Co-funded by the European Union

YRKESHÖGSKOLAN NOVIA

KALALEADER

Österbottens Fiskeleader
Pohjanmaan Kalaleader

Alternative fish waste solutions

Final Report

Eben Pelsmakers Fabiënne Kuiper Aurélien Mur Senne De Wolff

European Project Semester (EPS)
Novia University of Applied Sciences

DEGREE THESIS

Authors: Eben Pelsmakers, Aurélien Mur, Fabiënne Kuiper, Senne De Wolff.

Degree Programme and place of study: EPS Semester – Novia University of Applied Sciences.

Specialisation: Sustainability, Mechanical, Architectural, Electronical .

Supervisor(s): Mikael Ehrs.

Title: Alternative fish waste solutions.

Date: 16.05.2025 Number of pages: 100 Appendices: 10

This report further explores innovative methods to stabilize and repurpose fish waste. Building further from the previous stages and experiments done by other EPS students. The primary objective was to upscale the value of fish waste so it's higher than the baseline value which is biofuel. This project as a part of the European project semester is conducted by a diverse team of international students. With different educations, cultures, backgrounds, strengths and work-points.

Different methods were used to make fish waste more valuable. From fermenting and making garum with spices, peppers and wine. To protein extraction with enzymes, ultrasonic vibrations and using the protein to 3D print edible fish nuggets. As stabilization methods, UV-sterilization was used to sterilize and preserve the fish waste longer with air and water experiments in combination with drying. These were tested in a small scale to gather data before implementing them in an industry and making them large scale operations.

Results and further research showed that fermentation could be a way to upscale fish waste by having garum as a byproduct. UV sterilization with ventilation showed signs of good drying and an opportunity to upscale it. Both are not guaranteed to be bacteria-free, lab results did not come in time. Protein extraction using ultrasound showed successful results of getting a fish paste with a decent protein content. Then the use of enzyme gave a good separation of the flesh from the bones, but no lab test was done for the protein contents. Alkaline and acidic solubilization didn’t go well, the protein content was too low. Finally, 3D printing fish nuggets with the paste from the ultrasonic method was successful. Frying them was the best option but further development for taste and texture should be done for the same results as a standard fish stick.

Language: English.

Key Words: Fish waste, Protein extraction, Stabilization method, Ultrasonic, Enzymatic hydrolysis.

Table of Contents

Table of Figures

Table of Tables

Table of Appendices

1. Introduction

The “Fish waste” project has been carried out as a main objective during the European Project Semester (EPS). This took place in Finland, Vaasa at Novia University of Applied Sciences. EPS is an International multidisciplinary program made for students from various educational backgrounds, cultural backgrounds, countries, strengths and work-points. This allows them to prepare and work on real-world problems where they have to work with different people.

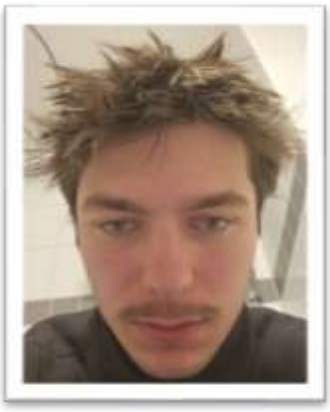
In this semester the group worked further on the fish waste project. As the project's last phase, focus was also put on sustainable solutions for fish waste. This is a known problem here in the Ostrobothnia region in Finland because the fishing industry is important there. Solutions were firstly investigated to preserve fish waste by using UV sterilization and fermentation. Then, for ways to upscale fish waste into more valuable products, such as garum, protein extraction and 3D printed fish nuggets. This is to reduce the fish waste that does not get used to its potential. Reducing environmental impact and strengthening local fishery economically.

The team was made up of four people and ranged from energy technology specializing in sustainability to mechanical engineering. This was needed to address the difficult challenges of dealing with fish waste. The team worked collaboratively together to research and test different experiments. To get results and findings to give the Finnish fishing industry insight to practical solutions.

1.1 Group members

Before going further into the research, it's important to know who will be working on this project and what the team will looks like. In the next few paragraphs, the team members will be introduced and will also explain the studies that every student practise. There will also be an overview of certain tests that are done by the team members which shows the group dynamics. This all is important to understand to get a better understanding of certain choses are made or to understand the way of working together.

1.1.1 Eben Pelsmakers



Eben Pelsmakers is 20 years old and currently studying for a bachelor's degree in Energy technology, specializing in sustainability at the University of Applied Sciences Geel in Belgium at the University Thomas More. This is the last semester of his degree and counts towards his obligated internship during my degree. He decided to embark on the EPS journey because he heard positive things from teachers and students. His parents also told him that it was a one-in-a-lifetime experience. The idea of being abroad and working with different people to tackle real-world problems really spoke to him. He thinks this is also really great for personal self-development.

1.1.2 Aurelien Mur

Aurelien Mur, from France, is a 21-year-old student and currently studying in the National Engineering School of Tarbes (ENIT) and majoring as mechanical engineer. He is in his fourth year and after the EPS project it will be his last year of school. Aurelien chooses the EPS project to strengthen his teamwork, to communicate better, to learn new competencies and of course work with people from different nationalities.

1.1.3 Anna Fabiënne Kuiper

Anna Fabiënne Kuiper is a 22-year-old student from the Netherlands. She studies Architecture and Construction Engineering in The Hague at The Hague University of Applied Sciences. Right now, she is in her fourth year and after the EPS project she will start with her thesis. Fabiënne started the EPS project because she thought it would be a great opportunity to study abroad. She also thinks that during one's study; it's the best time to try new things like studying in a different country. This is the most important reason why she started with this project. Also, it would be a great experience to try and work with people from different backgrounds.

1.1.4 Senne De Wolff

Senne de Wolff is a 23-year-old student from Groningen, the Netherlands. They are studying Electrical Engineering at Hanze University of Applied Sciences and specializes in Sensor Technology. This is their third year of doing a bachelor. Senne joined the EPS project because they like to do project-based work. They have always been interested in the Nordic countries because of their education system and the Nordic nature. Working with international students comes naturally since the bachelor's degree they are following right now is also international.

1.1.5 The team

The team consists of four members who all have different backgrounds in studies and learning experiences. This makes it important to understand with what kind of workers the group is formed and how people react in different situations. To get a better overview of this, a few tests are done. This to show what the strong and weak points are of the group and its members. These tests are shown in Appendix A. With this overview of the group, it can be related back to different phases during the program.

1.2 European Project Semester

The European Project Semester (EPS) is an education program for students from different cultures, educational backgrounds and countries (figure 1). That allows them to work in group with other diverse students to work on a real-world problem and find solutions for it.

Guided by a coach you are presented a problem by stakeholders. As a team, they need to find solutions or meet particular parameters set by them to resolve the issues. This enhances technical skills, teamwork, project management and cross-cultural communication within the team and individually. It also improves the educational experience for students and makes them more prepared for real-world scenarios and work. Making them essentially a global workforce that know what they're doing with proper methods and skills. (Novia UAS, 2025). The program is financed by the EU and the Erasmus + which makes it possible for the students to work on the project and still enjoy their time abroad.

Figure 1: Erasmus logo

1.3 Ostrobothnia

Ostrobothnia is a region located in Western part of Finland. Characterized by its extensive coastline and a total surface area of 7,932.36 km^2(Figure 2). The region is home to over 180,445 residents and is known for its strong connection to the sea. Its coastal geography and proximity to major urban centres have made the fishery industry one of the region's most significant economic sectors.

Vaasa is located roughly in the middle of Ostrobothnia and is one of the region's most prominent cities. Known as a hub for education and innovation, Vaasa attracts many young people who study at its universities and vocational schools. This influx of talent and its strategic location have contributed to Vaasa's prominence in both the energy and fishing industries. The city is a key player in advancing the region's economic growth, sustainability initiatives, and the development of its fisheries sector.

Figure 2: Ostrobothnia region.

Several types of fish are caught in this region which you can see in the table below (Table 1). And as you can see Herring is the most caught with an outstanding 14,715 Tonnes of fish caught in 2022. Which only is higher now in 2025 because of higher consumption. This fish has a good fat content per 100g and a below average for proteins per 100g. So, fish waste batches will mostly have that fish but are always mixed with other fish because some fishes are only seasonal.

Table 1: Fish in Ostrobothnia

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%**

Ostrobothnia Fisher Association

The Ostrobothnia Fisheries Association established in 1930, consists of 91 member organizations. Including water owner associations, fishery associations and Fisheries Regions. It operates along the coastal areas from Kokkola to Kristinestad focusing on promoting sustainable fish production, developing efficient fish utilization methods and encouraging domestic fish consumption.

As a government-funded advisory organization under the Federation of Finnish Fisheries Associations. The association supports its members by guiding on fishing grounds, fish stocks and the Fishing Act. This is done through newsletters, articles in fisheries journals and training courses. The association also helps the public with fishing-related inquiries and hosts "The Fishery Day" each June in Vaasa. This popular event draws around 10,000 visitors and highlights the importance of fishing and promotes domestic fish.

2. Plan of approach

2.1 Problem definition

Fishing is a large industry in Finland, especially along the coastline of the Ostrobothnia region. While fish fillets are harvested for consumption, 60-70% of fish waste is discarded after filleting mostly used minimally as biofuel (fishing.net.nz/fishing-advice, 2025). This inefficiency presents environmental and economic challenges. Especially as fish production in Finland continues to grow reaching 123,000 tons in 2022 and showing a consistent upward trend (foa.org/fishery, 2024).

Local fisheries in Ostrobothnia are increasingly concerned about optimizing fish waste management while keeping energy and labour inputs minimal. The need for solutions is urgent given population growth and the irregular number of fish caught at a time. Driving higher fish consumption and the commitment to achieving the United Nations' Sustainable Development Goals (SDGs) for 2030 and 2050 (statista.com/fish-and-seafood-industry-in-finland, 2025) (sdgs.un.org, 2025) (Figure 3).

To address this, the team investigated methods to preserve fish longer, extract proteins from fish waste and explore upscaling opportunities for added value. This involved structured planning, experimentation and analysis. With a focus on sustainability, reduced energy consumption and labour efficiency. The ultimate goal was to develop actionable solutions that align with both local fishery's needs and global sustainability objectives.

Figure 3: Sustainable Development Goals

2.2 Objectives and scope

For the next few months there will be worked on experiments, documentation, project management and research. If combined these things, there will form a solution for the fish waste problem with which this project was started. To combine these different elements, there will be needed some kind of a plan of approach. This is a text which explains how the main question will be tackled. In this text will often things as the objectives and scope mentioned and will give an idea of what the next steps will be.

For this project the problem is outlined in the previous paragraph, the excess fish waste in the region Ostrobothnia. This group is not the first that will work on the project, it's the third but final one that will look for the solutions for the fish waste problem. The first two groups did a lot off research about different stabilization methods, started some small experiments about these methods and looked at different byproducts. The final group will look at the end result and will try to give a solid alternative for the use of fish waste.

This will be done by dividing the tasks in the following objectives.

1. To identify effective stabilization methods for fish waste.
2. To develop protein extraction processes from fish waste.
3. To test the potential of a 3D food printer to create edible fish waste products.

For the first objective the previous reports will form a base for the resources about the stabilization methods; fermentation and the use of UV lights. During the resourcing and experimenting the goal is to find a way off storing fish waste for a longer period of time. The second objective will take a closer look at different ways to extract protein from the waste and to make this useful as a byproduct. The last objective is about experimenting with food products and 3D printing. With the 3D printer, 'fish' nuggets can be tried to create and make a new product to sell on the market.

The scope of this project is mainly about the objectives and the tasks that will be necessary to complete the resource for these objectives. A lot off the resource will be based on the conclusion of the previous groups. However, there are a few topics that are not included in this report because off time, budget and probability of success. These topics are listed in the following sentences.

1. Drying, pickling and freezing stabilization methods used in the previous reports.
2. Making the byproducts soap, candles and fish food.
3. Marketing, promoting and commercializing.

By following the objectives and the scope of the project, a solution should be developed for alternative ways off using fish waste.

2.3 Work Breakdown Structure and Planning

During this project multiple tasks and experiments will be done at the same time. For this it is necessary to make a Work Breakdown Structure to have a better overview of the whole project. A Work Breakdown Structure shows the objectives, also known as deliverables, and all off the actions and tasks that need to be done to success. (Hollins, 2025). After making a WBS (Work Breakdown Structure), the scheduling can start. Here all of the tasks will be listed, and a schedule will be made with the duration and the one who is responsible for the task.

During the lectures about project management from Philip Hollins, the different groups worked on the deliverables and tasks that need to be done for the project. With this the progress of making the WBS started. First the objectives were put on the board and the team members wrote down all of the tasks that matched the deliverable. See Figure 4, Figure 5 and Figure 6 for a visual representation of working progress for the WBS making.

Figure 4: Progress WBS deliverable 1

Figure 5: Progress WBS deliverable 2

Figure 6: Progress WBS deliverable 3

After the assemble of the tasks and the deliverable, the WBS was ready to be made. With this a clear view is shown which explains what needs to be done and to understand what task part of which objective is. In Figure 7 is shown a close-up of the first deliverable from the WBS. In this image is seen how the different assignments are linked to the different themes of the project. Also, it shows the different subtasks by numbering. In Appendix F the entire WBS shown and are all of the deliverables and tasks listed.

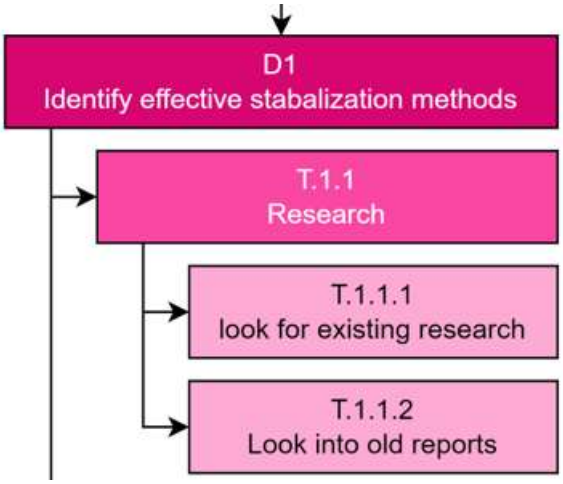


Figure 7: Close-up WBS deliverable 1.

One of the advantages of working with a WBS, is the easy connection with a scheduler. In a scheduler all of the tasks are listed with a timeframe and the people who are responsible for the finished product. (Hollins, 2025). In Figure 8 is a close-up from the scheduler shown which shows a glimpse of how the scheduler is structured, see the whole scheduler in Appendix G. In this figure is also shown the percentage of the completed task and the duration in days. This shows a nice overview of the tasks that are almost finished and the ones that need a bit more notice.

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (Days)	% of TASK COMPLETE
D0	General tasks					
T.0.1	Documentation	everyone	3-2-2025	20-5-2025	98	50%
T.0.2	Stakeholders contacting	everyone	3-2-2025	25-5-2025	98	10%
T.0.3	Meetings with coach	everyone	3-2-2025	25-5-2025	20	50%
T.0.4	Instagram updates	everyone	3-2-2025	25-5-2025	20	30%
T.0.5	Planning	everyone	20-2-2025	6-3-2025	10	50%
T.06	Make a WBS	everyone	20-2-2025	6-3-2025	5	100%
T.0.7	Make a schedule	everyone	20-2-2025	6-3-2025	5	100%

Figure 8: Close-up scheduler.

The tasks are numbered by codes that are linked to the WBS. For example, the general tasks are not an objective so are named D0 or deliverable 0. The tasks underneath use the same numbering which would be task 0.1 or also T.0.1. These numbers are also connected in the WBS, just like is shown in Figure 7 with deliverable 1. By using the WBS and the scheduler side by side, it creates a good overview on the project and progress.

2.4 Stakeholder updates

The problem with which this project started comes from the Ostrobothnia fisher industry and the excess waste of fish. In the following text are all of the stakeholders listed that will be playing a role in this project.

Stakeholders:

1. **Aktion Österbotten**
    a. Aktion Österbotten is committed to fostering sustainable rural development in the Ostrobothnia region. Through networking, collaboration, and support for local communities, businesses, and associations, they work to create opportunities for growth and innovation. Their aim is to empower rural actors, encourage cooperation, and drive positive change that benefits everyone in the region. (Aktion Österbotten, n.d.)
    b. Aktion Österbotten is the implementer of the following two stakeholders.
2. **Coast action group (KAG)**
    a. The Ostrobothnian Fishing Leader Coastal Action Group (KAG) is tasked to develop the fishing industry, aquaculture and coastal communities, and the main financier of the project. They are part of Aktion Österbotten and lead the FISH LEADER activities along the Ostrobothnian coast. (Aktion Österbotten, n.d.)
3. **Blue Products 3.0**
    a. The goal of Blue Products is to improve fish quality and improve fish product development. (Kalatalous verkosto, n.d.)
    b. The KAG and Blue Products have interest in the fish upcycling project because it is an example of the developments they do. They also have an interest in working with universities to encourage studying, and to make their name known to students in hopes to offer career opportunities.
4. **Novia University of Applied Sciences**
    a. The Fish Upcycling Project is part of the European Project Semester (EPS) offered by Novia University of Applied Sciences.
    b. Mikael Ehrs
    c. Mikael Ehrs is the project coach of the Fish Upcycling Project.
5. **Home universities**
    a. The project members of the Fish Upcycling Project are all enrolled in different universities in their home country.

To make a better overview of all of the different stakeholders, a stakeholder register with an analyse is made. These documents show the importance of every stakeholder and the way of contacting with them. In Figure 9 the stakeholder analyse is shown which is also linked with the register in Appendix H.

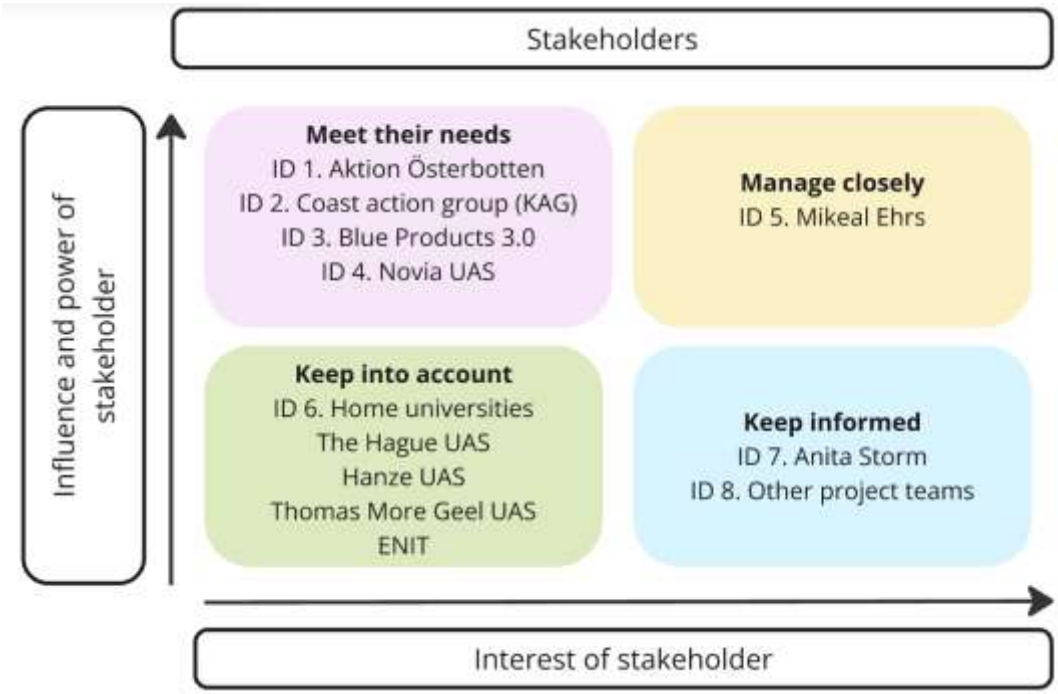


Figure 9: Stakeholder analysis.

In the figure are four different boxes shown which indicate the influence and the interest of every stakeholder. With this the project team can decide how often these stakeholders will need an update. In the register it also shows the way of contact with the stakeholders. In this way all of the stakeholders will get the right information at the right time.

3. Research

For this project different research has been done and so also different research methods, both qualitative and quantitative. Like stated in previous paragraphs, this project is split into three group. The first two group were participants in the previous EPS programs and started the project with looking for a solution for a more effective way of using fish waste. The third group will be the one that will closure the project and have to give a solution for the main problem. For the last part of this project, it's important that a lot of experiments are done followed by a list of solutions that may work or not. For the part of closure, multiple research methods are used and will be explained in the next text.

The first part of the research will be about document analysis, which is a qualitative technique of doing research (The University of Newcastle, 2024). The previous reports play a big role in the preliminary investigation because of the information that was already looked into and the scope of the project. It's still important to look with criticism at the reports because these reports were also made by students which means they aren't scientifically proven. But the reports can be used as a base for the scope and the research that need some more notice. Another part of the document analysis, is the looking for scientific documents which can be used as background information for the experiments.

The second research part will be quantitative and is about the experiments and test that will be done. It's a way of researching where based on a test in for example a lab will be used as a source (The University of Newcastle, 2024). For the final project group, the tests will be needed as proof for the usability of different methods. For every objective, experiments will be the base for the research. By following the objectives and basing the experiments on the objectives, the experiments will form the basis for a solution for the main problem.

4. Realization

This section discusses the realization of different experiments and some associated research. It presents how the technology/experiment works, the type of experiments executed, some troubleshooting processes and the results and conclusion about each topic.

To stabilize fish waste means to prevent its decomposition carried out by micro-organisms (E.S., 2015). Since fresh fish is extremely spoilable, its waste has to be stabilized quickly in order to be usable. Some stabilization methods include drying, pickling, smoking, brining, UV-sterilization, and fermenting. Since the goal is to make a profitable product out of fish waste, the stabilization methods cannot be energy intensive and expensive. The main two stabilization methods discussed in this report are fermentation and UV-sterilization.

4.1 Garum

Garum is a byproduct that is created after a fermentation process. Fermentation as a process transforms sugars into a new product through chemical reactions conducted by microorganisms. Humans have always used fermentation in the production of foods, medicines, fuels, and more (Großkinsky, 2020). Fermentation can be seen as a stabilisation method because the product is still edible after sometimes months of preserving. The chemical reaction of the microorganisms slows down the rotting process which makes it a natural stabilisation method. This method was selected because it was already experimented by previous group and has shown great result. The goal was to produce a garum from it that can be consumed by human.

4.1.1 Method

4.1.1.1 Fermentation and garum process

In this text the fermentation process will be explained. The cells in organism need glucose to create the power source that stimulates a lot of processes in the cell. This process is called glycolysis in which glucose and oxygen create carbon dioxide, water and adenosine triphosphate (ATP). ATP is the power source for many cellular processes. This process is mostly done with the access to oxygen, called aerobic. However, this process can also be done anaerobic. There are only a few cells that can do this process without oxygen: most bacteria, yeast and muscle cells. Then, there are two ways to create ATP without oxygen: anaerobic respiration and fermentation. Furthermore, fermentation can also be divided in alcoholic fermentation and lactic acid fermentation. In this text the focus will be on lactic acid fermentation process. To make ATP in a lactic acid process, a shortage oxygen is found in its surroundings which starts the fermentation. This is where cells use a little bit of their own power to start breaking down the molecules which create lactate. (Amoeba Sisters, 2018). This lactate is the molecule that gives fermentation products its sour taste (Britannica, 2025), this will not be explained furthermore to keep the theory simple and easy to understand.

The lactic acid fermentation process is often done with vegetables or meats to preserve the food for much longer. It's the oldest preservation technique for storing food and it only needs the ingredients salt, water, and the vegetable or meat. The salt takes care of the bacteria; most bacteria cannot survive in a salty environment. The water (in combination with the salt) will create an environment without oxygen which stimulates the lactic acid fermentation process. Lastly the food is necessary to start the glycolysis in the vegetables/meat. When the chemical process in the food starts, the lactate that is created will start to convert in lactic acid, (Ramirig, 2018). An acidic environment is created by the lactic acids which preserves the food safely and makes it sour.

In addition of being a stabilisation method, a by-product can be obtained resulting from the fermentation of fish waste that is of interest for this project, garum. Garum is a fish oil sauce that was popular in ancient Mediterranean countries. In 2020 Sally Grainger wrote the book "The Story of Garum; Fermented Fish Sauce and Salted Fish in the Ancient World" in which she explains how garum was made and its origin. She also explains that there were multiple fish sauces used in ancient history. Fish sauces are famous in the southeast of Asia. The Asian fish sauce is usually made with small fishes, salt and some kind of liquid. Garum was in some way the Roman version of a fish sauce and was usually made with the same ingredients. (Grainger, 2020). The base for the garum also consists of fish, salt and sometimes water. In the Roman Empire this sauce was used a lot, and it was even used more than salt. But it was also a luxury product, and it belonged more to the rich. After some time, the sauce became less important, and the product was not necessary for basic cooking. Nowadays garum is not used in the everyday life and is often described as an ancient ingredient that is used for culinary cooking.

To summarize, by using the fermentation process to preserve fish waste it will give a byproduct called garum, thus it combines two objectives in one experiment. The fermentation can be used as the stabilisation method which was proved by the previous group. The fermentation process will create a byproduct that may be interesting for an upscaling process. The goal was to make a suitable garum for human consumption.

4.1.1.2 Design and build

To utilize fermentation, two machines were made by the previous project group. These machines were designed to rotate buckets with fish waste in order to ferment the fish and create garum as a side-product. When testing the machines, it was discovered that the machines were broken. The motors to drive the rotation did not work properly. Short pulses of around half a second were given.

Even though the machines were broken, the garum experiment would still be conducted. During the troubleshooting and repairing of the machines the buckets with fish were shaken manually for two minutes a day.

To troubleshoot what was wrong, the motors were first connected to a laboratory power supply. Because the motors rotated as they should, it was concluded the motors were not the problem. Secondly the original power supplies were tested by using a load and a multi-meter. It was discovered the power supply cuts of its supply of power when six Ampere are reached. After around half a second it tries again. These explain the short pulses the motors were rotating in. The motors only use between 1.5 and 3 Ampere while running, but as any electromotor, it has a much higher startup current. While the actual startup current is unknown, it is most likely to be higher than 6 Ampere and would thus explain the failure of the power supplies (Figure 10).

Figure 10: Troubleshooting the garum rotation machine.

The first proposed solution was to make a soft-start circuit (Figure 11 and Figure 12). This circuit puts an electrical resistor before the motor when starting up to reduce the startup current. After a certain time, defined by the capacity of the capacitor, a relay switches, the resistor will be bypassed, and the motor can use full power again. When using the soft-start circuit, it did exactly what it had to do. However, after switching to full power, the power supplies still failed, and the solutions was deemed unsuccessful.

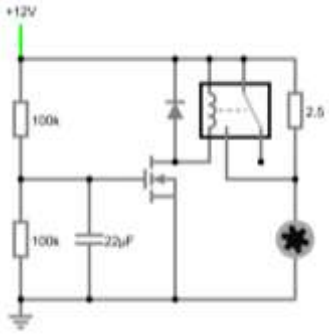


Figure 11: Soft-start circuit schematic.

(de Wolff, Soft start circuit, 2025)

Figure 12: Soft-start circuit picture.

The second solution was to try to have a 12 Volt battery charger to power the motor. The battery charger that was already in possession is an “intelligent” battery charger. It sensed that the motor was in fact *not* a battery and thus refused to supply the motor of power. This solution was deemed unsuccessful.

As third solution an impact drill was bought to substitute the motor. The construction required to install the drill to the machine was very fragile and making a proper construction would be too time consuming. There was also a risk of overheating the drill. This solution was deemed unsuccessful.

Time to repair the was running out. All group members would leave for 5 days so the buckets of fish would be unable to be stirred. To prevent the garum from failing, it needed the machines repaired. With one day left the fourth and final solution was proposed. A 20 Ah 12 Volt lithium battery was found and after testing it was found that the battery could supply the motor with sufficient power. Because the motors should not be running constantly, relays were put in between the battery and the motors. These relays were powered by a normal power socket with a timer in between. The timers made sure the motors would only be on for 2 times 2 minutes a day. The final circuit was proposed, realised and tested (Figure 13 and Figure 14). This system did exactly what it had to do, and the solution was deemed successful.

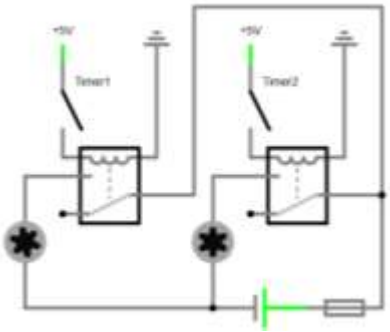


Figure 13: Battery and relay circuit schematic.

(de Wolff, Relay circuit, 2025)

Figure 14: Battery and relay circuit picture

4.1.1.3 Experimental protocol

The task was to experiment with different recipes to make the garum. To test the best taste, three different recipes were realized. Of all three recipes, two variations were made in the ratio of salt and fish waste. Groceries were done and all the ingredients were collected as described in Figure.

Figure 15: Ingredients of the garum.

In addition, because there weren't enough buckets available, the garum was made in two batches. The first batch was made on February 24, 2025. The second batch was made on March 13, 2025. Each batch consists of three buckets. Each bucket contains different ingredients. In Table 2 the ingredients of all buckets are presented. Table 3 presents the distribution of the fish parts in each bucket. The fish consists of a mix of roughly 40% spike, 40% zander, and 20% perch. All buckets were placed in the rotation machines in a closed container (Figure 16). This container was heated between 32°C and 38°C.

Table 2: Ingredients garum buckets.

Batch 1, 24.02.2025			Batch 2, 13.03.2025		
Bucket 1	**Bucket 2**	**Bucket 3**	**Bucket 4**	**Bucket 5**	**Bucket 6**
800g fish	814g fish	800g fish	509g fish	505g fish	502g fish
100g salt	102g salt	100g salt	102g salt	101g salt	100g salt
400ml water	250ml water	250ml wine	250ml water	250ml water	251 ml wine
26g thyme	50g chilis		26g thyme	50g chilis	
25g fennel			25g fennel		
10 bay leaves			10 bay leaves		
30g rosemary			30g rosemary		
25g oregano			25g oregano		

Table 3: Distribution of fish parts per bucket.

Batch 1, 24.02.2025			Batch 2, 13.03.2025		
Bucket 1	**Bucket 2**	**Bucket 3**	**Bucket 4**	**Bucket 5**	**Bucket 6**
4 heads	4 heads	4 heads	2 heads	1 head	2 heads
5 bodies	5 bodies	5 bodies	3 bodies	4 bodies	3 bodies
2 skins	2 skins	2 skins	2 skins	3 skins	2 skins
6pc. flesh	6pcs. flesh	13pcs. flesh	7pcs. flesh	7 pcs. flesh	3 pcs. flesh
2 organs/eggs	2 organs/eggs	2 organs/eggs	0 organs/eggs	0 organs/eggs	0 organs/eggs

4

Figure 16: Garum rotation machines with six buckets.

4.1.1.4 Results

The buckets were left in the rotation machine for eight weeks to let the fermentation process work. During these weeks some check-ups were done by opening the cabinet where the buckets were located. After the first two weeks, one extra batch (three buckets with the herbs, chilli peppers and the wine) were added to the machine.

During the weekly check-ups it became clearer that the buckets were starting to bloat up and some air needed to get out. This was done by using a nail and hammer with which one hole was carpentered in each bucket. Some that was very noticeable was the smell, this was almost not bearable. This would indicate that something is happening which could be a good sign. If this smell would get worse, would it still be edible after a few months? And if the smell is already this strong, is it maybe already rotting and not fermenting?

To have an answer for that, after eight weeks some samples were taken out from the batches and sent to a lab for bacterial analysis, as described in Figure 17, to see if it is edible by human consumption. The think that is quite noticeable is the turbid colour. If the goal was to make garum, the liquid should be clearer and oilier. This is not the case unfortunately and this would also suggest that the experiment with the different flavours has failed.

Figure 17: Garum samples.

The different flavours garum buckets also gave different results. The batch with the herbs smelled not too strong which made it look quite promising. However, the mixture in the bucket did not contain a lot of liquid which would be expected. The second bucket which contained the chili peppers had a lot more liquid but also was the one with the strongest smell. This smell was so strong that the sample was not send to the lab because of the doubt of being able to work with the sample with the bad smell. The last bucket was filled with wine which gave it enough liquid and also not that bad of a smell. The first and the third sample were sent to the lab for microbiology analysis; this will check if the samples contain harmful bacteria. If the samples do not contain any harmful bacteria, the garum process is good but it means that the garum needs more time to ferment. If the samples come out with bacteria and it is not safe to eat, something already went wrong during the garum making process. This is why the lab test are done so the process can be checked on safety. One thing that must not be forgotten, is the fact that garum is usually made more than just a few months and closer to a year.

4.1.2 Conclusion

Unfortunately, the lab results from the microbiology takes longer than expected to arrive which made it impossible to include this in this report. This makes it difficult to state if the fermentation process works and if the garum is successfully made. However, some conclusions can still be drawn from these experiments. One the one hand, the texture of the three different mixtures weren't good, it wasn't oily enough. It can be explained by several factors: the species use for this experiment didn't contain enough fat in it (perch, spike and zander) which make it difficult to obtain an oil solution. The system used to rotate the buckets, which was designed by the previous group wasn't very efficient. This did not allow the mixture to be stirred sufficiently to ensure that it was homogeneous throughout the reaction. Another explanation might be that the water that was added to the fish waste was not sufficient enough to maintain a good fermentation process. On the other hand, the fermentation process for garum usually takes at least six months to settle, and it can last one year. The sample that was taken were samples after eight weeks of fermentation which might explain the results.

4.2 UV-sterilization

As a stabilization method, UV radiation technology was looked into. This is so fish slaughterhouses could prolong their fish waste or already start processing them. To earn some money instead of losing money by paying for the fish waste to be taken away. This is to make their own product or to stabilize and make it more valuable to sell to other companies. This is needed because the fish waste amount is irregular. Finally diving deeper into the effects of UV radiation on fish waste itself and in combination with drying/heating the fish waste.

4.2.1 UV-radiation

UV sterilization is also known as UV disinfection or ultraviolet germicidal irradiation. It is a process that uses ultraviolet (UV) light to kill or inactivate microorganisms such as bacteria, viruses, and fungi by disrupting their DNA or RNA. This disruption prevents microorganisms from replicating, effectively rendering them harmless. In fact, UV light is a type of electromagnetic radiation with wavelengths ranging from 100 to 400 nm and it is categorized into different types based on its wavelength (Figure 18) (Waite, 2025):

- **UV-A (315–400 nm):** premature aging and the development of skin cancer.
- **UV-B (280–315 nm):** Responsible for sunburns and also linked to skin cancer.
- **UV-C (200–280 nm):** Used for disinfection and sterilization. Highly effective at killing microorganisms but is mostly absorbed by Earth's atmosphere.
- **Vacuum-UV (100–200 nm):** Absorbed by most substances and can only travel in a vacuum or specific gases like nitrogen.

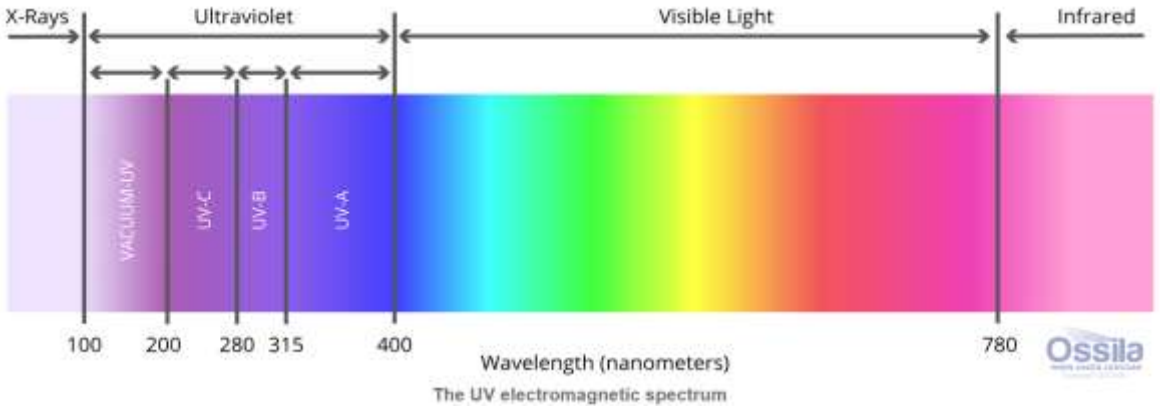


Figure 18: Wavelength UV (Waite, 2025).

Thus, UV-C light should be suitable for the goal. It works by penetrating the cells of microorganisms and damaging their nucleic acids. Forming covalent bonds between adjacent thymine (in DNA) or uracil (in RNA) molecules (Figure 19). This process disrupts the genetic material preventing the microorganisms from replicating and leading to their inactivation or death. UV photons carry energy levels between 3.3 and 6.5 eV per molecule which is sufficient to cause significant electronic excitation and damage unlike lower-energy thermal motion at body temperature (Waite, 2025).

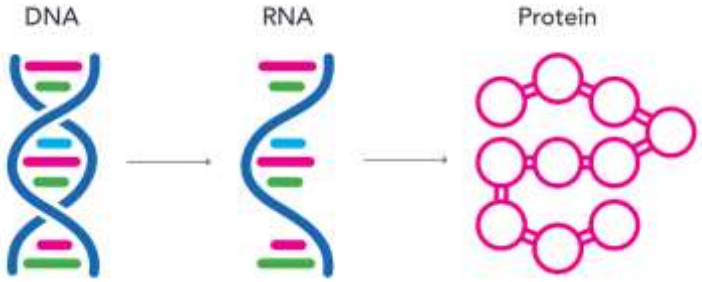


Figure 19: DNA & RNA (rna-vs-dna-whats-the-difference, 2024)

Applications of UV Sterilization

UV sterilization has a wide range of applications, including:

- **Disinfecting drinking water:** Ensures safe consumption by inactivating harmful microorganisms.
- **Surface sterilization:** Used to clean high-contact surfaces, reducing the spread of infections.
- **Medical sterilization:** Decontaminates personal protective equipment (PPE), patient rooms, and other critical healthcare environments.
- **Laminar flow hoods:** In laboratory settings, UVC lamps (200–280 nm) are used to sterilize the work area. These lamps operate when the hood is not in use, ensuring sterile conditions before and after experiments.

Safety Precautions for UV Light

While UV-C light is highly effective for sterilization it poses significant risks to human health. Direct long-term exposure to UV-C light can harm the skin and eyes causing burns or other damage. To mitigate these risks safety measures are essential including wearing UV-blocking personal protective equipment (PPE), avoiding direct exposure and using motion sensors that deactivate UV-C lamps when movement is detected.

The experiments were done with the easiest safety solutions. Turning the experiment off while checking the inside. Putting it in a place where only certain people can access it. And putting warning signs on the experiment.

UV-C Radiation in Air

UV-C radiation in the air is primarily used for disinfection in hospitals, laboratories and ventilation systems. It targets airborne pathogens such as viruses, bacteria, and fungi. With wavelengths between 200–280 nanometres, UV-C effectively breaks down microbial DNA or RNA preventing replication because of the damaged protein within the bacteria. However, UV-C light gets absorbed by oxygen in the air (below 240 nm). This can lead to the formation of ozone. This is a gas that is harmful to both respiratory health and equipment if not properly controlled. Human exposure to UV-C is dangerous as it can cause skin burns and serious eye injuries, so devices must be installed with shielding or motion sensors to ensure safety. Factors like air movement, humidity, and the placement of the UV-C source all influence its efficiency in air disinfection (ultraviolet-radiation, 2020) (2589, 2025).

UV-C Radiation in Water

In water treatment, UV-C radiation is a powerful tool for microbial inactivation, widely used in drinking water purification, wastewater treatment and industrial processes. UV-C disrupts the genetic material of microorganisms such as E. coli, Giardia, and Cryptosporidium, neutralizing their ability to infect. This method has gained popularity because it does not involve chemicals and doesn't alter the taste or pH of water. The effectiveness of UV-C in water depends heavily on water clarity—suspended particles or organic matter can shield pathogens from UV light, reducing its disinfection capacity. Regular maintenance is crucial and UV lamps degrade over time and may lose intensity. Overexposure to UV-C can damage materials like plastic or rubber in the system so compatibility should be considered. When properly applied UV-C is a safe, sustainable and efficient means of water disinfection (ultraviolet-disinfection-guidance-manual, 2006).

UV in the meat industry

UV-C radiation with wavelengths between 200–280 nanometres is increasingly being used in the meat industry as a non-thermal method for improving food safety and shelf life. By breaking down the DNA and RNA of harmful microorganisms such as Escherichia coli, Salmonella, and Listeria monocytogenes. UV-C effectively prevents these pathogens from multiplying on the surface of meat products. This makes it especially useful during packaging or when direct contact with meat occurs in processing environments. A 2023 study demonstrated that applying UV-C light to beef, chicken, and salmon fillets combined with vacuum packaging extended their shelf life by 66.6%. The treatment significantly lowered microbial counts while preserving important quality attributes like pH and appearance (mdpi, 2023).

The benefits of UV-C come with important considerations. Overexposure can lead to oxidative changes in fats and proteins, potentially causing undesirable flavours or texture changes. This is why dosage control and treatment time must be carefully optimized for each type of meat product. When properly applied, UV-C sterilization offers a promising chemical-free way to enhance food safety and reduce spoilage in the meat industry especially for a cleaner and sustainable future. This makes it an ideal addition for treating stabilizing fish waste (mdpi, 2023).

4.2.2 UV-drying

UV drying is a modern way to preserve meat that builds on traditional methods by using ultraviolet light to improve drying and hygiene. This process slowly removes moisture from evenly cut pieces of meat using controlled heat airflow low humidity and UV light. The UV light also helps reduce bacteria which makes the product safer and lasts longer (fao.org, 2024). In older times they used to hook or wrap a string around a piece of meat and let it dry in the sun, as shown below (Figure 20). In more recent times they use a controlled dry cabinet with hooks, as shown below (Figure 21).

Figure 20: Ancient drying method. (dry-meat-processing-news, 2024)

Figure 21: Modern drying method. (dry-curing-cabinet, 2024)

According to studies, the best results come from warm conditions with about 30 percent humidity and small changes in temperature between day and night. At the start of drying most of the water leaves from the surface then slowly from the inside layers. After a few days the meat can lose up to 70 percent of its weight. This weight loss shows how much water has been removed and helps track the drying progress (fao.org, 2024).

As the meat dries it becomes smaller firmer and sometimes slightly wrinkled. Its texture changes and chemical reactions create a new flavour that is different from fresh meat. A small amount of fat oxidation adds to the taste but if the meat has too much fat it can turn rancid and taste unpleasant (fao.org, 2024).

Good results depend on proper handling from the time the animal is processed to cutting preparing and drying the meat. Even with UV drying it is important to manage weather and surroundings. Focus on keeping the right balance between moisture leaving the surface and water moving from inside the meat to the outside (fao.org, 2024).

4.2.3 Water sterilisation

4.2.3.1 Design and build

For this method a simple design was created. A bucket was used and filled up with water of distilled water. UV-C lamps were put in a cross pattern in the water. This to fit the lamps better in the bucket so the lid could rest on the bucket better. With an air pump installed to blow air in the bucket to have some rotation in the water. This later proved futile and did not rotate the water with the fish in it. (Figure 22).

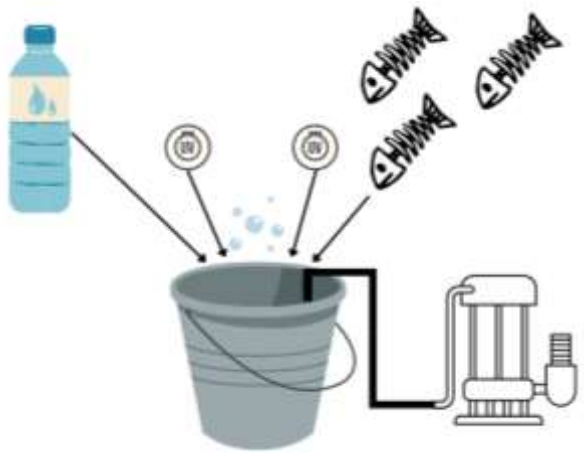


Figure 22: Water sterilization design.

4.2.3.2 Application

This experiment was done to see the effects of fish waste sterilized in water. And to get familiar and to do the practical things. With the focus on prolonging the fish waste by stabilization methods. This with simultaneously testing how effective UV lamps are in water.

4.2.3.3 Limitations

The sterilizing of the fish waste in water was done until it became smelly and bad, to see how long it would take. The sterilization of the fish waste in water to preserve the fish longer than the day the fish has been filled. The limitations are the smell of the fish and the rotation of the fish in the bucket. A special designed machine has to be created to ensure an even flow to not damage the fish. Simultaneously keeping the fish afloat so it does not sink to the bottom. It could speed up the process of the fish breaking down and you would need buck vats and machine working at all times.

4.2.3.4 Experimental protocol

Here is the experimental protocol that has been carried out:

1. Using a bucket.
2. Sterilising water.
3. Fill the bucket with 8 Liters of sterilized water.
4. Put UV-C lights in the bucket in a way so a lid can still sit/lay on tip.
5. Putting air pump end in the water.
6. Insert 660 grams of fish waste in the bucket.
7. Put the lid on top of the bucket.

4.2.3.5 Results

The experiment began on 19/03 at 16:00. Using 661 grams of fish waste mixed into approximately 8–9 litres of water (Figure 23). A lid was placed on the bucket as a safety feature while still allowing airflow (Figure 24). Foam started to form on top of the water after day two (Figure 25). This is probably because of the air bubbles from the air interacting with mucus of the fish waste.

Figure 23: UV-C water 19/03.

Figure 24: UV-C water lid.

Figure 25: UV-C water 20/03.

The experiment was partially carried out in the basement storage. The fish waste batch was not fresh, it was frozen, and defrosted before using it. The fish waste was also not washed before the experiment. After a few days it became really smelly, so it was moved up on to the roof after a complaint about the smell. After two days there were already signs of a bad smell, which is was not good (Figure 25). After a few days (four/five) it already showed signs of fish waste breakdown, and the water turned murky brown (Figure 26). The skin turned into a type of soft (plastic) sheets (Figure 27). After 1 week the meat was still on the spine/bones (Figure 28). It was concluded that it is almost certain that the fish was breaking down and that there were bacteria build up.

Figure 26 : UV-C water 24/03

Figure 27 : UV-C water 25/03

Figure 28 : UV-C water 26/03

4.2.4 Air sterilisation

Different experimental design was made for this experiment. Two ideas which each containing two experiment designs.

The first idea consisted of the first experiment being done in a plastic box with a shelf system where the fish lay on. This box would be best out of HDPE because it is anti-bacterial but for convenience, PC or PP could also be used. The UV-C lights to all sides to sterilize the surrounding area. While the box was to be shut tight with duct tape as described in Figure. A second experiment was designed, with an air pump that was installed to pump the air out (Figure 30).

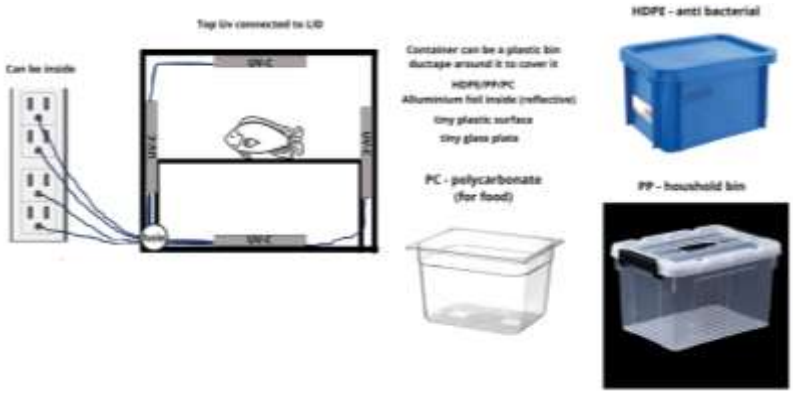


Figure 29: Idea 1 bench 1.

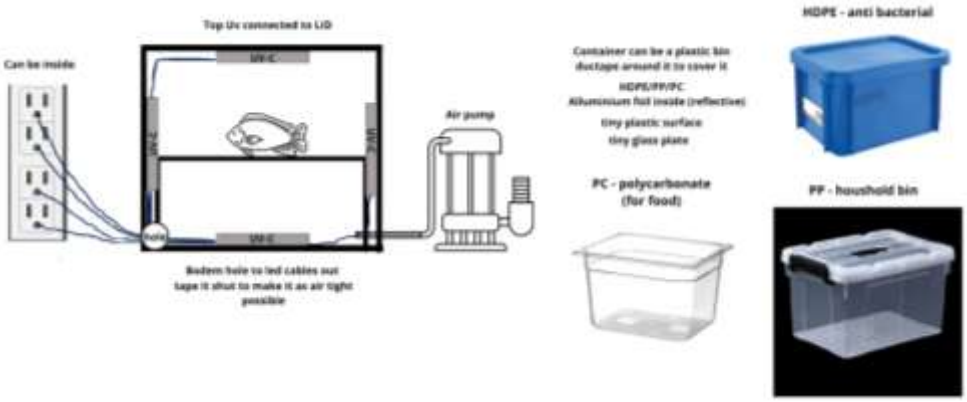


Figure 30: Idea 1 bench 2.

Then, the second idea took inspiration from the first idea. With this idea, the shelf system with an air pump has been included (Figure 32). This box would be best out of HDPE because it is anti-bacterial but for convenience, PC or PP could also be used. The second experiment would consist out of a bucket where fish is hanged on hooks (Figure 31). For convenience, a trash can that could be used outside would fit this perfect. The UV-C lights would be hanging from the lid and between the fish bodies.

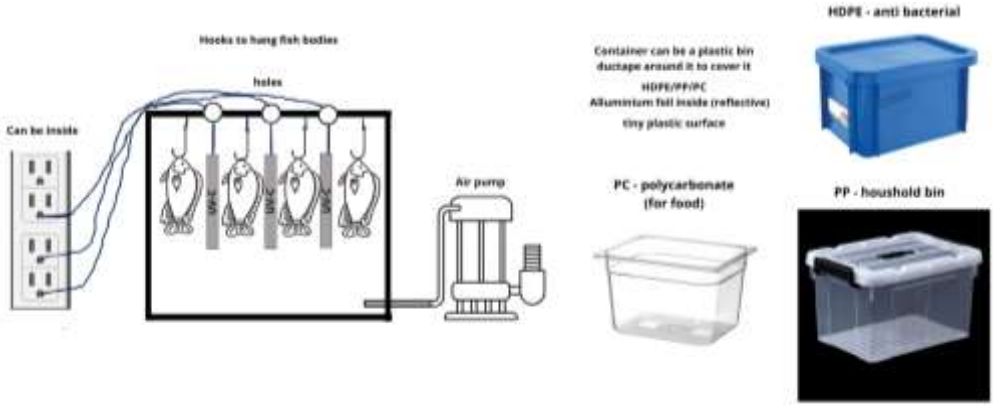


Figure 31: Idea 2 bench 1

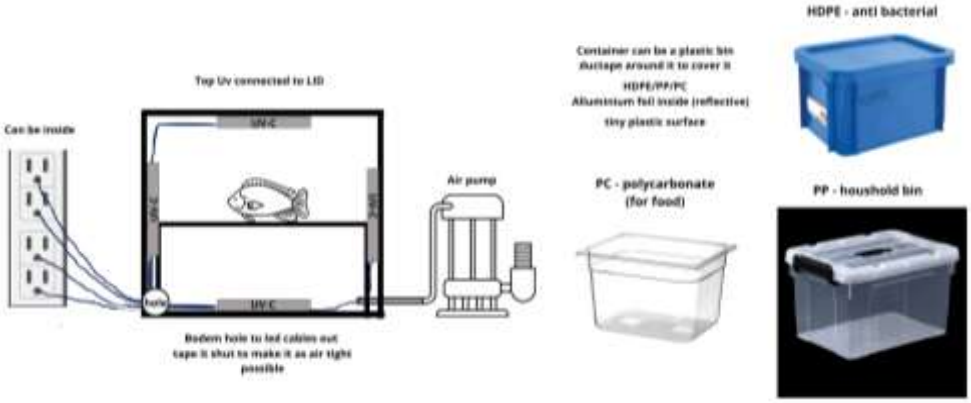


Figure 32: Idea 2 bench 2

4.2.5 Air sterilisation 1

4.2.5.1 Design and build

For this design, it was looked at how they used to do in ancient times and how modern slaughterhouses store meat. Two ideas were explored. One idea was to do it with a shelf system. The difference between those two would be, one with an air-tight seal and one with a nonairtight seal. This first idea was not selected, and the second one was opted. This was the idea to do two different ways of sterilizing the fish. One of the ideas was hanging the fish bodies on hooks in a bucket (Figure 33).

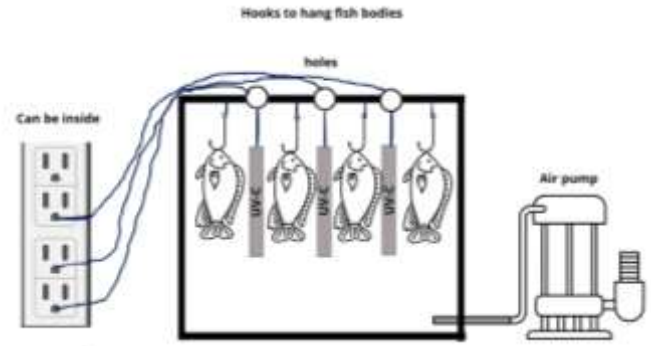


Figure 33: Fish hanging design.

Because the breaking of one of the UV-C lamps, the hook and light distribution had to be changed. Four hooks surrounding each light were settled. Three lights were shared with the light next to it, resulting in nine hanging hooks. The radiation from the UV-C lights would reflect from the aluminium foil on the sides and top of the trashcan/bucket. While also reflecting the infrared (heat) waves back. Aluminium foil had reflective properties and reflected up to 97% of infrared signals and up to 55% of UV-c radiation which would be in perfect conditions. With folds, cracks, unpolished and oxidation this would decrease (sciencedirect, 2020) (Fairfoull, 2021).

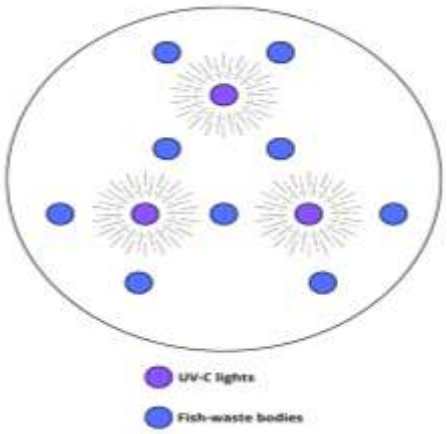


Figure 34: Light & lamp design

A plastic trashcan/bucket was used to make this design (Figure). This has a volume of 70L and a dimension of H66xØ57mm. A ventilator was secured on the side to suck air out and have a suctioned environment (Figure 41). Round bend (size 3/0) hooks were used to penetrate the fish heads with two hooks at once to ensure secure hanging (Figure 36). Those hooks were hanged with nylon rope to the lid with a knot (Figure). Between the ropes with hooks the UV-C lamps of 13 watts and a UV radiation wavelength of 254nm, were secured to the lid with zip ties (Figure 42). On the sides and lid, aluminium foil (Figure) was secured using blu-tack (Figure). All of the electrical equipment was connected to an extension cord that was connected to an outlet (Figure 43).

Figure 35: Trashcan/bucket
(jula.fi, 2025)

Figure 36: Hooks 3/0
(mustad-fishing, 2025)

Figure 37: 3mm rope
(mustad-fishing, 2025)

Figure 38: Aluminum foil
(alumiinifolio, 2025)

Figure 39: UV-C 13 watt
(ebay, 2025)

Figure 40: Blu-tack
(toimistotekniikka, 2025)

Figure 41: 24V ventilator
(ventilator-24-volt-dc, 2025)

Figure 42: Zipties
(8-inch-uv-resistant, 2025)

Figure 43: Extension cord
(power-extension-cord, 2025)

4.2.5.2 Application

This experiment was done to see the effects on fish waste in a warm air-controlled space. With the focus on prolonging the fish waste by stabilization methods. To eventually have dried fish bodies and heads that could turn into fish jerky, animal food, bonemeal. This with simultaneously testing how effective UV lamps are in controlled environments. This method was also chosen because an air-controlled environment with warmth and UV radiation is how they used to dry meat and still do it to this day. The design was chosen because the way the UV-C lamps were made, it was undesired to cut an unnecessary part of the lamps so other people could still use it in the future. This way of hooking meat on hooks is still done till this day. The method of processing and stabilizing the fish waste would be easily done by fish slaughterhouses.

4.2.5.3 Limitations

The aim was to see if there would be no bacteria in the dried fish by using the heating and UV sterilization. Fully drying every part of the fish bodies in the span of at least a week time. The limitation with this was the time for the fish to dry because a small-time problem appeared. Because of delivery time, troubleshooting and mishaps with the lamps. The experiment had to be stopped to use these lamps for the other experiment. Space wise, The whole bucket could not fully be filled because the UV-C would not penetrate every fish enough. The bucket would have need to be only a bit longer than the fish itself to not waste space. Time efficiency could also be limitation if you upscale this process because some fish that dried on the hooks were really firmly hooked.

4.2.5.4 Experimental protocol

1. Measure and assign the holes to drilled with a marker. This should be done with a ruler and a proper marker to ensure proper and correct design.

2. Drill holes in the assigned and drawn places in the lid. To not damage yourself or the bin where it's not needed use an extra person to hold it tight.

3. Saw out a hole a bit smaller than the ventilator itself, use an extra person to hold it tight.
4. Drill holes on the corners so the ventilator can fit on top of it.

5. Screw on the ventilator with nuts and bolts.

6. Drill a small hole on the bottom for future fish liquid leaking out of the fish (Figure 44).

7. Put aluminium foil to the sides and lid with blu-tack. And tape of the holes next to the ventilator (Figure 45) (Figure 46).

8. Secure lamps on the same height with zip ties through the holes you have drilled previously. Attention where you lay them. (Figure 47) (Figure 48) (Figure 49).

Figure 44: leaking hole

Figure 45: Aluminium foil

Figure 46: Ventilator tape

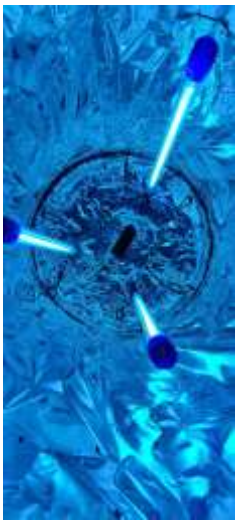


Figure 47: light bottom

Figure 48: Light top

Figure 49: Light broken

9. Put the rope through the fish hook holes and tighten them with a knot. Put the rope ends through the hole and secure them on top of the lid with a knot or zip ties .

10. Hang the fresh fish bodies on the hooks. Hook the head on at least 2 hooks to ensure a good fit, so the weight is distributed more, and the fish does not fall off (Figure 50).

11. Put the bucket in a secure and restricted place. Place it in a more elevated area so a bucket can be placed underneath to let fish liquid out (optional). Place a heater underneath the bucket so that heat gets distributed evenly (Figure 51).

Figure 50: Fish on hooks

Figure 51: Elevated bucket

12. Plug in the electrical equipment in the extension cord. Plug the extension cord in an outlet and turn it on.

13. Let it run for at least a week to get okay results. Let it run longer for more dryer results. Running it longer would theoretically make the taste better.

Figure 52: Electrical connection

Figure 53: Running bucket

4.2.5.5 Results

The experiment started on the 18th of April (Figure 55), fresh fish was used. After two days it already showed signs of drying (Figure 55). There was still a strong fishy smell, but it was beginning to get less pungent. The fish were still hooked properly on the hooks and nothing went wrong. A bit of blood/fish liquid also dripped out of the bucket. This was not a lot and dried up because of the heat (Figure 56).

Figure 54: 18/04 Fish hooked

Figure 55: 20/03 Fish hooked

Figure 56: Dried liquid

The experiment was stopped on the sixth of May. The experiment ran for 18 days. The pungent fish smell was mostly gone; the smell was tolerable. The fish was fully dried and was stiff because of that (Figure 57). The fish were dried all the way through, even the head (Figure 58). The fish is quite brittle; with a small amount of force, you could snap the fish (Figure 59). Some parts of the fish were looking oily. This is probably because of the fat content in the fish. The samples were send to Eurofin but the results have not been delivered yet. This means that it is not sure that the sample was bacteria free.

Figure 57: End product hooks

Figure 58: Dried fish head

Figure 59: Dried fish body

4.2.6 Air sterilisation 2

4.2.6.1 Design and build

For this design, it was looked at how they used to do in ancient times and how modern slaughterhouses store meat. Two ideas of different experiments were designed. One idea was to it with shelf systems. The difference between those two would be, one with an air-tight seal and one with a nonairtight seal. A second idea was not included in the experiment. This included the second experiment from idea one which would be a shelf system (Figure 60). But instead of using an air pump, a ventilator was opted for airflow out of the experiment and decided to shut holes with duct tape (Figure 61).

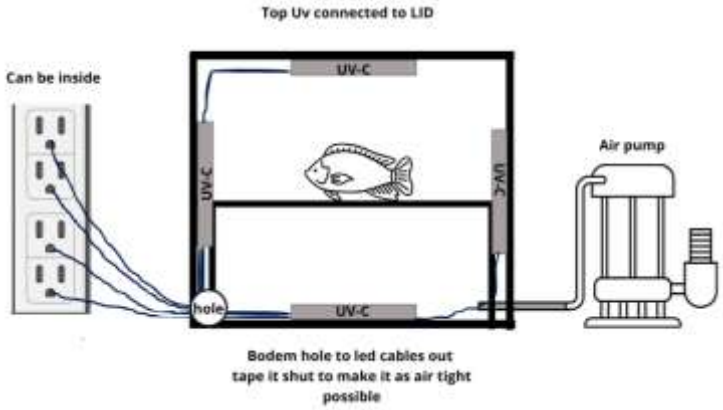


Figure 60: Fish shelf air pump design

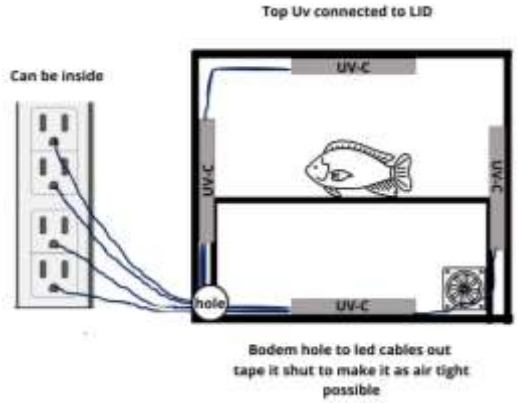


Figure 61: Fish shelf ventilator design

For this design a metal cabinet was used. The UV-C lamps from the previous experiment were used against. These were 13 watts 254nm radiation wave-length lamps. A 12V ventilator was used to suck air out and create a suctioned environment. 3D printing was utilized to print parts to make a shelf where a glass plate would be used to let UV-C light be passed through while simultaneously be able to support fish bodies. Also making grid blocks to let the shelves rest on them were also printed.

4.2.6.1.1 Electrical

An on/off button with a fuse and a gland would be secured in the side of the cabinet. To have safety, operate it properly and to make it neat. A ventilator would be secured on the bottom inside right corner to let air flow better out of the cabinet and create a suctioned environment.

Eight lamps would need to be placed on the sides of the cabinet. To ensure an evenly UV radiation spread, below and above each shelf would consist of two UV-C lamps (Figure 62). They would be secured with nut and bolt by drilling a hole in the cabinet. This was later changed because of the way the UV-C lamps that were bought had to be connected. This required a ballast which a lot of stores don't sell anymore because of the switch to all LED lights. This was managed to get on so it was made into a new design which would use four UV-C lamps. This design would place them in the middle pointing toward yourself. While ensuring a UV-C lamp below and above each shelf (Figure 63).

A last change was made because of troubleshooting and a time shortage with the UV-C lamps that were locally ordered. The connection of the UV-C lamps to the ballast was not successful which also did not have the right amount of UV lights. The fish hook experiment was stopped, and the lights from that experiment were used to make this experiment come true. The other UV-C lamps which required a ballast were still placed on the top and bottom to know how it would look. This means it would like the picture below (Figure 63), but the top and bottom would not be working.

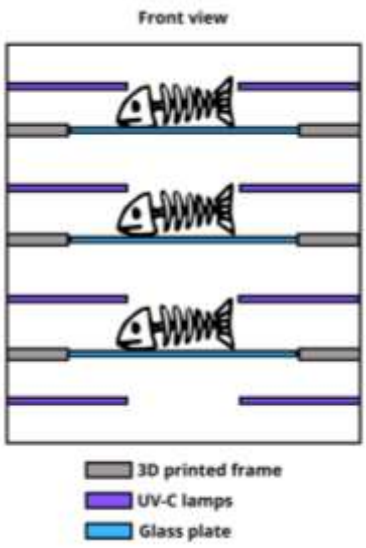


Figure 62: Shelf lamp design 1

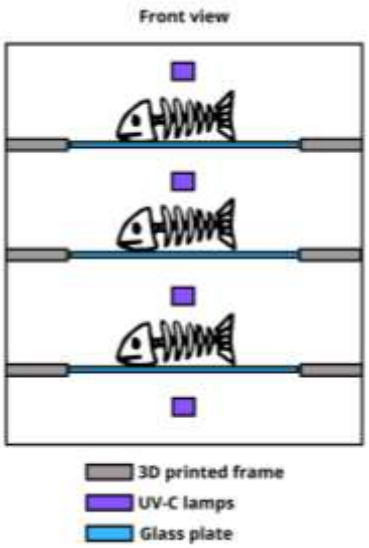


Figure 63. Shelf lamp design 2

4.2.6.1.2 3D printing

The parts for the shelves were made using 3D printing. White filament was used and the program SolidWorks 2022 licensed by Novia University of Applied Sciences to design the parts that could put around the glass plates. This was done by experimenting and measuring the glass plate and cabinet. Different 3D printers were available in Ostrobothnia lab and were used. This included the UltiMaker S3 (Figure 64) and S5 printers (Figure 65). The UltiMaker S5 had a bigger printing bed which made it possible to print the parts for the shelf and the support where the shelves would be placed on. These blocks were easily placeable in the already existing grid from the cabinet where a shelf could be installed.

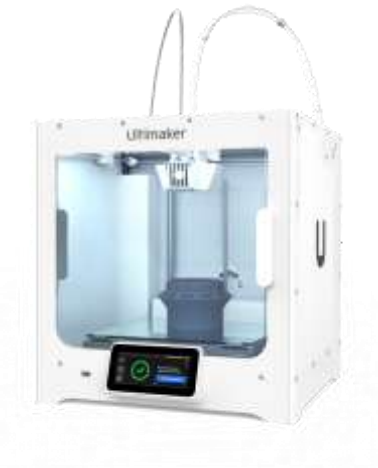


Figure 64: UltiMaker S3

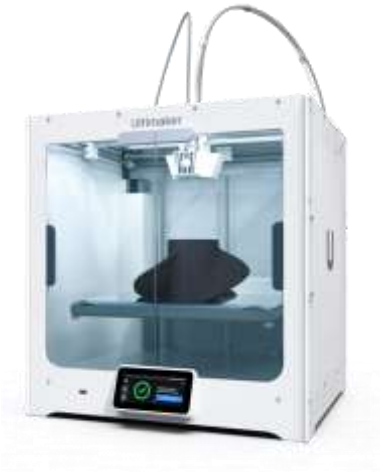


Figure 65. UltiMaker S5

The resolution that was chosen was 0.2 which was fast printing. Infilling of 20% was also chosen for enough support while also not using too much filament. This amounted to 19 hours and six minutes of printing time(Figure 66). Surrounding temperature should be accounted for when using 3D printing filament.

The shelf was 10 mm thick because the glass plate is three mm thick and a groove of three point four mm was made for the glass plate to fit easily on with a bit of space to ensure glue could be used and spread over the edges. This was chosen because it was the most prominent material that would still allow UV-C light to pass through. The design that was chosen was a design where each corner was a piece itself with two middle part that would be extra secured with glue in the grooves (Figure).

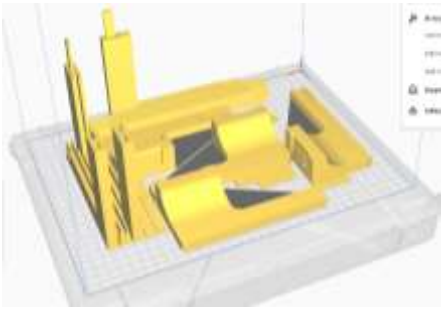


Figure 66: Printing bed design

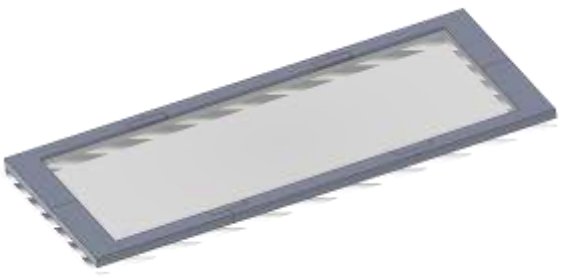


Figure 67: Chosen shelf design

4.2.6.2 Application

The aim was to see if there would be no bacteria in the dried fish by using the heating and UV sterilization. Fully drying every part of the fish bodies in the span of at least a week time. A shelf design was chosen for an easy reusable and retractable design, This so it would be easy to take out the shelves get the fish out and put the shelf back with other fish on it.

4.2.6.3 Limitations

The limitation with this was the time for the fish to dry because a small-time problem appeared. Because of delivery time, troubleshooting and mishaps with the lamps. The previous experiment had to be stopped to use those lamps for this experiment. Space-wise, there is a limit of how many shelves you can fit in and how many fish waste one can putt on them. The material used to lay the fishes on is glass and the bigger the surface of that the more fish you lay on it and how thicker it needs to be. This means you will need to balance it out because UV-C light still gets absorbed by glass.

4.2.6.4 Experimental protocol

1. Measure and draw dots and line for the holes. Use painters tape to easily draw on the cabinet and remove it afterwards (Figure 69).

2. Drill with a small drill on the assigned places first, then use a bigger one and do that with increments (Figure).

3. Use an angle grinder to cut a square that's smaller than the ventilator on the bottom of the cabinet (Figure).

4. Drill holes for the corners of the previously cut square hole.

Figure 68: Location holes

Figure 69: Written information on tape

5. Start 3D printing your parts for the shelves. Make 3D-printed blocks that easily fit/slide into the already existing groove of the cabinet. And make parts that fit the glass plate (Figure 70). Do this as soon as possible because it can take some time to print, especially when something goes wrong. Designing the parts also takes time and you always have to adjust (Figure 71).

Figure 70: Finished 3D printing

Figure 71: Process 3D printing

6. Putt the button, fuse and gland in place.

7. Connect the lamps and ventilator parallel together on the fuse and connect the fuse on the button. Solder the electrical cables together to connect the ventilator and use heat shrink tubing on the exposed conductor part. Use terminal blocks to connect cables together.

8. Connect the ventilator and lamps to the cabin by the made holes.

9. Secure the aluminium foil with blu-tack to every surface inside the cabinet and doors (Figure 72).

Figure 72: Aluminium foil cabinet

10. Connect all the 3D-printed parts around the glass plate put super glue in the grooves for an extra secure fit. Hold it for a minute so it properly dries or follow instructions on the chosen glue (Figure 73).

Figure 73: Glueing together

11. Put the 3D-printed blocks that fit in the side grooves in the cabinet. Lay the glass plate shelves in the cabinet (Figure 74). Test the shelves by putting weight on them to be sure that the shelves will stay strong (Figure 75) (Figure 76).

Figure 74: Completed shelves

Figure 75: Liter of water

Figure 76: Weight testing

12. Putt the fresh fish on the shelves and turn on the system (Figure 77) (Figure 78). Putt a radiator in front of the shelves and close it and let it run for a minimum of a week (Figure 79).

Figure 77: Putting fish on shelves

Figure 78: Shelf slide system

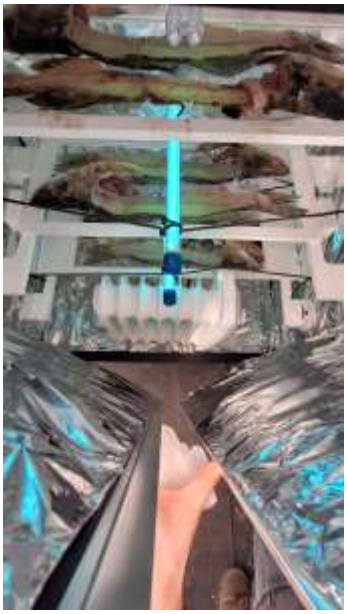


Figure 79: Radiator in cabinet

The experiment started on the sixth of May and ended 16th of May. The experiment ran for ten days with fresh fish. In the beginning, there was still moisture under the fish while the top part was drying. The fish on the shelves did not weigh too much. Each major fish body weight is around 300g so each shelf did not even have one kg of fish waste, the total sum was two +/- kg. It could hold more than one kilogram because of testing the shelves. This could be improved on and maximized.

As the previous experiment, the smell got less pungent. The fish was fully dried, body and head (Figure 80) (Figure 81). The moisture under the fish and on the glass plates dried up. The dried fish resulted from two +/- kg. The shelves were a bit bend because of the surrounding temperature getting high during the day because of the greenhouse rooftop room/cabin (Figure 83). This also caused the side that is on the glass plate to burn a bit (Figure 82). No sample was send of this experiment. If the lab results from the previous experiment would be bacteria free, this experiment would likely be also bacteria free.

Figure 80: 16th of May fish dried

Figure 81: 16th of May head dried

Figure 82: Burned fish parts

Figure 83: Bended shelves

4.2.7 Conclusion

These experiments explored UV-C sterilization and drying methods as sustainable solutions for stabilizing fish waste. The aim was to reduce spoilage, improve storage potential and ultimately make better use of by-products that are often discarded. Different methods were tested including UV-C treatment in water and air. As well as theoretical analysis of combining UV-C with traditional drying techniques.

In the water-based experiment, an experimental created by using a bucket as setup, UV-C lamps and an air pump. Although the system was designed to allow for proper sterilization. The results showed limited effectiveness due to poor circulation, uneven UV-C exposure and the natural sinking of fish waste out of the lights' range. Foam formation and strong odours were observed over time indicating continued decomposition. A filter would have been needed because the UV-C lamps become ineffective after troubled water from the fish waste oxidation. Bacteria use water to reproduce which was a less prominent idea. A special designed and engineered machine would have to be created to filter and keep movement in the fish waste. No sample was sent to a lab because it was obvious that the fish was decomposed.

The UV-C in air method was explored more from a theoretical standpoint. This by using examples from air filtration and surface disinfection. It demonstrated strong potential for use in controlled environments but would need specific adaptations for fish waste processing.

The idea of UV-C-assisted drying showed great promise. Based on supporting research from the meat industry where similar techniques have increased product shelf life and safety. Accounting the surrounding temperature should be done because this will affect the 3D printed shelves because the melting/bending temperature is already around 60°C.

The experimental results were mixed due to design limitations. The concept of using UV-C for fish waste stabilization is sound. Future setups should focus on improved flow, suspended exposure and possibly integrating UV-C with controlled drying systems. While it can't be concluded that it was bacteria-free because the results did not arrive on time. The lack of pungent smell, proper thoroughly dried fish and lack of labour costs. UV-C based stabilization could become a highly effective and eco-friendly solution in stabilizing and byproduct production in the seafood industry.

4.3 Protein extraction

One of the alternatives of the use of fish waste is to extract protein from the fish waste to use it in the food sector. In that way, after some research, three selected methods of extracting protein were developed and experimented: Ultrasonic extraction, Acid and alkaline solubilization (pH shift) and Hydrolysis method (the use of enzymes). The interest of that is protein from aquatic sources, like from fish waste, have a variety of bio-functionalities, including antioxidant, antibacterial, anti-hypersensitive and anticancer properties, sometimes better than from animal's sources. (Ghaly AE*, 2013)

In fact, the composition of the fish varies according to the type of species, sex, age, nutritional status, time of year and health. Most of the fish contains 15-30% protein, 0-25% fat and 50-80% moisture. Solid fish waste consists of head, tails, skin, gut, ins and frames. (Ghaly AE*, 2013). These byproducts of the fish processing industry can be a great source of value-added products such as proteins.

4.3.1 Ultrasonic extraction

The first method will deal with the use of ultrasound as a way of extracting protein. The goal was to prepare a fish paste that was sent to a lab for nutritional analysis in order to 3D print it into fish nugget.

4.3.1.1 Principle

Ultrasound-assisted extraction can be categorised into the following three main classes:

- low-frequency ultrasound (20 to 100 kHz)
- high-frequency ultrasound (100 to 100 kHz)
- diagnostic ultrasound (1 to 500 MHz) (Zheng et al., 2019).

Generally, low-frequency ultrasound (20 to 100 kHz) is widely used for protein extraction. (Hina Kamal, 2021)

Parameters such as ultrasound amplitude, type of solvent (often water), type of reactor [ultrasonic bath (easy to use) vs. ultrasonic probe (more efficient)], solvent/mass ratio [a higher ratio favours solubilisation of the extracted proteins], and pre-treatment time are relevant factors for the ultrasonic experiment.

4.3.1.2 Application

The goal was to use ultrasound waves on fish waste, to filter the solution and then centrifugate the solution in order to obtain different layers including protein solution in it. From these layers, a fish paste was prepared and used for in a 3D printer.

Studies have shown that insufficient energy at low amplitudes or brief ultrasound exposure does not alter or break the fish skin structure and collagen cross-links, hindering extraction, while high amplitudes or prolonged durations release non-collagenous components and fragmented collagen polypeptide chains, decreasing yield. (Dian Haryati, 2024)

Thus, the strategies were consisting of studying all of the following combination:

- Influence of time for ultrasonic.
- Influence of heating.
- Influence of solvent/mass ratio.
- Influence of fresh/frozen batch.

A study has shown that 35 kHz and an exposure time of 30 minutes provides good performance. (Silvino Sasso Robalo, 2025). In fact, the machine use for the experiments delivers 45 kHz.

4.3.1.3 Methods

a. General information

The 45 kHz ultrasonic cleaner which was used for experiments is described in Figure 84. The centrifugation machine used is described in Figure 85.

Figure 84: Ultrasonic cleaner.

Figure 85: Centrifugation machine.

For this experiment the ultrasonic cleaner is used to extract protein from fish waste. The machine is filled with water in which breakers are placed with fish waste. The ultrasonic cleaner is turned on by using the rotary knob on the right and the on the left is a knop which sets the temperature. The machine works on a timer for 30 minutes, after these 30 minutes the machine must be turned on again by setting up the time for another 30 minutes.

The general method can be described in the following experimental protocol:

- **Pre-treatment**
  - Wash fish waste with water to remove impurities
  - Mince fish waste in small pieces
  - Homogenise the fish waste with distilled water in a 2:1 w/v ratio.
- **Treatment**
  - Set the temperature of the ultrasonic cleaner around 50°C
  - Once the temperature is reached , set up the different batches of fish in the ultrasonic cleaner
  - Let the machine run
  - Filter the solution
- **Recovery**
  - Centrifuge the mixture at 4.700 rpm for 20 minutes
  - Remove the solid phase from samples
  - Allow the mixture to settle
  - Dry the mixture

Furthermore, in the recovery part, different methods already exist in order to obtain a protein powder. In fact, after centrifugation, 3 different layers can be obtained, as described in Figure 86 . The bottom layer consists of a layer of heavy protein sludge. Then, to extract the semi-solid layer from the oil layer, the oil layer can be removed by using a laboratory-scale pipette. In this way, the protein hydrolysis solution and the fish paste (bottom layer) can be freeze-dried or simply dried and the final product is then stored at 4°C or below.

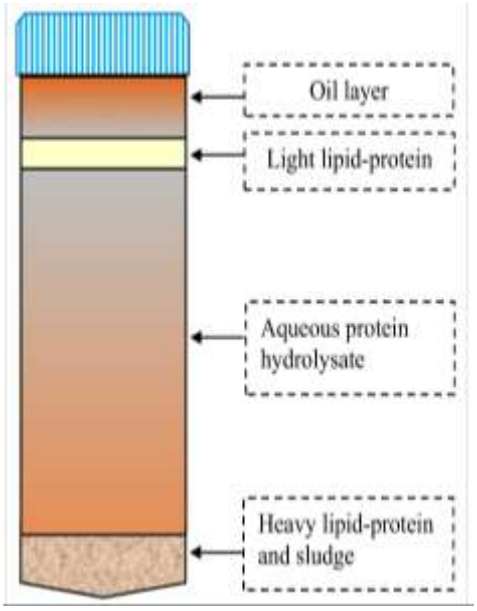


Figure 86: Centrifugation principle.

In addition, the choice of centrifugation was chosen as it appeared to be the simplest way of separating the phases. Other methods such as microfiltration, freeze-drying or ion exchange chromatography already exist but won't be discussed in this report.

b. Influence of time

The first experiment was about studying the influence of time**.** Are a few hours of ultrasound enough or not? The fish used for this experiment was from a batch including perches, spikes and zanders. The protein content of the fish is described in Table 1, on page 5.

The batch used was fresh, the fish waste was washed with distilled water to remove impurities. Afterwards, it was minced in small pieces to obtain a fish mixture. Then, 150ml of water was added to a 300g fish paste in a 1000ml beaker. The details of the experiment are described in Table 4. The fish mixture ran for different periods of time: 30, 60, 120 and 240 mins.

Table 4: Initial condition of the experiment.

Fish types	Fish Weight	Fish parts	Water amount
Perch, Spike and Zander	300g	Heads, skins, scales, bodies	150ml

Once the ultrasonic running was done, the samples were removed and filtered. Once the filtration was done these tubes were then centrifugated in order to separate the phases as described in Figure 86.

Figure 87: Methods for ultrasound.

c. Influence of solvent/mass ratio

Another experiment was to study the influence of fish waste/water ratio. Three different ratios were settled and experimented: 1:10 w/v; 1:8 w/v; 1:6 w/v. The batch of fish waste was fresh; it ran for two hours in the ultrasonic cleaner. Then it was filtered and centrifugated.

d. Influence of fresh/frozen batch.

This influence was tested in order to know if fresh batch give different result than a frozen batch. Ultrasound method was performed for both batch and the results were compared.

e. Influence of heating

This experiment was tested to know that if ultrasonic method performed at low temperature could give equivalent or better results than at high temperatures, to know if energy can be saved during the process. In addition, another experiment was tried only using heat and no ultrasound to understand and see if ultrasound as an effect on fish waste.

4.3.1.4 Results

a. Influence of time

The samples ran for different periods of time 30mins; 60mins; 120mins; 240mins. After the centrifugation three phases can be distinguished: the oil layer as the top one, the middle one that looks like the aqueous protein hydrolysate and the bottom one that contain solid particles and may be the heavy lipid-protein and sludge, as described in Figure 88.

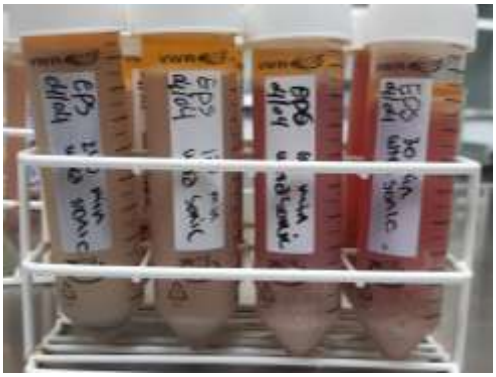


Figure 88: Result of influence of time (ultrasound).

b. Oil extraction (top layer)

From the results it can be stated that the longer the mixture is in the ultrasound machine, the greater the oil layer on top is until it reached a threshold. The 60 and 120 mins of treatment allowed the greatest quantity of oil to be extracted, see Figure 89 for a clear view on the oil layer.

Figure 89: Oil extraction result.

c. Heavy lipid protein and sludge (bottom layer)

After 30 mins the sludge (the lower phase) contained large particles visible to the naked eye, probably containing the collagen from the fish waste. After 60 mins, the particles were much thinner still containing some big particles but looked like a powder. After 120 mins only a thin particle was observable and after 240 mins it was the same.

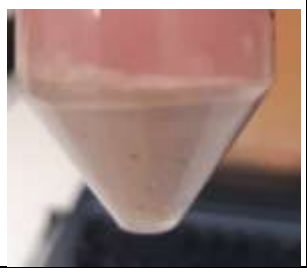
30 mins	60 mins	120 mins	240 mins
			

Table 5: Ultrasound bottom layer result.

d. Aqueous protein hydrolysate (middle layer)

After 30 and 60 minutes the tubes contained a red protein solution and after 120 minutes the solution chanced from a red colour to a grey colour, see Table 5 . This was not investigated furthermore because of the scope of the project. This batch was too small to send it to the lab and was mostly used as an example of how the layers should look.

Another experiment was also carried out, where the fish waste was cut in small pieces and put in the ultrasound for six hours at high temperature (50°C) to see what would happen. In Figure 90 is the fish waste shown after the six hours run in the ultrasonic machine, which doesn't provide more results, the flesh was still sticking to the bone.

Figure 90: Fish waste after 6 hours in ultrasonic machine.

e. Influence of solvent/mass ratio

Three different fish waste/water ratios were made. The 1:6 w/v ratio had the best result compared to the 1:10 w/v ratio and 1:8 w/v ratio.

f. Influence of fresh and frozen batch.

Experiments have shown that working with a fresh batch of fish waste gave better results especially regarding the extraction of oil. The solution is much more trouble for a frozen batch than for a fresh batch, see Figure 91. This could be because if the fish gets frozen, the texture of the fish changes. Thus, the use of the fresh batch became more important for the experiments.

Unfortunately, not for all of the experiments this is possible, because of the time fresh fish can't be preserved, and the number of experiments one can do in one day. But for the most important experiments, a fresh batch was used to get the best results.

Figure 91: Fresh batch (left) and frozen batch (right).

g. Influence of temperature

For the final part of the experiments, the effect of the temperature was tested in the ultrasonic cleaner. The ultrasonic cleaner controls the temperature and the time that the ultrasound runs for. The plan was to check the difference between low and high temperatures (20-50°C) and see what the impact during the ultrasound process was. The first part was to see if the ultrasounds would have an effect on the fish waste without the heating (room temperature 20°C). This means that the waves of the sounds would be enough for the fish waste to dissolve in the water.

However, when the ultrasonic cleaner was turned on, the movement of the water created some heat which warmed the water. After letting the experiment run for an hour, the water was almost 50°C.This indicates that even if tried to monitor the temperature, it will always get warmer (it can reach 50°C, which is already close to the cooking temperature of fish, because fish starts cooking at 60 degrees Celsius, (British Columbia Centre for Disease Control, 2014)). Because of this, it was decided to not test the different temperatures anymore but focus on the other variables. For the rest of the experiments the temperature was kept on 50°C because this was below the cooking temperature but also the minimum temperature the machine could work on.

Moreover, after the success with the use of the ultrasonic cleaner which created the paste for the 3D food printer, the question was asked if the success came from the ultrasounds or the heating. If the experiment would give the same results with only heat and without the ultrasound, this would change the view on the method. Therefore, the same experiment was done but without turning on the ultrasound waves and with a temperature of around 50°C. The result is described in Figure. The same fresh fish batch was used, and both of the experiments were done on the same day. The two batches did not show any differences in layering, in texture or in colour. Also, the paste from the batches looked similar which is described in Figure 93. This would suggest that the ultrasonic cleaner does not have an effect on the fish waste and just heating the fish for two hours would be enough. However, conclusion about that can't be drawn because nutritional analysis of the only heating sample was not conducted. Therefore, it may results in variation in the protein content.

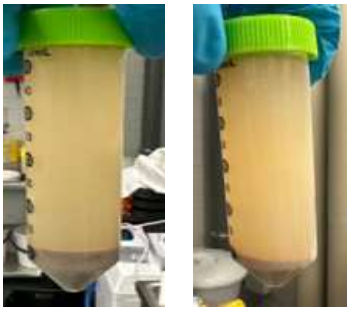


Figure 92: Heating without ultrasound (left) and heating with ultrasound(right).

Figure 93: Paste with ultrasound (left) and paste without ultrasound (right).

h. Final byproducts

Finally, in the experiments with the ultrasonic cleaner a total of three byproducts was produced: the fish oil (the top layer), the protein solution (middle layer) and the paste residue (bottom layer). The bottom and middle layers were separated in small containers and sent to a lab for a nutritional analysis. The oil layer was not analysed since it was certain that it was fish oil because of the colour and the texture, see Figure 94.

Figure 94: Fish oil after ultrasound experiment.

The bottom layer and top layer were tested for nutritional analysis to check if they contain protein. The results from the lab test are summarized in Table 6 and described in Appendix B and Appendix C.

However, an important mistake was made during the preparation of these two samples: the samples that were sent contained a lot of moisture, and the nutritional analysis considered the moisture in food which is something that was not known at that time. Therefore, the protein solution was tested as a liquid which explains the high moisture contain. If the samples would be sent again, it would be more efficient if this solution was sent as a powder. In this way the proportions will be more in balance. On the other side, the paste residue came back quite positive, high in protein and low in fats which is good for human consumption. This would be a good example for a protein paste which could be used for the 3D food printer. Besides the high value in moisture, the paste still strong enough to hold its shape which is required for the printing. The texture and the high protein level would suggest that the heating and the centrifugation of the fish waste could produce a nice paste for future purposes.

Nevertheless, the fish solution contains few proteins in it, which was something quite surprising. According to studies the protein content should have been higher. Thus, only the fish paste is a good byproduct.

Table 6: Results nutritional analysis lab tests ultrasound experiment.

Food nutrients	Results fish solution (EPS 1)	Results paste residue (EPS 2)
Crude fat	0,12 g / 100 g	3,56 g / 100 g
Moisture	97,6 g / 100 g	80,4 g / 100 g
Crude Protein	2,15 g / 100 g	15,5 / 100 g
Carbohydrate	0,35 g / 100 g	0,46 / 100 g
Ash total	-0,22 g / 100 g	0,08 / 100 g
Energy value kJ	41 kJ/ 100 g	397 kJ/ 100 g
Energy value kcal	10 kcal / 100 g	94 kcal / 100 g

4.3.2 Acid and alkaline solubilization (pH shift)

Another method was developed and experimented using the pH in order to extract protein from the fish waste. A fish paste was prepared and analysed in a lab for a nutritional analysis. If the fish paste is good, it will be 3D print into fish nugget.

4.3.2.1 Principle

The principle involves varying the pH of the solution of the fish waste. In fact, at extreme pH levels (acidic or basic), the solubility of proteins increases, making them easier to extract, they will dissolve into the water. A simple method consists of raising the pH in alkaline (pH 10-12) and acidic (pH 2-3) conditions which enables the proteins to be selectively solubilised into the water. After solubilisation, the proteins are precipitated and recovered by adjusting the pH to the isoelectric point. The isoelectric point is reach when the fish proteins have a minimum solubility close to pH ≈ 5.5. At the isoelectric point, proteins tend to aggregate and precipitate, as there is no longer any electrostatic repulsion between them (Batista, 1999). This isoelectric point varies according to the type of species.

4.3.2.2 Application

The goal was to try both acid and alkaline solubilization to know which one can give the best yield. Once this was done, a fish paste was prepared and sent to a lab for a nutritional analysis.

4.3.2.3 Method

a) Acidic and alkaline comparison

A frozen batch was used. Both acid and alkaline solubilization were experimented in order to compare both methods with different water ratio: 1:10 w/v, 1:8 w/v and 1:6 w/v. The experiments were performed on cold environments (< 10 °C). 50g of fish waste was used for every experiment. Here is an experimental protocol that was used:

- **Pre-treatment**

  - Wash fish waste with water to remove impurities.
  - Mince fish waste in small pieces.
  - Homogenise the fish waste with distilled water in a 1000ml beaker using different ratio: 1:10 w/v , 1:8 w/v and 1:6 w/v.

- **Treatment**

- Adjust the pH using citric acid (to lower the pH) or NaOH (to raise the pH) until it reaches an acidic (~2-3) or alkaline (~11-12).
- Let the solubilization run for 45mins to 1 hour
- Stir the mixture to improve solubilisation every 15 mins
- Filter the solution to remove bones, skins, scales, etc.

It solubilises the proteins while separating out the lipids and other undesirable components.

- **Recovery**

  - Centrifuge the mixture at 4,500 rpm for 20 minutes (optional)
  - Perform isoelectric precipitation (~pH 5,1–6) by adding a solution of 1 N citric acid or NaOH

The pH of the solution is adjusted to the isoelectric point (~5.5 in average) to cause protein precipitation.

- Perform a second centrifugation at 4,500 rpm for 20 minutes.
- Allow the mixture to settle.
- Put the mixture in a cold environment in order to store it properly.

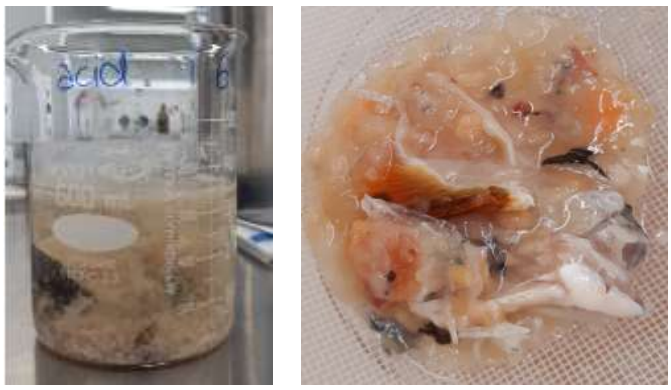


Figure 95: Solubilization and filtration of the fish waste.

During the experiment is it important to do cold processing because it preserves the protein's ability to gel. Using these methods, it is important to try to have the pH closer to 5.5 (average value).

4.3.2.4 Results

a. Alkaline solubilization

The alkaline solubilization worked quite well. Good quantities of paste were obtained. The water ratio doesn't really affect the yield, even if a 1:6 ratio was the best (small difference).

b. Acid solubilization

Acid solubilization was less efficient than alkaline solubilization. The quantities were much lower than for alkaline solubilization. The water ratio doesn't really affect the yield. Even if a 1:6 ratio was the best (small difference), more fish paste was in this one.

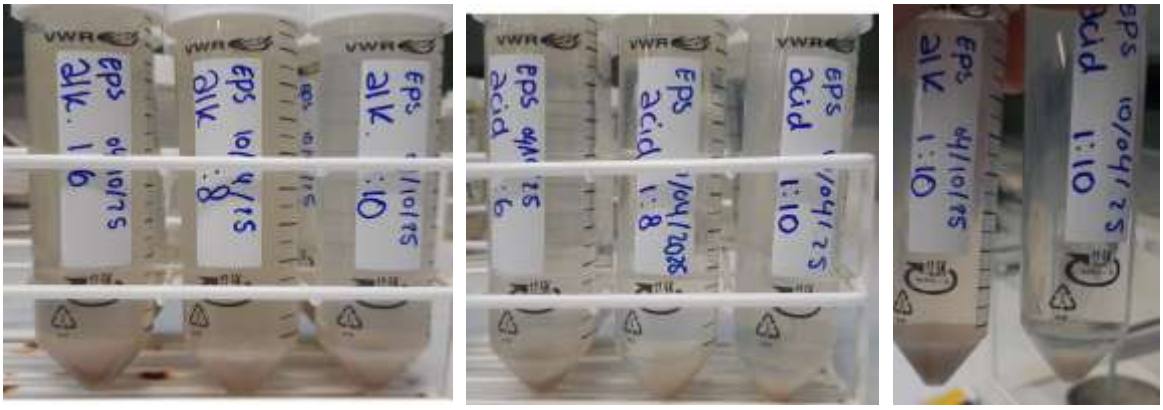


Figure 96: Alkaline and acidic solubilization comparison.

c. Fish paste & fish solution byproducts

From the alkaline solubilization a slimy paste was extracted from the tubes after centrifugation, which corresponds to the bottom layer of it. The middle layer was also extracted from the tubes as described in Figure 97.

Figure 97: Fish paste & fish solution obtained from pH shift.

Once the extraction was done, these two samples were sent to a lab for nutritional analysis. The results are summarized in Table 7 or described in Appendix D and Appendix E.

However, an important mistake was made during the preparation of these two samples: the samples that was sent contained a lot of moisture, and the nutritional analysis considered the moisture in food which is something that was not known at that time.

Table 7: Results nutritional analysis lab tests pH shift experiment.

Food nutrients	Results fish solution (EPS 3)	Results paste residue (EPS 4)
Crude fat	0,40 g / 100 g	2,75 g / 100 g
Moisture	99,5 g / 100 g	92,8 g / 100 g
Crude Protein	0,49 g / 100 g	4,08 / 100 g
Carbohydrate	0,39 g / 100 g	0,25 / 100 g
Ash total	<0,10 g / 100 g	0,12 / 100 g
Energy value kJ	23 kJ/ 100 g	175 kJ/ 100 g
Energy value kcal	6 kcal / 100 g	42 kcal / 100 g

Regarding the fish paste, despite in contained a lot of water in it, the protein content is higher than the fat content which is good for human consumption but still very low. From another perspective, if dry samples could have been sent, the moisture in food could have been much lower and the ratios would have increased.

Another explanation is that experiments were conducted <12°C, it is known that the use of low temperatures throughout the process (2-4°C) prevents protein degradation and enables the recovery of proteins with good textural properties. (Carlos Álvarez, 2018)

Studies have shown that pH shift methods is an efficient and cheap methods to extract protein. The result obtained shown that it is quite different (which is surprising), but they can be explained from the teams mistake.

Moreover, another study has shown that if the solubilization part is repeated several times you can extract more than 95% of the protein using sequential alkaline solubilization. (Helgi Nolsøe, 2008)

However, the nutritional analysis about the fish solution from the pH shift wasn't good. The protein content and fat content is very low and not significant. It is therefore not an interesting byproduct to use for food purposes.

4.3.3 Hydrolysis method

The following text will deal with a method of hydrolysis using enzyme to extract protein from the fish waste. The goal is to prepare a paste containing the fat and protein of the fish waste in order to 3D print it into fish nugget.

4.3.3.1 Principle

First of all, hydrolysis of fish waste consists of cleaving molecular bonds through different biological processes in order to break down macromolecules (proteins for instance) into the form of peptides and amino acids, through the action of water, chemicals and enzymes. The protein extracted is called *protein hydrolysate*. In this case it is a fish solution containing a combination of amino acids and peptides of different molecular sizes. (ADLER-NISSEN, 1985; LAHL et BRAUN, 1994)

Protein hydrolysates are well known in the market, existing methods such as chemical hydrolysis (acidic and alkaline) and enzymatic hydrolysis enable to extract protein from animals or plants/vegetables. However, in this case, only enzymatic hydrolysis was selected because of the simplicity of this method and the feasibility of it at the university. Thus, only enzymatic hydrolysis will be discussed.

4.3.3.2 Enzymatic hydrolysis

Hydrolysis enzymatic consists of adding enzymes in a fish waste solution (often with water) in order to facilitate and accelerate the extraction of the protein in it. Not all of the enzymes are suitable for this. Studies have shown that protease, which are enzymes present in the stomach that helps to break down the proteins in food, are the most suitable. Thus, proteases were used as catalysts for hydrolyse. (Swapna C. Hathwar, Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases, 2010).

Several types of proteases can be used if they are of animal, plant or microbial origin. Working on different range of pH: alkaline (e.g. Alcalase), neutral (e.g. papain, bromelain, Alcalase, neutrase, flavour) or acidic (pepsin). Enzymes of animal (pepsin), vegetable (papain, bromelain) or microbial origin (Alcalase, flavourzyme, neutrase) are enzymes used in the production of protein hydrolysates. According to studies, microbial enzymes are more tolerant of pH and temperature.

Studies have shown that the main parameters for this experiment that influence the reaction are the temperature, the pH, the initial enzyme concentration and the initial substrate concentration, in this case fish waste. (Swapna C. Hathwar, Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases, 2010). Moreover, hydrolysis enzymatic only required monitoring temperature and pH.

4.3.3.3 Application

Enzymatically hydrolysed proteins have a wide range of food and non-food applications, linked to their nutritional or functional properties. According to the size of the peptides, different kind of applications can be used:

- Large: (2- 5kDa) are mainly used as personal care products (KUNST, 2003).
- Medium: (1 - 2kDa) are used in sports nutrition (FROKJAER, 1994).
- Small: (<1kDa) are used in food products

However, as the protein extracted from the fish waste will be used for food purposes, enzymatic hydrolysis is strongly recommended over strictly chemical methods for the production of hydrolysates, and also because it doesn't generate chemical waste. Thus, enzymatic hydrolysis was selected as a protein extraction for food purposes.

In this case, protein hydrolysates from fish waste will be used as a nutritional supplement as they possess important and unique properties such as water retention capacity and oil absorption capacity for instance. (Miriam Hubinger, 2011)

It is also interesting to note that protein hydrolysates can also be produced using proteases present in the digestive system of fish, such as pepsin, trypsin, chymotrypsin, collagenase and elastase. Although this idea seems interesting, as it avoids the need to buy additional enzymes. However this is not suitable for this project, because the variation in the type of fish waste (therefore in the variation of its protein content), does not allow to have a sufficient enzyme content to perform the reaction. Thus, this idea was not selected.

4.3.3.4 Method

For this experiment commercialised protease such as Alcalase 2.4 L (Alcalase® Enzyme, Bacillus licheniformis, s.d.), which is a bacteria source and contains only protease enzyme in it, seemed to be the best solution. In fact, studies have shown that Alcalase 2.4L was the most efficient enzyme to use in order to extract protein from fish waste. (J. Araujo, 2020) (Babji, 2011) (Swapna C. Hathwar, Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases, 2010). Also, other proteases such as Protease-P-Amano6, Alcalase®, Flavourzyme® and Neutrase could be suitable as well.

However, due to long delivery times and its expensive cost (175€ taxes included), other strategies were settled, such as buying enzymes directly from pharmacies. A drawback from this is that the product does not only contains protease enzymes. It is a mix of different enzymes including protease. Thus, as an alternative, Creon 25 000 ((Pharmacie Kivihaka Stenhaga Apotek, 2013) was bought (50€ taxes included). This product contains 300 mg pancreatin (derived from the pig), equivalent to (Ph*Eur*unit):

- lipase 25 000
- amylase 18,000
- protease 1000

4.3.3.5 Experimental protocol

Even if the experiment wasn't conducted with Alcalase enzyme, an experimental protocol was set for this method, using Alcalase protease, it is fully described in Figure 99. The fermentation machine is shown in Figure 98.

Figure 98: Fermentation machine (Alibaba Group, 2025).

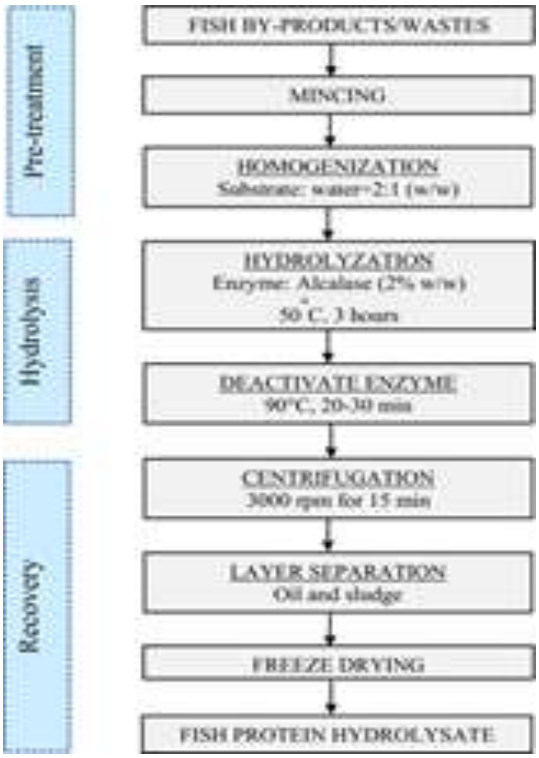


Figure 99: Enzymatic hydrolysis protocol.

- **Pre-treatment**
  - Wash fish waste with water to remove impurities.
  - Mince fish waste in small pieces
  - Homogenise the fish waste with distilled water in a 1:1 w/v ratio.
- **Treatment**
  - Add enzymes at a ratio of 0.5% to 2% w/v.
  - Adjust hydrolysis conditions (time, temperature & pH)
  - Shake the solution at a speed of 300 rpm, every 10 mins for 2h to 3h
  - Heat the mixture again to between 85 and 95°C to deactivate the exogenous enzymes for 15 to 20 mins.
- **Recovery**
  - Centrifuge the mixture at 3,000 rpm for 20 mins.
  - Remove the solid phase from samples.
  - Allow the mixture to settle (e.g. 1day)
  - Dry the mixture.
  - Store the final product in a room (<4°C)

However, the fat content of fish protein hydrolysates must be carefully controlled. According to the Food and Agriculture Organisation of the United Nations, the fat content of fish protein hydrolysates must be less than 0.5% (w/w) for human consumption. In fact, a higher fat content darkens the finished products, due to the release of brown pigments by oxidation of the lipids. It is therefore necessary to degrease the fat of oily fish before mixing with water.

4.3.3.6 Results

The enzymatic hydrolysis would be used as a method to extract protein from the fish. However, because of the long delivery time to get the right enzymes and the expensive price, a cheaper alternative was selected: buying enzyme from the pharmacy, enzymes under the brand of 'Creon 25 000'. This enzyme contains the right enzyme but in a smaller quantity. During the experimental phase of the project, the focus was more on the use of the ultrasound and the pH shifting methods than the enzymes. This because the enzymes that are bought from pharmacy may not be strong enough for the experiment.

The Creon 25000 contains 300 mg pancreatin per capsule and with hundred capsules, the pancreatin quantity would be 30 grams. These 30 grams would only be enough for one experiment which wasn't sure if it would be successful. Also, the experiments in general took more time than expected which led to some delays with the results. Besides having these delays, if the samples needed to be tested in the laboratory, some experiments wouldn't be finished in time. This led to the choice of not going further with the experiments with the enzymes.

Even though the original experiment did not take place, the enzymes were still used in a small experiment. The volume of the capsules was mixed with 5L of water and a few fish bodies. This was left in a cooking pot for 46 hours with a temperature of around 30°C. The solution was checked regularly.

In Figure 100 is shown how the bones looked after just 24 hours, completely clean with no flesh. This would suggest that the enzymes did work even in bad conditions. The thing that is left is some kind of soup.

Figure 100: Fish spine after the use of enzymes

The next step would be to remove the bones and the fish waste that is left and bake the soup in the oven to get rid of the water. After the oven, a powder should be left which would contain protein in it. After putting it in the oven at 80 degrees, the soup was left to bake for approximately eight hours. In the eight hours the soup was checked every hour and little by little the soup dissolved. When all of the water was dissolved, the bottom of the oven tray was covered in the residue. Unfortunately, this was not the powder which was expected but more some kind of dried paste. The paste still had some moisture in it, but if this was left in the oven for longer, it would burn (Figure 101). To conclude, the baking progress of the soup did not give usable results.

Figure 101: enzyme soup after baking process.

Because of the progress of the ultrasound method and the success of use with the centrifugation machine, the enzyme residue was also tested with this method. The soup was put into tubes and was put in the centrifugation machine for 20 minutes at 4700 rpm. The tubes were filled of the soup mixture and after the centrifugation less than 5 ml solid residue was left. In Figure 102 the before and after is shown which indicates that the centrifugation does give some residue.

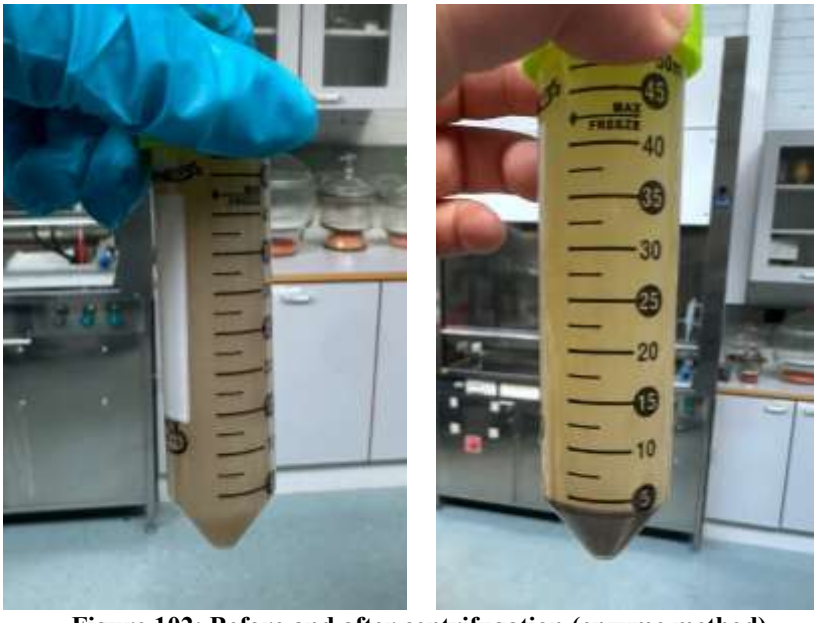


Figure 102: Before and after centrifugation (enzyme method).

When getting the solid residue out of the tubes, it was not the same paste as the residue from the previous experiments. Figure 103 demonstrates the liquidness of the paste and if compared to the paste from the previous experiments, it is not the same. The paste is more liquid and thinner which makes it unusable for the 3D food printer.

Figure 103: Residue enzyme centrifugation

Even though the enzyme experiment did not go as planned, some conclusions can be taken from these experiments. The enzymes do work even though the conditions were not ideal. The bones were clean and can be used for its collagen, for example if ground as a powder. This is something that was not tested because of the time management but this could be tested in a future experiment. The soup that is left after the filtration of the bones did not have the right consistency for the 3D food printer. But also, for this result applies that only one experiment is done. So, with more research in variables like the quantities of the enzymes, the time that the enzymes are working, the deactivation of the enzyme and the water-fish ratio, the perfect paste for the 3D printer could be created. This would be a good solution for the fish waste problem because you are left with two useful byproducts; the bones of the fish and the paste that can be used for printing.

From the scientific studies that have already performed enzymatic hydrolysis some limitations can be identified for this process: the high price of industrial enzymes, low yields, long production cycles: the enzymatic process takes several hours, the need for special care to deactivate enzymatic hydrolysis and the complexity of managing the process to achieve a certain level of quality. (A Das, 2021)

To conclude, the production of high yield, highly pure protein hydrolysate from fish waste by enzymatic hydrolysis has generally been reported from small-scale or controlled laboratory systems (Muhammad A.B. Siddik, 2020). This process can require expensive large-scale processing, isolation, purification and characterisation techniques. The commercial, technical and economic feasibility of large-scale systems therefore needs to be tested.

4.3.4 Ultrasonic extraction + Enzymatic hydrolysis

This chapter will only be discussed about the interest of this method as a way of extracting protein from fish waste. This method was not experimented due to lack of time.

4.3.4.1 Principle

Studies have shown that ultrasonic as a non-thermal pre-treatment improves enzymatic hydrolysis efficiency thanks to cavitation effects. In fact, ultrasonic waves create pressure cycles in the water, forming microscopic bubbles during rarefaction when the negative pressure exceeds the tensile strength of the liquid. These bubbles absorb energy until they become unstable and burst, generating shock waves and high-speed microjets. This cavitation effect results in high-pressure conditions that break molecular bonds and enhance mass transfer. The cavitation effect makes collagen more accessible to enzymes by disrupting its structure. (Dian Haryati, 2024)

In a nutshell, pre-treatment with ultrasound before applying the enzyme breaks down the collagen structures, thereby increasing the breakage sites for the enzymes. The combination of these methods should make it possible to reduce the high cost of using enzymes thanks to a reduction in extraction time, a lower temperature, less stirring during extraction and it also may require fewer enzymes to produce the same yield.

Enlarged pores and the production of highly reactive free radicals, resulting in more efficient penetration of the enzymes and solvent into the matrix cell, allowing the enzyme to interact better with the fish raw material and improving extraction.

Thus, the combination of these two methods, can be a good idea in order to extract protein, such as collagens from fish waste. Parameters such as ultrasound amplitude and pre-treatment time, enzyme concentration and hydrolysis time play an important role.

4.3.5 Conclusion

First of all, the ultrasound method has proved to be an interesting method for extracting proteins from fish waste. Several combinations were studied: influence of time, influence of heating, influence of solvent/mass ratio and influence of fresh/frozen batch. It appeared that working with fresh batch of fish waste give better results than frozen batch. After centrifugation, the following by-products were extracted: fish oil, fish solution and heavy protein paste. The fish solution and the heavy protein paste were sent to a lab for nutritional analysis. However, from the result of the lab, it appeared that the fish solution was not an interesting byproduct to use because of its low content in protein. On the other hand, the heavy protein paste was rich in protein and low in fat which makes it edible for animal consumption. For human consumption one more test needs to be done to make sure no harmful bacteria are in the paste. Furthermore, a fish paste was extracted from the bottom layer after centrifugation and used to 3D print fish nugget because the shape, the texture and the content of it was suitable for the 3D printing. Nevertheless, after the success with the use of the ultrasonic cleaner which created the paste for the 3D food printer, the question was asked if the success came from the ultrasounds or the heating. The heating has shown equivalent layering compared to ultrasonic method. However, conclusion can't be drawn about the fact that heating gives same result than ultrasound because the only heating sample was never tested on nutritional analysis. Several assumptions were made and back up with studies that already work with fish waste such as ultrasound can be a method of extracting protein by itself but not the most efficient one, it can be used as a boost method if combined with other techniques such as enzymes. It can also be used as a way of not using extra heating elements for water, because ultrasound already warm the water quite easily, thus it can save energy. To sum up, from these experiments, ultrasound appeared to be a feasible solution, but further studies need to be done about the effect of heating in this process.

Moreover, acid and alkaline solubilization (pH shift) method was used as a way of extracting protein from the fish waste. Experiments were first conducted to see what between acid and alkaline solubilization could give the best yield. The outcome of it has shown that alkaline solubilization was better than acidic solubilization, which is confirmed by other scientific studies. From this, alkaline solubilization method was performed and two byproducts were made after centrifugation: fish solution and a fish paste. These two byproducts were sent to a lab for nutritional analysis. The result of it has shown that both of these by-products were not suitable, the protein content was too low. Regarding the protein solution it makes sense because it contains a lot of water in it, but maybe method such as freeze drying can be used to remove water and obtain a powder from it. Regarding the fish paste extracted from the pH shift method the results were quite surprising because it was completely different from what scientific studies that already performed this method with fish waste have demonstrated. From these results it is not possible to conclude that the pH shift method is a good way of extracting protein.

The first plan was to buy industrial enzyme such as Alcalase 2.5L derived from microbial source, because according to studies it was the most suitable enzyme to use for protein extraction. However, long delivery time and the high cost of it led to other strategies such as buying enzymes from pharmacy. Thus, Creon 25000 was bought, containing 300 mg pancreatin (enzymes derived from the pig). An experiment was done by adding enzymes into a fish waste solution and letting the reaction ran for several hours. The result of it led to a complete separation of the flesh attached to the bones. The solution was dried in an oven, but the temperature was too high and burnt the sample. The solution that is left after the filtration does not have the right consistency for the 3D food printer. However with more research the perfect paste for the 3D printer could be created. This would be a good solution for the fish waste problem because you are left with two useful byproducts; the bones of the fish that can be grounded into powder and can be used for its collagen content and high nutrients value and the paste that can be used for printing. Further studies have to be done about this subject, especially about the minimal among of enzyme that can be used to separate the flesh from the bones, the way of having a powder from the fish solution without damaging the protein in it, the cost of the enzyme and the feasibility of it at industrial scale.

4.4 3D printing fish waste

To make nuggets out of protein extracted from the fish waste, experiments are going to be conducted where a paste made from fish waste is going to be 3D-printed in a nugget shape. These nuggets can then be coated in fry batter to be fried, cooked or baked. Before printing with fish waste, the team had to become familiar with the 3D printer. To achieve this, the team will print with other kinds of food. These include Chocolate, Butter, Baby food, and Tuna paste. The products are printed in a simple fish shape that the final product will also take.

4.4.1 Method

4.4.1.1 Choosing a 3D printer

The first step to this experiment is buying a food 3D printer. The market around food 3D printers is quite new and small so it was quite hard to find a printer that would suffice for the experiment. After thoroughly looking through the internet to find printers, a list with seven different printers was made. In the list some key characteristics, pricing, pros, and cons were listed. In Table 8 a simplified overview is given. A complete overview can be found in Appendix I.

Table 8: Simplified overview of the 3D printers.

	Steakholder	*Felix Single*	*Felix Twin*	*Felix Switch*	*Procusini*	*Foodini*	*Lincsolutions*
Printing speed	100kg/hour	Not found	Not found	Not found	Not found	Not found	Not found
Filament capacity	Custom	100 cc	2 x 100 cc	2 x 100 cc	60 ml	5 x 100 ml	Not found
Print area	Not found	220 x 195 x 170 mm	220 x 195 x 170 mm	220 x 195 x 170 mm	250 x 300 x 100 mm	Ø278 x 110 mm	300 x 300 x 50 mm
Heated printbed	Yes	Yes	Yes	Yes	Not found	Yes	60°C
Nozzle size	Not found	Ø0.5 – Ø4.0 mm	Ø0.5 – Ø4.0 mm	Ø0.5 – Ø4.0 mm	Ø1.0 mm, Ø1.2 mm	Ø0.8 mm, Ø1.5 mm, Ø4.0 mm	Ø0.3 mm – Ø1.2 mm
Delivery	Not found	2-3 weeks	2-3 weeks	2-3 weeks	5-6 weeks	Not found	Not found
Price	Not found	€4510.88 - €5332.29	€7931.55 - €9025.15	€7931.55 - €9025.15	€4245.00 - €5344.00	€6000	Not found
Most notable extra	Waterjet cleaning	Automatic calibration	Automatic calibration	Automatic calibration	Illuminated production room	5 different ingredients	Built-in UV sterilization

The Steakholder printer is primarily for industrial use. It can quickly print large quantities of fish. However, the primary function of this printer is to print plant-based substitutes for fish. If 3D-printing fish from fish waste is going to be commercialized, this would be a worthy printer to look into further. For the current phase in the research the Steakholder printer is not relevant. All printers have a good amount of choice for the nozzle size, although the Felix printers have by far the most choice. Pricewise the printers are very similar to each other, but it mainly depends on the abilities of the printers. Printing multiple ingredients at the same time, an option for the Felix Switch and the Foodini, would be fun to experiment with, but not a requirement. Due to the increase in price, it would be more cost-effective to not choose one of those printers just for that option. The built in UV sterilization of the Lincsolutions printer would be very appealing for the application of using fish waste. This is definitely worth looking further into, but to find more details about that printer,

contact with the company should be established. After carefully considering all the options, the Felix Foodprinters Single was chosen (Figure 104). The Felix Single has the best comparison between price and user-friendliness, it is able to print with different materials varying between a viscosity of 5Pa·s (liquid chocolate) to 5000Pa·s (cold butter), and it has the most choice in varying nozzle diameters. Since Felix is a Dutch company, the delivery time was relatively quick. The company also keeps interest in their clients work and give support where necessary. A list of the included and additional products, some additional motivation, and pricing can be found in Appendix J.

Figure 104: Felix Food 1.6 - Single Head 3D Printer (Felixprinters, 2024).

4.4.1.2 Setting up the 3D printer

After a couple of the weeks the printer arrived. The printer had to be assembled first. Assembly instructions were provided both physically and on a USB stick. Following these instructions was quite easy, it was similar to assembling an IKEA product. The printer was installed withing a fume hood so the smell of fish during printing is reduced (Figure 105). Included with the printer was a license for the slicer software "Simplify3D". This software is used to slice 3D models, and to set all the different settings for printing food. There are a lot of options available in the software to ensure printing even with difficult materials (Figure 106). This made the software quite complicated. Luckily the printer was also provided with a quick-start guide on the software.

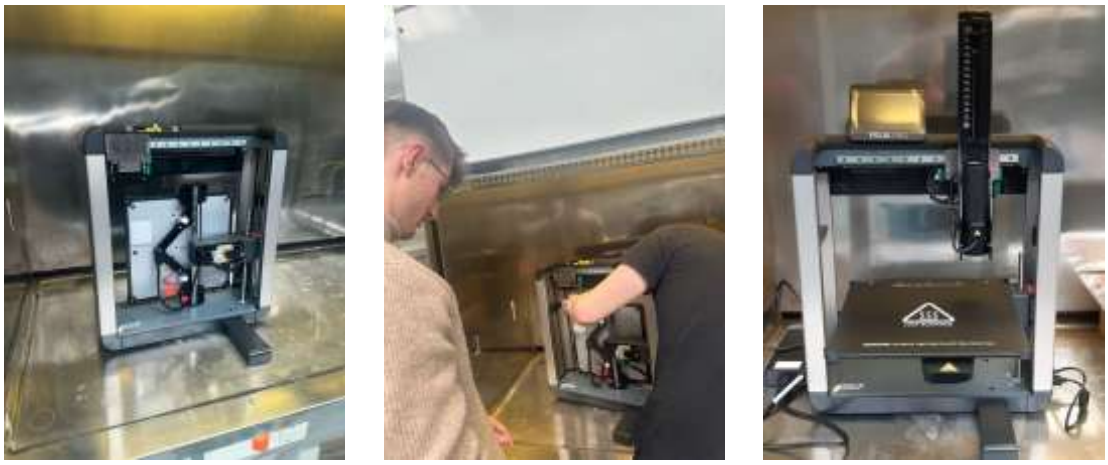


Figure 105: Setting up the printer.

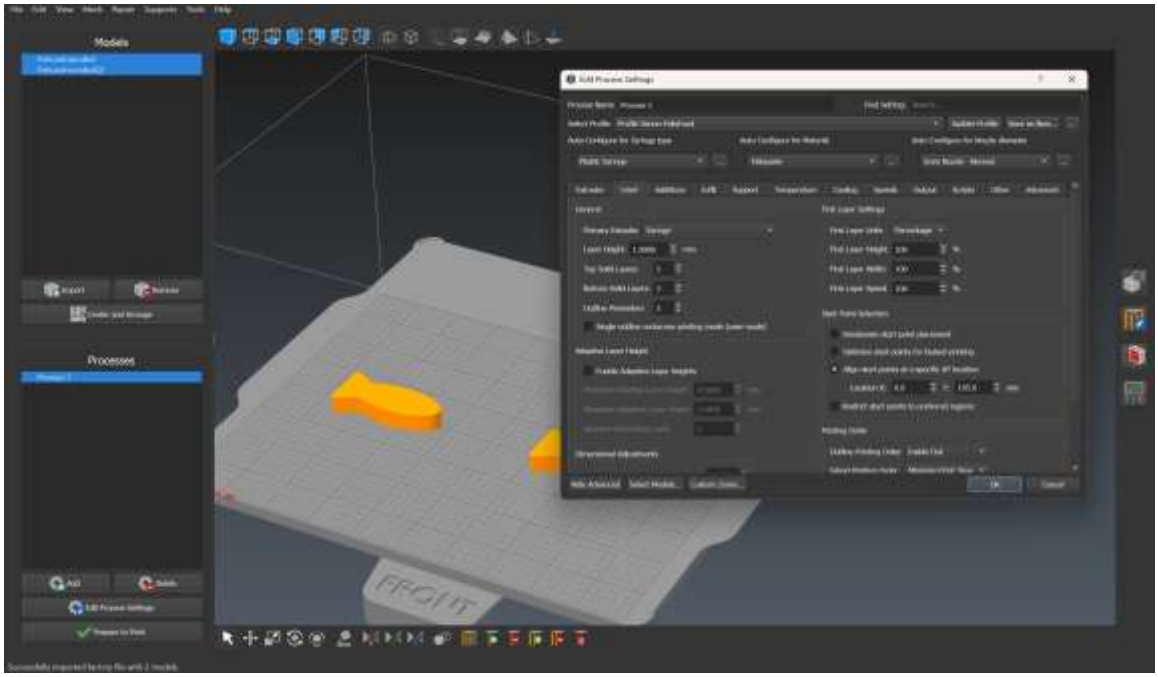


Figure 106: A screenshot of Simplify3D.

Felix Foodprinters also provided an online training session. The team was already a bit familiar with using it and everything was already set up so starting up the training went really smooth. The training was given by Michael Bergman. Michael wrote his thesis about combining the culinary industry with the 3D printing industry and thus had a big part in developing the Felix Foodprinter. He was able give a lot of helpful insight into using the printer. The training was really helpful. It gave the team a lot of small details to be able to really finetune the printing. Michael showed a lot of interest in the project and also asked to be updated on the experiments. The involvement of Felix in the project was a very pleasant experience.

4.4.1.3 Application

The idea of printing fish nuggets is for human consumption. Would the fish nuggets be safe to eat, nutritious, and have a good taste, they could potentially be released upon the market. Would the taste not be that great for human consumption but would it still be safe to eat and nutritious enough, it could also be fit for animal consumption.

4.4.1.4 Limitations

The main goal of this experiment is to test the potential of using the produced fish paste as an edible product. Testing with different recipes to improve the taste and texture of the nuggets would be nice to do but not necessary. Due to time constraints it was decided to not go too deep into this.

A common limitation of printing with food is the difficulty of print supports. This makes printing complex shapes with a lot of overhang close to impossible. The nuggets that will be printed are a simple shape and don't need any kind of support so for this experiment it will not be a problem.

4.4.1.5 Experimental protocol

1. Design or download a 3D object.

The first step to print something is to design a download a 3D object. This object can be an STL, OBJ, X3D, or 3MF file. For designing a custom 3D object software like SolidWorks or Fusion360. For this project SolidWorks was used to create a simple 3D fish shape around the size of a chicken nugget. This was then saves as an STL file and uploaded into the Simplify3D slicer.

2. Slice the object in Simplify3D.

In the Simplify3D slicer the process settings can be edited. These settings can vary wide between different materials. For this experiment chocolate, butter, baby food, tuna paste, and fish waste paste are used. These materials are very varying in viscosity and texture. This means that each process can widely vary. These settings include options of for nozzle size, ooze control, layer height, infill, temperature of the syringe and the bed, cooling fan, printing speed, and a lot more (Figure 106).

Chocolate has to be melted but also not too liquid. The ideal temperature was found to be around 35°C. The cooling fan was put to 100% so the chocolate could harden. The other materials do not have to be heated or cooled. The nozzle size has to correspond to the physical nozzle that is installed on the syringe. The other settings have to be finetuned to the material and it can require some test printing to really see how the settings affect the printing process.

3. Upload the sliced object to the 3D printer.

When the object is sliced it can be uploaded to the printer. This can be done in two ways. The file can be saved onto an USB stick and put the USB stick into the USB slot in the 3D printer. On the printer itself the USB can be selected and the file can be downloaded to the local storage in the printer. The printer is able to print the file from the USB stick directly but this is advised against.

A second option is to connect wirelessly to the printer. This is possible from a device that is on the same Wi-Fi network as the printer. The easiest way to achieve this is to turn on a hotspot on the PC the slicer is installed on. When the printer is connected to the PC's hotspot, the printers IP address is put into a web browser on the PC. The printers interface is now accessible. From here the sliced object can be uploaded.

4. Load the material in the syringe.

The printer prints by pushing the material out of a syringe. Using a spoon, material is inserted into the syringe (Figure 107). When enough material is inserted into the syringe, the plunger can be put in place. The syringe pressed in for around two centimetre. Tap the backside of the syringe on a soft surface multiple times until the material is resting on the plunger. Finally press the plunger into the syringe until the material is at the nozzle (Figure 108).

Figure 107: Inserting material in the syringe.

Figure 108: A filled syringe.

5. Load the syringe in the 3D printer.

If the premium nozzle is used, it is fixed on the heating element of the printhead. If another nozzle is used, it is fixed on the syringe itself. The syringe is loaded into the heating element of the printhead (Figure 109). The plunger holder is changed to the height of the plunger and the plunger is fixed in place. The syringe is now fixed and ready (Figure 110). If the material should be heated up before printing, the temperature of the syringe heater should be turned on to the desired heat before printing so the material can heat up. This is especially important for chocolate since that has to melt before it can be printed. By turning the knob on top of the printhead the syringe can be purged until a little material is pressed out. This is done so the material is gets extruded immediately when printing.

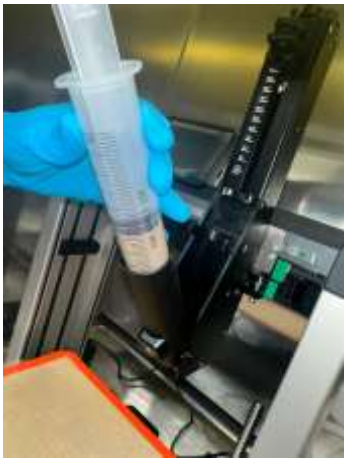


Figure 109: Loading the syringe.

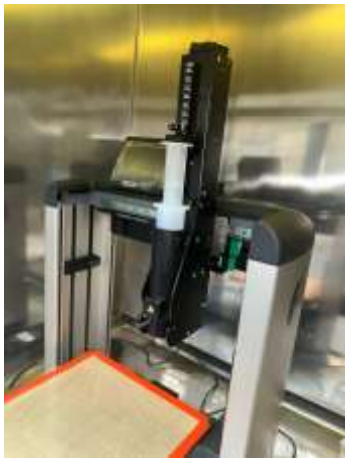


Figure 110: The syringe is fixed in place.

6. Start the printing.

When the syringe is fixed in place, the material is the correct temperature, and the 3D object is uploaded into the printer, the print can start (Figure 111). It is recommended to keep monitoring the first layers in case something goes wrong. The small fish nuggets take between four and eight minutes to print depending on the slicing settings.

Figure 111: Printing a 3D object

7. Post processing

After the printer is done printing, the entire printing surface along with the printed object can be taken off. Depending on the material of the print, a different post processing technique should be utilized.

Butter, baby food, and tuna paste are consumer ready right after printing. Chocolate needs some time to cool down to harden. To speed up the hardening process, the chocolate can be put in a fridge or freezer.

For the first test the nuggets that are printed are put in the oven (Figure 112). The oven is set on 150°C. The fish nuggets are checked every five minutes to monitor the baking process. After a total 30 minutes the nuggets are taken out of the oven.

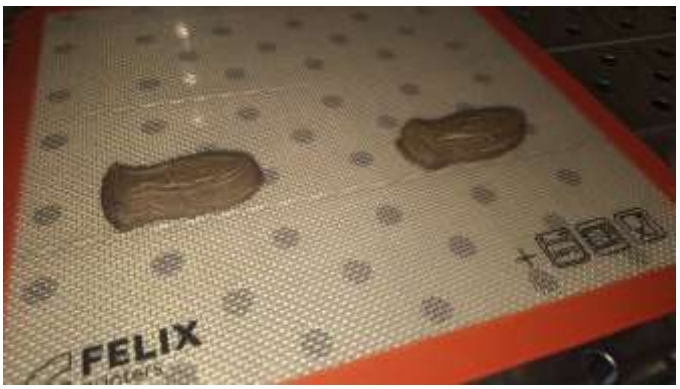


Figure 112: Fish waste nuggets in the oven.

The fish nuggets can also be deep fried. First, this nugget is frozen so it keeps its shape. The frozen nugget is submerged in egg, then coated in a mixture of flour, paprika, chili, salt, pepper, and thyme. This is done two times. The coated fish waste is then submerged in frying oil of a temperature of 160°C (Figure 113). After around six minutes the nugget can be taken out of the oil. Measure the internal temperature of the nugget (Figure 114). This should be at least 80°C so all the possible bacteria are dead.

Figure 113: Deep frying the fish nugget.

Figure 114: The internal temperature of the nugget.

4.4.1.6 Results

The chocolate fish came out quite nice. It was difficult to print the chocolate without it sagging, but in the end some nice looking chocolate fish was printed (Figure 115). Printing chocolate fish definitely smelled much better than the fish experiments that were conducted. After having the chocolate fish in the freezer for around 20 minutes it had become a nice looking fish (Figure 116). The taste was also good but unfortunately the chocolate had not been tempered so the texture was a bit lacking. Figure 118 demonstrates really well how the different slicing settings effected the final texture of the chocolate. After the solid fish chocolates, some different shapes where tried like a silhouette of a fish (Figure 117). The fish was quite good looking and would be fit to decorate a cake for example. During the training it was discovered that chocolate was actually one of the hardest materials to print with. So it wasn't the best choice to print with to get familiar with the printer. But at least the complexity of chocolate printing helped to become more skilled.

Figure 115: Freshly printed chocolate fish.

Figure 116: Hardened printed chocolate fish.

Figure 117: A printed chocolate silhouette of a fish.

Figure 118: Different inside textures.

During the training, printing with room temperature butter was used to demonstrate printing. 12 butter fishes were printed to make use of the full printbed (Figure 119). This material was far easier to print with than the chocolate. Theoretically the fishes could be served with a piece of bread immediately after it was done printing.

To get a bit closer to the texture and viscosity of the fish waste paste, baby food was used to print with. The texture is a bit grainy and jelly but it keeps its shape well. First the standard fish shapes were tested and they came out really well (Figure 119). This could definitely improve the eating experience of a young child, if they are old enough to care. Printing a castle was also tried (Figure 121). The baby food was too jelly for this so the towers fell after getting around four centimetres high.

Figure 119: Butter fish

Figure 120: Baby food fish

Figure 121: Baby food castle

To finetune the slicing settings to the fish waste paste, printing was tested with tuna paste. The texture and viscosity of this paste is the closest to the fish waste paste of any food type found. The choice of using this material was made so no fish waste paste went to waste during finetuning the printer settings. The tuna paste was very easy to print with because it has a high viscosity but still extruded with ease. After a couple tries and finetuning the settings a tuna paste fish was printed with good precision and clearly defined layers (Figure 122). The print settings were deemed good to use to print the fish waste paste.

Figure 122: Tuna paste fish

Since the viscosity of the fish waste paste is a bit higher than the tuna paste, a little more fine tuning was needed. The paste could just be put back into the syringe after printing so no paste was wasted. One fish nugget takes only about four minutes of printing time. The layers are well defined and the paste keeps its shape (Figure 123).

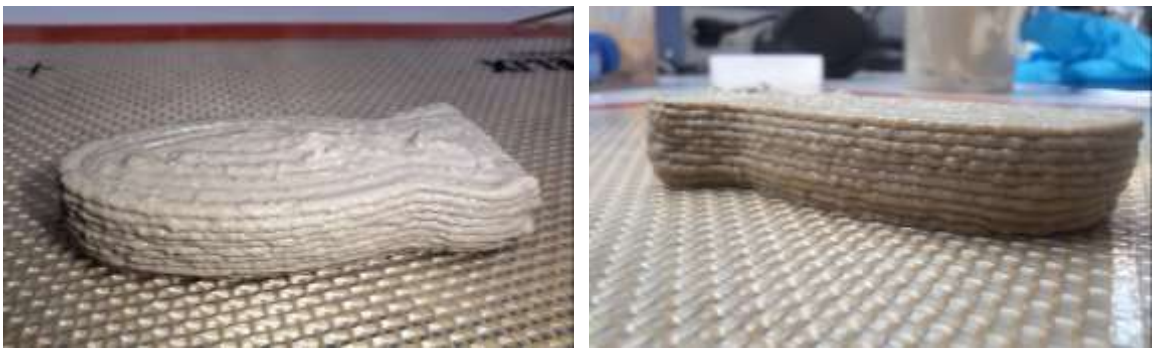


Figure 123: Printed fish waste nugget.

The first try to see the potential of the fish nuggets as a consumable product was to put the nugget directly into the oven. The nugget was monitored every five minutes and it was discovered that slowly there was a brown layer forming on the outside of the nugget. After 30 minutes when the layer seemed dark enough, the nugget was removed from the oven. When the nugget was cut open is was discovered that only the outside layer of the nugget has browned while the inside is very similar to the original paste, just a bit dryer (Figure 124). The colour of the fish is still grey and unappetizing. The taste of the nugget was reminiscent of the taste of fish sticks but with a stronger fish flavour. Unlike fish sticks, there was not crispy outer layer to create a flavour and texture contrast with the fish. In combination with the soft, grainy texture, a chewy outer layer with a slightly burned flavour, the nugget was not very pleasant to eat.

Figure 124: Fish nugget out of the oven.

The second try was made to make the fish nugget more enjoyable to eat. For this it was decided to deep fry the nugget. A batter was created to create a crispy outer layer and make it easy to add some spices and herbs. The frying process took much less time than baking it in the oven. The fish did lose its distinct fish shape due to the frying process. The nugget was very crispy when cutting into it (Figure 125). The colour of the fish itself was still unappetizing but that does not influence the flavour. The flavour and texture of the nugget was definitely an improvement over the nugget that came out of the oven. The crispiness of the outer layer created a nice contrast with the soft fish. The spices and herbs improved the overall flavour. The nugget still has a very strong fish flavour, a bit too strong, because it does taste too processed and not fresh. The texture of the fish itself was still grainy but not too much of a problem. The nugget was a bit too thick and maybe thinner nugget might improve the texture. While the experience was not unpleasant, there is still much room for improvement.

Figure 125: Deep fried fish nugget.

4.4.2 Conclusion

While chocolate might not have been the best choice to become familiar with the printer, it was still a very pleasant and interesting experience. Printing with butter, baby food, and tuna paste was not any less interesting.

The main goal of this experiment was to print a consumable fish nugget. This was achieved. The most pleasant consuming experience of a nugget that was tried is to deep fry it with a crispy outer layer and some spices and herbs. The nugget definitely has potential to become a product fit for human consumption. What also reinforces the potential of the nuggets is the nutritional value of the paste residue seen in Table 6, page 53. While eating this nugget was not unpleasant, there is much room for improvement. To really improve the nugget, a recipe has to be made that puts the paste to its highest potential. This can include making a better mix of spices and herbs, making a different kind of batter, and putting spices and herbs into the fish paste itself before printing. Making the fish nugget a bit thinner will increase the crispiness of the nugget and possible improving the texture of the nugget. In the case it turns out that the nuggets will not be fit for human consumption, it may be fit for animal consumption which is worth looking into.

5. Upscaling value

One of the most important things to do with fish waste in this project is to upscale the value of it. Otherwise, there would be no use in processing it. Today's use of fish waste is to create biogas out of it. In order to utilize other processes, it has to be more profitable than biogas. In order to upscale the value is to focus on products used for primarily human consumption, secondarily for animal consumption. These products can include fish jerky, fish nuggets, fish oil, protein powder and supplement powder, cat food, and garum.

The main four things to determine the production cost of certain products are energy consumption, product cost, material cost, and labour cost. The material cost include the machinery used to produce the products. Labour cost include the wages of the people operating the producing of the products. Due to the difficulty of determining the material and labour cost on mass production, these costs are not included in the calculations of the value of the products. Energy consumption includes the amount of electricity that was consumed in the producing of the products. This is multiplied by the electricity market price. As of May 2025, the electricity market price in Finland is 5.51 eurocents per kWh (Helen Ltd, 2025). The product cost includes additional products that are added during production to create a final product. This includes water. The water rate as of January 1st 2025 in Finland is €0.63/m^3 (Helsinki Region Environmental Services HSY, 2025). The total value of the product consists of the sum of the energy consumption and the sum of the product cost.

5.1 Cost calculation equations

a. The energy consumption per device is calculated using the following equation:

$$E_n = \frac{P * t}{60{,}000}$$

E_n = Consumed energy of device n in kilowatt-hour (kWh).
P = Power rating of the device in Watts (W).
t = time in minutes (min).

b. The total energy consumption of the production is calculated using the following equation:

$$E_t = E_1 + E_2 + \cdots + E_n$$

E_t = Total consumed energy in kilowatt-hour (kWh).
E_n = Consumed energy of device n in kilowatt-hour (kWh).

c. The cost of the energy consumption of the production is calculated using the following equation:

$$cost_E = \frac{E_t * emp}{100}$$

$cost_E$ = Cost of the energy consumption in euro (€).
E_t = Total consumed energy in kilowatt-hour (kWh).
emp = Electricity market price in eurocent (c).

d. The product cost is calculated using the following equation:

$$cost_p = product_1 + product_2 + \cdots + product_n$$

$cost_p$ = Product cost in euro (€).
$product_n$ = Cost of product n in euro (€).

e. The total production cost is calculated using the following equation:

$$cost_t = cost_E + cost_p$$

$cost_t$ = Total production cost in euro (€).
$cost_E$ = Cost of the energy consumption in euro (€).
$cost_p$ = Product cost in euro (€).

5.2 Garum

To appeal to the market, different garum recipes were made. Two batches of herbs, two batches of chilis, and two batches of wine. Garum is a type of fish sauce. Fish sauce is a staple in many Asian cuisines and is increasingly adopted in Western cooking. (Grand View Research, 2025) The garum will not be aimed towards the Finnish market too much because the biggest market of fish sauce is in Asia (Figure 126).

Figure 126: Fish sauce market across the world (Grand View Research, 2025).

Garum can easily be bought online if one knowns were to pay attention for. It is important to know if it is real garum or not, this can be found in ingredients list. Real garum is made with fish, salt and water and maybe some extra herbs or spices for flavour. The price for garum fluctuates between €5 per 100g and €20 per 50 ml, see Figure 127 for the different products. (Garre, 2025) (de Mar Selo, 2025).

Figure 127: Garum fish sauce products.

To make garum, a rotation machine is used. This machine is powered by an electric motor. The garum should also be heated between 32°C and 38°C using an electric heater. For these calculations only the garum made with herbs will be used since that was the most promising one.

Table 9: Power rating of equipment for garum making.

No.	Required equipment	Power rating
1	*DC motor*	*24W*
2	*Heater*	*2000W*

Even though the garum experiment ran for 2 months, these calculations will be made for a year, since that is generally considered the optimal time for garum production. The heater is constantly heating for the whole year, while the motor only rotates the garum for four minutes per day. Over a span of a year this is 1460 minutes. The energy consumption of the garum making should be as followed:

$$E_1 = \frac{24 * 1460}{60{,}000} \approx 0.6kWh \qquad E_2 = \frac{2000 * 525{,}600}{60{,}000} \approx 17{,}520kWh$$

$$E_t = 17{,}520 + 0.6 \approx 17{,}521$$

During this process, three buckets can be used by the same machine. Although the heater can heat up multiple machines. 800g of fish waste can be put in each bucket together with 100g of salt costing €0.22, 100g of herbs costing €1.20 and 400ml of water. It can be assumed that the heater can heat up 21 buckets. The total price of producing garum using this setup would be:

$$cost_p = 21 * (0.22 + 1.20 + 0{,}0004 * 0.63) \approx €29.83$$

$$cost_E = \frac{17{,}521 * 5.51}{100} \approx €965.40 \qquad cost_t = 965.40 + 29.83 = €995.23$$

Unfortunately it is unclear how much garum this would produce. So a price per kilogram is impossible to accurately determine. Garum is known to be quite expensive, and looking at the process of making it of fish waste, especially the heating increases the price a lot. It is also unclear if the garum is safe for consumption.

5.3 UV-sterilization

To appeal to the market, the idea of combining UV sterilization with heat drying was explored as a preservation method for fish waste. This process mimics the traditional use of sun-drying, which uses both UV radiation and heat, but brings it into a controlled, scalable, and potentially more hygienic environment.

UV sterilization is already being used in the meat industry to extend shelf life and improve safety, particularly for dried meat products like jerky. This technology has potential applications in transforming fish waste into dried products such as fish powder or meal. Which can be used as supplements in animal feed.

These products are widely used around the world. For example, dried salted anchovies are commonly sold as food or feed ingredients and can cost up to €43 per kilogram (Figure 128). The price this is sold ass depends on the quality and thus also the type of fish. Selling dried fish (waste) would also need to be marketed enough because people who hear: “fish waste”. Are less likely to buy it because it is associated with waste.

Figure 128: Dried anchovy (salted-dried-anchovy, 2025)

The dried products made from fish waste could be positioned as a more affordable and sustainable alternative to higher-grade dried fish products. Offering value especially in feed or agricultural sectors. UV sterilization can offer a cleaner and safer drying process compared to traditional methods that rely solely on heat or air drying. While these products may not be marketed directly for human consumption due to raw material quality. They can be attractive in secondary markets such as pet food, livestock feed or even fertilizer production. The price of dried fish products depends heavily on quality and origin. The addition of UV sterilization can help ensure a more consistent and safer product. Potentially opening up access to international markets with stricter hygiene regulations.

Two different devices were able to produce dried fish. Air-sterilization 1 and air-sterilization 2. Both devices are using UV lights, a fan and a heater. Since the power consumption of both devices would be very similar, only one calculation will be made.

Table 10: Power rating of equipment for air sterilization.

No.	Required equipment	Power rating
1	*UV light*	*13W*
2	*Heater*	*600W*
3	*Fan*	*9W*

The energy consumption will be calculated for a run-time of two weeks. Four UV- lights will be used in the calculation, this is for the ideal experiment. The actual experiment used less lights but that is not taken into account to prevent overcomplicating the calculations. The energy consumption of this process should be as followed:

$$E_1 = \frac{4 * 13 * 20160}{60{,}000} \approx 17kWh \qquad E_2 = \frac{600 * 20160}{60{,}000} \approx 200kWh$$

$$E_3 = \frac{9 * 20160}{60{,}000} \approx 3kWh \qquad E_t = 17 + 200 + 3 = 220kWh$$

Since this method uses only the fish waste, no product cost exists. So the total production cost consists only of the cost of energy consumption. That would be:

$$cost_E = \frac{220 * 5.51}{100} \approx €12$$

This process can dry around 2.5kg of fish waste. That would make the price per kilogram:

$$price\ per\ kg = \frac{12}{2.5} \approx €4.80/kg$$

This is much cheaper compared to the retail price of dried anchovy of €43/kg. It is worth noting that the dried fish waste is not a finalized product and wouldn't be consumed in its current form.

5.4 Fish paste

5.4.1 Ultrasonic extraction

To explore potential market applications, multiple extraction methods were tested. Only the ultrasound method successfully yielded two by-products suitable for upscaling: fish oil and a fish paste that could be processed further into a fish-based nugget. Only the ultrasound method was considered for further development because of this reason.

The fish paste produced through this method shows potential for incorporation into familiar processed food products. One comparable item is the widely available "fish stick" product which is sold at an average price of €8.76/kg (Figure 129). These processed fish products are already well integrated into both Western and global markets, making them a useful benchmark for pricing and consumer expectations.

By utilizing fish waste to create a fish paste base through ultrasound extraction. A more sustainable and potentially lower-cost alternative to standard fish sticks or nuggets can be introduced. While the raw material may come from lower-grade sources. The final product can be designed to match the texture and flavour of existing market items.

Fish oil, the second by-product is already a high-value commodity in both health supplement and animal feed industries. Which is sold at €99,5/kg without any discounts (Figure 130). Its production from waste material provides a compelling sustainability angle that could appeal to environmentally conscious consumers. The combination of familiarity (fish nuggets) and value-added sustainability (recovered fish oil) positions the ultrasound method as a promising path for circular product development and market entry.

Figure 129: Fish sticks

(findus-frionor-kalapuikko-250-g, 2025)

Figure 130: Fish oil supplement

(omega-3, 2025)

.

For the ultrasonic method the following devices were used: an ultrasonic cleaner with an ultrasound and a heating element, and centrifugation machine.

Table 11: Power rating of equipment for ultrasound method.

No.	Required equipment	Power rating
1	*Ultrasound*	*600W*
2	*Heating element (from the ultrasonic cleaner)*	*600W*
3	*Centrifugation machine*	*1400W*

The ultrasonic method takes at least four hours in the laboratory of the school. The duration of using ultrasound that gave the best results was two hours. This was done in two different options. One option is using both the ultrasound and the heating element, and the other is using just the heating element. in and the centrifugation machine need to run twice for 20 minutes to process the entire batch of fish waste from the ultrasonic cleaner. From this information, the energy consumption should be as followed:

$$E_1 = \frac{600 * 120}{60{,}000} = 1.2kWh \qquad E_2 = \frac{600 * 120}{60{,}000} = 1.2kWh$$

$$E_3 = \frac{1400 * 40}{60{,}000} \approx 0.9kWh \qquad E_{t(1+2+3)} = 1.2 + 1.2 + 0.9 = 3.3kWh$$

$$E_{t(2+3)} = 1.2 + 0.9 = 2.1kWh$$

This method produces 224ml of fish waste paste. From this amount, 14 fish nuggets with a volume of 16ml can be made. Assuming a factory produces 100,000 nuggets a day, 1600L of fish waste paste is needed, using around 13,000kg of fish waste and 6500L of water. The fish waste is assumed free of charge. That means that this process should run around 7100 times. The price of producing the paste using both ultrasound and heating needed for 100,000 nuggets would be:

$$E_{t(1+2+3)} = 3.3 * 7100 \approx 23{,}000kWh \qquad cost_E = \frac{23{,}000 * 5.51}{100} \approx €1300$$

$$cost_p = 6{,}5 * 0.63 \approx €4 \qquad cost_t = 1300 + 4 = €1304$$

Using only the heating element the cost would be:

$$E_{t(2+3)} = 2.1 * 7100 \approx 15{,}000kWh \qquad cost_E = \frac{15{,}000 * 5.51}{100} \approx €830$$

$$cost_t = 830 + 4 = €834$$

The difference in cost would be:

$$\Delta cost_t = 1304 - 834 = €470$$

The fish oil is a by-product of this process so could be deemed free. The oil has not been researched properly due time restraints, so it is unclear if this can be sold for a profit.

5.4.2 3D printing nuggets

The equipment used for turning the fish waste into nuggets was a 3D food printer and a freezer.

Table 12: Power rating of equipment for 3D printing nuggets

No.	Required equipment	Power rating
1	*3D printer*	*220W*
2	*1800L Freezer*	*750W*

Printing the nugget would take around four minutes of printing. For a total of 100,000 nuggets, that would take 400,000 minutes. Would this be done, more printers than one are being used. The 400,000 minutes is the combined time for each individual printer. Theoretically a fridge of 1800L is able to freeze 100,000 nuggets. It can be assumed that all the nuggets are deeply frozen after eight hours, 480 minutes. The energy consumption of this process should be as followed:

$$E_1 = \frac{220 * 400{,}000}{60{,}000} \approx 1500kWh \qquad E_2 = \frac{750 * 480}{60{,}000} = 6kWh$$

$$E_t = 1500 + 6 = 1506kWh$$

To coat the nuggets in a crispy layer, 700kg flour costing around €820, 360kg of eggs costing around €500 and 250kg of spices and herbs costing around €280 (Selina Wamucii, 2025) are needed. For the pricing of the fish paste itself, €834 is used (see chapter 5.4 Fish paste

Ultrasonic extraction, page 86). The energy of deep frying the nuggets is not taken into account since that would be done by the customers themselves. The total cost of producing the fish nuggets would be:

$$cost_E = \frac{1506 * 5.51}{100} \approx €83 \qquad cost_p = 820 + 500 + 280 + 834 = €2434$$

$$cost_t = 83 + 2434 = €2517$$

To compare the production price of these nuggets with store-bought fish sticks, a price per kilogram should be calculated. That is done using the following calculations:

$$m_{100{,}000\ nuggets} = 700 + 360 + 250 + 1600 = 2910kg$$

$$price\ per\ kg = \frac{2517}{2910} \approx €0.9/kg$$

This is much cheaper than the retail price of €8.76/kg. The retail price of the fish waste nuggets can be higher to make a profit and taxes have to be added. This will make the difference between the retail price and the fish waste nugget price a bit smaller. The specifics of this is out of scope so will not be looked into.

5.5 Conclusion

The production of garum involves both material and energy costs that contribute significantly to its overall expense. While the ingredients themselves are relatively simple fish waste, salt, herbs and water. The process requires constant heating for an entire year and periodic mixing using a motor. This results in an annual energy consumption of approximately 17,521 kWh, leading to an estimated energy cost of €965.40. Including material costs like herbs and water, the total cost of production comes to around €995.23. Due to the lack of clear data on the actual output of garum from the process. It is not possible to determine a reliable cost per kilogram. Concerns about product safety and consumer perception may pose challenges for commercialization. Because lab results did not arrive on time.

UV drying of fish waste presents a more controlled and hygienic method for preserving and processing fish byproducts. The use of UV light in combination with a heater and fan over two weeks results in a total energy consumption of approximately 220 kWh, with an estimated energy cost of €12. This method can process around 2.5 kilograms of fish waste per cycle leading to a cost of about €4.80 per kilogram. While the resulting dried fish is not suitable for direct human consumption in its current form (Lab results did not arrive in time) it holds potential for use in animal feed, pet food and fertilizer. The application of UV sterilization improves product safety and consistency making it a suitable approach for markets with strict hygiene regulations.

The nuggets show the most potential. It is not very energy intensive and can produce a lot of nuggets for only €0.90 per kilogram, much cheaper than the market price, and much cheaper than the dried fish. While the recipe for the nuggets need improvement before ready for consumption, it has a lot of promise to become a product ready for the market. Even if the market for fish nuggets fails, another plan is to use the paste for other products like cat food, supplement powder, or protein powder. These other options are not researched yet, but it is worth looking at.

6. Final conclusion

First of all, the aim of the project was to investigate and experiment ways to add extra-value to fish waste in order to boost the fishing industry in the Ostrobothnia region. The stakeholders in this project were the fishing industries and the slaughterers which are confronted with the problem of the fish waste management. When fish waste is in large quantities and management problems arise, these industries convert it into biogas. However, the fish slaughterers have to pay to do this which is not desirable. Therefore, the vision of this project, was to respond to this issue. The objectives were to investigate and experiment stabilization methods such as UV-stabilization and fermentation, extracting proteins from the fish waste and print fish nuggets using the proteins extracted from it. The fermentation method was conducted to obtain a byproduct called Garum, the goal was to go further on the process of making garum edible by human.

The fermentation process started promising with two batches and six buckets in total. The texture of the three different mixtures weren't oily enough after checking the buckets at eight weeks. This can be because of the fish batch that was used for this experiment which may not have been fatty enough to start the garum making process. Another reason will be because of the rotation machine which did not stir well enough to mix the solution every day. Another explanation might be that the water that was added to the fish waste was not sufficient enough to maintain a good fermentation process. The thing that must not be forgotten is the fact that the fermentation process for garum usually takes at least six months to settle, and it can last one year. The sample that was taken were samples after eight weeks of fermentation which might explain the results. Even though the samples were sent to a lab, the results did not came back in time to conclude in this report. This would clarify if the garum contained harmful bacteria or not which would conclude if the fermenting process was successful. Unfortunately, this is not included in this report.

UV sterilization was also tested as a method of preservation. Combined with heat drying, UV radiation is an established method to reduce microbial activity and extend the shelf life of organic materials like meat and fish. This was traditionally done centuries ago naturally with sunlight, but industrial methods now use UV chambers. This method showed promise in terms of preservation. More importantly it ties into an existing and scalable product market. Products such as dried salted anchovy are widely sold globally. UV-treated and dried fish powders are also used as animal feed supplements. These are already in production at scale making UV sterilization a viable method for adding value to fish waste. Although the experiments were small-scale, the method showed that with the right parameters (controlled drying and UV exposure), the dried material retained a firm texture and reduced odor, which is promising for upscaling. More optimization and microbial testing would be needed to confirm product safety for either human or animal consumption. Because the lab results did not come in time.

Then, protein extraction experiments have shown that it is possible to extract protein from fish waste using simple and efficient methods. Ultrasonic extraction has shown that extracting protein works and give good yield. Two byproducts from it have been identified: fish oil and fish paste rich in protein. However, Alkaline and Acidic solubilization methods haven't shown good results, the protein content of the fish paste derived from it was too low. Finally, enzymatic hydrolysis method was tested and gave good results, a full separation of the flesh from the bones occurred which gave potentially two byproducts suitable for human: bones and fish solution. However, further studies need to be done regarding enzymatic hydrolysis. But for now, the paste that was extracted from the fish waste using the ultrasonic cleaner which does contain a lot of protein was usable for the 3D food printer.

Lastly, the progress for the 3D printer. After research about different 3D food printers, the Felix Foodprinter Single was chosen for this project and was bought. While first successfully experimenting with some different products, the protein fish paste from the ultrasound experiment was used for the final fish nugget. The printing with this paste went very well and afterwards two methods of "cooking" were used: the baking and the frying. Even though the baking did not show the wanted result, the frying was a good solution and could even be compared to a normal fish nugget. This still needs a lot of experiments before it can become a real product, but the first steps are done.

To conclude the possibility of the use of fish waste there has also been some research about upscaling possibilities. In this the use of the ultrasounds to create the protein fish paste in combination with the 3D food printing to create the fish nuggets show the most promising results. This still needs some experiments and research, but it definitely has a lot of potential. The alternative use of fish waste still needs some more research and experiments however with the experiments that have been done, some really nice outcomes have been created which do give a nice start of a bigger solution.

7. Reflection

In the past few months, we learned the importance of teamwork and how essential it is to a project's success. Working as a team allows us to support each other and ensure we are not only focused on individual tasks. It also helps us to push each other to explore different approaches, even if it involves challenges. This mindset is crucial for finding innovative solutions.

One lesson was the value of starting early to account for unexpected troubleshooting and the time experiments costs in general. For example, when working on the Garum-making machine it took us several weeks to source the right materials, make repairs, and experiment with different methods. This experience taught us that it is often better to act when conditions or resources are not perfect. We gained valuable insights by doing that and identified new directions. Also, during the experiment itself things would take longer than expected. For example, during the experiment with the ultrasonic cleaner, the solution needs to be centrifugated, filtered and put into tubes which take times. When the planning for an experiment was done, we also looked at the time it would take. This so we had an idea at what time we needed to start the experiment and to finish in a reasonable time. However, this does take longer than one might expect. With this, some days became very long which also let to delays.

Time management also proved to be a critical factor. We realized with only a limited amount of time to complete everything. That the importance of prioritizing tasks and addressing issues quickly is important. This is a lesson that we also carried into the second half of the semester and one that is highly relevant in real-world businesses and projects. Recognizing the value of time and resolving challenges as efficiently as possible is essential for success and meeting goals. Eventually we did learn from our mistakes and started most processes as soon as possible. Still some experiments had some delays because of designing process or the preparations for the experiments. This also happened with the process of sending the samples. There were a few samples that needed to be tested by the lab, we had to be sure that we had enough of this sample which resulted in making extra batches which also took time. This created the situation that the samples were delivered quite late at the lab and that is also the reason why we did not have all of the results back in time. This is something that was really a shame because this is also one of the reasons why we could not complete conclusion of the garum and the UV lights experiments.

However, we did work hard these past few months and tried to finish the whole program as successful as possible while still enjoying the Finnish student life. We will say we look proudly back at this whole project and our stay in Finland. We learned a lot in the courses we got and about the whole fish waste industry. Also, we learned a lot about each other’s background, studies and culture. In the end we look back at the EPS program very positively with lots of beautiful moments.

8. References

(2020, 03). Retrieved from sciencedirect: https://www.sciencedirect.com/science/article/pii/S2215017X1930373X#:~:text=Furthermore%2C%20both%20sides%20of%20the,and%20available%20as%20supplementary%20materials.

(2020, 03). Retrieved from sciencedirect: https://www.sciencedirect.com/science/article/pii/S2215017X1930373X#:~:text=Furthermore%2C%20both%20sides%20of%20the,and%20available%20as%20supplementary%20materials.

(2023, 02 1). Retrieved from mdpi: https://www.mdpi.com/2304-8158/12/3/606

(2025). Retrieved from jula.fi: https://www.jula.fi/catalog/rakentaminen-ja-maalaus/sailytys/sailytyslaatikot/varastointilaatikot/kannellinen-tynnyri-020522/

(2025). Retrieved from mustad-fishing: https://mustad-fishing.com/eu/product/tr78np?colorName=Black+Nickel&hookSize=3%2F0

(2025). Retrieved from ebay: https://www.ebay.com/itm/315325657627

(2025). Retrieved from toimistotekniikka: https://www.toimistotekniikka.com/toimistotarvikkeet/bostik-blu-tack-sinitarra-60g-tarramassa-40292-5753/p/7311020057534/

(2025). Retrieved from aasiamarket: https://www.aasiamarket.fi/en/product/salted-dried-anchovy/

2589. (2025). Retrieved from .who.in: https://tbksp.who.int/en/node/2589

8-inch-uv-resistant. (2025). Retrieved from ziptie: https://ziptie.com/products/8-inch-uv-resistant-black-multi-purpose-cable-tie-120-lb-tensile-strength-ul-21s-listed-1000-pack

A Das, Y. N. (2021). *Fish protein hydrolysate production, treatment methods and current potential uses: A review*. Retrieved from Academia: https://d1wqtxts1xzle7.cloudfront.net/81032832/9-2-8-211-libre.pdf?1645291359=&response-content-disposition=inline%3B+filename%3DFish_protein_hydrolysate_production_trea.pdf&Expires=1742647645&Signature=Zc4isuSr~3coEDFtEH6H~DbWFfWHHmcEmwXNBf9S0UW6Lb2J~pEM

Aktion Österbotten. (n.d.). *Aktion Österbotten*. Retrieved from Aktion Österbotten: https://aktion.fi/en/

Aktion Österbotten. (n.d.). *Kustaktionsgruppen – KAG*. Retrieved from Aktion Österbotten: https://aktion.fi/fiske/

Alcalase® Enzyme, Bacillus licheniformis. (n.d.). Retrieved from Merck: https://www.sigmaaldrich.com/FI/en/product/mm/126741

Alibaba Group. (2025). *15L Lipgloss Filling machine Lipstick Heating Stirring Mixing Hopper Heater Tank Lip balm Chocolates Cream Nail Polish Lipgloss*. Retrieved from AliExpress: https://www.aliexpress.com/i/1005008158205296.html

alumiinifolio. (2025). Retrieved from maku.kitchen: https://maku.kitchen/tuotteet/alumiinifolio/

Amoeba Sisters. (2018, april 30). *Fermentation*. Retrieved from Amoeba Sisters: https://www.youtube.com/watch?v=YbdkbCU20_M&t=81s

Asorey, L. G. (2021). *Fresh Fish Degradation and Advances in Preservation Using.* Foods.

Babji, A. S. (2011, January). *Optimization of enzymatic hydrolysis of salmon (Salmo salar) skin by Alcalase*. Retrieved from ResearchGate: https://www.researchgate.net/publication/274080586_Optimization_of_enzymatic_hydrolysis_of_salmon_Salmo_salar_skin_by_Alcalase

Batista, I. (1999, December). *Recovery of proteins from fish waste products by alkaline extraction*. Retrieved from Springer nature: https://link.springer.com/article/10.1007/s002170050539

Britannica. (2025, march 27). *Fermentation; chemical reaction*. Retrieved from Britannica: https://www.britannica.com/science/fermentation

British Columbia Centre for Disease Control. (2014, januari). *Fish Cooking and Storage Temperatures.* Retrieved from British Columbia Centre for Disease Control: http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/FPS/Fish/FishStorageJan14.pdf

Carlos Álvarez, P. L. (2018, February). *Optimised protein recovery from mackerel whole fish by using sequential acid/alkaline isoelectric solubilization precipitation (ISP) extraction assisted by ultrasound*. Retrieved from ScienceDirect: https://www.sciencedirect.com/science/article/abs/pii/S002364381730720X?casa_token=xuXIxmHWMJgAAAAA:dpR3a1xFMPnf3ijUo_YWrTDrBujYYFvTE5xpoRvRU5qn1nrZaSQqMRyWRXDHP7Co92CtnTo0N-Fr

de Mar Selo. (2025). *Atlantic Horse Mackarel Garum*. Retrieved from Selo de Mar: https://selodemar.com/shop/en/product/atlantic-horse-mackarel-garum/

de Wolff, S. (2025, March 13). *Relay circuit*. Retrieved from Falstad: https://www.falstad.com/circuit/circuitjs.html?ctz=CQAgjCAMB0l3BWEBmAHAJmgdgGzoRmACzICcpkORKkISJdApgLRhgBQAbiOutfjhr8Eg2rSK0w6KDJgJ2AJRClBRVMsFhRMiXVlRo8gObhc4dOrBnk0sewDOGkGqdT11CADMAhgBt7jCAAKgCWALaMAE4cVpZmWrQq4DiSHga2BpBIYPDwmdLoYrBgSDCIUOwS1MiQwoLIOO

de Wolff, S. (2025, March 13). *Soft start circuit*. Retrieved from Falstad: https://www.falstad.com/circuit/circuitjs.html?ctz=CQAgjCAMB0l3BWEBmAHAJmgdgGzoRmACzICcpkORKkISJdApgLRhgBQYWqIRcIpHL35hS6EEIgxx0uKkrpFyLFnRFUpKLCRh48LZHHpaMSGCSnIO9gCdwYgZIfGetXXtv2jkHqPHJjKHA9SHYAExRkJ38oxxBxMMYAMwBDAFcAGwAXdiT41B4XSKEigPBoC1h0dgBjeIQSn3

Dian Haryati, A. N. (2024, December 30). *Characterization of yellowfin tuna (Thunnus albacares) skin gelatin extracted by bromelain hydrolysis and ultrasound pre-treatment*. Retrieved from Food Science: https://ift.onlinelibrary.wiley.com/doi/abs/10.1111/1750-3841.17610?casa_token=hGonveDAXQkAAAAA%3A7PKjZjTK56Wpni-naO7RkoNbMYb0rsVUQigIN4X88lTNmCwGw5e0LQmW9_TN3i24a0sFUJ9DJ5Edx5WnlA

dry-curing-cabinet. (2024). Retrieved from sausagemaker: https://sausagemaker.com/product/stainless-steel-digital-dry-curing-cabinet/

dry-meat-processing-news. (2024). Retrieved from bxdryer: https://www.bxdryer.com/news/industry-news/dry-meat-processing-news.html

E.S. (2015, March 11). *Stabilization, not only high temperatures*. Retrieved from Italian Foodtech: https://www.italianfoodtech.com/stabilization-not-only-high-temperatures/#:~:text=To%20stabilize%20and%20preserve%20food,extend%20the%20product%20shelf%2Dlife.

Fairfoull, P. d. (2021). *Comparison of Reflective Properties of Materials Exposed to Ultraviolet-C Radiation.* Inverness IV2 5NA, Scotland : National Institute of Standards and Technology . Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://nvlpubs.nist.gov/nistpubs/jres/126/jres.126.017.pdf

fao.org. (2024, 05). Retrieved from foa: https://www.fao.org/4/x6932e/x6932e02.htm

Felixprinters. (2024). *FELIX Food 1.6 - Single Head*. Retrieved from FelixFood: https://felixfood.nl/felix-food-single-head-1

findus-frionor-kalapuikko-250-g. (2025). Retrieved from minimani: https://www.minimani.fi/findus-frionor-kalapuikko-250-g.html

fishing.net.nz/fishing-advice. (2025). Retrieved from fishing.net: https://www.fishing.net.nz/fishing-advice/fishing-hints-tips-and-how-to-articles/how-to-make-every-scrap-count-when-filleting-your-fish/#:~:text=When%20you%20fillet%20a%20fish,the%20fish%20is%20potentially%20wasted.

fishpoint.net. (2025). Retrieved from fishpoint: https://www.fishpoint.net/english

foa.org/fishery. (2024, 06). Retrieved from Foa.org: https://www.fao.org/fishery/en/facp/fin

Garage, D. (2024, march 1). *Ultrasonic Cleaners.. Do they actually work ?* Retrieved from Delboy's Garage: https://www.youtube.com/watch?v=5dfvY1xU8-Q

Garre. (2025). *Garum Fish Sauce| Weight: 100 grams*. Retrieved from Salazonesgarre: https://www.salazonesgarre.com/salted-and-smoked/product-detail/salsa-garum-bote-100g/41/eng.html

Ghaly AE*, R. V. (2013). *Fish Processing Wastes as a Potential Source of Proteins, Amino Acids*. Retrieved from Microbial & Biochemical Technology: file:///C:/Users/33783/OneDrive/Documents/PREPARATOIRE%20ENIT%20DE%20TARBES/MOBILITE%20S7%20ou%20S8/EPS%20PROJECT/protein%20extraction/General%20information/Bible.pdf

Grainger, S. (2020). *The story of Garum; Fermented fish sauce and salted fish in the ancient world. .* London: Routledge.

Grand View Research. (2025). *Fish Sauce Market Size, Share And Growth Report, 2030*. Retrieved from www.grandviewresearch.com: https://www.grandviewresearch.com/industry-analysis/fish-sauce-market

Großkinsky, D. (2020, July 28). *Fermentation: Humanity's Oldest Biotechnological Tool*. Retrieved from Frontiers: https://kids.frontiersin.org/articles/10.3389/frym.2021.568656#:~:text=Fermentation%20is%20a%20process%20in,foods%2C%20medicines%2C%20and%20fuels.

Helen Ltd. (2025, 05). *Market Price Electricity*. Retrieved from Helen: https://www.helen.fi/en/electricity/electricity-products-and-prices/marketpriceelectricity

Helgi Nolsøe, I. U. (2008, June). *The Acid and Alkaline Solubilization Process for the Isolation of Muscle Proteins: State of the Art*. Retrieved from Springer Nature: https://link.springer.com/article/10.1007/s11947-008-0088-4

Helsinki Region Environmental Services HSY. (2025, 01). *The pricelist and service fee price list for HSY Water Services 2025*. Retrieved from HSY: https://julkaisu.hsy.fi/en/index/the-pricelist-and-service-fee-price-list-for-hsy-water-services-2025/2_2.html

Hina Kamal, C. F. (2021, April). *Extraction of protein from food waste: An overview of current status and opportunities*. Retrieved from Wiley Library: https://ift.onlinelibrary.wiley.com/doi/full/10.1111/1541-4337.12739

Hollins, P. (2025, February 27). Project Managment scoping; Work Breakdown Structure and scheduling . *Planning WBS and scheduling* . Vaasa , Ostrotbotnia, Finland: Novia UAS.

J. Araujo, P. S. (2020, March). *Enzymatic Hydrolysis of Fish Waste as an Alternative to Produce High* . Retrieved from Springer Nature: https://link.springer.com/article/10.1007/s12649-020-01029-x

Kalatalous verkosto. (n.d.). *Blue Products 3.0 – New product development program*. Retrieved from Kalatalous verkosto: https://maaseutuverkosto.fi/en/national-fisheries-network/research-networks-and-innovation-programs/blue-products/

Mackenzie, R. (2025). *technologynetworks.com/genomics/articles/what-are-the-key-differences-between-dna-and-rna*. Retrieved from technologynetworks: https://www.technologynetworks.com/genomics/articles/what-are-the-key-differences-between-dna-and-rna-296719#:~:text=DNA%20is%20double%2Dstranded%2C%20forming,uracil%2C%20cytosine%2C%20and%20guanine.

Miriam Hubinger, V. M. (2011, February). *Production and shelf life of mussel meat powder flavor*. Retrieved from ResearchGate: https://www.researchgate.net/publication/287289439_Production_and_shelf_life_of_mussel_meat_powder_flavor

Muhammad A.B. Siddik, J. H. (2020, July). *Enzymatic fish protein hydrolysates in finfish aquaculture: a review*. Retrieved from Wiley Online Library: https://onlinelibrary.wiley.com/doi/full/10.1111/raq.12481

Novia UAS. (2025). *European project semester*. Retrieved from Novia: https://www.novia.fi/en/eps

Objectgears. (2018, December 27). *Objectgears*. Retrieved from Objectgears: https://doc.objectgears.cz/vcd/en-US/team-roles-by-belbin

omega-3. (2025). Retrieved from bodylab: https://www.bodylab.fi/shop/bodylab-omega-3-4934p.html?gad_source=1&gad_campaignid=15491093005&gbraid=0AAAACuKxhiVUwP8aYU1yxF4qZ1qy05jW&gclid=Cj0KCQjwoZbBBhDCARIsAOqMEZV6vM9sB5ySX9SIVrJvxBHmBL_gIDwD2V-w5JkrpJNKJp12njsNPIIaAoMhEALw_wcB&gclsrc=aw.ds

Pharmacie Kivihaka Stenhaga Apotek. (2013). *Pharmacie Kivihaka Stenhaga Apotek*. Retrieved from Pharmacie Kivihaka Stenhaga Apotek: https://www.apteekkikivihaka.fi/fi/tuotteet/vatsa/creon-25-000-enterokaps-kova-100-kpl.html

pmc.ncbi.nlm.nih.gov. (2025). Retrieved from pmc.ncbi: https://pmc.ncbi.nlm.nih.gov/articles/PMC9397527/

power-extension-cord. (2025). Retrieved from sencor: https://www.sencor.com/power-extension-cord/spc-30

product/stainless-steel-digital-dry-curing-cabinet. (2024). Retrieved from sausagemaker: https://sausagemaker.com/product/stainless-steel-digital-dry-curing-cabinet/

Ramirig, D. (2018, july 28). *What happens when you ferment foods?* Retrieved from Fermented Food Lab: https://www.fermentedfoodlab.com/what-happens-when-you-ferment-foods/

rna-vs-dna-whats-the-difference. (2024, 4 14). Retrieved from genomicsengland: https://www.genomicsengland.co.uk/blog/genomics-101-rna-vs-dna-whats-the-difference

salted-dried-anchovy. (2025). Retrieved from aasiamarket: https://www.aasiamarket.fi/en/product/salted-dried-anchovy/

sdgs.un.org. (2025). Retrieved from sdgs: https://sdgs.un.org/goals

sdgs.un.org. (2025). Retrieved from sdgs: https://sdgs.un.org/goals

Selina Wamucii. (2025). *Finland Prices, Trends & Insights*. Retrieved from Selina Wamucii: https://www.selinawamucii.com/insights/prices/finland/

Silvino Sasso Robalo, G. C. (2025). *Ultrasound applied at low temperature on the extraction and modification of proteins from by-products of the fishing industry*. Retrieved from Scielo Brazil: file:///C:/Users/33783/Downloads/p%20fr.pdf

southafrica.campusfrance.org/erasmus-programmes. (2009). Retrieved from southafrica.campusfrance: https://www.southafrica.campusfrance.org/erasmus-programmes

statista.com/fish-and-seafood-industry-in-finland. (2025, 02 19). Retrieved from Statista: https://www.statista.com/topics/12023/fish-and-seafood-industry-in-finland/#topicOverview

Swapna C. Hathwar, B. B. (2010, November). *Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases*. Retrieved from Springer nature: https://link.springer.com/article/10.1007/s12010-010-9119-5

Swapna C. Hathwar, B. B. (2010, November). *Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases*. Retrieved from Springer Nature: https://link.springer.com/article/10.1007/s12010-010-9119-5

Swapna C. Hathwar, B. B. (2010, November). *Simultaneous Recovery of Lipids and Proteins by Enzymatic Hydrolysis of Fish Industry Waste Using Different Commercial Proteases*. Retrieved from Springer Nature: https://link.springer.com/article/10.1007/s12010-010-9119-5

The University of Newcastle. (2024, November 26). *Research Methods: What are research methods?* Retrieved from The University of Newcastle, Australia : https://libguides.newcastle.edu.au/researchmethods

ultraviolet-disinfection-guidance-manual. (2006). Retrieved from epa.gov: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.epa.gov/system/files/documents/2022-10/ultraviolet-disinfection-guidance-manual-2006.pd

ultraviolet-radiation. (2020). Retrieved from who.int: https://www.who.int/news-room/fact-sheets/detail/ultraviolet-radiation?

vaasa.fi/en/about-vaasa-and-the-vaasa-region/the-vaasa-region-in-numbers/statistics-business-activity-and-regional-economy. (2025). Retrieved from vaasa.fi: https://www.vaasa.fi/en/about-vaasa-and-the-vaasa-region/the-vaasa-region-in-numbers/statistics-business-activity-and-regional-economy/

ventilator-24-volt-dc. (2025). Retrieved from smorenberg: https://smorenberg.com/product/ventilator-24-volt-dc-120-x-120-x-25-mm/

Waite, Z. (2025). *ossila.com/pages/uv-sterilization*. Retrieved from ossila: ossila.com/pages/uv-sterilization

wikipedia.org/wiki/Ostrobothnia. (2025, 03 11). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Ostrobothnia_%28region%29

yleiskoysi-3mm. (2025). Retrieved from minimani: https://www.minimani.fi/retki-yleiskoysi-3mm-15m.html

YRKESHÖGSKOLAN NOVIA

9. Appendices

Appendix A: Belbin test
Belbin Test

The Belbin test is a team role test identifier that categorizes an individual's traits and puts them into a specific team role (Figure 1). This test was made because the Belbin theory suggests that if you understand how you contribute to a team, you can develop your leadership skills and strengths and manage your weaknesses. This is divided into 3 categories: thinking, action, people -roles.

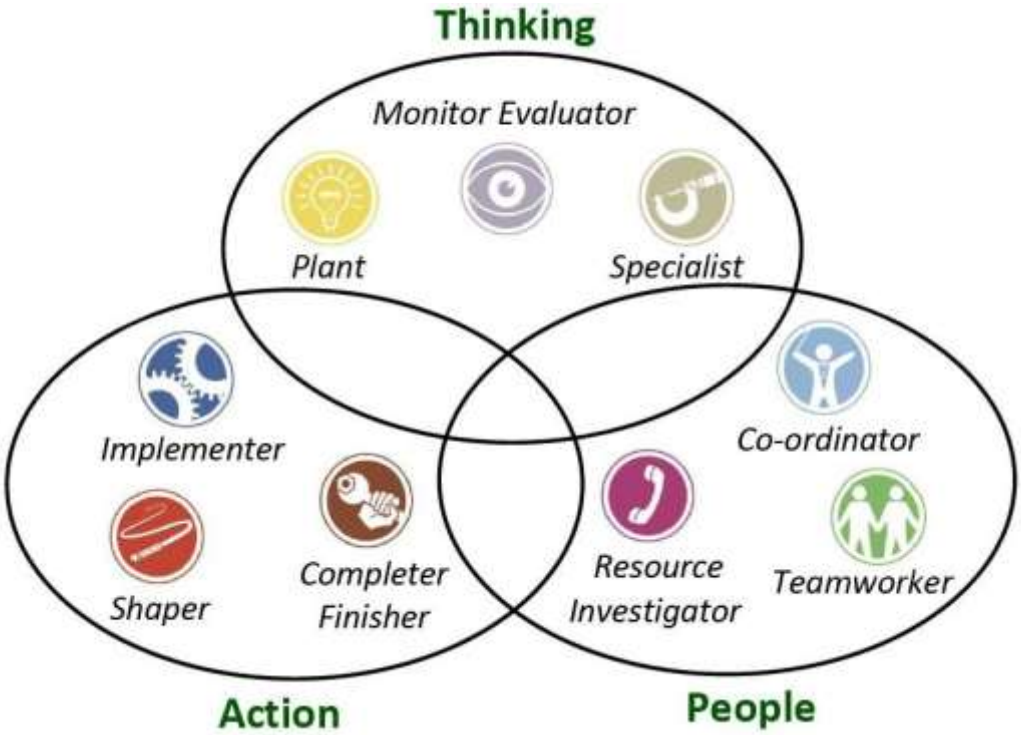


Figure 1: Belbin roles (Objectgears, 2018)

Summary:

- **Plant:** Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.
- **Monitor Evaluator:** Sober, strategic, discerning, sees all options and judges accurately.
- **Specialist:** Single-minded, self-starting, dedicated, provides knowledge and skills in rare supply
- **Coordinator:** Mature, confident, identifies talent, Clarifies goals and delegates effectively.
- **Teamwork:** Co-operative, perceptive, diplomatic, listens and averts friction.
- **Resource investigator:** Outgoing, enthusiastic, communicative, explores opportunities and develops contacts.
- **Complete finisher:** Painstaking, conscientious, anxious, searches out errors, polishes and perfects.
- **Shaper:** Challenging, dynamic, thrives on pressure, has the drive and courage to overcome obstacles.
- **Implementer:** Practical, reliable, efficient, turns ideas into actions and organizes work that needs to be done.

Individual results

Eben Pelsmakers

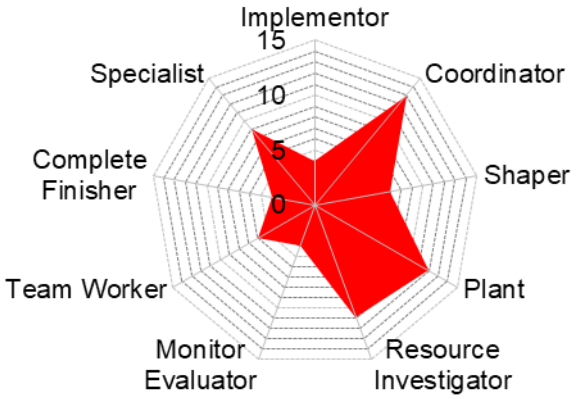


Chart 1: Belbin test Eben Pelsmakers

Strongest roles

- **Coordinator [13]:** Mature, self-confident, clarifies goals to be achieved, promotes decision-making, delegates well.
- **Plant [12]:** Challenging, dynamic, works well under pressure, has initiative and courage to overcome obstacles.
- **Resource investigator [11]:** outgoing, enthusiastic, communicative, seeks new opportunities, develops contacts.

Weakest roles

- **Implementor [4]:** Disciplined, loyal, conservative, efficient, transforms ideas into action.
- **Monitor evaluator [4]:** Serious, perceptive, strategic, perceives all options, accurate judgment.
- **Complete finisher [4]:** Painstaking, conscientious, anxious, looks for errors and omissions, completes tasks on time.

Evaluation

I see myself as a coordinator because I am professional and confident, and set clear goals for myself and my team. I support decision-making, though I haven't focused on it much. This role aligns well with resource investigator, as I am social, communicative, and able to manage people based on their strengths and preferences.

As a plant, I am dynamic and work well under pressure. I often complete tasks late, which increases my efficiency. I seek challenges but sometimes struggle with obstacles due to a lack of courage or initiative.

Resource investigator fits me perfectly. I am outgoing, enthusiastic, and always looking for new opportunities. I agree with my weaker areas but disagree with my low teamwork score. I think I am a good team player.

Aurélien Mur

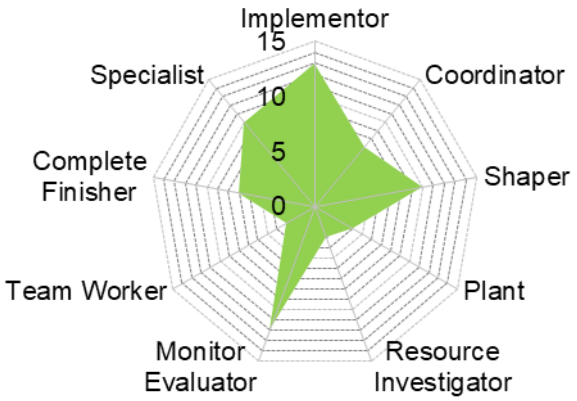


Chart 2: Belbin test Aurélien Mur

Strongest roles

- **Implementor [13]**: Disciplined, loyal, conservative, efficient, transforms ideas into action.
- **Monitor evaluator [12]:** Serious, perceptive, strategic, perceives all options, accurate judgment.

Weakest roles

- **Plant [4]:** Challenging, dynamic, works well under pressure, has initiative and courage to overcome obstacles.
- **Resource investigator [3]:** outgoing, enthusiastic, communicative, seeks new opportunities, develops contacts.
- **Team worker [3]:** Cooperative, gentle, perceptive and diplomatic. Listens and avoids confrontation.

Evaluation

The Belbin test reveals that I'm mainly an implementor and monitor evaluator, which means that I listen to other people, I am disciplined, serious, perceptive and strategic. Which is quite true, I like to first consider all the options before acting. I'm surprised with the team worker score that I had, 3 for me is a bit low, even if I prefer to work alone. However, I don't agree with the shaper things, because I'm not that creative and imaginative. I don't agree with my score for coordinator, I was expecting to have a higher score, because I'm a mature, self-confident person. I like to clarify goals to be achieved.

Fabiënne Kuiper

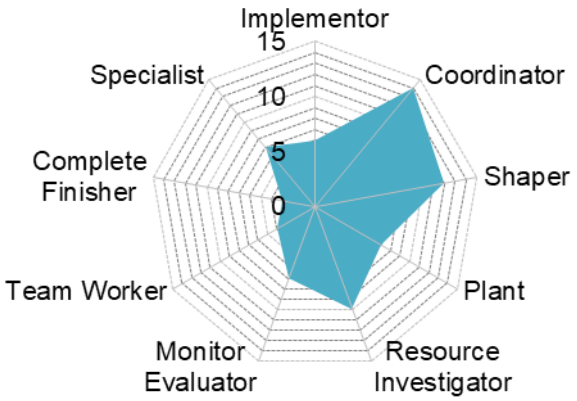


Chart 3: Belbin test Fabiënne Kuiper

Strongest roles

- **Coordinator [14]:** Mature, self-confident, clarifies goals to be achieved, promotes decision-making, delegates well.
- **Shaper [12]:** Creative, imaginative, unorthodox.

Weakest roles

- **Team worker [4]:** Cooperative, gentle, perceptive and diplomatic. Listens and avoids confrontation.
- **Complete finisher [3]**: Painstaking, conscientious, anxious. Looks for errors and omissions. Completes tasks on time.

Evaluation

In my BELBIN test for the European Project Semester, my strongest roles were Coordinator and Shaper, indicating leadership and the ability to push a team forward. Though sometimes I can be manipulative or argumentative. I enjoy teamwork and leading when making decisions or planning. My lowest scores were for Team Worker and Completer Finisher. I agree with the latter as I prefer starting projects over finishing them. However, I see myself as a team player. The low score surprised me, I believe it resulted from prioritizing other roles. I expected a higher score in Resource Investigator (despite scoring 10) due to my enthusiasm and networking skills. Also given my architecture background, I thought I'd score higher in the Plant role as creative problem-solving suits the field. Overall, the test results reflect a well-balanced assessment.

Senne De Wolff

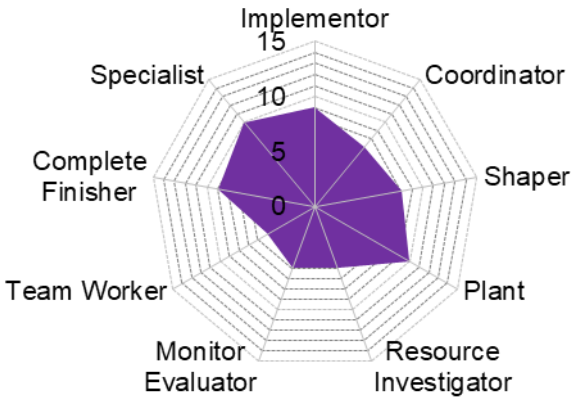


Chart 4: Belbin test Senne de Wolff.

Strongest roles

- **Plant [10]:** Challenging, dynamic, works well under pressure, has an initiative and courage to overcome obstacles.
- **Specialist [10]:** is only interested in one thing at a time. Brings specific qualities and knowledge.

Weakest roles

- **Resource investigator [6]:** outgoing, enthusiastic, communicative, seeks new opportunities, develops contacts.
- **Monitor evaluator [6]:** Serious, perceptive, strategic, perceives all options, accurate judgment.
- **Team worker [5]:** Cooperative, gentle, perceptive and diplomatic. Listens and avoids confrontation.

Evaluation

My top 2 scores are for the Plant and the Specialist. I did expect those two to come out on top since they are very accurate with how I view myself. I am very solution oriented and try to simulate my creative thought processes as much as I can. I also really enjoy specializing in very specific topics. You can see this in my educational background, I am very specialized in Sensors. Implementor and complete finisher are also quite high, which I think is quite accurate. I am very fond of organizing things as efficiently as possible, and I can be quite a perfectionist sometimes.

I would suspect team worker would be higher because I can be quite flexible in working with people. But the test is still quite accurate since there are a couple of specific working methods that I do have to follow, otherwise I have a really hard time adapting.

Team results

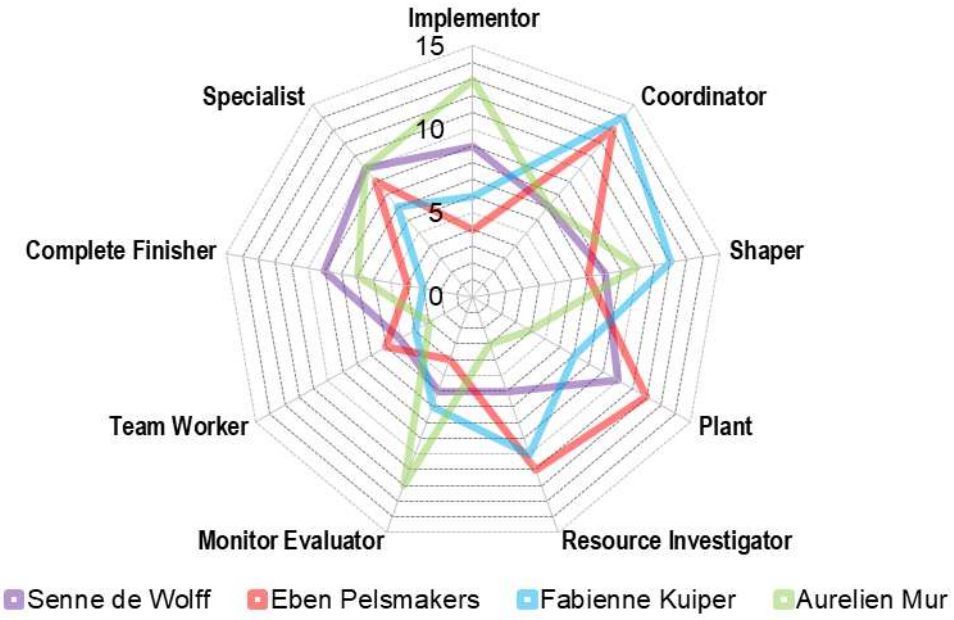


Chart 5: Belbin test team.

Our group has a well-rounded role chart, except for the role of team worker. This means we should be able to work well together. But we need to be aware that we are weaker in the team worker role. This could result in a pitfall for us as a team. We need to be more attentive to being gentle with each other and cooperative to support one another and compensate for our other weak points. Additionally, we should be diplomatic in establishing a common goal and resolving issues between parties. Both within and outside the group. We must listen to each other's ideas and concerns and strive to avoid conflicts within the team. We should pay extra attention to these aspects of the team worker role.

Appendix B: Nutritional analysis result EPS1

eurofins | Scientific Finland

Sample code Nr.	**493-2025-00027034**	**Date**	**7.5.2025**	**Page 1 / 1**
Analytical Report Nr.	**AR-25-FL-014002-01**			

Ab Yrkeshögskolan vid Åbo Akademi
Mikael Ehrs
Wolffskavägen 31
65200 Vaasa
FINLAND

Client Code:: FL0003758

Copy to: Aurelien Mur (aurelien.mur@edu.novia.fi), Mikael Ehrs (mikael.ehrs@novia.fi)

Sample described as:	EPS 1		
Sample reception date:	25.04.2025	**Analysis Starting Date:**	25.04.2025

Food nutrients			Results (MU)
LW1RG	**LW**	**Crude Fat in food and cereal products Method: NMKL 160:1998 mod. Gravimetry**	
(a)	Crude fat		0,12 (± 0,04) g/100 g
LP06U	**LW**	**Moisture in food Method: NMKL 206:2024 Gravimetry**	
(a)	Moisture		97,6 (± 9,76) g/100 g
LP021	**LW**	**Crude Protein (Nx6.25) (Kjeldahl) Method: NMKL 6:2003 mod. Kjeldahl (titrimetry)**	
(a)	Crude Protein Kjeldahl (Nx6,25)		2,15 (± 0,22) g/100 g
LP06V	**LW**	**Ash in food Method: NMKL 173:2005 mod. Gravimetry**	
(a)	Ash total		0,35 (± 0,04) g/100 g
LP06Z	**LW**	**Carbohydrates calculated Method: EC reg 1169/2011 Calculation**	
(a)	Carbohydrate (calculated)		-0,22 g/100 g
LP072	**LW**	**Energy calculated Method: EC reg 1169/2011 Calculation**	
(a)	Energy value kJ (calculated)		41 kJ/100 g
(a)	Energy value kcal (calculated)		10 kcal/100 g

SIGNATURE

Sirpa Kaukonen
Analytical Service Manager (ASM) CFI001
+358 447819005

EXPLANATORY NOTE
This report shall not be reproduced expect in full. The results relate only to the sample analyzed. The laboratory is not responsible for the accuracy of the information received from the customer. Accredited methods of the analyzing laboratory have been evaluated by the national accreditation body of the country in question. Additional information on measurement uncertainties are available upon request. This report has been created electronically and has been verified and authorized. The results apply to the sample as received.
(a) = Accredited analysis
(MU) = Expanded measurement uncertainty (k=2)

LW - Eurofins Food & Feed Testing Sweden (Lidköping), SWEDEN - ISO/IEC 17025:2017 SWEDAC 1977

Appendix C: Nutritional analysis result EPS2

eurofins | Scientific Finland

Sample code Nr.	**493-2025-00027035**	**Date**	**7.5.2025**	**Page 1 / 1**
Analytical Report Nr.	**AR-25-FL-014003-01**			

Ab Yrkeshögskolan vid Åbo Akademi Client Code:: FL0003758

Mikael Ehrs
Wolffskavägen 31
65200 Vaasa
FINLAND

Copy to: Aurelien Mur (aurelien.mur@edu.novia.fi), Mikael Ehrs (mikael.ehrs@novia.fi)

Sample described as:	EPS 2		
Sample reception date:	25.04.2025	**Analysis Starting Date:**	25.04.2025

Food nutrients			Results (MU)
LW1RG	**LW**	**Crude Fat in food and cereal products Method: NMKL 160:1998 mod. Gravimetry**	
(a)	Crude fat		3,56 (± 0,36) g/100 g
LP06U	**LW**	**Moisture in food Method: NMKL 206:2024 Gravimetry**	
(a)	Moisture		80,4 (± 8,04) g/100 g
LP021	**LW**	**Crude Protein (Nx6.25) (Kjeldahl) Method: NMKL 6:2003 mod. Kjeldahl (titrimetry)**	
(a)	Crude Protein Kjeldahl (Nx6,25)		15,5 (± 1,55) g/100 g
LP06V	**LW**	**Ash in food Method: NMKL 173:2005 mod. Gravimetry**	
(a)	Ash total		0,46 (± 0,05) g/100 g
LP06Z	**LW**	**Carbohydrates calculated Method: EC reg 1169/2011 Calculation**	
(a)	Carbohydrate (calculated)		0,08 g/100 g
LP072	**LW**	**Energy calculated Method: EC reg 1169/2011 Calculation**	
(a)	Energy value kJ (calculated)		397 kJ/100 g
(a)	Energy value kcal (calculated)		94 kcal/100 g

SIGNATURE

Sirpa Kaukonen
Analytical Service Manager (ASM) CFI001
+358 447819005

EXPLANATORY NOTE

This report shall not be reproduced expect in full. The results relate only to the sample analyzed. The laboratory is not responsible for the accuracy of the information received from the customer. Accredited methods of the analyzing laboratory have been evaluated by the national accreditation body of the country in question. Additional information on measurement uncertainties are available upon request. This report has been created electronically and has been verified and authorized. The results apply to the sample as received.
(a) = Accredited analysis
(MU) = Expanded measurement uncertainty (k=2)

LW - Eurofins Food & Feed Testing Sweden (Lidköping), SWEDEN - ISO/IEC 17025:2017 SWEDAC 1977

Appendix D: Nutritional analysis result EPS3

eurofins | Scientific Finland

Sample code Nr.	**493-2025-00027036**	**Date**	**7.5.2025**	**Page 1 / 1**
Analytical Report Nr.	**AR-25-FL-014004-01**			

Ab Yrkeshögskolan vid Åbo Akademi
Mikael Ehrs
Wolffskavägen 31
65200 Vaasa
FINLAND

Client Code:: FL0003758

Copy to: Aurelien Mur (aurelien.mur@edu.novia.fi), Mikael Ehrs (mikael.ehrs@novia.fi)

Sample described as: EPS 3
Sample reception date: 25.04.2025 **Analysis Starting Date:** 25.04.2025

Food nutrients			Results (MU)
LW1RG	**LW**	**Crude Fat in food and cereal products Method: NMKL 160:1998 mod. Gravimetry**	
(a)	Crude fat		0,40 (± 0,12) g/100 g
LP06U	**LW**	**Moisture in food Method: NMKL 206:2024 Gravimetry**	
(a)	Moisture		99,5 (± 9,95) g/100 g
LP021	**LW**	**Crude Protein (Nx6.25) (Kjeldahl) Method: NMKL 6:2003 mod. Kjeldahl (titrimetry)**	
(a)	Crude Protein Kjeldahl (Nx6,25)		0,49 (± 0,1) g/100 g
LP06V	**LW**	**Ash in food Method: NMKL 173:2005 mod. Gravimetry**	
(a)	Ash total		<0,10 g/100 g
LP06Z	**LW**	**Carbohydrates calculated Method: EC reg 1169/2011 Calculation**	
(a)	Carbohydrate (calculated)		-0,39 g/100 g
LP072	**LW**	**Energy calculated Method: EC reg 1169/2011 Calculation**	
(a)	Energy value kJ (calculated)		23 kJ/100 g
(a)	Energy value kcal (calculated)		6 kcal/100 g

SIGNATURE

Sirpa Kaukonen
Analytical Service Manager (ASM) CFI001
+358 447819005

EXPLANATORY NOTE
This report shall not be reproduced expect in full. The results relate only to the sample analyzed. The laboratory is not responsible for the accuracy of the information received from the customer. Accredited methods of the analyzing laboratory have been evaluated by the national accreditation body of the country in question. Additional information on measurement uncertainties are available upon request. This report has been created electronically and has been verified and authorized. The results apply to the sample as received.
(a) = Accredited analysis
(MU) = Expanded measurement uncertainty (k=2)

LW - Eurofins Food & Feed Testing Sweden (Lidköping), SWEDEN - ISO/IEC 17025:2017 SWEDAC 1977

Appendix E: Nutritional analysis result EPS4

eurofins | Scientific Finland

Sample code Nr.	**493-2025-00027037**	**Date**	**7.5.2025**	**Page 1 / 1**
Analytical Report Nr.	**AR-25-FL-014005-01**			

Ab Yrkeshögskolan vid Åbo Akademi
Mikael Ehrs
Wolffskavägen 31
65200 Vaasa
FINLAND

Client Code:: FL0003758

Copy to: Aurelien Mur (aurelien.mur@edu.novia.fi), Mikael Ehrs (mikael.ehrs@novia.fi)

Sample described as:	EPS 4		
Sample reception date:	25.04.2025	**Analysis Starting Date:**	25.04.2025

Food nutrients			Results (MU)
LW1RG	**LW**	**Crude Fat in food and cereal products Method: NMKL 160:1998 mod. Gravimetry**	
(a)	Crude fat		2,75 (± 0,27) g/100 g
LP06U	**LW**	**Moisture in food Method: NMKL 206:2024 Gravimetry**	
(a)	Moisture		92,8 (± 9,28) g/100 g
LP021	**LW**	**Crude Protein (Nx6.25) (Kjeldahl) Method: NMKL 6:2003 mod. Kjeldahl (titrimetry)**	
(a)	Crude Protein Kjeldahl (Nx6,25)		4,08 (± 0,41) g/100 g
LP06V	**LW**	**Ash in food Method: NMKL 173:2005 mod. Gravimetry**	
(a)	Ash total		0,12 (± 0,01) g/100 g
LP06Z	**LW**	**Carbohydrates calculated Method: EC reg 1169/2011 Calculation**	
(a)	Carbohydrate (calculated)		0,25 g/100 g
LP072	**LW**	**Energy calculated Method: EC reg 1169/2011 Calculation**	
(a)	Energy value kJ (calculated)		175 kJ/100 g
(a)	Energy value kcal (calculated)		42 kcal/100 g

SIGNATURE

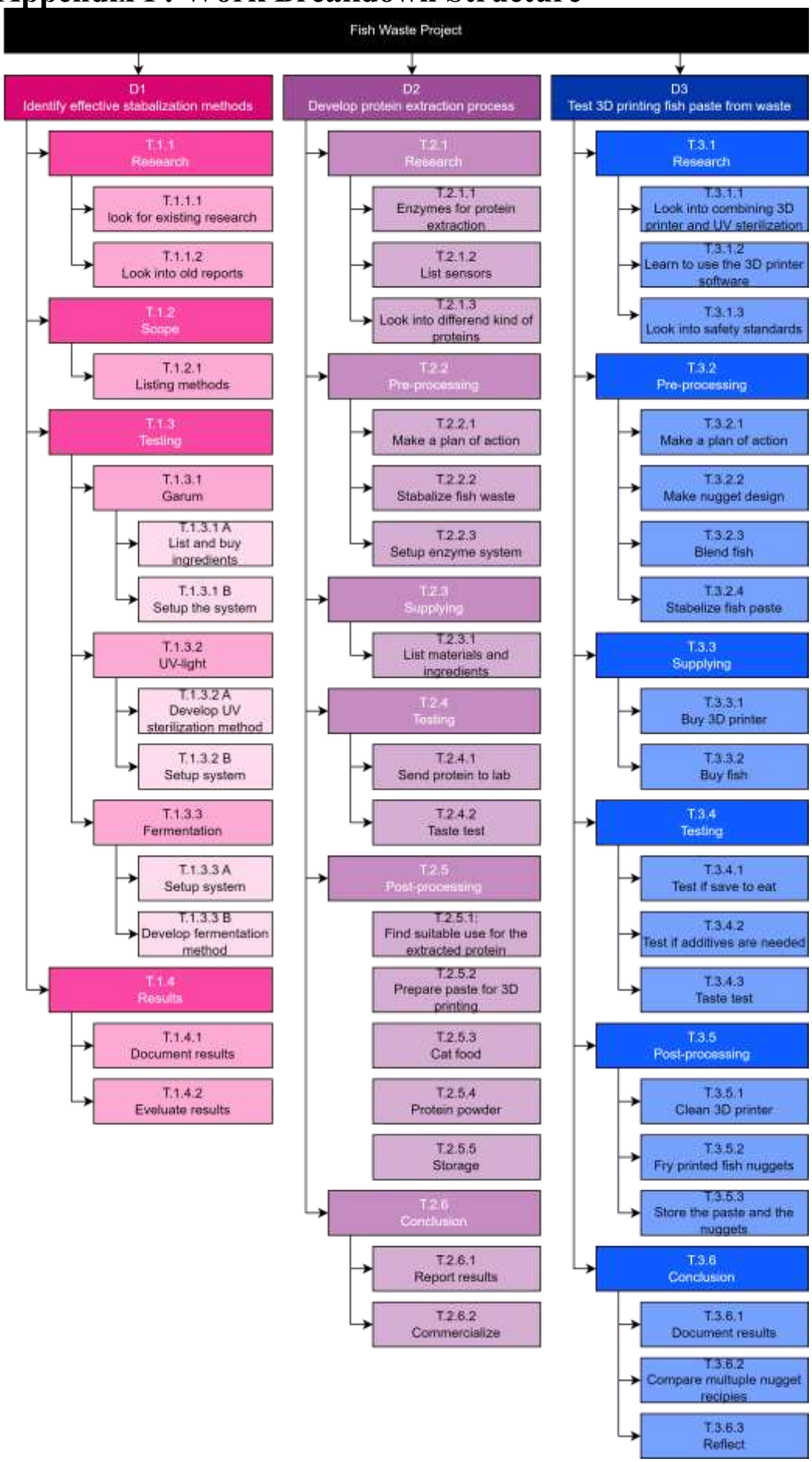
Sirpa Kaukonen
Analytical Service Manager (ASM) CFI001
+358 447819005

EXPLANATORY NOTE

This report shall not be reproduced expect in full. The results relate only to the sample analyzed. The laboratory is not responsible for the accuracy of the information received from the customer. Accredited methods of the analyzing laboratory have been evaluated by the national accreditation body of the country in question. Additional information on measurement uncertainties are available upon request. This report has been created electronically and has been verified and authorized. The results apply to the sample as received.
(a) = Accredited analysis
(MU) = Expanded measurement uncertainty (k=2)

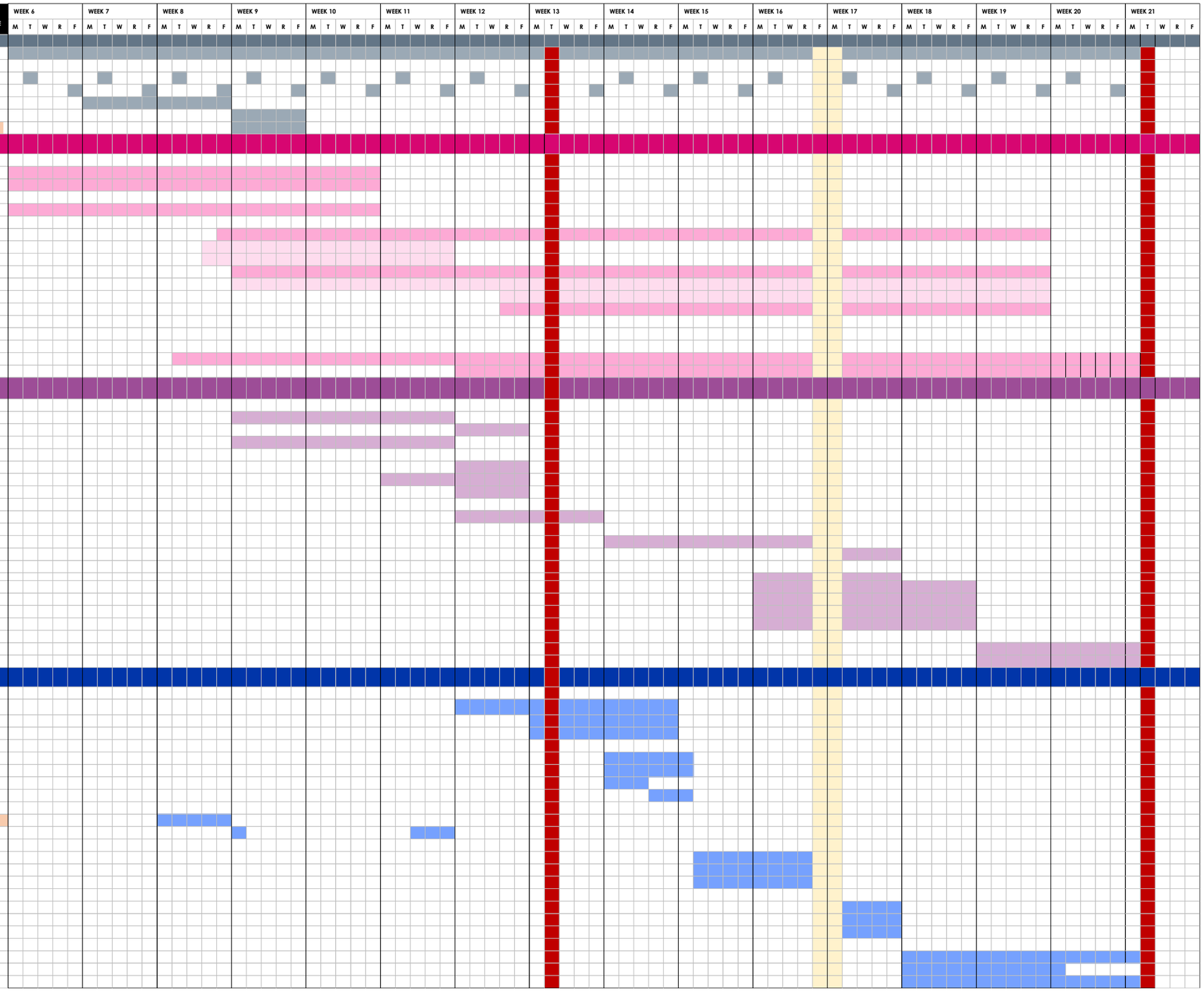
LW - Eurofins Food & Feed Testing Sweden (Lidköping), SWEDEN - ISO/IEC 17025:2017 SWEDAC 1977

Appendix F: Work Breakdown Structure



Appendix G: Schedule

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (Days)	% of TASK COMPLETE
D0	General tasks					
T.0.1	Documentaion	everyone	3-2-2025	20-5-2025	98	10%
T.0.2	Stakeholders contacting	everyone	3-2-2025	25-5-2025	98	5%
T.0.3	Meetings with coach	everyone	3-2-2025	25-5-2025	20	25%
T.0.4	Instagram updates	everyone	3-2-2025	25-5-2025	20	0%
T.0.5	Planning	everyone	20-2-2025	6-3-2025	10	30%
T.06	Make a WBS	everyone	20-2-2025	6-3-2025	5	80%
T.0.7	Make a schedule	everyone	20-2-2025	6-3-2025	5	90%
D1	Identify effective stabilization methods					
T.1.1	Research					0%
T.1.1.1	Look into old reports	everyone	3-2-2025	7-3-2025	25	80%
T.1.1.2	Look for existing research	everyone	3-2-2025	7-3-2025	25	70%
T.1.2	Scope					0%
T.1.2 .1	Listing methods	everyone	3-2-2025	7-3-2025	25	0%
T.1.3	Testing					0%
T.1.3.1	Garum	everyone	21-2-2025	19-5-2025	54	50%
T.1.3.1 A	List and buy materials	everyone	18-2-2025	14-3-2025	17	80%
T.1.3.1 B	Setup system	everyone	18-2-2025	14-3-2025	17	60%
T.1.3.2	UV-lights	everyone	24-2-2025	16-5-2025	53	0%
T.1.3.2. A	Develop UV sterilization method	Eben	24-2-2025	16-5-2025	53	5%
T.1.3.2. B	Setup system	everyone	20-3-2025	16-5-2025	35	0%
T.1.3.3	Fermentation	everyone	20-3-2025	16-5-2025	35	0%
T.1.3.3 A	Setup system	everyone				0%
T.1.3.3 B	Experiment with fermentation box	everyone				0%
T.1.4	Results					0%
T.1.4.1	Document results	everyone	18-2-2025	16-5-2025	62	5%
T.1.4.2	Evaluate results	everyone	14-3-2025	16-5-2025	38	1%
D2	Develop protein extraction process					
T.2.1	Research					0%
T.2.1.1	Ezymes for protein extraction	Fabiënne, Aurelien	24-2-2025	14-3-2025	15	30%
T.2.1.2	List sensors	Fabiënne, Aurelien	17-3-2025	21-3-2025	5	0%
T.2.1.3	Look into differend kind of proteins	Fabiënne, Aurelien	24-2-2025	14-3-2025	15	10%
T.2.2	Pre-processing					0%
T.1.2 .1	Make a plan of action	Fabiënne, Aurelien	17-3-2025	21-3-2025	5	0%
T.1.2.2	Stabilize fish waste	Fabiënne, Aurelien	10-3-2025	17-3-2025	10	0%
T.1.2.3	Setup enzyme system	everyone	17-3-2025	21-3-2025	5	0%
T.2.3	Supplying					0%
T.2.3.1	Listing materials and ingredients	everyone	17-3-2025	28-3-2025	10	0%
T.2.4	Testing					0%
T.2.4.1	Send protein to lab	everyone	31-3-2025	17-4-2025	14	0%
T.2.4.2	Taste test	everyone	22-4-2025	25-4-2025	4	0%
T.2.5	Post-processing					0%
T.2.5.1	Find suitable use for the extranced protein	Fabiënne, Aurelien	14-4-2025	25-4-2025	8	0%
T.2.5.2	Prepare paste for 3D printing	everyone	14-4-2025	2-5-2025	13	0%
T.2.5.3	Cat food	everyone	14-4-2025	2-5-2025	13	0%
T.2.5.4	Protein powder	Fabiënne, Aurelien	14-4-2025	2-5-2025	13	0%
T.2.5.5	Storage	Fabiënne, Aurelien	14-4-2025	2-5-2025	13	0%
T.2.6	Conclusion					0%
T.2.6.1	Report results	everyone	5-5-2025	9-5-2025	7	0%
T.2.6.2	Commercialize	everyone	5-5-2025	9-5-2025	7	0%
D3	Test 3D printing fash paste from waste					
T.3.1	Research					0%
T.3.1.1	Look into combining 3D printer and UV sterilization	Senne, Eben	17-3-2025	4-4-2025	15	0%
T.3.1.2	Learn to use the 3D printer software	everyone	24-3-2025	4-4-2025	10	0%
T.3.1.3	Look into safety standards	everyone	24-3-2025	4-4-2025	10	0%
T.3.2	Pre-processing					0%
T.3.2 .1	Make a plan of action	everyone	31-3-2025	7-4-2025	6	0%
T.3.2.2	Make nugget design	Senne, Eben	31-3-2025	7-4-2025	6	0%
T.3.2.3	Blend fish	everyone	31-3-2025	2-4-2025	3	0%
T.3.2.4	Stabelize fish paste	everyone	3-4-2025	7-4-2025	3	0%
T.3.3	Supplying					0%
T.3.3.1	Buy 3D printer	Senne, Aurelien	17-2-2025	21-2-2025	5	100%
T.3.3.2	Buy fish	everyone	21-2-2025	14-3-2025	4	50%
T.3.4	Testing					0%
T.3.4.1	Test if save to eat	everyone	7-4-2025	17-4-2025	8	0%
T.3.4.2	Test if additives are needed	everyone	7-4-2025	17-4-2025	8	0%
T.3.4.3	Taste test	everyone	7-4-2025	17-4-2025	8	0%
T.	Post-processing					0%
T.3.5.1	Clean 3D printer	everyone	22-4-2025	25-4-2025	4	0%
T.3.5.2	Fry printed fish nuggets	Senne	22-4-2025	25-4-2025	4	0%
T.3.5.3	Store the paste and the nuggets	everyone	22-4-2024	25-4-2025	4	0%
T.3.6	Conclusion					0%
T.3.6.1	Document results	everyone	25-4-2025	12-5-2025	15	0%
T.3.6.2	Compare multuple nugget recipies	everyone	25-4-2025	12-5-2025	11	0%
T.3.6.3	Reflect	everyone	25-4-2025	12-5-2025	15	0%



Appendix H: Stakeholder register

PROJECT NAME	Team Fish	**BEGIN DATE**	3-2-2025	**VERSION NUMBER**	1.0
Project coach	Mikeal Ehrs	**END DATE**	23-5-2025	**DATE PREPARED**	16-3-2025
POINT OF CONTACT	mikael.ehrs@novia.fi	**DURATION**	133 days	**AUTHOR**	Fabiënne Kuiper
PROJECT DESCRIPTION	This project will do a research to different stabilisation methods and byproducts from using fish waste.				

STAKEHOLDER REGISTER									
OVERVIEW							CONTACT		
ID	**STAKEHOLDER**	**TITLE / ROLE**	**COMMUNICATION TYPES**	**COMMUNICATION VEHICLES**	**STAKE IN PROJECT**	**ADDITIONAL NOTES**	**ADDRESS**	**EMAIL**	**PHONE**
1	**Aktion Österbotten**	Client	Progress reports, important results.	E-mail	The client whom we try to help.		Kauppapuistikko 18A, 65100 Vaasa		
2	**Coast action group (KAG)**	Client	Progress reports, important results.	E-mail	The client whom we try to help.		Kauppapuistikko 18A, 65100 Vaasa		
3	**Blue Products 3,0**	Client	Progress reports, important results.	E-mail	The client whom we try to help.		Fiskets hus, Fiskstranden, 65100 Vaasa	info@fishpoint.net	+358 (0) 50 527 2314
4	**Novia University of Aplied Sciences**	Finincial support	End results	E-mail	Finincial and supporting the project and research.		Wolffintie 32 65200 Vaasa Finland	studentservices@novia.fi	+358 6 328 5050
5	**Mikeal Ehrs**	Project coach	Weekly meetings, results experiments, during diffuculties, financial updates.	MS Teams, E-mail and meetings in person.	Giving advice on the progress of the project team.		Wolffintie 32 65200 Vaasa Finland	mikael.ehrs@novia.fi	35863285536
6	**Home universities: a. Thomas More Geel UAS b. The Hague UAS c. Hanze UUA d. ENIT**	Sending institution	End results	E-mail	Monitor and support students' academic performance & mobility program	No need to update weekly	a. Kleinhoefstraat 4, 2440 Geel, Blegium b. Johanna Westerdijkplein 75, 2521 EN Den Haag, The Netherlands c.Zernikeplein 7, 9747 AS Groningen, The Netherlands d. 47 Av. d'Azereix, 65000 Tarbes, France	1. info@thomasmore.be 2. itd@hhs.nl 3. info@org.hanze.nl d. admissions@enit.fr	a.+32 145 623 10 b.+31 (0)70 - 445 84 00 c.+31 505 955 555 d.+33 562 442 700
7	**Anita Storm**	Novia teacher and intersted in project	Results and questions about ultrasonic cleaning and the use of enzymes.	E-mail	Giving information and advice on the use of enzymes and ultrasonic cleansing		Wolffintie 32 65200 Vaasa Finland	anita.storm@novia.fi	+358 632 858 61
8	**Other project groups**	EPS colleagues	The end result, updates on project managment.	Confersations in person.	Giving persenal advice on project managment.	No need to update weekly	Wolffintie 32 65200 Vaasa Finland		

Appendix I: 3D-printing comparison table

Picture	Country	Brand	Model	Power supply	Printing speed	Filament Capactity	Print area	Heated	Print resolution	Available nozzle size	Minimal price	Maximum price	Extra's	Notes	Link
	Israel	Steakholder	HD144		max 100kg/h	Continuous input			Uses DLS printing	Uses DLS printing			Waterjet cleaing	Mainly for industrial use. Out of scope for current project	Steakholder HD144
	The Netherlands	FELIX	SINGLE	Standard EU plug	max 40 mm/s	100 ml	220 x 195 x 170 mm	Extrusion max 100°C - Base max 60°C	0.25 ~ 2.00 mm	Ø0.5, Ø1.0, Ø1.6, Ø2.0, Ø 3.0, Ø3.5, Ø4.0 mm	€ 4,510.88	€ 5,332.29	Webcam and touchscreen interface. Automatic calibration.	Delivery time 2-3 weeks	FELIX SINGLE
	The Netherlands	FELIX	TWIN	Standard EU plug	max 80 mm/s	2 x 100 ml	221 x 195 x 170 mm	Extrusion max 100°C - Base max 60°C	0.25 ~ 2.00 mm	Ø0.5, Ø1.0, Ø1.6, Ø2.0, Ø 3.0, Ø3.5, Ø4.0 mm	€ 7,931.55	€ 9,025.15	Webcam and touchscreen interface. Automatic calibration.	Delivery time 2-3 weeks	FELIX TWIN
	The Netherlands	FELIX	SWITCH	Standard EU plug	max 40 mm/s	2 x 100 ml	222 x 195 x 170 mm	Extrusion max 100°C - Base max 60°C	0.25 ~ 2.00 mm	Ø0.5, Ø1.0, Ø1.6, Ø2.0, Ø 3.0, Ø3.5, Ø4.0 mm	€ 7,931.55	€ 9,025.15	Webcam and touchscreen interface. Automatic calibration	Delivery time 2-3 weeks	FELIX SWITCH
	Germany	Procusini	Research	12 volts, 100-240 VAC, 50 - 60 Hz, with standard plug		60 ml	250 x 300 x 100 mm	Stainless steel cartridge heated 15 - 60° C		1.0 mm, 1.2 mm et 2.0 mm	€ 4,254.00	€ 5,344.00	Ideal for research and educational institutions. Illuminated production room. An integrated 3.5-inch screen	Initially use for chocolate but suitable for paste	Procusini Research
	Spain	Natural Machines	Foodini	110-220V	10 ~ 60 mm/s	5 x 100 ml	Ø278 x 110 mm	Capsule bay heater max 90°c	0.2 ~ 1.00 mm	Ø0.8, Ø1.5, Ø4.0 mm	€ 6,000.00	€ 6,000.00	Each one of the 5 capsules can house a different ingredient.		Natural Machines Foodini
	South Korea	Lincsolution	Monopure Food	220V AC 15A	5.3 ~ 60 ml/min	Continuous input	300 x 300 x 50 mm	Base max 60°C	0.05 ~ 0.85 mm	Ø0.3, Ø1.2 mm			Built-in UV sterilization process. Able to print materials with viscosities over 1,000,000 CPS. Able to print low-viscosity semi-fluid materials.	Suitable for High-viscosity materials	Lincsolution Monopure Food

Appendix J: 3D-printer choice

FELIX Food 1.6 - Single Head 3D Printer

What is included :
- FELIX Single Head Food 3D Printer
- Foot bracket
- AC Power supply cord
- Power Supply unit
- USB cable
- Touchscreen unit
- Small tool kit including 1x Allen key, tweezers, 6x M4x8 bolts
- 1x MicroSD card and USB reader
- QuickStart Guide

Standard starter set	Premium starter set
•Silicone Baking Mat •Standart Luer Nozzle Set: six nozzles in three sizes (2x 1.50mm, 2x 2.50mm, and 2x 3.50mm) and 3x luer endcaps. •Allen Key Maintenance Kit **€60.44 taxes included**	•Silicone Baking Mat •Stainless Steel Nozzle Set: Comprising four 304 stainless steel nozzles in sizes 1mm, 2mm, 3mm, and 4mm •Nozzle fixating tool •Allen Key Maintenance Kit **€60.44 taxes included** **Need to choose Premium pack before**

FELIX Food 1.6 - Single Head 3D Printer Accessories

Types	Quantities	Standard pack	Quantities	Premium Pack
Syringes	5	+ €7.20 *	1	+ €180.90**
Nozzle set	1	+ €18.09	1	+ €72.54
Silicone Mat	1	+ €24.14	1	+ €24.14
Glass Build Plate	1	+ €60.44	1	+ €60.44

**Stainless Steel Syringe
* Plastic syringue

FELIX Food 1.6 - Single Head 3D Printer Recommendation

We recommend to buy the following things :
- 1xFELIX Food 1.6 - Single Head 3D Printer **€4,178.13**
- 1x Starter Set - Standard - FOOD 1.6 **€60.44**
- 5 x Basic Plastic Syringe - 100ml **€7.20**
- 1 x Nozzle set - Food 1.6 - Basic Printers **€18.09**
- 1 x Glass Build Plate **€60.44**

TOTAL = €4,685.85

The Steakholder printer is primarily for industrial use. It can quickly print large quantities of fish. However, the primary function of this printer is to print plant-based substitutes for fish. If 3D-printing fish from fish waste is going to be commercialized, this would be a worthy printer to look into further. For the current phase in the research the Steakholder printer is not relevant.
To print a decent size fish steak, you need a bit more than 60ml of the Procusini or 100cc of the Felix Single. The Felix twin and the Foodini have a big enough filament capacity to print a decent size fish steak. It is still easy to work with smaller capacities by printing fish nuggets for example.
All printers have enough are to print decently sized steaks, or a few nuggets.
All printers have a good amount of choice for the nozzle size, although the Felix printers have by far the most choice.
Pricewise the printers are very similar to each other, but it mainly depends on the abilities of the printers.
Printing multiple ingredients at the same time, an option for the Felix Switch and the Foodini, would be fun to experiment with, but not a requirement. Due to the increase in price, it would be more cost-effective to not choose one of those printers just for that option.
The built in UV sterilization of the Lincsolutions printer would be very appealing for the application of using fish waste. This is definitely worth looking further into, but to find more details about the printer, contact with the company should be established.