DEVELOPMENT OF

A COMMON FRAMEWORK FOR A SUSTAINABLE AND CIRCULAR BIOECONOMY

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Exemplary case for a sustainable and circular bioeconomy in the Polish South Baltic Area Region

Fish Processing and utilization of residues at Limito S.A.

Mission and vision

At various stages of the industrial processing of fish, body parts of fish are separated, most commonly this is edible, so-called fish waste. This waste can either be a serious threat to the environment, if it is not disposed of properly, or can become a source of extra income, after converting it to valuable products. The types and properties of fish wastes at the place of their generation are very diverse and depend on the species, the initial form of the raw material, and the extent and method of processing. The main business of the Fish Processing Plant Limito S.A. in Grudziądz is the production of smoked fish products, in which the raw material is gutted salmon with heads, coming from aquaculture. Salmon is a relatively large fish, with an average weight of ca. 4 kg, and the individual weight of the processed salmon ranges between 2 and 6 kg. The value of this weight is important, because it determines the physical properties of the waste. According to the information received by the Limito company, the amount of raw fish material processed in the company is, on average, ca. 18 tons per day.

Principle 1: Cascading approach
Promising opportunity for the production of collagen and gelatin from fish skin.

Principle 2: Use of waste, by-products and residues
Use of fish waste.

Principle 3: Circular economy approach
Production of renewable energy and promising opportunity for recycling of nutrients.

Figure 1. Products categories Limito S.A.

Technology description

The pretreatment of the raw material provided in the form of gutted fish with the heads attached involves removing the head of fresh fish or defrosting frozen fish, which are then reworked, i.e. removing heads, skins, filleting.

In the next step the half-product is processed into finished products in accordance with the following process.

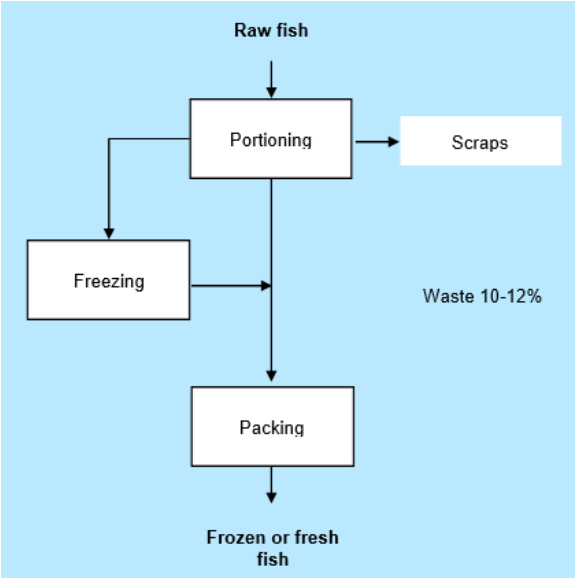


Figure 2. The Limito S.A. Salmon processing - production of fresh and frozen fish.

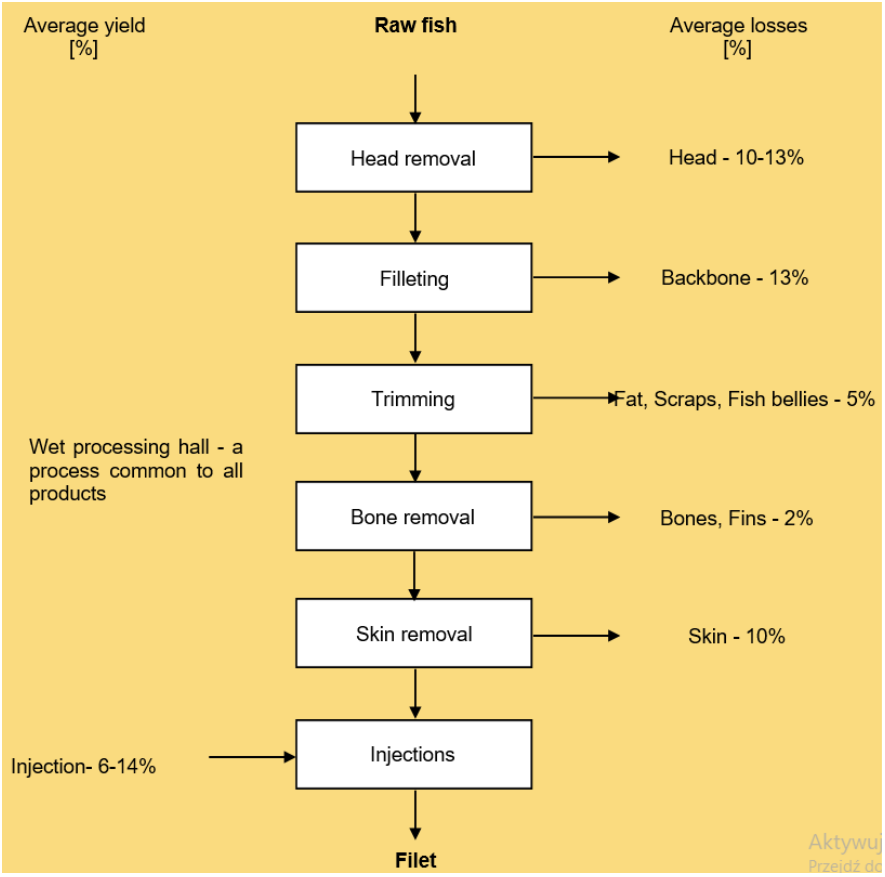


Figure 3. The Limito S.A. Salmon processing – a process common to all products.

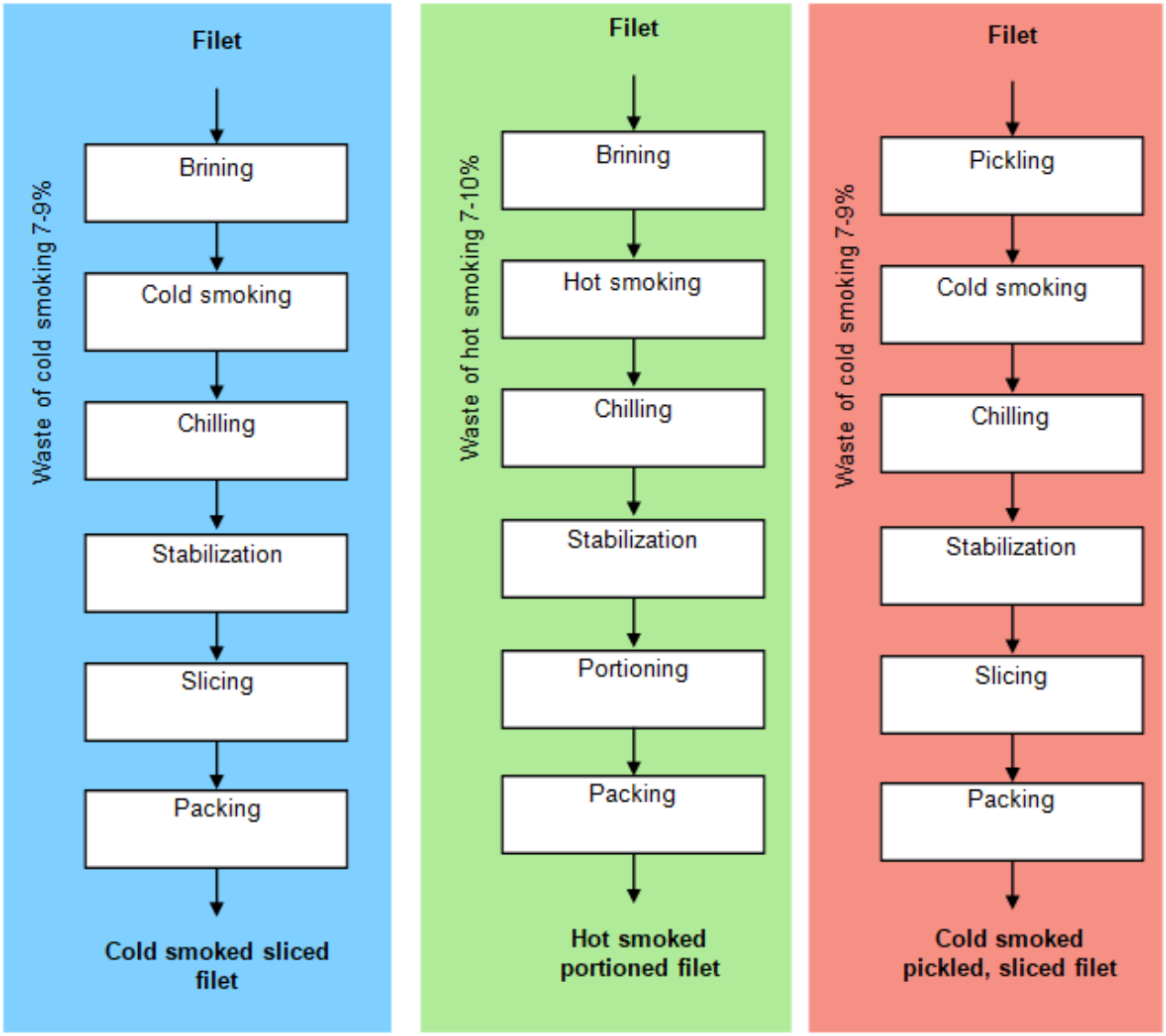


Figure 4. The Limito S.A. Salmon processing – final processing.

Machines, productivity and working staff

FILETING DEPARTMENT

MAREL filleting line with injecting machine FOMACO	performance: to 21,9 tons per shift, 43,8 tons per two shifts
MAREL Portion Cutter	performance: to 6,20 tons per shift, 12,40 tons per two shifts
Multivac R245	performance: to 5,2 tons per shift, 10,4 tons per two shifts
Multivac T-700	performance: to 4,3 tons per shift, 8,60 tons per two shifts
Multivac R-535	performance: to 12 tons per day
Filleting machine FR9000	performance: 7,00 tons per shift
Slicing machine (GEBA SC250)	performance: to 1,4t per shift, 2,9 t per two shifts
Fillets freezing tunnel:	performance: 3,1 t per shift, 6,2 t per two shifts
portions:	performance:1,9 t per shift, 3,8 t per two shifts

SLICING DEPARTAMENT

Skinning machine MAJA	performance: 6,5 tons per shift, 13 tons per two shifts
Skinning machine Uni Food V1558	performance: 8,2 tons per shift, 36 tons per two shifts
4 Slicing lines:	
3 Sets of GEBA SC250	
1 Set of Geba SC250	performance: 3,90 tons per shift, 7,80 tons per two shifts
3 Lines with Multivac R535	performance: 21.600 – 32.400 pcs.
3 Multivacs C-500	performance: 4,4 t per shift, 8,80 t per two shifts

Currently Slicing Department with working 2 lines has productivity between 2,5 - 6 t for one shift and 5 – 12 t in 2 shifts.

Staff - 34 workers

As a result of the pretreatment of gutted salmon, representing 100% of the initial material, 31- 45% total waste is produced, which includes:

- heads: 11%
- backbones, with other parts of the carcass and adjacent to the backbone, remnants of fish muscle: 11%
- raw skins, with scales and remnants of meat and fat remaining on the skins: 7,5 – 9,0%.

The data obtained from the Limito company shows that the percentage of this main waste in relation to the overall weight of the processed raw fish material is:

- heads: 11,0%
- backbones with remains of meat: 11,0%
- skins with a subcutaneous layer and other minor scraps: 7,5 – 9,0%.

In addition to the three main waste products, a small quantity of waste (salted and smoked) is formed during the portioning (trimming) of fish fillets for smoking as well as after their smoking, when slicing.

The post-production waste not categorized as Cat. 3 (Trimming - Fat, Scraps, Fish bellies), is sold to various types of plants producing salads, pastes, peppers and smoked meats. Products for reprocessing and human consumption account for up to 30% of the total amount of waste.

Figure 5. The Limito S.A. Salmon processing.

Investment and economy

The Limito company was established in April 2004 in Grudziądz, and in a relatively short period of time has become one of the leading providers of Norwegian salmon and other fish on the Polish market. Today, the Limito company also successfully exports its products to countries in Europe, Asia and Australia. The estimated annual turnover of the company is ca. 200 million PLN. The company has 150 employees.

Material flow

Based on the presented percentage breakdown of the three main types of waste in relation to the initial weight of the processed materials, it can be estimate that the amount of waste generated in this company is:

- heads: ca. 1,98 tons/day,
- backbones and attached waste: ca. 1,98 tons/day,
- skins with attached waste: ca. 1,35 – 1,62 tons/day.

The actual quantity of each type of waste arising in the Limito company may be different in different periods of time and may be different than estimated. However, this variability should not significantly affect the nature and importance of the issues arising from the need for the disposal or management of so large an amount of fish waste originating from one species of fish and generated in one company in terms of the fishing industry in Poland. According to the latest data obtained from the Limito company, segregated and separately collected waste is used in the following ways:

- heads: are frozen and sold to customers as a product intended for human consumption –the amount of heads sold for consumption purposes is small in relation to the total weight of this kind of wastes and is ca. 15%, (ca. 0,3 tons/day); the remaining amount of unprocessed heads is sold to external recipients together with other waste (heads, backbones, waste from separator, etc.), as a raw material for processing into fish-meal, animal feed, etc.
- backbones: after filleting fish from the parts of the backbone, a significant amount of meat can be manually recovered, approx. 10 - 12% of the total weight of this wastes (probably a similar amount of meat can be recovered using mechanical separation), meat recovered in this way is sold as a product for human consumption; part of the backbones is frozen in its entirety and is sold to customers as a product for human consumption – the amount of meat that is recovered from the backbone, frozen and then sold on to the consumer is variable and depends on the market demand. The demand reaches up to ca. 21% of the total weight of this waste, that is ca. 0,4 tons/day; the remaining quantity of untreated backbones is sold to external customers, with other waste, as a raw material for processing into fish-meal, animal feed, etc.
- skins: are not used in any way in the Limito company – all raw skins, separated after deskinning, ca. 1,5 tons, are sold to outside customers together with other waste as a raw material for processing into fish-meal, animal feed, etc.

The Limito company has a 2 MW power connection. The actual daily energy demand of the company is about 0,8 MW, of which 0,28 MW and 0,52 MW is used in the operation of technological lines and cooling systems, respectively. The company does not have its own energy sources. Production uses:

- electrical energy (used for the functioning of technological lines and cooling systems),
- cold water
- natural gas.

Power supply:

- Electricity:
  - Power supply 3,2 MW
  - Power installed 3 MW
  - High peak power use 2,02MW
  - Average use of power 0,8 MW
  - No alternative source of electricity
  - Guarantee of emergency power supply 0,24 MW
- Gas fuel:
  - Power installed 0,8 MW heat power
  - Average monthly use of gas power
  - waste heat from the cooling machinery is used to heat water
- Water and sewage:
  - Water for the production plant is supplied by the municipal system
  - Limito has no internal supply of water
  - Average water usage 6.500 m^3 per month

The waste Cat. 3 is transferred to fish meal. Companies receiving this waste are: Biovast- Latvia, Bioceval-Germany, TripleNine - Denmark, Agro Fish – Poland. Currently, most of the wastes generated in the fish industry is transferred to the production of fishmeal.

After the delivery of the raw material (by-products from fish), it is ground and then pumped to a smelting unit. The raw material is heated by steam generated in a special LNG-powered boiler. The heating process takes place via direct or indirect (jacket) steam injection. Direct injection of steam allows the quick heating of the raw material with limited oxygen availability and with a minimum time for protein coagulation and oil melting. Then, the heated mass goes to the 2 or 3-phase decanter to separate the phases. Proper selection of the decanter ensures maximum separation efficiency within the distribution of all two phases (solid particles, sticky water + oil). The solid phase is transported to the dryer, where, after drying to fish meal, it contains about 10% of the water content. Fish meal is cooled and packed in big bags. The fat phase is taken to an intermediate tank from which it is pumped into a vertical separator in order to clarify the fish oil. During the oil clarification process, the separation of oil and sticky water occurs. The sticky water (rich in protein) is directed to the evaporation station system where, after the compaction process, it is pumped directly to the solid phase (from the decanter) and after mixing it is dried in a tumble dryer. The clarified oil is directed to the storage tanks. Optionally, fish oil can be bottled in 200-litre barrels.

Characteristics of commonly used installations:

I. Transport of raw material.

First, the raw material (hard and soft waste) from the silo is transported by means of a screw feeder (capacity approx. 10-25 tons/h and engine power about 5-10 kW) to the tank (capacity approx. 600 m^3). It is allowed to create a "cold" zone in a part of the building with a temperature of min. 0□C in the part of raw material receipt and its temporary storage.

II. Thermal treatment.

In the next stage, the raw material with two HM35 pumps (approx. 4-10 kW) is supplied to the cooker/stove type SFC 1110 (capacity approx. 10-20 tons/h, engine power approx. 7-11 kW), Bioash from the company could be sold to local farmers as fertilizers. According to EU regulations (EU

834/2007) wood ash can be used as fertilizers in ecological farms. Due to the fact that the number of ecological farms is constantly growing, it could be a large opportunity for the company.

III. Ironing / pressing / drying pulp / oil separation.

The overcooked raw material goes to a two-screw press type MS-56 F (engine power about 50- 80 kW and efficiency correlated with the digester). The press squeezes all fluids (oil, water) from the given raw material under high pressure, and the resulting pulp is sent to the disk dryer HM 2555 type (drive power about 120-190 kW and capacity about 10-30 tons /h) where, using high temperatures, it is dried into meal. The liquid obtained goes to a tank equipped with a stirrer (with a capacity of about 17-35 m^3 and a power of approx. 2-6 kW), then from there to a decanter, which constantly separates the remaining solid material, which is added to the obtained pulp. The water and oil separated in this way go to the decanter and oil separator (capacity approx. 8-18 m^3/h and engine power about 25-40 kW). Depending on the raw material, only decanters can be used on the production line, without using the press.

IV. Cooling and grinding of the product.

The solid material - mostly fishmeal after drying, goes to the refrigerator CAC 1609 type (main engine power about 10-15 kW, fan motor 10-15 kW, capacity about 7.000-9.000 m^3 / h airflow) where it is cooled to about 20-25˚C. From the refrigerator the meal goes to the grinding section - hammer mill HM 630 type (power approx. 80-140 kW - and then to a silo for the finished product)

V. Oil separation stage II.

The liquid in the separator are separated into decoction and almost pure oil, pumped to the oil tank with a capacity of approx. 2-8 m^3. Next, the liquid goes to the next separator (capacity about 2-3 m^3 / h, power about 5-10 kW), which finally separates the remaining particles of the decoction from the clean oil. After this process, the oil goes to the silo for the finished product (oil silos should be able to contain about 75-500 tons).

VI. Inside the production hall, a system for utilizing odors that captures up to 98% of the compounds are used. They are based on a modern system of exhausts and ventilation finished with tanks, from which the odors are burned after condensation. The described installation has a target production capacity of about 70 tons of fishmeal a day and about 20 tons of fish oil per day, using raw fish material (fish waste) in the amount of about 300 tons per day. It is assumed that the raw material contains about:

- 18% dry mass;
- 7% fats;
- 75% water.

The obtained fishmeal contains about:

- 84% dry mass;
- 8% fats;
- 8% water.

Estimated environmental and economic benefits

The fish industry produces a lot of pollutants in the form of sewage requiring purification. For this reason, fish

processing plants carry out intensive investments towards the construction of their own sewage pretreatment systems and their own treatment plants. Sewage from production and washing processes (installations and vehicles transporting raw materials) will be sent to the factory sewage treatment plant in order to bring them to such a degree of purity that they meet legal requirements and requirements specified by the administrator of the municipal sanitary sewage system.

In technological sewage the main type of contaminants are organic substances, i.e. proteins and fatty substances. They are the reason for a significant increase in sewage parameters such as:

- BOD, COD;
- substances extracted with petroleum ether (oil impurities);
- total nitrogen
- phosphorus compounds

To reduce the value of indicators of these pollutants, mechanical and physico-chemical methods are used in the process of pre-treatment and the treatment of technological wastewater:

- defatting flotation;
- sewage suction on mechanical sieves;
- coagulation;
- flocculation;
- pressure flotation.

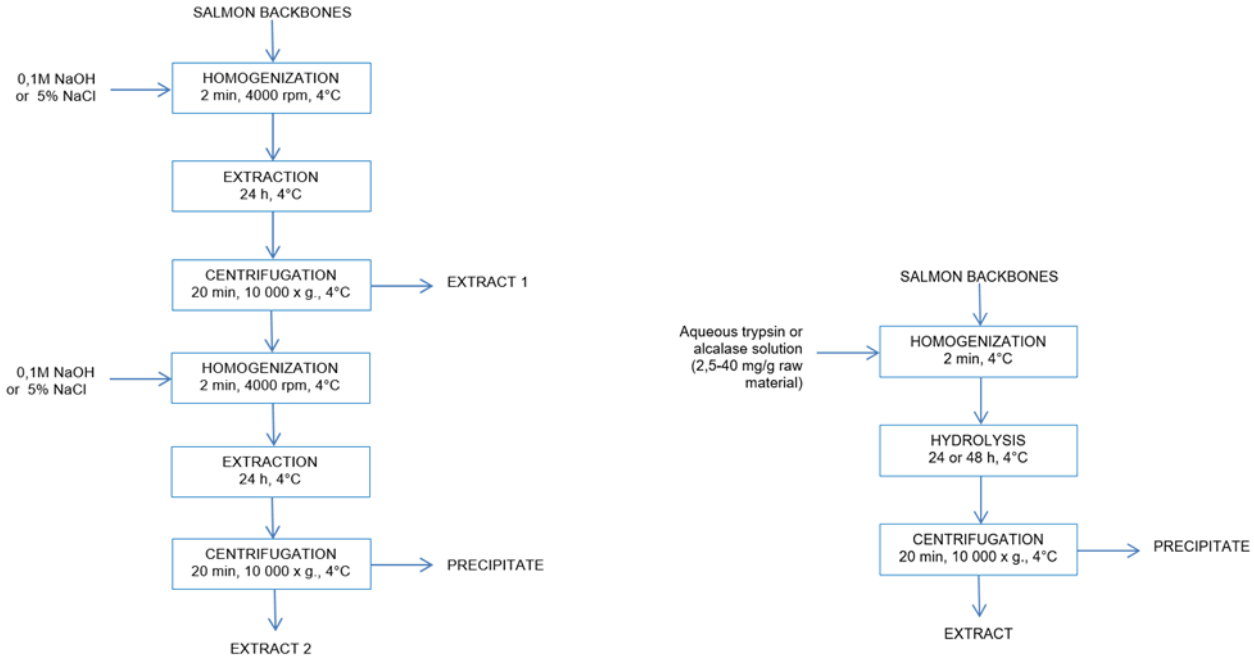
Lessons learned and recommendations

Fish processing enterprises should cooperate with scientific centers to diversify waste treatment technologies. The resulting waste can be used to produce collagen and fish gelatin. The first stage of the separation of collagen connective tissue is to remove the accompanying components, i.e. other proteins, glycosaminoglycans, lipids and mineral salts, which impair the physico-chemical properties of collagen. These three methods of collagen secretion are the most common:

- direct extraction of connective tissue with an organic acid;
- extraction of collagen with organic acid from connective raw materials after initial chemical treatment;
- extraction of collagen with organic acid from enzymatically processed material.
  The direct extraction of collagen with an organic acid is only practical for connective tissue, in which the collagen is intermolecularly cross-linked with acid-labile bonds. Such properties have fish skin collagen. The most commonly used acids for extraction are solutions of acetic, glycolic or lactic acid. The temperature and time of action of acid solutions depends on the origin of the connective tissue.

Heads, spines and skin obtained after fish filleting contain adherent muscle tissue, which is an unused source of muscle proteins. In order to obtain collagen, it is necessary to isolate these proteins by extraction with inorganic solvents or by carrying out enzymatic hydrolysis. The most conservative conditions for the secretion of collagen from connective tissues containing adherent muscle tissue create methods involving the extraction of non- connective tissue proteins using a salt solution. The most commonly used solvents are NaCl or NaOH solutions (see the figure below). Another method is the initial mechanical scraping of the muscles from the backbones. In addition to muscle protein, a bone crumb containing its residues is formed. For the separation of proteins from the backbones of the fish and from the bone crumb, enzymes of bacterial origin (alcalase 2,4 L, neutrase, protamex), animal - (trypsin) and vegetable (papain) can be used. The most commonly used is trypsin and alcalase. The efficiency of

enzymatic hydrolysis depends among others on: the enzyme used, the type of waste to be treated, the time of incubation, the pH of the mixture and the temperature of the process.



a) b)

Figure 6. Obtaining collagen from hard waste – salmon backbones – deproteinization.

Hard waste, such as fish heads or backbones, often requires additional chemical or enzymatic treatment leading to demineralization. The process is carried out using EDTA or HCl solutions as presented below. The product after drying is called ossein.

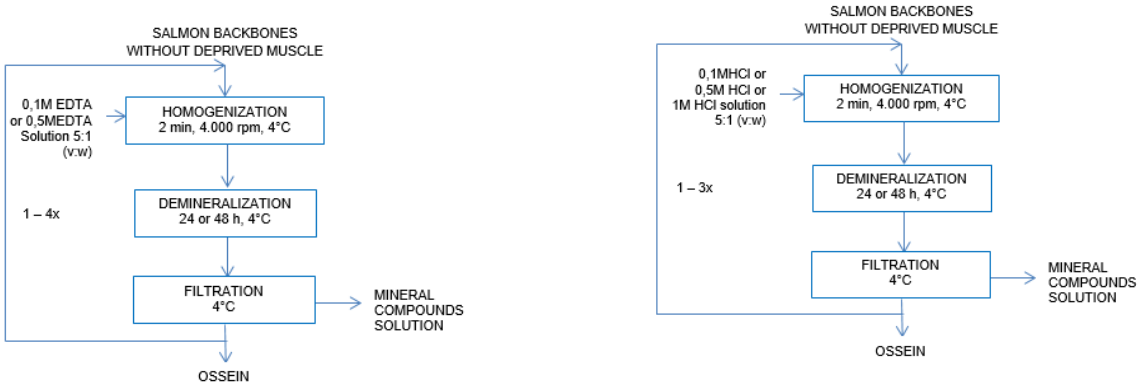


Figure 7. Obtaining collagen from hard waste – salmon backbones – deproteinization.

From ossein, it is possible to obtain collagen solutions by conducting extraction using diluted organic acids, as shown below:

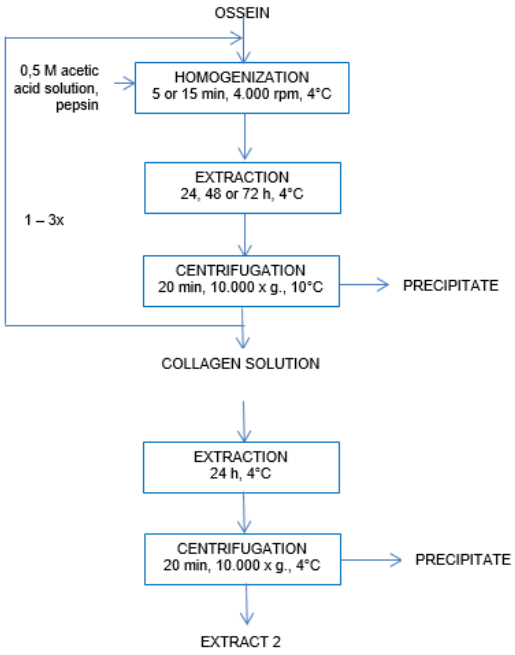


Figure 8. Obtaining collagen solution from ossein.

A much easier material from which it is possible to obtain collagen is soft waste such as fish skin. The efficient filleting process allows the minimization of the number of non- collagenous proteins, making the collagen in the skins much less cross-linked than in hard wastes. Collagen from fish skins can be obtained according to the scheme shown below:

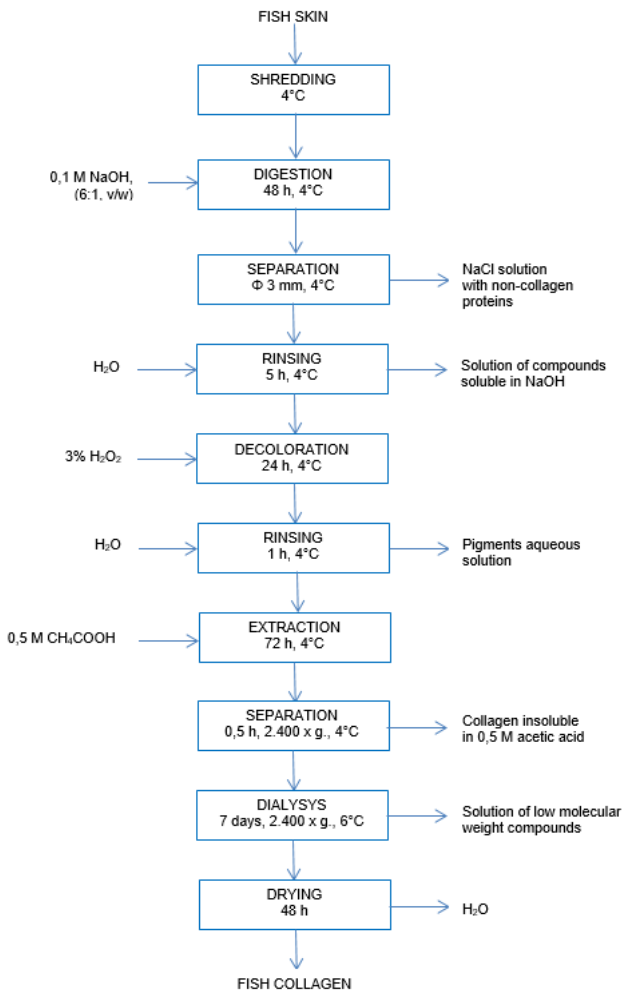


Figure 9. Schematic diagram of the process of obtaining collagen from fish skins.

After pre-removal of non-collagen proteins from connective tissue waste such as skin, head and backbone, fish gelatin can also be produced. The standard technology for obtaining gelatin is:

- Maceration of connective tissue waste in solutions (alkaline or acidic) from a few to several hours.
- Neutralisation of connective tissue waste.
- Washing of connective tissue waste multiple times with water (3 times or more) to remove salt formed during neutralisation.
- Thermolysis of collagen and multi-stage (at least 2 times) hot gelatin extraction (40 - 60 °C) with water (most preferably with distilled or deionized water). As a result of cooking, dirty, aqueous solutions of gelatin with a concentration of approx. 5% are obtained.
- Separation of gelatin solutions from solids through filtration or centrifugation.
- Compaction of gelatin solutions in vacuum evaporators to a concentration of 12 - 30%.
- Chilling and solidifying a thickened gelatin solution (gelation).
- Extrusion of solidified gelatin in the form of strands suitable for drying in air dryers.
- Drying of gelatin at a temperature of 30 ÷ 60 ° C.
- Grinding dried gelatin.

As it results from the presented technological process stages, the installation for the production of gelatin must cover a whole series of specialized devices that should be carefully designed, accurately selected and correctly assembled, in accordance with specific technological and production conditions and production scale. It is also possible to obtain fish gelatin from soft fish waste, such as skin, according to the scheme shown below:

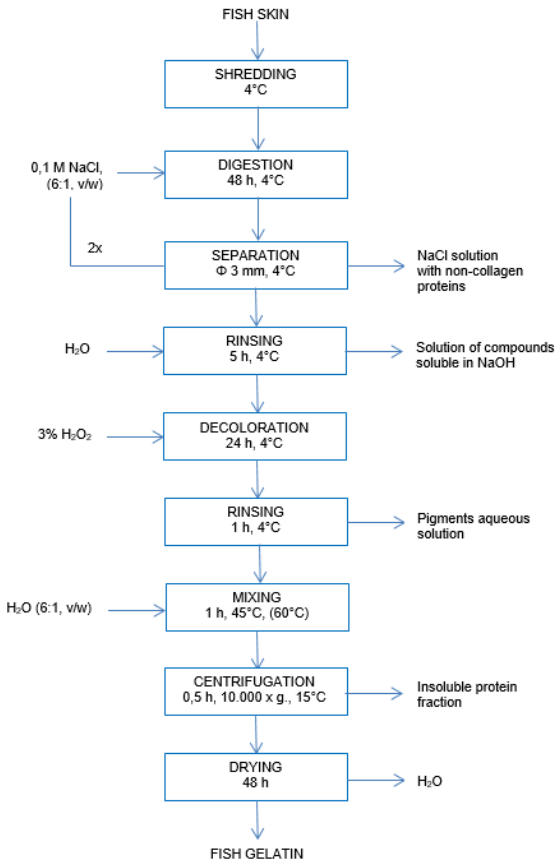


Figure 10. Schematic diagram of the process of obtaining gelatin from fish skins.

The future

Limito S.A is currently focused on special products that will improve the company's market competitiveness in the future:

- The development of functional foods due to the increase in interest in pro-health food.
- Organic food development - the organic food market is growing at a rate of 10-15% per annum, and currently its value is estimated at approx. PLN 750 million, which is 0,3% of the entire food market. In Western Europe, the share of organic food in total sales ranges from 2 to 6%, which in the opinion of experts proves the potential development of the organic food market in Poland.
- The development of convenient food - the market of convenience food, especially ready-made frozen dishes.

The priority for innovation in Limito S.A. includes activities in the field of innovative technologies of production and waste management.