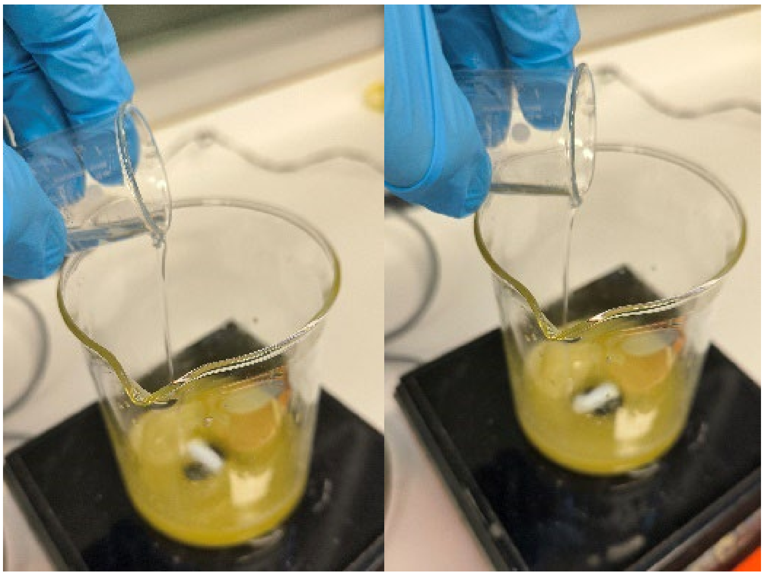

Figure 49: Combining lye and oils

6) Add fragrance and colour:

Add lavender fragrance, blue food colouring and stir it well to incorporate evenly.

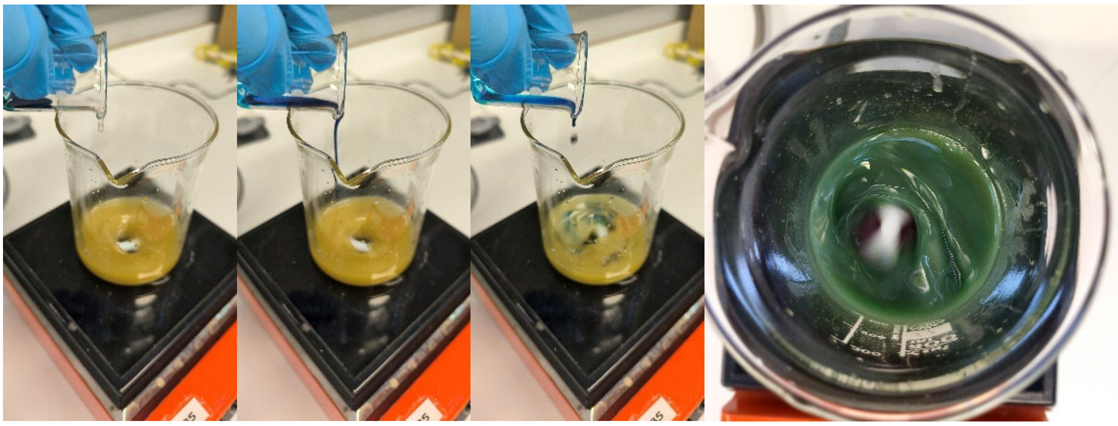

Figure 5050: Adding fragrance and colours

7) Pour into moulds:

Pour the soap mixture into a mould, smooth the top, and tap it to remove air bubbles.

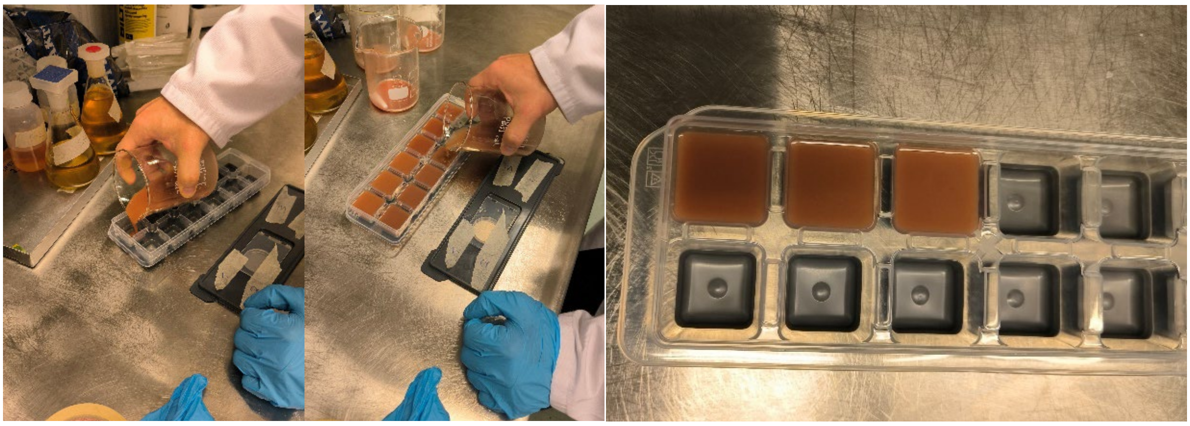

Figure 51: Pouring the soap into moulds

8) Curing:

Allow the soap to sit in the mould for 24-48 hours. After unmoulding, let it cure for 4-6 weeks for a harder, long-lasting bar.

8.2.1 Results

The following pictures represent the first results of soap production from batch one to batch seven. The moulds are listed from top left to top right and continue with bottom left to bottom right.

1) Empty
2) Batch three (50% oil)
3) Batch two (20% oil)
4) Batch one (70% oil)

Figure 52: Results of soap production, batch one, two and three

1) Batch four (60% oil)
2) Batch six (80% oil)
3) Batch five (70% oil)
4) Batch seven (90% oil)

Figure 53: Results of soap production, batch four, five, six and seven

As can be seen in the two pictures above, the soap becomes more liquid as the concentration of oil increases. All the solid soaps (batches one to four) were tested by trying to wash the team members' hands and some water.

Figure 54: Soap testing

The insight of this test was that as more oil was used on the soap less foam appeared and it was harder to solve the soap from the hands, finding that the batch that had more oil but still had good results was batch three (50% of oil), even though it was not completely hard. Regarding the smell, the foam smelled good and if the hands had some bad smell before cleaning it got almost everything out, however, some fishy smell remained on the hand once these were dried.

Having the results of the first batches the next step was to use the batch three recipe and correct the ingredients by adding more hardening ingredients (sunflower wax and xanthan gum) and also changing the fragrance essence for an oil fragrance to make sure that the remaining fish smell got out, which was tried on batch eight. In addition, for trying new things batch nine was made using the same percentages as batch three but without any hardening ingredients and changing the fragrance.

Figure 55: Soap cubes

The outcome of Batch eight (depicted as the soaps on the right in both images) was deemed the most successful, producing a solid soap that generates foam, emits pleasant fragrance, and retains minimal residual fish odour. In contrast, batch nine (depicted as the soaps on the left in both images) demonstrated sufficient hardness but was observed to produce limited foam and exhibited difficulty in being effectively rinsed from the hands.

8.2.2 Definitive Batch of Soap

The definitive batch of soap was made of the best results from the previous tests of the soap making. The best result was from batch eight because of the hardness, smell and the foam. This batch is now used on a larger scale in the definitive batch of soap making.

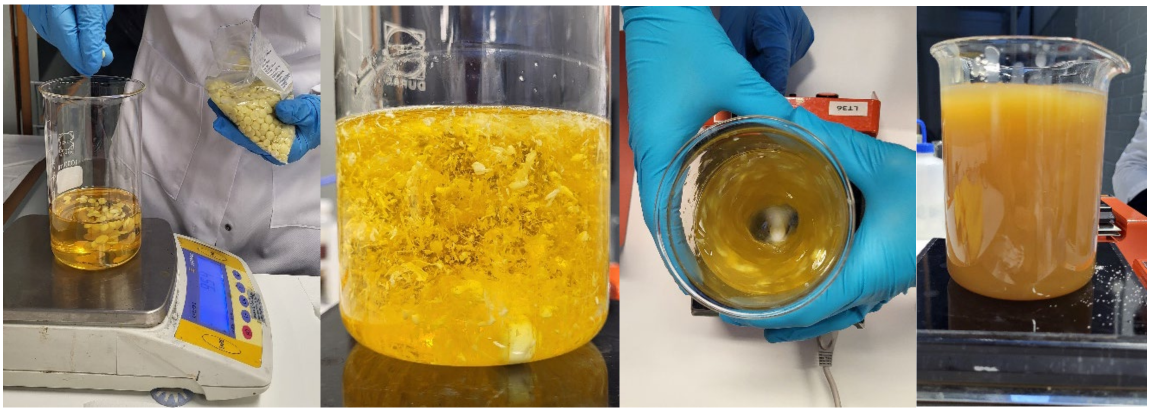

Figure 56: Melting and mixing the ingredients

During the soap making, there were difficulties with stirring the soap mixture. The mixture could not mix well because of a mixing error, instead of adding the clay, the sodium lactate and the xanthan gum separately, they were first mixed, and then added to the oil mixture. This made the stirring and mixing difficult because there were hard particles in it.

The last batch of the soap was done in different moulds. The mould was 3D printed with a logo of the fish waste project. The 3D printed mould was larger than the normal mould cubes, so the soap had a size similar to a commercial soap.

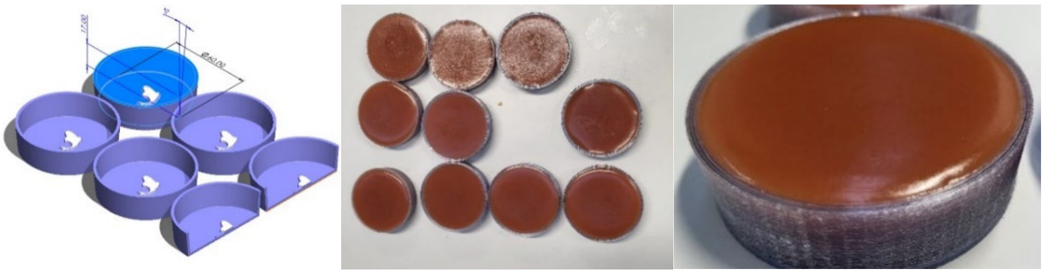

Figure 57: 3D-Model of moulds and poured soap

After pouring it into the moulds, the soap rested for two days and then it cured for three weeks, which led to a hard soap with good smell.

Figure 58: Result of the cured soap

8.3 Candle Experiment

Making candles was a side project of the soap-making process with the aim of showing that there exists more products that can be created out of fish oil. A key requirement was that the smell of fish waste would not be noticeable. To prevent this, orange-scented drops were added as a fragrance. The candles were made using materials already available for soap making. This made the experiment with the candles simple and inexpensive.

To make the candles, butter pellets and coconut fat had to be melted. Once melted, fish oil, colour dye and orange fragrance were added. However, the colour dye did not mix properly with the candle mixture. This resulted in blue spots in the candle mixture that were unable to mix.

After pouring the mixture into glass containers, it remained liquid even after the recommended drying time of two hours. In addition, the candle was put in the shack on the roof so that it would stay into the cold temperature. Nevertheless the candle was still not hardened. A hardener could resolve this issue, but depending on the type of hardener, it could make the candles less organic and sustainable.

When burning the candle, it burnt like a standard candle and stayed on for the whole time. Noticeable was that the oil layer went up which made the candle into multiple layers. This trapped the fragrance, resulting in a burnt smell rather than the intended orange scent.

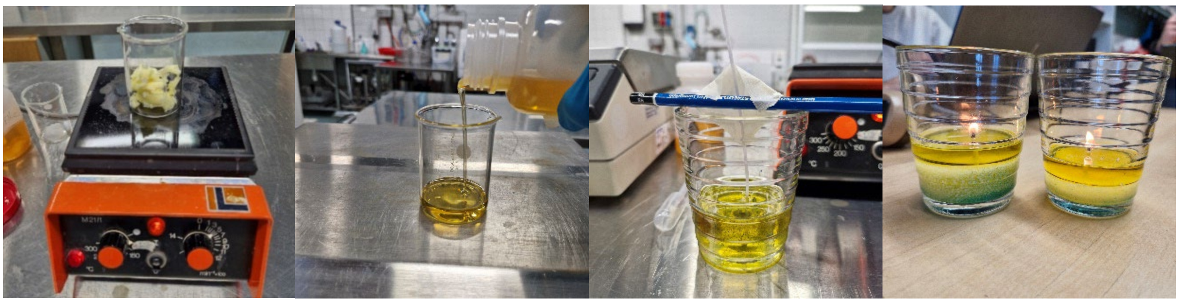

Figure 59: Candle production and lighting the candles

8.4 Conclusions

The results show that making soap out of fish oil is feasible, which is a good insight because it means that extracting oil from fish waste can benefit economically the fishermen by selling it to the cosmetic industry or by producing it by themselves.

At first, the testing revealed that the soap had low foaming properties and was occasionally greasy, which made rinsing challenging, and the fragrance of the herbs was noticeable, and the fish smell was almost not present anymore. However, after more testing and some corrections, the best recipe for soap was found (batch eight). This soap was hard, made foam, had a good smell, and was the least greasy to wash off the hand.

Regarding the candle making, it is a process that did not have useful results. However, producing candles out of fish oil still seems an interesting way of using fish oil. That is why further projects should experiment more with this process.

9 Protein Extraction

Protein is one of the most essential components in the nutrition of every living being and fish has high concentrations of protein, compared with most of the food. These proteins are mainly found in the flesh of fish, which is the most eaten part of the fish, however, fish waste still contains high quantities of flesh that is not used because it is not worth the effort to separate from the not edible parts. Therefore, extracting protein out of fish waste is a promising process that the team wanted to research.

As being a complex topic, the team needed to research about the background of protein extraction and proteins in the fish itself. Then different extraction methods could be described, generating an own opinion of the team about the topic, which is given at the end. In addition, the team tried to use an ultrasonic process as a protein extraction method.

9.1 What is Protein?

"Proteins are large, complex molecules that play many critical roles in the body. They do most of the work in cells and are required for the structure, function, and regulation of the body's tissues and organs."[35] Subsequently, various parts of the fish are presented with regard to their different proteins.

9.1.1 Protein from Fish By-Products

Fish skin, which makes up about 8–10% of the total weight of fish, is a significant by-product of fish processing. It is particularly valuable because it contains high levels of collagen and hydrolysed collagen, which are essential proteins in many biological functions. Collagen constitutes approximately 30% of total protein in the animal body and plays a crucial role in the structural integrity of various tissues.

The structure of collagen is primarily based on tropocollagen, characterised by its triple-helical configuration and repeating amino acid sequence, where Glycine is consistently present, while Proline and Hydroxyproline are the most common residues at the X and Y positions, respectively. This unique structure contributes to the mechanical strength and

[35] (MedlinePlus, 2021)

stability of collagen, making it a key component in applications ranging from biomedical materials to food products.[36]

Fish viscera is a significant by-product of the fishing industry, recognised as a rich source of digestive enzymes. Key among these are acid proteases, like pepsins from the stomach, and alkaline proteases found in the pancreas, pyloric caeca, and intestines.

By extracting these proteases and other bioactive compounds from fish viscera, the environmental issues related to the improper disposal of fish waste will be reduced. This process also unlocks potential for developing high-value products with various industrial applications. This approach emphasises sustainable practices in fish processing while enhancing resource efficiency.[37]

In the fish processing industry, fish bones and frames are frequently discarded as waste, despite their valuable composition. Collagen, which makes up about 30% of the total weight of fish bones, is the main organic component, while the remaining 60–70% consists of inorganic materials, predominantly calcium phosphate and hydroxyapatite. Recent research on these underutilised fish bone by-products has primarily aimed at characterising protein hydrolysates and developing value-added products.

The fish head, known for its rich nutritional profile, is an excellent source for producing high-quality marine polypeptides and reclaiming premium protein. Studies have demonstrated that administering tilapia head protein hydrolysate (THPH) significantly improves cognitive behavior in mice and helps restore the cholinergic system and reduce oxidative stress in the brain.

9.2 Different Extraction Methods

Protein extraction is the process of isolating and purifying specific proteins from biological samples such as cells, tissues or body fluids. [38] There are several processes for extracting proteins but not all of them can be used for fish. In this chapter it will be explained what the

[36] (Ye, 2024)
[37] (Ye, 2024)
[38] (Excedr, 2023)

most relevant processes are for extracting protein from fish. It is worth mentioning that those processes do not obtain the final product, which will be explained in the next chapter.

9.2.1 Chemical Extraction

Detergents are special molecules that can change how hydrophobic (water-repelling) and hydrophilic (water-attracting) interactions work in biological samples. In protein research, detergents have several important uses as in cell lyses, where they help to break cells to release soluble proteins.[39]

Detergents, like the components of biological membranes, have hydrophobic parts that allow them to mix with water and help disperse water-insoluble compounds. This makes them useful for extracting and solubilising membrane proteins. At low concentrations in water, detergents form a monolayer at the surface. As the concentration increases, detergent molecules come together to form micelles. A micelle is a stable structure where the hydrophobic (non-polar) tails of the detergent are tucked away from water, while the hydrophilic (polar) heads are facing outward, interacting with the water.

Key characteristics of detergents include their critical micelle concentration (CMC) (the concentration above which micelles start to form) and the aggregation number, which is how many detergent molecules make up a micelle. Each type of detergent has its own specific CMC and aggregation number. The critical micelle temperature (CMT) is the lowest temperature at which micelles can form, and it can change depending on conditions like temperature and the presence of other substances.

For example, increasing the temperature can lower the CMC of certain non-ionic detergents. In ionic detergents, adding counter ions can also lower the CMC by reducing repulsion between charged parts. Other additives, like urea, can disrupt water structure, which may also lower the CMC. Additionally, higher ionic strength usually leads to an increase in the number of detergent molecules that form micelles.

Detergents can be classified as either denaturing or non-denaturing. Denaturing detergents, such as sodium dodecyl sulfate (SDS), break apart membranes and denature proteins by

[39] (Fischer, 2024)

disrupting protein interactions. Non-denaturing detergents, like Triton X-100 and bile salts, help maintain protein structure while solubilising them.[40]

Given below is the procedure to prepare a lysis solution containing 10mM Tris-HCl buffer, 1mM EDTA as the chelating agent, and 0.5% SDS as the detergent.

1. Dissolve 121g Tris-HCL (molecular weight = 157.60g) in 800ml distilled water, adjust the pH to 8 using HCl solution, and make up the volume to 1l using distilled water
2. Dissolve 93.0g of EDTA [$EDTA.Na_2.2H_2O$] (molecular weight = 372.24g)] in 400ml of distilled water, add 10g (approx.) NaOH pellet to adjust pH to 8, and make up the volume to 500ml using distilled water.
3. Dissolve 10g of SDS in 90ml distilled water and make up the volume to 100ml using distilled water.
4. Add 5ml of 1 M Tris-HCl (pH 8), 1ml 0.5 M EDTA, and 5ml of 10% SDS solution to 400ml of distilled water. Make up the volume to 500ml.

The two commonly used buffers for making cell lysis solutions are Tris-HCL and Phosphate buffer.

For protein extraction, section the tissue of interest on ice. Transfer the tissue into microcentrifuge tubes with a round bottom and shock-freeze by immersion in liquid nitrogen. Add 300µl of cold lysis buffer for every 5mg of tissue and homogenise using an electric homogeniser. During homogenisation, add an additional 300-600µl of lysis buffer. Shake the contents for 2 hours at 4°C. Centrifuge the tubes for 20 minutes at 4°C. Collect the supernatant in a new tube and keep it on ice. Discard the pellet.[41]

9.2.2 Repeated Water Washing and Refining

The goal of the repeated water washing and refining process is to obtain surimi, a fish flesh mince that contains 16% water-insoluble protein, 75% moisture, and 8 to 9% cryoprotectants.

The production of surimi involves a series of steps designed to achieve a high-quality and preservable product. The process begins with mincing, where the flesh is separated from the rest of the fish, resulting in a fine mince composed solely of fish flesh. This mince is then

[40] (Fischer, 2024)
[41] (sigmaaldrich.com, 2024)

subjected to a leaching process, where it is mixed with cooled water to wash away impurities. The number of repetitions and the volume of water used in leaching can vary depending on factors such as the type and freshness of the fish, the washing equipment, and the desired quality of the final product. Typically, this step is repeated two to four times to ensure thorough cleaning.

After leaching, the mixture undergoes straining, where it is dewatered after each cycle. During the final cycle, residual scales and connective tissues are removed, and the mixture is pressed to extract excess water. Following this, cryoprotectants are added to the processed mince to safeguard the protein against damage during freezing. This crucial step ensures that the surimi maintains its structural integrity and quality during storage.

Once these steps are complete, the surimi is shaped into blocks, frozen at a temperature of minus 20°C, and packaged in cardboard boxes. At this stage, the surimi is ready for storage; however, further processing is often required to refine the protein before it can be used in various applications. This thorough sequence ensures the production of a high-quality surimi product suitable for a range of uses.[42]

9.2.3 pH Shift Method

The production of fish protein isolate (FPI) involves a series of carefully controlled steps to extract and preserve high-quality protein. The process begins with mincing or chopping the fish flesh to achieve a finely sized mince. This minced material is then subjected to solubilisation by mixing it with water at five to ten times its volume, with either acid or alkali added to adjust the pH to approximately 2.5 or 11. This step ensures the proteins are solubilised effectively.

Once solubilization is complete, the mixture undergoes centrifugation. During this step, oil and insoluble particles are separated from the protein solution. Following this, the pH of the solution is adjusted to the isoelectric point of myofibrillar proteins, which is around 5.2 to 5.5. At this pH, the proteins precipitate out of the solution, allowing for their isolation.

The precipitated proteins are then subjected to a second centrifugation step, where the fish protein isolate (FPI) is sedimented and collected. To preserve the FPI for future use,

[42] (Shaviklo, 2013)

cryoprotectants are added, and the product is frozen. This freezing step ensures that the isolated proteins remain stable and can be utilised in a variety of applications.[43]

9.2.4 DIY Enzymatic Hydrolysis

Protein extraction from fish waste can be achieved through a DIY method using enzymatic hydrolysis, similar to the approach followed for fermentation and oil extraction. This method allows sustainable repurposing of fish waste, reducing environmental impact and creating valuable protein products for food, pet food, or cosmetics. The following steps outline the procedure for protein extraction using basic equipment and commercially available proteolytic enzymes, such as papain or bromelain.[44]

Materials

The materials and their purpose are listed below.

Material	Purpose
Fish waste	Heads, bones, skin, internal organs
Papain or bromelain	Available from health stores or online
Water	Cleaning and dissolving
Meat grinder or blender	To process fish waste
Large container	For enzyme reaction
Hot plate or stove	To maintain temperature
Thermometer	To monitor temperature
pH strips	To monitor pH
Cheesecloth or fine strainer	To separate solids
Filter paper or coffee filters	For purification
Drying rack or dehydrator	Optional, for drying protein extract

Table 12: Materials and corresponding purposes for enzymatic hydrolysis

Process

To begin the process, thoroughly clean the fish waste to remove any residual scales or contaminants. The fish waste is then ground or blended into smaller pieces to increase the surface area, allowing for better enzyme activity.[45]

Prepare the enzyme solution by dissolving papain or bromelain in warm water (40°C - 50°C). The enzyme concentration should follow the instructions provided on the packaging, but

[43] (Shaviklo, 2013)
[44] (Kamal, Le, Salter, & Ali, 2021)
[45] (Kamal, Le, Salter, & Ali, 2021)

typically one to two teaspoons of enzyme per litre of water is sufficient. The warm water activates the enzymes and optimises their activity.[46]

Place the prepared fish waste in a large container and add the enzyme solution, ensuring the fish waste is fully submerged. Stir the mixture to ensure the enzyme is evenly distributed. Maintain the temperature between 40°C and 50°C using a hot plate or similar heat source. The optimal pH for this process is six to seven**,** so use pH strips to monitor and adjust, if necessary, by adding a small amount of vinegar (to lower the pH) or baking soda (to raise the pH).[47]

Allow the mixture to incubate for four to six hours, stirring occasionally to enhance protein breakdown. The enzymes will break down the proteins in the fish waste into smaller peptides and amino acids. Maintain a stable temperature and pH throughout the process to ensure efficient hydrolysis.[48]

After the incubation, strain the mixture using cheesecloth or a fine strainer to separate the liquid protein hydrolysate from the solid residues (such as bones and skin). The liquid contains the extracted proteins, while the solids can be further processed or discarded.[49]

For further purification, filter the liquid protein hydrolysate through coffee filters or filter paper to remove any remaining fine particles. This step is optional but recommended to ensure a cleaner protein product.[50]

If you wish to create a protein powder, the liquid protein extract can be dried. Spread the liquid extract in thin layers on a drying rack or use a dehydrator at low temperatures (below 60°C). Once dried, grind the solidified protein into a fine powder. Store the protein powder in an airtight container in a cool, dry place.[51]

[46] (Kamal, Le, Salter, & Ali, 2021)
[47] (Kamal, Le, Salter, & Ali, 2021)
[48] (Kamal, Le, Salter, & Ali, 2021)
[49] (Kamal, Le, Salter, & Ali, 2021)
[50] (Kamal, Le, Salter, & Ali, 2021)
[51] (Kamal, Le, Salter, & Ali, 2021)

9.3 Ultrasonic Cleaner

As progressing further in the project, the idea from the teacher Mikael Ehrs was using an ultrasonic cleaner to decompose the fish waste. Ultrasonic cleaner is using high frequency sound waves to clean items placed in a liquid. These sound waves, usually around 40 kHz, cause rapid vibrations in the liquid, which can be water or a special cleaning solution. This vibration causes a process called cavitation.

The caviation process is created, because Ultrasonic cleaners use sound waves to create tiny, powerful bubbles in the water. Sound energy creates small voids, or empty spaces in the liquid. These spaces turn into microscopic bubbles that are full of energy. When the bubbles collapse or implode, they release a powerful force that helps to dislodge material and contaminants from surfaces. This process scrubs parts at a microscopic level without the need for brushes or harsh chemicals. Thousands of tiny bubbles doing the job.[52]

This process is now to be used to dissolve fish residues. The team hopes that this will result in a method that is less labour-intensive. In addition, it does not require much prior knowledge and can be operated easily.[53]

9.3.1 Practical Work

In the first test, a whole whitefish was placed in the ultrasound cleaner and the machine was switched on for one hour. The focus here was on testing the machine and familiarising the team with it. As the ultrasonic cleaner is only designed to work for 30 minutes, its operational capability was initially put to the test.

Figure 60: Ultrasonic cleaning process with a whole whitefish

[52] (besttechnologyinc, 2024)
[53] (F.J. Fuchs, 2015)

The picture on the left shows the entire whitefish as it was placed in the basket of the ultrasound cleaner. The machine was then filled to the top with water. In the centre picture you can see the fish from the top, while in the right-hand picture the fish from the underside is shown. The top side of the fish has dissolved on the surface, while the bottom side has dissolved considerably, as can be seen in the right-hand picture.

In the second trial, the whole fish was not placed in the ultrasonic cleaner. Instead, the individual parts of the fish were put in separately. Also, the fish was not a whitefish but a pike. The picture on the left shows the individual parts of the fish before it was placed in the tank. On the bottom left is the spine with flesh. Above this there is a part of the fish's skin. On the right you can see some of the fish's intestines and on the bottom left the part of its fin is shown. The process was carried out at 80 degrees for 11 hours.

Figure 61: Ultrasonic cleaning process with different fish parts of pike

In the middle picture you can see how the liquid looked like during the process. The colour of the liquid became cloudy and a yellow film formed on the surface.

The results of the ultra sonic process are shown in the right picture. The spine has solved from the flesh and both the fin and the skin disappeared completely. The intestines are still seen on the right, but they also lost some tissue. After viewing the results, the team tried to filter the liquid, as all the proteins and components of the fish that dissolved during the process had to be in it.

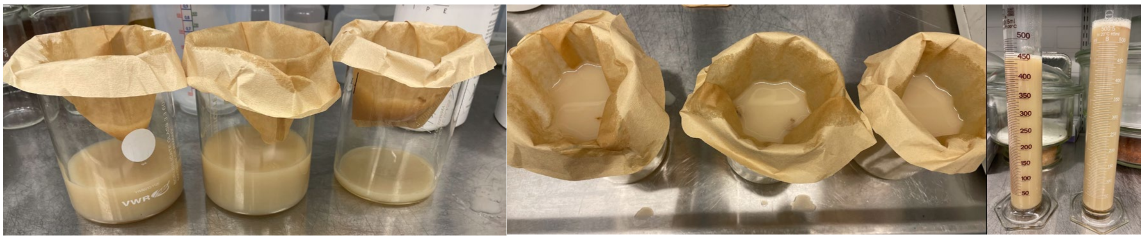

Figure 62: Filtering the liquid of the ultrasonic cleaner

Some problems occurred during the filtering process with the coffee filters. On the one hand, the coffee filters are often torn and on the other hand, the filters that were not torn become clogged quickly. After a morning of trying to filter the liquid and not getting a reasonable result, the team tried to heat the liquid to extract oil from the liquid during the cooling process (third picture from the right). When this attempt also failed, the attempt to filter the liquid was terminated.

As promising results were achieved with the ultrasound cleaner in the first and second experiment, the focus of the third and final experiment was to push the machine to its limits and fill it completely with fish waste. The machine was then filled to the brim with water and switched on for 10 hours.

Figure 63: Ultrasonic cleaning process with fish skin

On the left and centre picture you can see the container completely filled with fish waste. The picture on the right shows the final result after 12 hours in the machine. You can see that the fish waste has only dissolved superficially. As no better filtration methods had been found and procured at this time and the last attempt at filtration had failed, it was decided not to try this experiment again.

9.3.2 Conclusion

The experiments with the ultrasonic cleaner showed some promising results in decomposing fish waste. In the first and second batches, the ultrasonic cleaner effectively dissolved parts of the fish, such as the skin, fins, and spine, indicating potential for this method to break down fish residues. However, in the third batch, when the machine was filled to capacity with fish waste, the results were less favourable. Only superficial dissolution of the waste occurred, suggesting that the ultrasonic cleaner may not be effective when dealing with large volumes of material. Despite the promising outcomes in earlier trials, the final experiment highlighted the limitations of the process when too much fish waste was used.

10 Upscaling

Even though good results have been achieved in this project, all the processes were done on a small scale and DIY, therefore, it cannot be claimed that they can be used in the real industry. That is why upscaling all these processes is so important, to study the possibilities fishermen companies have and analyse if they are feasible for them, always considering the resources needed, the economic aspects, and benefits.

In addition, it is worth mentioning that the project team visited a fishery factory to gain more knowledge on how the processes could be upscaled. One of the insights from the visit was that the quantity of fish waste produced depends on the period of the year, however, in most of the months 500kg of fish waste a day is the average made in a factory as big as the one visited. Therefore, all this upscaling process is done trying to enable fishermen's factories to process 500kg of fish waste a day.

10.1 Fermentation

Upscaling the fermentation would be simple because the fishermen would only need to buy a fermentation machine. This machine would only need to have a mixer powerful enough to mix the fish waste, it should be able to be programmed to mix only once a day and have a heating system.

The market price of this type of machine is €2,853[54]. In addition to this cost, energy expenses must be considered. The machine is assumed to operate for two minutes daily at a mixing power of 1.5kW, while the heating power is 0.7kW, maintaining a temperature of approximately 35°C throughout the process. The calculations are provided for various time periods, as the experiments were conducted over a duration of only three months.

Time	Price
One month	€131
Three months	€395
Six months	€790
One year	€1581

Table 13: Fermentation electricity costs

As stated in the fermentation experiments, we extracted on average around 13.6% of garum out of the starting weight after one to two months. Because of the fact that we did this

[54] (ZONESUN ZS-MB1000L Stainless Steel Paste Mixing Tank, sd)

experiment on small scale in a DIY method for a short period these numbers are not completely accurate. In the ancient recipes and methods that are currently used in Asia the average extraction should be way higher, but therefore the process needs more time. On the current market a bottle of 100ml of Garum should costs on average around €15.00. On a upscale scenario from 500kg to a 13.6% extraction, it would result in 68kg of garum that would be worth around €10.200. This is a rough calculation considering that the percentage and quality of the garum is not known.

Figure 64: Fermentation tank

10.2 Pickling

Using pickling as a stabilisation method is a process that could easily be done by every fisher company without the need of machinery or a significant amount of labour. However, the costs of the ingredients on an industry scale should be calculated, for that, the quantities used in the experiments already done in this project will be used.

The ingredients of pickling for 1kg of fish waste are the following:

Ingredient	Amount
Salt (human-consumable)	150 g
Vinegar(human-consumable)	1 litre
Sugar	100 g

Table 14: Pickling ingredients per one kilogram of fish waste

As we already explained, the calculations will be done for 500kg of fish waste. The amount of ingredients would be the following:

Ingredients	Price per unit	Amount	Total cost
Salt	€ 0,30/kg	75 kg	€ 22.50
Vinegar	€ 0,60/litre	500 litres	€ 300
Sugar	€ 0,80/litre	50 kg	€ 40
Total			€ 362.50

Table 15: Pickling ingredients for 500kg of fish waste

The total cost for pickling 500kg of fish would be €362.50.

10.3 Oil Extraction + Drying

The upscaled process would start by putting the fish waste in the crusher (1), after this, the crushed fish waste would go automatically inside the boiler tank (2) thanks to a worm gear. Once all the minced fish waste is inside the tank, the boiling would start and after half an hour the valve below the tank should be opened to let the fish waste pass through the oil presser (3). The oil press would separate the liquid (60%) from the solid parts (40%), here is where the two different processes split their paths.

On one hand, the liquid would be filtered on a centrifuge machine (4) to separate the oil from the rest of the liquid, then the oil would be stored in a tank (5).

On the other hand, the solid parts would start to exit the oil presser, and a worker should be filling trays, those trays will be positioned inside the dryer machine (6). Once all the trays are in place, the drying will start. After the drying, a worker should put the dried fish waste in the blender (7) to get powder, which will directly be stored in a tank (8).

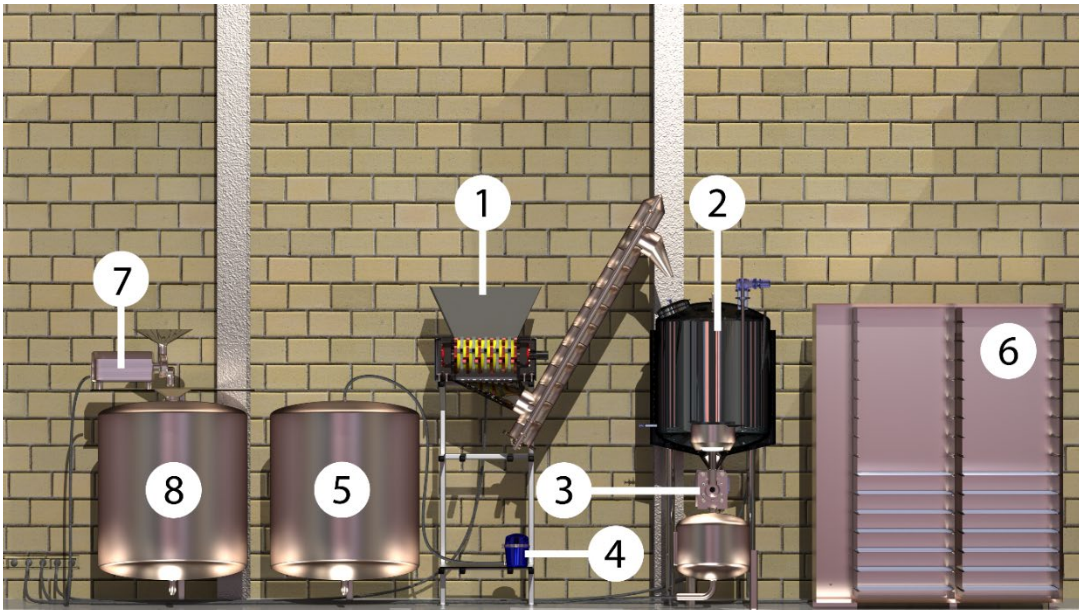

Figure 65: Upscaling process, oil extraction+ drying (1)

Figure 6666: Upscaling process, oil extraction+ drying (2)

10.3.1 Machinery Costs

For this process, at least six machines are needed. It is listed in the table.

Machine	Price in €
Crusher	€5,000[55]
Boiler tank	€1,450[56]
Oil presser	€1,100[57]
Drying machine	€10,000[58]
Centrifuge machine	€2,000[59]
Blender	€1,500[60]
Total	€19,550

Table 16: Machinery costs for oil extraction + drying

The total price for all the machinery listed is €19,550. The drying machine is the most expensive item at €10,000, while the oil presser is the least expensive at €1,100. Together, these machines represent a significant investment for industrial processes.

10.3.2 Electricity Costs

The costs for electricity were also calculated, taking into account that the price in Finland for the kWh is €0.25 and that the calculation is done for producing 500kg of fish waste.[61]

Machine	Power (kW)	Production Rate	Operating Time	Electricity Cost (€)
Crusher	3.0	3.5 L/sec	2.5 min	0.01
Oil presser	5.5	3 tons/day	4 hours	5.50
Drying machine	5.3	-	10 hours	13.25
Centrifuge machine	4.0	180 litres/hour	1 hour 40 minutes	1.67
Blender	1.1	100 kg/hour	1 hour	0.28
Total	-	-	-	20.71

Table 17: Electricity costs for oil extraction + drying

Taking advantage of having calculated already the time for each process, the total time for processing was also calculated:

[55] (TASKMASTER® TITAN, 2024)
[56] (Stainless steel movable storage tank with sealed lid, 2024)
[57] (Screw Oil Press, 2024)
[58] (Dryer Machine, 2024)
[59] (MP090 Centrifugal Filter, 2024)
[60] (Electric Flour Mill, 2024)
[61] (Finland-electricity prices, 2024)

The oil crusher would take 2min and 30 seconds. After the crushing, the boiling would take 30 min. Furthermore, the oil pressing would take 4 hours. At last centrifuging take up to 1h and 40 min. This makes in total 6 hours 12 minutes and 30 seconds.

For the dried powder, until the oil pressing the time and the fish waste is the same as extracting oil. However, after this process, the solid parts will dry for 10 hours and then get blended for 1 hours, making a total of 15 hours 32 minutes and 30 seconds.

10.3.3 Manual Labour Costs

Manual labour costs were calculated, considering the money a fishery company spends on a normal worker is approximately 30 euros an hour.

Process	Description of Process	Manual Work Time Required
Crushing	Easily automatised by putting a conveyor belt that puts the fish waste on it.	0 h
Boiling	The only manual work is powering on the boiling tank when full and opening the valve to let fish waste flow into the oil presser when boiling is finished.	0h 10min
Oil Presser	The machine works automatically, so no manual work is needed.	0h
Centrifuge	The liquid flows continuously and automatically from the oil presser to the centrifuge.	0h
Drying	A worker fills the trays of solid parts coming out of the oil presser (64 trays fit, taking ~1 hour). When drying is complete, the worker removes the trays and places the dried fish waste into the blender (~1 hour).	2h
Blending	The blending process is automatic, as the dried fish waste falls directly into the tank.	0h
Total		**2h 10 min**

Table 18: Manual labour costs oil extraction + drying

Adding the time of each process, the oil extraction would need approximately 10 minutes of manual work and the drying process 2h and 10 min. Therefore, the total amount spent on manual work for processing 500kg of fish waste would be €70.

10.3.4 Cleaning and Maintenance

All machines need maintenance and cleaning, and the ones chosen for this process are no different.

The crusher would need cleaning after each process to prevent the remaining fish waste from rotten. The crusher would need a weekly and monthly regular inspection and lubrication of the motors and belts. The blades and cutters also need to be checked and maintained.

The inside of the boiler and the heating elements should be cleaned after each process to prevent the remaining fish waste from rotten. It also needs weekly and monthly inspections. Furthermore, the boiler needs cleaning ventilation and safety valve tests to let it stay in a good shape.

The oil presser requires cleaning of the oil extraction chamber, feeding system, oil filter, and discharge ports after each process. Additionally, the machine should be lubricated, the electrical system inspected, and worn parts replaced on a monthly basis.

The drying machine requires after each process a cleaning of the trays, the intake and the exhaust filter. Every week and month the evaporator and condenser coils need to be cleaned. Additionally, the fan blades, humidity sensors and temperature sensors should be inspected. At last, the compressor and the heat exchanger should be checked on a monthly basis.

The centrifuge machine requires cleaning of the rotor, bowl, drum, lid and drainage system after each process. In addition, every week and month moving parts must get lubricated. Also the seals, gaskets, motor, drive system and bearings need to be inspected.

After each process the blender grindings chamber millstones, feed hopper and flour path need to be cleaned. Additionally, every week the moving parts should be lubricated and the motor and vents cleaned.

Even though the most important aspect of maintenance and cleaning is the manual work it implies, here a high accuracy can not be achieved, that is why assumptions will be made making sure that they are always more expensive than what could be in reality just to have a margin error.

Using the same salary as for the other manual work (30€/h) and assuming that two people working for 8 hours would be needed for the maintenance of each process, the money spent would be 480€.

10.3.5 Economical Profit

In the experiments conducted, the percentage of oil extracted from fish waste varied depending on the type of fish, ranging from 14% to 1.6%. For the purpose of calculation, the average extraction rate of 10% will be used. Consequently, the estimated quantity of oil extracted from 500kg of fish waste would be approximately 50kg.

Normally a good way of selling fish oil is to sell it to omega-3 industries, as its products are highly valuable economically. Nevertheless, for producing omega-3 out of fish oil, it should have been extracted from fish with a cold pressing process, and the processes from this project involved boiling, therefore it is not a feasible option.

The fisher companies could also benefit economically from the fish oil by selling it to cosmetic companies to make soap. If the companies used the recipe achieved by experimenting during this project, each soap bar would contain 50% of fish oil, therefore from 50kg of oil, 100kg of soap can be produced. Assuming that each bar of soap of 100g costs €5 (average cost), the final product could cost €5,000. Assuming that the raw material is sold at one-third of the final product, and that only 50% of the raw material would be the oil, the fishermen could earn €800 by selling the fish oil for making soap.

Regarding the dried powder, it could be sold for producing pet food supplements, for which the average cost is 22.07€/kg.[62] Therefore, if 40% of the fish waste is solid parts, for every 500kg of fish waste, 200kg of dried powder could be produced, and assuming that it could be sold at one-third of the final price of the pet food supplements, the fishermen could sell it for €1471.44.

[62] (Shahbandeh, 2024)

10.3.6 Alternative for Small Companies

Even if it is a process that you can make profit from, the investment is not little, therefore, all the little fishery companies and even the middle ones will struggle to make this process real, either for the money or the resources (workers, space, time...) needed.

Instead of doing all the process, these companies could sell the fish waste to bigger fisher companies that did the process and in order not to have to send everyday fish waste, they could pickle the fish waste to stabilise it and make less deliveries with bigger quantities.

10.4 Soap Production

In order to produce soap from scratch, because the fish oil would be the raw material, the fisherman companies would need a whole soap production line, which not only would need a high investment in the machinery but also a significant amount of resources would be needed, like 300m³ workshop, 10 to 12 workers and 200kW electric power. In addition, the final product price for the soap made from 500kg of fish waste was already calculated, which would be €5,000. Therefore, making soap is a possible but not feasible solution for fisherman companies because the number of resources needed is not comparable to the benefits.[63]

[63] (COMPLETE SOAP PRODUCTION LINES, 2024)

11 External Meetings

Throughout the EPS project, the project team attended several external meetings with different companies and organisations. The contents of these meetings are summarised in this chapter.

11.1 Anita Storm

Anita Storm is a project manager currently leading the Dammusla project, which focus on investigating the possible uses for mussels. Anita, as being specialised in aquaculture, has a wide knowledge of the fishing industry and the processes for creating different products.

The meeting with Anita covered various methods and techniques for processing fish waste, focusing on innovation and efficiency in areas such as ultrasounds, fermentation and drying. Below is a summary of the key points.

Ultrasound technology can be used in combination with enzymes like protease to separate bones and meat. Additionally, ultrasound is effective in extracting minerals within 30 minutes. The process can also involve the use of alcohol to aid extraction.

Drying fish does not require heat, as high temperatures can destroy certain properties of the material. It is best to use dryers at lower temperatures. Cold smoking fish at 28°C was mentioned as a suitable method, and fish with lower fat content are more appropriate for drying.

Vegetable fermentation was discussed, with an optimal temperature of 18°C and a process duration of 4–8 weeks. The mixture must remain still during this time. Sugar, such as fructose (similar to what is found in onions), can enhance fermentation. Both wild bacteria and freeze-dried bacteria (capable of surviving up to 3% salt) are used. Fermented food is preferred as it contains more minerals and essential vitamins, particularly B12.

11.2 Dermosil

Dermosil is a Finnish brand known for its high-quality skincare, cosmetics, hair care, and wellness products. Designed with Nordic simplicity and functionality in mind, the brand emphasises gentle formulations using natural and sustainable ingredients, making its products suitable for sensitive skin. Dermosil also offers eco-friendly options with recyclable packaging and adheres to ethical practices. Popular in Nordic countries, the products are sold primarily online and cater to a wide range of beauty and personal care needs.

During the meeting with Dermosil on the 3rd December, the team discussed key points about their soap production and sustainability practices. Dermosil explained that their soaps have a basic formula, but they adjust the amounts of certain ingredients, like glycerin and panthenol, to create different products. Currently, they use less than 1% oil in their recipes and have not tried using fish oil. However, they agreed that fish oil could be an option if it is safe and free from allergens. They also mentioned that fish oil might be appealing for marketing because of its health benefits.

Their production method uses cold processing, which can handle up to 3000kg in one batch. This process helps keep the ingredients intact. Dermosil sources collagen from Denmark, but they use very small amounts. They see potential for collagen-based products because of growing consumer interest. They also mentioned that Finnish customers like scents such as berry and apple, though they currently do not create custom products for other regions.

11.3 Ådö Fiskehamn – Fiskboden Kala-Aitta

On the second December, we visited Ådö Fiskehamn – Fiskboden Kala-Aitta, a local fish farm in Jakobstad, Finland. The CEO of the farm, Sebastian Höglund, provided us with an insightful overview of their fish farming operations. Unlike traditional fishing methods, this farm focuses on cultivating and growing fish in controlled environments, harvesting them once they reach maturity. Currently, it is the only fish farm in the region employing such a method.

The nature of fish farming results in fluctuating production volumes. During the high season, specifically in October and November, the farm experiences a peak in production, processing approximately 20 tons of fish per day for several weeks. This peak generates around four tons of fish waste per day. In contrast, during the low season, production drops significantly, processing only a few hundred kilograms of fish per day, mostly sourced from small-scale local fishermen. This inconsistency poses challenges for handling fish waste, especially when considering scalability for industrial processes. However, it is important to note that this analysis is based on a single fish farm and does not necessarily represent the average fishing practices in Ostrobothnia.

One positive observation was that the processing of fish at the factory does not require a significant increase in labour to separate organs, heads, or spines. Although manual labour is currently used, the introduction of machinery capable of deboning fish could further optimise this process. It was also noted that separating different types of fish waste, which could potentially be used in various processes for blue products, does not appear to increase labour intensity significantly.

A critical issue highlighted by the CEO pertains to the handling of fish blood, a by-product of waste. While fish blood accounts for only 1% of total waste, during the high season, this can amount to almost half a ton per day. Fish blood contains potentially valuable materials and nutrients, presenting an opportunity for further investigation into its utilisation in blue product development.

12 Conclusions

This final chapter consolidates the conclusions drawn from each distinct process explored in the document. Each section has been meticulously separated to reflect the individual methodologies and their outcomes. The aim is to provide a comprehensive summary of findings, highlighting the effectiveness, challenges, and insights gained throughout the series of experiments and processes.

12.1 Fermentation

Two fermentation benches were built, one aerobic and one anaerobic, each of these had three fish waste buckets with different ratios of salt, enabling to compare the results between buckets and benches. The results of these experiments showed that after fermenting for 42 days in case of aerobic and 64 in case of anaerobic, the fish waste was not rotten, and some liquid remained on the buckets, which was filtered, leaving a brownish liquid that looked and smelled like a fish sauce.

Regarding the comparison of buckets, the anaerobic ones led to darker and cloudier liquids, especially at higher ratios, and the aerobic ones produced lighter-coloured, less cloudy liquids, which showed more decomposition of meat the less salt was added. To have more information on these results these samples were sent to a Eurofins laboratory. However, in this report these lab results will not be shown because the analysis will finish after the final delivery of this project.

Even though fermentation requires time and storage, the process could be beneficial for fishermen because they could turn out fish waste into a sellable product and while the fish waste is fermenting, they are also stabilising it.

12.2 Pickling

The experiments aimed to determine the feasibility of extracting oil from pickled fish waste, specifically using pike. Although the pickling process effectively preserved the fish waste and prevented it from rotting, the attempts to extract oil were unsuccessful in both trials. In the first experiment, fish waste was pickled with salt, vinegar, and sugar for two weeks. Despite boiling the mixture and trying to separate the oil, no oil was obtained. Moreover, the process produced a strong sour smell and irritating fumes, which made handling the substance challenging.

In the second experiment, the fish waste was shredded before pickling, and the mixture was boiled for a longer duration. Despite these adjustments, the results were consistent with the first experiment, as no oil was successfully extracted. The low oil content in the fish skin and the emulsifying properties of vinegar, which hindered the separation of oil from water, were significant factors contributing to the unsuccessful outcome.

While pickling proved to be an effective stabilisation method for preserving fish waste, it was not suitable for oil extraction. The experiments highlighted the need for alternative methodologies post-pickling to achieve effective oil extraction. The findings suggest that the pickling process, though beneficial for preservation, does not facilitate oil extraction due to the inherent properties of the materials used and the limitations of the pickling process itself.

12.3 Drying

The fish waste was dried and blended after having extracted oil from it. After this process, the result was powder which could be used for making pet food.

Even though this is already done in the industry, the contribution of this project lies in the concept of getting the powder after extracting the oil. So, from the same fish waste, there were two different sellable products as the powder will be easier to stabilise. After testing the powder in a lab, it can be concluded that the fish powder meets nutritional standard values, and safety standards for most microorganisms tested, with acceptable levels of Listeria monocytogenes, Clostridium perfringens, and Sulphite Reducing Clostridia. However, the presence of Escherichia coli, even at low levels, requires attention due to its zero-tolerance safety standard. The absence of Salmonella is a positive result, confirming the powder is free from this pathogen. Ensuring the complete absence of Escherichia coli is critical for maintaining the product's safety for human consumption.

12.4 Oil Extraction

The team tried to extract oil from fish waste with different processes: pressing, boiling + pressing, blending + pressing, and blending + boiling + pressing. After this experiment, it could be observed that the best one was blending + boiling + pressing because more oil was extracted.

In addition, different types of fish were used, extracting 14% of oil out of the salmon, 9% out of pike, and 1,4% out of whitefish. Therefore, it can be concluded that the type of fish used is a key factor to consider for this process and that the best type from the ones used is salmon.

Regarding the feasibility for the fishermen, the effort made for the process would be worth it for them considering that they can extract oil that can be sold to other companies for other purposes, like making soap.

12.5 Soap Production

The team managed to get the soap out of the oil extracted previously and experimented with different percentages of oil, fat, and butter pellets. This helped to see that without changing any other ingredient, the limit to make soap solid is 70% oil. However, the optimal recipe found was with 50% oil because of its hardness, ease of taking out of the hands after using it, and the good smell of its foam. After finding the optimal quantity of oil, the recipe was improved by adding ingredients to harden it more and changing the fragrance to make sure there was no remaining fish smell after its use.

Having made functional soap out of oil, extracted from fish waste, gives a good insight because it confirms that the oil could be sold to the cosmetic industry.

12.6 Protein Extraction

The team made deep research on protein extraction and had a meeting with Anita Storm who is an expert on this topic. After all the research it can be concluded that the best method that could be tested is enzymatic hydrolysis.

Regarding the ultrasonic process, the team tried to extract protein three different times, with an ultrasonic cleaner machine. In the first two, some parts of the fish were dissolved effectively, leaving bones, a brownish liquid, and some solid parts on the top, which the team tried to extract without good results. On the third try the fish did not dissolve because the machine could not handle the amount of fish waste added. Therefore, we can conclude that the ultrasonic process can be an effective method if a way to extract the residues from the two first experiments is found, and the quantity of fish waste added is controlled.

13 Future tasks

This project team worked on the second of the three semesters that the "future fish waste products" project will endure. Therefore, an incoming team will continue developing the project for the next semester. That is why it is important to suggest to them, or even external researchers, what could be done for further research on each of the processes studied in this project.

13.1 Fermentation

It should be tested whether anaerobic or aerobic fermentation is more suitable to produce garum. To do this, the samples must be tested and analysed. Once this has been discovered, this method should be researched further. Several different salt concentrations should be tried here.

13.2 Pickling

The team found out that pickling is a good stabilisation method for fish waste. However, it could not be concluded if extracting oil with blending + boiling + pressing is effective after pickling. Therefore, oil extraction after pickling should be tested in a proper way in order to be able to conclude if it is feasible.

13.3 Drying

Ensuring the complete absence of Escherichia coli is critical, so additional measures for contamination prevention during processing and storage should be implemented, including enhanced hygiene protocols and possible refinement of drying and grinding processes. To make the process more economical, different methods with different temperatures and air flows should be tested and calculated. Further studies could focus on developing packaging materials to extend shelf life and exploring antimicrobial packaging options. Additionally, long-term storage studies to control bacteria and rancidity caused by high fat contents would be important. Improving energy efficiency in drying, possibly through the use of renewable energy or process automation, could also be a key focus. In summary, the powder results show that it is good enough to proceed with further testing and field trials to try to reach the market.

13.4 Oil Extraction

It could be interesting to see from which fish could get extracted the largest quantity of oil and how you could extract the oil from the head of the fish, as this could not be used in the team's experiments because it could not be shredded. Another option would be to carry out the oil extraction process without heat (cold processing) so as not to destroy possible ingredients such as omega-3 fatty acids to increase the value of the oil. To this end, laboratory tests could be carried out on the oil from the hot and cold processes to recognise the differences and narrow down the application areas, as well as the impact of heating.

13.5 Soap Production

Further experiments in soap production would be necessary to improve the hardness, pH value and foam formation as well as to increase the colour and fragrance. To achieve this, further batches could be produced by adjusting the percentages of ingredients that were not previously changed. Consideration can also be given to adding new substances from studies or even omitting substances. Another option is to try your hand at producing liquid soaps. In principle, contact with Dermosil (liquid soap production) and the local company Vasa Tvål Ab (hard soap production) can be informative for further steps.

13.6 Protein Extraction

The enzymatic hydrolysis process identified needs to be further researched, followed by experimental trials to evaluate its effectiveness. In addition, alternative methods for protein extraction should be further investigated in order to find new approaches for this process. One of these methods could be carried out using protease, which was discussed in more detail during the meeting with Anita.

Regarding the ultrasonic process, further experiments could involve optimising ultrasound parameters such as frequency, intensity, and duration to improve the separation of bones from meat and enhance mineral extraction efficiency. Combining ultrasound with other enzymes, like collagenase or lipase, could further improve the extraction of proteins and fats. Research could also focus on refining the conditions for extracting minerals like calcium and phosphorus from fish bones to increase the nutritional value of the final product. Developing automated systems for real-time monitoring and adjustment of ultrasound parameters could improve scalability and consistency in industrial applications. To reduce environmental impact, future studies might explore the use of renewable energy sources or optimise the process to decrease water and energy consumption. Finally, investigating how ultrasound treatment affects the quality of extracted proteins, lipids, and minerals in terms of texture, flavor, and nutrient retention could lead to better-quality products for both food and animal feed industries.

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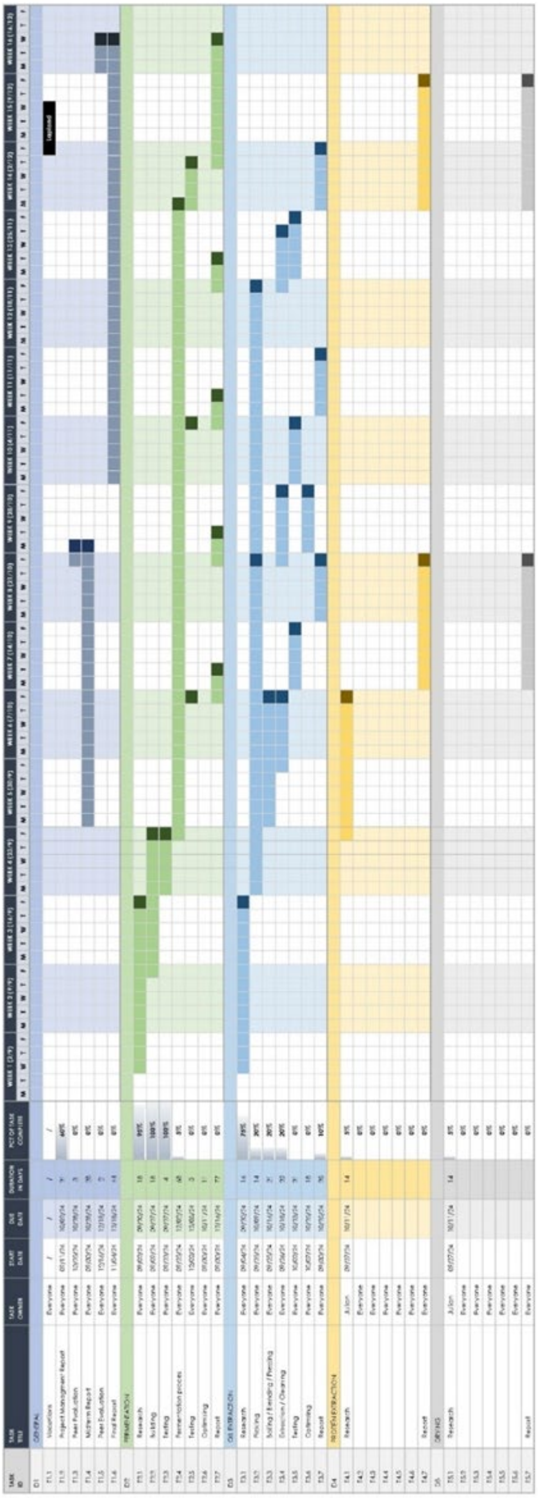
15 Appendices

15.1 Gantt-Chart



15.2 Stakeholders Register

ID	Role	Contact	Category	Interest	Influence	Expectations	Communication	Meeting frequence
1	Project Team	/	Internal	high	high	Reaching Deliverables	Whatsapp	3 times a week
2	Project Managers (Mikael Ehrs and Biniam Tefera)	mikael.ehrs@novia.fi biniam.tefe	Internal	high	high	Reaching Deliverables	Email	1 time a week
3	Kag I Österbotten	/	Internal	medium	low	Reaching Deliverables	Email	/
4	Aktion Österbotten	/	Internal	medium	low	Reaching Deliverables	Email	/
5	Österbottens Fiskarförbund	/	Internal	medium	low	Reaching Deliverables	Email	/
6	VTT Technical Research Centre of Finland	/	Internal	medium	low	Reaching Deliverables	Email	/
7	Natural Resources Institute of Finland (LUKE)	/	Internal	medium	low	Reaching Deliverables	Email	/
8	Marina Nyqvist	marina.nyqvist@fishpoint.net	Internal	medium	low	Reaching Deliverables	Email	1 time a month
9	Novia University	/	Internal	medium	high	Reaching Deliverables	Email	/
10	Home University from team members	/	External	low	low	Reaching Deliverables	Email	/
11	Fisheries / Potential Customers	/	External	medium	low	Reaching Deliverables	Email	2 times a month

15.3 Financials

A total budget of 5000 euros has been allocated for the Future Fish Waste Products project. As of 18 December 2024, expenditures amount to € 4.049,14. The table below provides a detailed breakdown of all expenses incurred during this period.

Product	Quantity	Price	Total
Bucket + lid 3 l	7,00	€ 2,59	€ 18,13
Kitchen mixer	1,00	€ 22,99	€ 22,99
Measuring cap	2,00	€ 5,59	€ 11,18
Kitchen sieve	1,00	€ 3,59	€ 3,59
Freezer box	1,00	€ 3,29	€ 3,29
Lid for a bucket 10 l	4,00	€ 1,99	€ 7,96
Bucket 10 l	4,00	€ 2,59	€ 10,36
Freezer box	1,00	€ 3,19	€ 3,19
Baking tray and lid	2,00	€ 4,99	€ 9,98
bags	3,00	€ 1,50	€ 4,50
sieve	1,00	€ 4,99	€ 4,99
Spoon sieve	1,00	€ 6,79	€ 6,79
Soup spoon	1,00	€ 6,69	€ 6,69
Potato pestle	2,00	€ 3,99	€ 7,98
Hadley	2,00	€ 5,19	€ 10,38
Cutting board	2,00	€ 9,99	€ 19,98
Cooking pot 10 l	2,00	€ 69,90	€ 139,80
Scale 0kg – 10 kg	1,00	€ 14,90	€ 14,90
Cooking thermometer	1,00	€ 10,99	€ 10,99
Ice cube mould	2,00	€ 2,99	€ 5,98
nuts	1,055 kg	€ 5,99	€ 6,32
Meal box	3,00	€ 5,89	€ 17,67
Steam cleaner	1,00	€ 29,99	€ 29,99
Bucket 3 l	10,00	€ 2,59	€ 25,90
goggles	7,00	€ 3,99	€ 27,93
Overall xxl	3,00	€ 7,99	€ 23,97
Overall xl	1,00	€ 7,99	€ 7,99
Overall L	2,00	€ 7,99	€ 15,98
Bag	2,00	€ 0,50	€ 1,00
Shoe protector	1,00	€ 7,99	€ 7,99
Wheel	8,00	€ 2,99	€ 23,92
Wheel	5,00	€ 3,49	€ 17,45
Gloves xl	1,00	€ 8,99	€ 8,99
Gloves M	1,00	€ 8,99	€ 8,99
Screws	1,00	€ 10,19	€ 10,19
Dish brushes	3,00	€ 1,00	€ 3,00
Silicon	3,00	€ 4,79	€ 14,37
Wheels	13,00	€ 2,99	€ 38,87

Screws	0,805 kg	€ 5,99	€ 4,82
Fruit press 6 l	1,00	€ 74,99	€ 74,99
Flour funnel	1,00	€ 7,99	€ 7,99
Filter for the fruit press 6 l	1,00	€ 9,98	€ 9,98
Blender 400 W l	1,00	€ 27,99	€ 27,99
Blender 1200 W	1,00	€ 79,99	€ 79,99
Bag	1,00	€ 3,00	€ 3,00
Digital socket timer	1,00	€ 9,99	€ 9,99
Fruit dryer	1,00	€ 29,99	€ 29,99
Water pump tongs	1,00	€ 35,98	€ 35,98
Hedge trimmer	1,00	€ 9,99	€ 9,99
Pruning shears	1,00	€ 9,99	€ 9,99
Cutter knife	1,00	€ 7,99	€ 7,99
Battery charger	1,00	€ 69,90	€ 69,90
V-belts	2,00	€ 20,90	€ 41,80
Alternator pulley	2,00	€ 49,90	€ 99,80
Alternator pulley	2,00	€ 41,90	€ 83,80
Kaolin 200g	1,00	€ 7,90	€ 7,90
Jasmin fragrance 10 ml	1,00	€ 2,60	€ 2,60
Xanthan gum 50 g	1,00	€ 2,60	€ 2,60
Sodium lactate 250 ml	1,00	€ 8,40	€ 8,40
Sunflower oil 25 g	1,00	€ 2,30	€ 2,30
Butter pellets 200 g	1,00	€ 12,50	€ 12,50
Shea butter 200 g	1,00	€ 9,95	€ 9,95
Lime fragrance 10 ml	1,00	€ 3,85	€ 3,85
Sodium hydroxide 3,5 kg	1,00	€ 91,60	€ 91,60
Lavender fragrance 10 ml	1,00	€ 5,75	€ 5,75
Blue food colour	1,00	€ 2,49	€ 2,49
Vinegar	2,00	€ 6,99	€ 13,98
Bag	2,00	€ 1,52	€ 3,04
Sea salt	10,00	€ 0,99	€ 9,90
Wood 22 mm x 50 mm	5,1 m	€ 0,79	€ 4,03
Wood 48 mm x 48 mm	4,8 m	€ 1,34	€ 6,43
Wood 48 mm x 48 mm	4,8 m	€ 1,39	€ 6,67
Power source	2,00	€ 15,73	€ 31,46
Bergen nitrile glove black	2,00	€ 8,99	€ 17,98
Batteries	2,00	€ 9,99	€ 19,98
Glass jars	6,00	€ 3,79	€ 22,74
Buckets	4,00	€ 9,19	€ 36,76
Bags	2,00	€ 0,5	€ 1,00
Candle strin	1,00	€ 1,99	€ 1,99
Filter bags	2,00	€ 14,9	€ 29,80
Small filter bags	1,00	€ 14,9	€ 14,90
Suits	10,00	€ 7,99	€ 79,90
Plastic bags	1,00	€ 0,25	€ 0,25
Suits	9,00	€ 7,99	€ 71,91

Taxi	1,00	€ 750,10	€ 750,00
Glassware/gloves lab	1,00	€ 838,22	€ 838,22
EUROFINS Nutrition & Pathogen tests	1,00	€ 716,10	€ 716.10
			€ 4.049,14