Unlocking the potential of macroalgae for a thriving European blue bioeconomy

2022

Characterisation of SeaMark products

SEAMARK DELIVERABLE 8.1

Sjókovin – Blue Resource

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SEAMARK DELIVERABLE 8.1: CHARACTERISATION OF SEAMARK PRODUCTS

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Abstract

The main objective of the SeaMark project is to demonstrate how to scale up innovative seaweed cultivation and processing into price competitive product applications making the entire supply chain attractive for commercial investments. This report is the first outcome from work package 8 (WP8) of the SeaMark project, titled 'Conduct Techno-Economic and Socio-Economic Assessments'. This report creates a critical foundation for the contribution of WP8 to two overall specific objectives (SO) of the SeaMark project: SO9 on 'identification of viable business cases and provision of feedback to WP3, WP4, WP5 and WP6' and SO10 on 'assessing the social, technical, environmental and economic viability of scaling up seaweed cultivation and biotransformation'.

This report characterises the production processes of the SeaMark products. It reports on the work conducted in task8.1 (T8.1) on 'characterisation of SeaMark production processes'. This task entails mapping the key processes to produce twelve SeaMark products. Flow charts are presented for each product and its seaweed biomass. The visualisations detail the flow of raw materials and products, as well as the interaction, position, and function of critical supply chain actors. The characterisation has largely been based on expert interviews with key partners in the SeaMark supply chains. Where relevant, supplementary material has also been provided by other partners involved in the development of the products.

The report serves as the foundation for assessing SeaMark innovations on market potential (WP7), techno-economic and business analyses (WP8) and life cycle assessments (WP9) and policy recommendations (WP10).

'Scaling-up innovative seaweed cultivation and processing into price competitive product applications making the entire supply chain attractive for commercial investments" is an ambitious endeavour, which requires innovations across the entire supply chain: in breeding and genetics to improve growth rates and desired composition of the seaweed, mechanical seeding and harvesting to reduce costs, to upscaling biorefinery processes using enzymatic and microbial processes to create novel products with potential applications within food, feed, packaging, nutraceuticals, cosmeceuticals and medical devices. In addition to the innovation processes within production processes and product development, significant work will be done on market-related challenges to increase demand, and on the regulatory framework to remove barriers facing the industry.

This report describes the production processes of the twelve SeaMark products produced by industry partners Oceanium (OCE), Fermentation Experts (FEXP) and Algaia (ALG). In addition, it also describes the cultivation and production processes of two different species of seaweed: sugar kelp (*Saccharina latissima*) cultivated at sea in France and the Faroe Islands and sea lettuce (*Ulva sp.)*, cultivated in a land based Integrated Multitrophic Aquaculture (IMTA) system in Portugal. Each of the seaweed products serve as input into several of the SeaMark products.

Each of the product sections outlines the characteristics of the products, their main selling points, technological readiness level (TRL) and what innovation actions will be taken to advance the respective products within the SeaMark project before the descriptions and flow charts of the production process are presented.

This report showcases the diversity of these production approaches, technological maturity, and products, which can be used in product applications from feed supplements to nutraceutical and medical devices (Figure 1).

There are still many challenges to overcome to upscale and improve economic profitability within the European seaweed industry. One of the potential ways of unlocking the success of the sector is to fully utilise the full range of compounds that this versatile resource contains. This can be achieved through the adoption of biorefinery concepts, enabling the production of a range of products from the same biomass, thereby maximising the value of the resource. Ten of the SeaMark products are produced in three separate co-extraction processes for different end users. SeaMark will produce bioactive beta-glucans (P1), fucoidan (P2 and P8), oligosaccharides (P12) to be used as medical devices, and the nutraceutical and cosmeceutical sectors. Alginates for food (P7), cosmetics (P7 & P8) and medical devices (P8); mineral concentrates (P10) and proteins (P11) for be used in food and feed; fibre and protein food ingredients (P4) and bio-packaging (P3) material to reduce the use of plastic; a co-fermented meat replacer product (P6), which can be used to partially or fully replace meat and a co-fermented feed supplement (P5) to be used for sows and piglets.

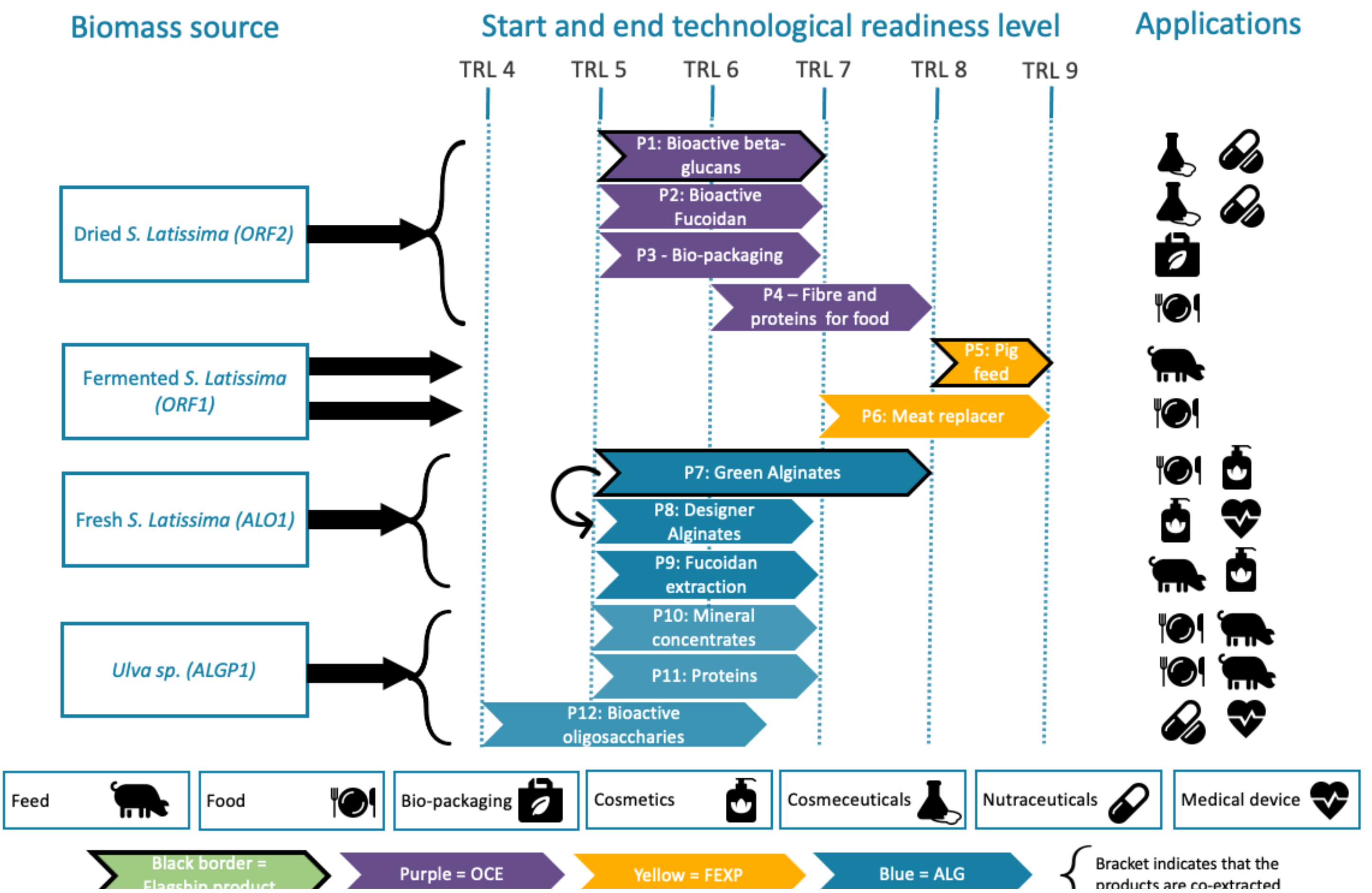

Figure 1: An overview of the SeaMark products, illustrating their relationships, biomass source, start and end technology readiness level (TRLs), and applications. SeaMark Flagship products have a black border. The brackets indicate that the products are co-extracted in a biorefinery process. Purple products are produced by Oceanium (OCE), yellow by Fermentation Experts (FEXP) and Blue by Algaia (ALG). (Note: A medical device is any article that is used to diagnose, prevent, mitigate, treat., or cure disease or other conditions, e.g. dressings for wounds)

This report provides the foundation for understanding all the production processes involved in SeaMark. In upcoming work with WP8, the focus will be on the three flagship products:

- P1: Bioactive beta-glucans
- P5: Pig feed supplement
- P7: Green alginates.

In subsequent WP8 deliverables, the attention will be on analysing the value chain of the respective flagship products (D8.5); the techno-economic feasibility of the production (D8.6) and the socio-economic impacts of upscaled seaweed production and biotransformation (D8.4). This will provide a more detailed understanding of the potential opportunities and challenges facing the production of seaweed-derived products.

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LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
AAU	Aalborg University
ALG	Algaia
ALGP	ALGAplus
ALO	Algolesko
AVE	Aventure
CARL	Carlsberg Ingredients
DTU	Technical University of Denmark
FEXP	Fermentation Experts
G	guluronic
IMTA	Integrated Multi Tropic Aquaculture
LUN	Lund University
MAT	Matis
M	mannuronic
NUIG	University in Galway
OCE	Oceanium
ORF	Ocean Rainforest
P	Product
RUI	Ruitenberg Ingredients
SBR	The French National Centre for Scientific Research
SO	Specific objectives
TRL	Technology readiness level
UF	Ultra-filtration
UTR	University of Utrecht
ww	Wet weight
WP	Work package

CONTENTS

INTRODUCTION

The main objective of the SeaMark project is to demonstrate how to scale up innovative seaweed cultivation and processing into price competitive product applications making the entire supply chain attractive for commercial investments. This report is the first outcome from work package 8 (WP8) of the SeaMark project, titled 'Conduct Techno-Economic and Socio-Economic Assessments'. WP8 contributes to two specific objectives (SO) of the SeaMark project. Through value chain analysis (T8.2), techno-economic assessments (T8.3) and creation of business plans for SeaMark flagship products (T8.5), WP8 contributes towards SO9 which is "Through analysis of markets and consumer preferences, identify viable business cases in supply and provide feedback to WP 3, 4, 5 and 6". Through techno-economic assessments (T8.3) and socio-economic assessments (T8.4), it contributes towards SO10 which is to "assess the social, technical, environmental and economic viability of scaling up seaweed cultivation and biotransformation". This report creates a critical foundation to perform the above tasks.

The overall objective of this report is to characterise the production processes of the twelve SeaMark products. It reports on the work conducted in T8.1 on 'characterisation of SeaMark production processes'. The task entails mapping the key processes to produce SeaMark products. The main features of the deliverable are flow charts for each respective product, which detail the flow of raw materials and intermediates, as well as the interaction, position, and function of relevant supply chain actors. The characterisation is largely based on expert interviews with key partners in SeaMark supply chains.

This report is a critical deliverable within the SeaMark innovation process, which employs a prototyping loop (Figure 2). The report serves as the foundation for the work on assessing SeaMark innovations on market potential (WP7), techno-economic and business analyses (P8), life cycle assessments (WP9) and policy recommendations (WP10). The underlying idea is that all SeaMark partners and other interested parties should be able to get a good overview of the production processes involved in SeaMark and which actors are involved.

The document is structured as followed: first a brief overall introduction will be given to the SeaMark products, their relationships and the most important factors involved. This is to provide an overview of what follows in the product mapping sections. Following that, the methodological approach will be outlined. This will present the data collection approach and detail the TRL scale, which has been applied in the deliverable. It will also explain the overall concept of the flow charts and define the scope of the characterisation.

The sections after that focus on mapping the production processes, starting with the seaweed production processes, as seaweed is either a main or critical raw material for all products. First the seaweed production of Ocean Rainforest (ORF), Algolesko (ALO) and ALGAplus (ALGP) will be mapped and the flow charts for them presented and described. The next section focuses on the mapping of the production processes of the twelve products, focusing on the production processes within industry partners OCE, FEXP and ALG.

The chapters describing the SeaMark products start with an introductory product description. This focuses on outlining the characteristics of the products, their unique selling points[1], TRL

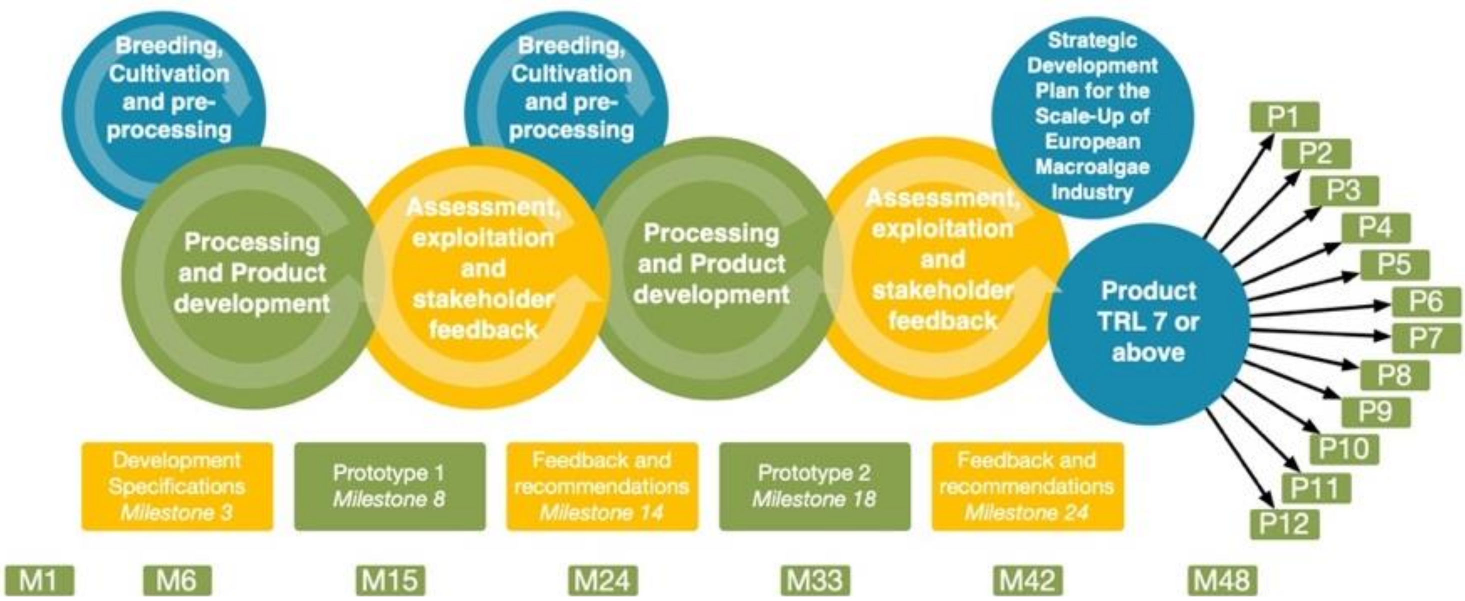

Figure 2: The SeaMark prototyping loop

[1] See Also D7.1 for the specification of flagship products and market strategies.

and what innovation actions are taken within the SeaMark project to advance the respective products. Then comes the main content of each of these chapters, where the mapping of the production processes is presented together with the flow chart and a description of the production process.

An introduction to the SeaMark products and their key actors

The SeaMark Ambition

Scaling-up innovative seaweed cultivation and processing into price competitive product applications making the entire supply chain attractive for commercial investments is an ambitious endeavour which requires innovations across the entire supply chain: In breeding and genetics to improve growth rates and desired composition of the seaweed, mechanical seeding and harvesting to reduce costs, to upscaling biorefinery processes using enzymatic and microbial processes to create novel products with potential applications within food, feed, packaging, nutraceuticals, cosmeceuticals and medical devices. In addition to the innovation processes within production processes and product development, significant work will also be done on market-related challenges to increase demand, and on the regulatory framework to remove barriers facing the industry.

Key Actors

The SeaMark consortium is in a good position to develop innovative and profitable products based on seaweed from lab to market. SeaMark has three competent processing industry partners, who have overall responsibility to produce the twelve SeaMark products: OCE in the UK, FEXP in Denmark and ALG in France. The product development will be supported by leading technical research institutions: Matís (MAT), Technical University of Denmark (DTU), University of Lund (LUN), University of Utrecht (UT), University of Aalborg (AAU) and University of Aarhus (AU), who in their various ways will support the upscaling of novel concepts with low TRLs in the fields of enzymatic and microbial biorefineries, as well as to investigate the potential benefits of the products. Furthermore, partners Carlsberg (CARL), Ruitenberg Ingredients (RUI) and Aventure (AVE) will as potential users of the products test and provide feedback on the functionality of the products. The SeaMark products will be made with seaweed from three seaweed producers:

- Sugar kelp (*Saccharina latissima)* from ORF in the Faroe Islands and ALO in France
- Sea lettuce (*Ulva* sp.*)* from ALGP in Portugal

Critical work to improve the seaweed production and the properties of the seaweed will be done by the French National Centre for Scientific Research (SBR), University in Galway (NUIG) and Carlsberg - Traitomics (CARL), who will support the implementation of breeding programs to provide farmers with high performing seaweed strains to improve yields and productivity. Through this work, they will also provide the foundation for genomic selection for seaweed breeding.

An overview of the SeaMark products

Seaweed has a range of attractive compounds which can have great benefits in numerous applications within food, feed, packaging, nutraceuticals, cosmeceuticals, and medical devices. Seaweed may replace conventional raw materials in products, improve the functionality of products and potentially bring about health benefits for the users of the products.

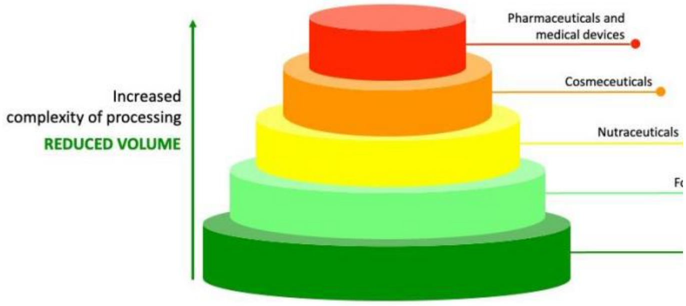

Figure 3: The value pyramid from the lowest value (feed) to the highest value (medical devices). Products will be produced for all these sectors within SeaMark.

The seaweed cultivation industry in Europe is however in its infancy. There are still many challenges to overcome to upscale and improve economic feasibility of seaweed production and use. One of the keys to success of the sector is to fully utilise the range of compounds that this versatile resource contains. This can be achieved through the adoption of a biorefinery concept, enabling the production of a range of low and high value products from the same biomass, thereby maximising the value of the resource. Figure 3 demonstrates the value tower of the wide range of applications. The level of complexity with regards to processing increases in line with the value of the products.

Companies in SeaMark will produce twelve products with a view to demonstrate how such biorefinery concepts may be commercialised (Figure 4). The products will have a range of applications, from feed supplements to nutraceuticals and medical devices[2]. Ten of the SeaMark products are produced in three separate co-extraction processes, meaning that several products are extracted from the same biomass. The unique characteristics of the respective products and how SeaMark will innovate to bring them to market will be presented below. Figure 4 also indicates the starting TRL of the products and the planned TRL level by the end of the SeaMark project. This demonstrates that the pig feed supplement (P5) and meat replacer product (P6) based on fermented sugar kelp from ORF (ORF1) have the highest start TRL and are expected

[2] A medical device is any article that is used to diagnose, prevent, mitigate, treat or cure disease or other conditions, e.g. dressings for wounds

to be fully commercialised by the end of the project (TRL=9). The product with the lowest start TRL is the bioactive oligosaccharides (P12), and this is expected to have an end TRL between 6 and 7. The rest of the products are currently at TRL 5 or 6 and are expected to reach TRL level 7 or 8 by the end of the project.

METHODOLOGY

In this section, the underlying methods used within this work will be outlined. Aspects relating to data collection will first be detailed before the attention goes to presenting concepts such as technology readiness levels (TRL). This section will also explain how 'actors' and intellectual property rights have been considered within the work.

Data collection

The information collected is largely based on expert interviews with the key personnel from the industry partners involved in the production of seaweed and the SeaMark products. In specific cases, representatives from research partners involved in the further processing and product development of the products have also provided supplementary information. Where feasible, the interviews were conducted on the production site. In other cases, they were conducted online. To make data collection more efficient across SeaMark work packages and reduce the strain on the industry actors, the data collection process was coordinated between WP7, WP8 and WP9. An interview guide was developed, and interviews were conducted from October 1st to November 10th with the producers of the SeaMark products (See appendices I and II).

The data collection framework draws inspiration from Olsen and Aschan (2010) where they provide a method for structured investigation of material and information flows and processing in a company or for entire supply chains. The approach in Olsen and Aschan (2010) is more extensive than what is required for our purposes here, but the core of the method and general guidelines have been followed. The core of this process mapping method is the grouping of questions into a set of questionnaire forms, where each form relates to one specific phase or transformation of raw materials or intermediate products.

The very first form records basic background information relating to company, interviewee as well as the basic product

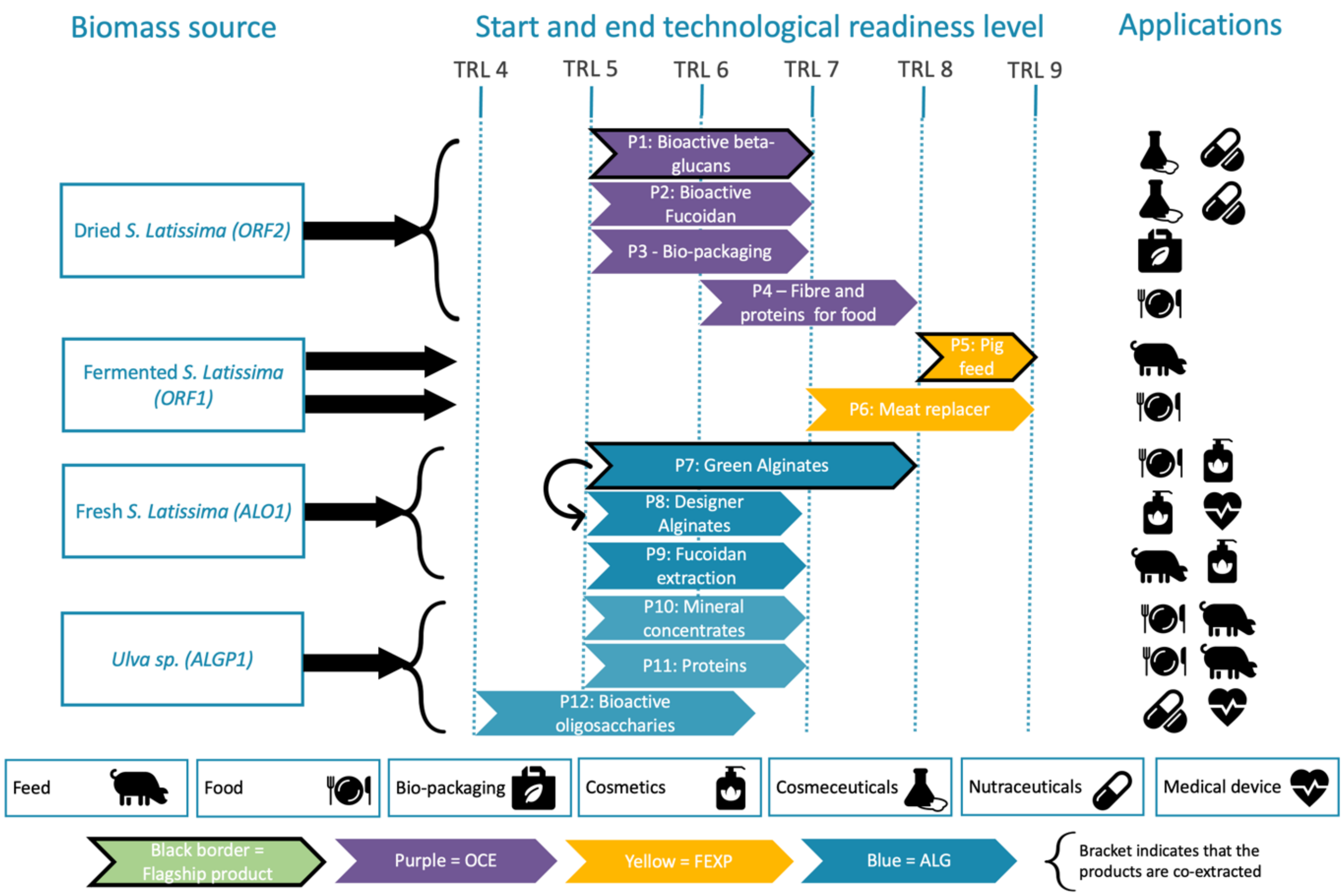

Figure 4: An overview of the SeaMark products (P1-12), their relationships, biomass source, start and end TRLs, and applications. SeaMark Flagship products have a black border. The brackets indicate that the products are co-extracted in a biorefinery process. Purple products are produced by OCE, Yellow by FEXP and Blue/Green by ALG. (Note: A medical device is any article that is used to diagnose, prevent, mitigate, treat, or cure disease or other conditions, e.g. dressings for wounds)

description, current and expected TRL, and how it relates to other SeaMark products. The second form is dedicated to the seaweed biomass serving as input to the production process (see example in Table 1**Error! Reference source not found.**).

Table 1: Example of completed form 2 for incoming raw material (seaweed)

		Answer, fill in	Description or example
2.10	Species of seaweed	*Saccharina latissima*	*Ulva, Saccharina latissima*
2.11	What type of raw material	Wet	Wet/dried/fer mented
2.12	Who is the supplier of	ALO & ORF	ORF / ALO / ALGP
2.13	What type of transport is used?	Truck for ALO and airplane for ORF initially	Truck / boat / airplane etc.
2.14	Which temperature	Cool	Cooled / frozen / none?
2.15	How long was the	3hrs for ALO; 24hrs for ORF	
2.16	In which quantities	Normally by tons	
2.17	How is it packaged?	Bulk usually but in this case, in 200 kg drums	Card board boxes, tanks, in which units (litres, kg) ?

After that, there was a separate form for each step of the production process, focusing on the description of the process, what input, equipment, labour, and actors were involved in each of the processing steps. Finally, there was a separate form for the packaging, logistics and transport, focusing on type of packaging, means and duration of transportation (see appendix 1 for a complete survey). The forms were slightly modified depending on whether the interviewee was working with biomass production or processing of the twelve SeaMark products.

This process was conducted with the seaweed producers ORF, ALO and ALGP, and the partners responsible for the SeaMark products FEXP, OCE and ALG. In addition to that, other partners (e.g. MAT; RUI; CARL; AVE) involved in the development or evaluation of the twelve products also provided input where relevant. The data collection was organised in such a way the information provided can be used in upcoming assessments, such as on value chain analysis (D8.2) and techno-economic assessments (D8.3).

Technological Readiness Level

One of the aspects that will be considered throughout the document is technological readiness level (TRL). This refers to how close a technology (or production process) is from being fully applied in its intended operational environment. The general annexes of the Horizon Europe Work 2021-2022 work programme define nine TRLs (see Table 2). The SeaMark products range from TRL 4 – 9, so they vary greatly in terms of commercial maturity. Whilst some products, for instance product 5: pig feed supplement, are already fully commercialised in the operational environmental (TRL 8-9), others (e.g. P10: Mineral concentrates and P12: Bioactive oligosaccharides) have at the start of the SeaMark project only been validated in lab (TRL4). In the chapters on each respective product, the current TRL will be indicated, and the innovations which will bring it to a higher TRL will be highlighted.

As several of the products are not yet in production, the optimal production processes are not yet developed. In those cases, the current plans for the production process will be outlined, acknowledging that these may change as the SeaMark project advances. These changes will be reflected in subsequent deliverables within WP8, for instance in the techno-economic assessment, which will be done for flagship products.

Table 2: Technological readiness levels (TRLs) as defined in the Horizon Europe 2021 – 2022 Work Program.

Level	Level of maturity
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in a lab
TRL 5	Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in an operational
TRL8	System completed and qualified
TRL9	Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies, or in space)

Definition of actors

According to the task description, the flow charts should detail the interaction, position, and function of relevant supply chain actors. Here it is important to state that only 'critical' actors will be mentioned by name. This means that the actor has a key role to play in relation to the process, providing specialised equipment or input material. In the cases where raw material, equipment or a service can be purchased 'off the shelf', only the *type* of actor will be given (e.g. transportation by truck; Feed distributors, pig farmers etc.). More effort has been made to describe the actors and processes specifically relating to the SeaMark objectives. This is why the production process of the seaweed biomass is also mapped, whilst other raw material readily available on the market has not been described. Where one product serves as input to another, the connection will be made explicit in the respective flowcharts.

Knowledge management and protection of IPR

This deliverable is largely about describing commercial production processes within the private industry partners of the SeaMark project. This means that industry partners have been asked to disclose information, which could be commercially sensitive, within the project consortium. Therefore, the team has taken great emphasis to respect intellectual property rights, and not to share individual product sections between the project writing team until approval has been granted from the individual partner institutions. The level of disclosure for the different section has been determined with respect for what each respective company has deemed not too sensitive to share publically.

MAPPING OF SEAWEED CULTIVATION PROCESSES

Sugar kelp (Saccharina latissima)

Sugar kelp is a brown cold-water seaweed, found in arctic waters surrounding the North Pole, down through the Baltic Sea, around northern Europe and the British Isles, Greenland, Iceland, and on the North American coasts from Alaska through California and through Canada as far south as New Jersey (Ocean Rainforest 2022).

Sugar kelp is deemed as one of the most promising species for commercial-scale cultivation in Europe and in the North Atlantic (Bak et al 2018). Kombu (*Saccharina japonica),* its asian sister species, is already being cultivated and widely eaten in East Asia. It is yellow brown, up to 4 m in length with a claw-like holdfast, a small, smooth, flexible stipe, and an undivided laminate blade up to 3 m long with parallel, ruffled sides and an elongated, tongue-like appearance (Figure 5). The frond is characteristically dimpled with regular bullations (depressions) (Ocean Rainforest 2022). Sugar kelp contains trace minerals and nutrients such as iodine, bromine, nitrogen, vitamins K, B12, and others. For this reason, sugar kelp extracts have also

Figure 5: Sugar kelp is a promising brown seaweed for cultivation in Europe. Picture: Ocean Rainforest

been used in cosmetic products. Alginate compounds extracted from sugar kelp are also used as thickening agents in food and cosmetic applications.

Ten of the twelve products developed in SeaMark contain Sugar kelp from two countries – six of the products contain biomass produced by ORF in the Faroe Islands, whilst four products contain biomass produced by Algolesko (ALO) in France. In this section, the production process of this versatile macroalgal species will be outlined.

The SeaMark products will be produced using sugar kelp in various conditions, these are:

- Fermented sugar kelp supplied by ORF from the Faroe Islands
- Dry sugar kelp supplied by ORF from the Faroe Islands
- Fresh sugar kelp supplied by ALO from France

The cultivation process is the same independent of whether it shall be used to make fresh, dry or fermented. For this reason, the cultivation will first be described, before going into specific processing steps for each sugar kelp product that serves as input into the SeaMark products.

Innovation actions relating to sugar kelp cultivation and pre-processing within the SeaMark project

The European cultivation of sugar kelp has taken steps in the right direction in recent years. However, European macroalgal cultivation is a young industry, so many challenges remain which the SeaMark project has been designed to overcome. The H2020 project Aquavitae recently released a profitability analysis on offshore macroalgal cultiation in the Faroe Islands. The conclusion from this analysis was that in particular two factors should be addressed in order to improve profitability of sugar kelp cultivation. These factors were increased yield and improved efficiency through technological advancements. SeaMark has taken on both of these challenges.
The first one relating to yield is addressed in SeaMark through a breeding program to provide seaweed producers with high performing strains. To this end, SeaMark will identify highly productive, and locally sourced sugar kelp strains to increase

productivity. In this work, sporophytes will be phenotyped for traits of economic interest, such as growth rate, and fucoidan and alginate composition, to increase the desired yields. This will be done in work package (WP) 1 on "selective breeding" and will be lead by Station Biologique De Roscoff SBR and involves partners from also the University in Galway (NUIG) and CARL. Another innovation action taking place within SeaMark relates specifically to reducing production costs. This is in WP2 on cultivation, harvesting and pre-processing. Here SeaMark will develop mechanised seeding and harvesting technologies. These will be developed by Sirputis (SIR) and tested by ORF. Moreover, offshore cultivation concepts will be developed and evaluated in the Faroe Islands and Norway.

Another relevant innovation action refers to the upscaled ensilage methods of sugar kelp, where the goal is to process 10 T wet weight (ww)/hour of sugar kelp into a storage stable intermediate product to be used for feed and food. Cultivating seaweed renders a multitude of eco-system services and in SeaMark an assessment of the eco-system services of the cultivation of sugar kelp will be conducted within the WP9 on ecosystem services and life-cycle assessment.

Cultivation of sugar kelp in the Faroe Islands

Sugar kelp from the Faroe Islands is produced by the Faroese company Ocean Rainforest (ORF). The technology to cultivate kelp under exposed conditions in the Faroe Islands was designed and developed by ORF for over a decade and the structure is referred to as a Macroalgal Cultivation Rig (MACR) (Figure 6). The MACR allows for macroalgal growth on vertical growth lines holding greater volume while using less marine space (Arias et al 2022). The first MACR was deployed in 2010 and has since then been updated and optimised to operate offshore. Nowadays, ORF uses two types of MACRs, one that is optimised for growing sugar kelp at sheltered conditions and one that is optimised for exposed conditions. Since 2016, the company has been implementing the multiple partial harvest method. This method allows for re-growth of the seaweed from the same holdfast, avoiding the need for re-seeding after each harvest (Bak et al, 2018). ORF had a production capacity of 600 tonnes ww in 2022 but produced 100 tonnes ww. They currently have licences on two fjords in the Faroe Islands, Funningsfjørður and Gøtuvík. In this section, the cultivation process of ORF will first be outlined, before emphasis is placed on the processing (Figure 7).

Seeding

ORF produces seed material from mother plants selected from their own lines. ORF operates their own hatchery and nurse spores to sporophytes in their own facilities, using a standard kelp sporulation process and trained personnel. The hatchery process is handled by two persons and involves 4-12 months in the company's hatchery.

Juvenile sporophytes are then seeded directly on the growlines with a binder mixture whereby they are ready for deployment. Currently, the seeding process is done manually involving 6 people for 8 hours, in total 48 hours, for 1000 seeded lines. The goal for the SeaMark project is to introduce a seeding machine which should reduce the total labour consumption from 48 hours to around 7 hours.

Figure 6: Ocean Rainforest's exposed cultivation site in Funningsfjørður, Faroe Islands. Photo: Ocean Rainforest

Deployment

At the farm site, the seeded growlines are attached to the production rig. There are 3,200 or 4,000 growlines on the rig, depending on the type of the MACR production rig. Currently the deployment is done manually, involving 6 people for 8 hours, in total 48 hours, attaching 1,000 growlines. The goal for the SeaMark project is to introduce a rope cutter and a knotting machine to increase the deployment speed. There is no estimate of the labour reduction when introducing the more mechanised method.

Harvesting

ORF uses the multiple partial harvesting method, which is a non-destructive harvesting method that facilitates regrowth. Currently, ORF is performing manual harvesting where the sugar kelp is cut with a knife, and 4 people for 8 hours can harvest 300 growlines, excluding sailing and breaks. The goal for the SeaMark project is to go towards mechanised harvesting. Mechanising the process is estimated to increase the harvesting speed to 1,200 growlines per day and can be performed by two people instead of four.

Transport

The harvested biomass is placed in nets and transported to the processing facility in a transport container. As the quality of biomass decreases quickly when extracted from the ocean, transportation to storage facilities must be swift to ensure the best quality of the biomass.

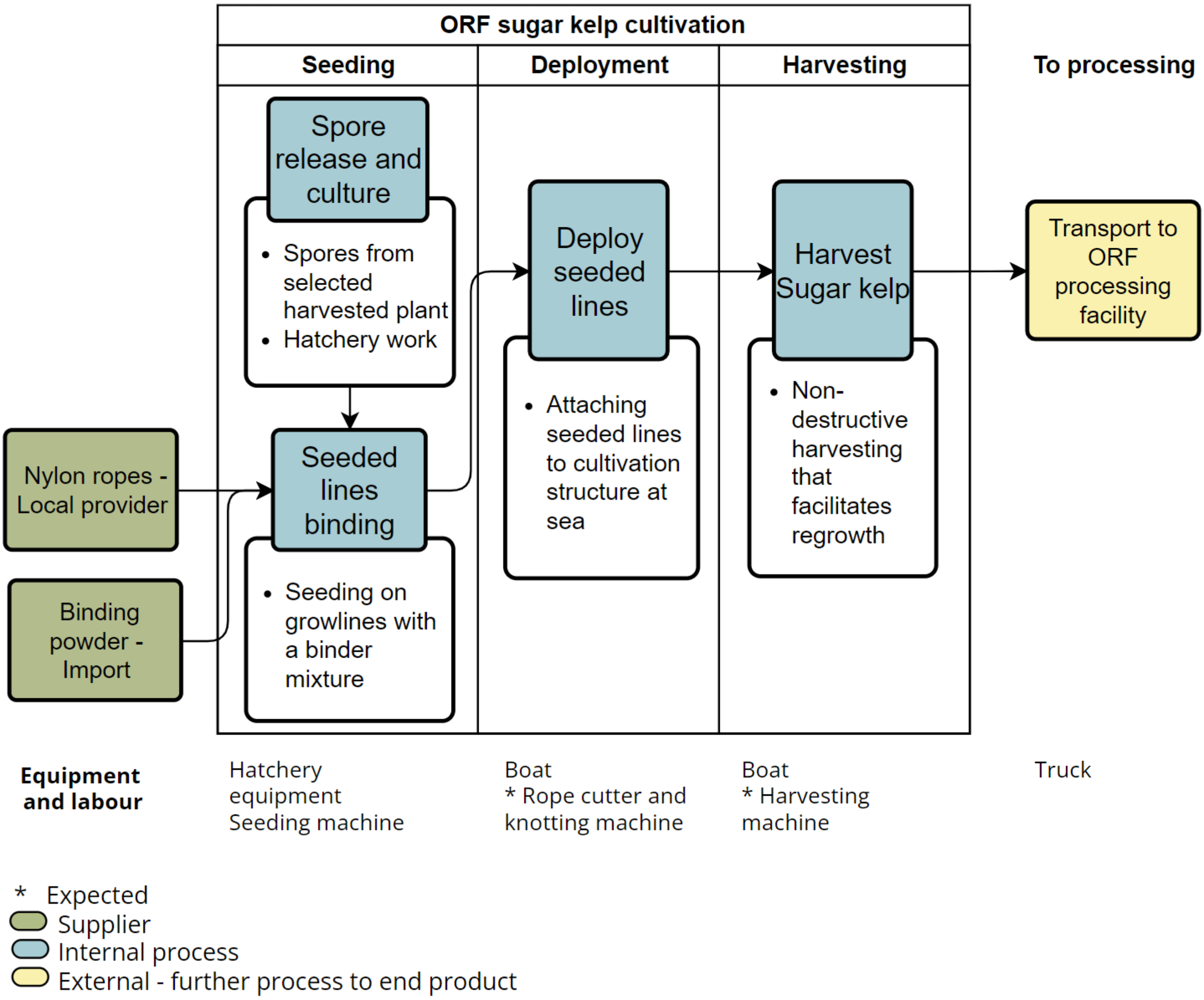

Figure 7: Flow chart for the cultivation and harvesting of sugar kelp by ORF in the Faroe Islands

Fermented sugar kelp from the Faroe Islands (ORF1)

In this section we outline the production process of the fermented sugar kelp product (ORF1) which is delivered to FEXP in Denmark and serves as input to product 5 and 6 (Figure 9).

Washing, screening, and sorting

The sugar kelp is washed in fresh water and screened for debris where rocks, snails and other entangled objects are removed from the seaweed, whereafter it is sorted by hand for quality control. Sorting is most relevant when the biomass is dried. This process needs to be swift to avoid biomass deterioration.

Grinding

The washed biomass is ground by leading it through a continuously pre-grinder and an after-grinder, making a 2 mm pieces soup.
The washing, screening, sorting, and grinding of 3 tonnes of seaweed requires three persons over 7 hours, in total 21 hours, excluding washing of the equipment afterwards.

Fermentation

Lactic acid bacteria and a sugar solution is added to the ground macroalgal soup to bring pH levels down from 7 to below 4 and make the product storage stable. The mixture is stored in airtight Intermediate Bulk Containers, IBC containers, of 1 tonne capacity to avoid contamination.
This fermentation process requires about 1 to 2 weeks and is not requiring any labour. Furthermore, ensiling does not require high energy consumption from the processing facilities.

Transportation for further processing

The sugar kelp is ensiled and ready to be transported to the buyer. The transportation takes 2-3 days by sea cargo. In the SeaMark project, it is sent to FEXP in Denmark to be processed into the products: 'P5: Pig Feed Supplement' and 'P6: Meat Replacement Product'.

Dried sugar kelp from the Faroe Islands (ORF2)

Ocean Rainforest also processes the sugar kelp into dried pieces with different particle sizes. This section outlines the processing steps from arrival of the freshly harvested seaweed to their processing plant (Figure 10).

Washing, screening, and sorting

The sugar kelp is washed and screened for debris where rocks, snails and other entangled objects are removed from the seaweed, whereafter it is sorted by hand for quality control.
This process needs to be swift to avoid biomass deterioration.

Spreading and stacking

The biomass is spread in trays containing a food-grade mesh layer, approximately 1 kilo in each tray. The trays are stacked.

Drying

The stacks of seaweed are placed in a heated room equipped with dehumidifiers and fans. The process takes more than 24 hours at low temperatures until <15% moisture content is reached. The seaweed must be inspected and turned frequently during the drying process to ensure even drying and that no section of the biomass is deteriorating. This requires a high level of labour effort.

Milling and packaging

The dried material is packed into food grade bags and boxes, in either mixed sizes (without milling) or after milling and sieving packed into particle sizes of <2 mm, 2-4 mm and 4-6 mm.

Storage

The product is stored in a dry and cool storage room. The shelf life of the product is two years.

Transport

The dried seaweed is shipped via sea transport. In the SeaMark project, the dried seaweed from ORF is used by OCE in P1-P4.

Cultivation of sugar kelp in France

In the SeaMark project, sugar kelp is also produced by SeaMark partner Algolesko (ALO1). The company is based in Lesconil, South Finistère, Brittany, France (Figure 8). They operate a cultivation site of 150 hectares in the heart of a natura 2000 classified area of the coast. They grow several species of brown laminarian seaweeds. All their production is certified organic farming. ALO deliver their biomass to ALG, who use it to produce products P7 – P10.

Figure 8: Algolesko cultivate seaweed in a 150-hectare Natura 2000 classified area off the coast of Lesconil, Brittany, France. Photo: Algolesko.

Seeding

ALO has their own hatchery and produces their own seedlings from their own seaweed. They have a machine that rolls up the ropes. They don't use direct seeding.

Deployment

For about 8 weeks in September/October, depending on the weather conditions, 4-5 members of the company work full time on the deploying the ropes with the seedlings in the water. The ropes are 100 m long. The rolled-up ropes with the seedlings are then taken by hand and deployed in the water by hand. The only equipment needed is the boat.

Growing

The seaweed is left in the water to grow for about 6 months.

Harvest

For about 8 weeks in March-May 4-5 company members work full time on the harvest, weather permitting. They go out with their own boat (17*6 meters) and collect the ropes with the seaweed with a winch machine (Figure 9). They take out all the ropes and leave only the buoys and ankers in the water. On land the seaweed is cut off from the ropes and filled into containers. The seaweed is not rinsed or blanched or dried.

Figure 9: Harvesting of sugar kelp by Algolesko. The seaweed is cut of the ropes on land. Photo: Algolesko

Packaging and transportation

The product is not stored, as within 24 h it will be ready for transport. There is no further processing of the seaweed. It is filled wet into containers of 500 L and loaded onto a cooled (4 degrees) truck. The containers are not packaged or covered. The drive to ALG takes about 2 hours. ALG only gets around 1-2 of those containers, with a total of around 150 kg seaweed.

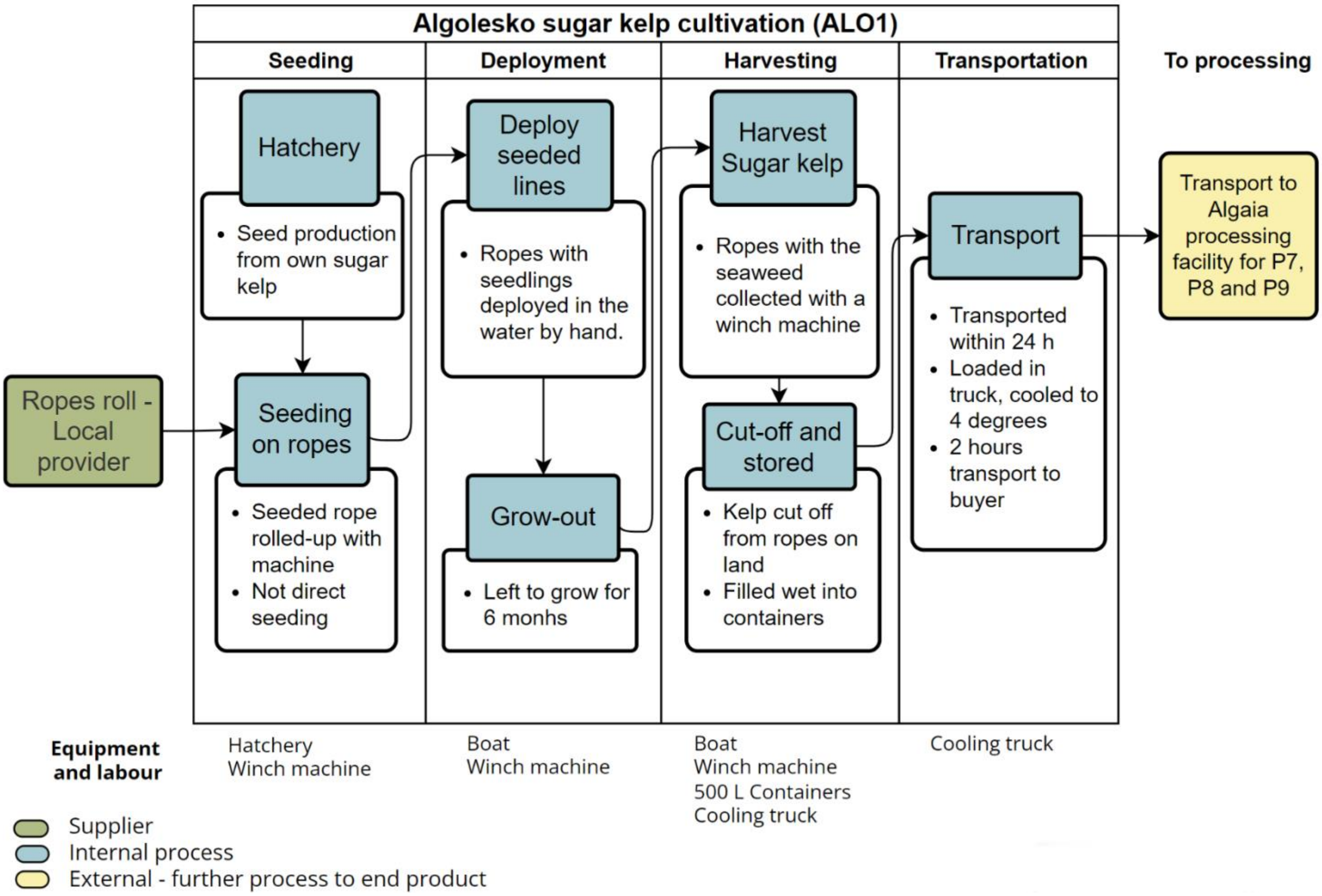

Figure 10: Flow chart detailing Algolesko's cultivation of sugar kelp

Cultivation of sea lettuce (Ulva sp.) from Portugal produced by ALGAplus

The sea lettuce biomass to serve as input into SeaMark products P6, P10, P11 and P12, is produced by the aquaculture company ALGAplus (ALGP), *located* in Ílhavo, Portugal, in a Natura 2000 zone. In Ria de Aveiro coastal lagoon, ALGP has been developing and validating a land-based/on-shore IMTA system for organic certified seaweed production since 2012, supplying the EU market with farmed seaweed biomass since 2014.

ALGP owns and manages a fully licensed site (14 ha), where all the sea lettuce production phases occur: the nursery, cultivation in tanks/raceways and biomass stabilisation. There is still potential to expand, either alone or in partnerships, in neighbouring areas at Ria de Aveiro coastal lagoon.

The cultivation happens in tanks and in raceways that were developed by refurbishing underutilised coastal infrastructures (old salt-ponds). This modular, versatile, and scalable production system is suitable for year-round cultivation of commercial valued seaweed species that are capable of vegetative propagation and/or cannot withstand offshore conditions. *Sea lettuce* is the main species in production occupying currently ca. 3130 m^2 of effective cultivation area; the production is organised so that harvesting, and biomass stabilisation activities occur daily, in production cycles dependent on the season and/or target for biomass chemical composition.

Product description

Sea lettuce is a small genus of marine water green algae found on rocky shores and is normally attached to stones and rocks. It can be up to 30 cm across, with a broad, crumpled frond that is tough, translucent, and membranous. It is attached to rock via a small holdfast. The sea lettuce is found at all levels of the intertidal, although in more northerly latitudes and in brackish habitats it is found in the shallow sublittoral. In very sheltered conditions, plants that have become detached from the substrate can continue to grow, forming extensive floating communities (Pizolla 2008).

Sea lettuce has great potential in food, nutraceutical, cosmeceutical and biomedical applications. Oligosaccharides derived from sea lettuce have great potential as a highly potent bioactive source with numerous health promoting effects (Seong et al., 2020; Ren et al., 2017). Ulvan can also be used for digestive health and biomedical applications, with special emphasis in tissue engineering and cosmetics.

Mineral concentrates from sea lettuce can also be integrated in drink mixes, sport supplements, energy bars, sauces, or ready foods with nutritional enriched profile. Sea lettuce farmed in ALGP has validated claims as a source of iron, magnesium, potassium, calcium, and iodine. Continuous trial of 2 years has demonstrated that the total mineral fraction in sea lettuce is kept constant throughout time, independently of the cultivation protocols or season. The mineral concentrates can also be used for cosmetics and as a functional additive for horse and pet feed.

Sea lettuce is also a good source of protein which may be looked at as a vegetative source for plant-based food and feed products. Most green seaweed species have a lower protein content, but sea lettuce cultivated by ALGP in land-based raceway systems has demonstrated a protein content of 20%.

Innovation actions relating to production of sea lettuce within the SeaMark project

In SeaMark, ALGP will improve and innovate pre-processing for washing/centrifuging, milling, and testing of the first solid/liquid separation through a new demonstration process. Within the project lifetime ALGP expects to develop an end-to-end solution for production management that includes management software, hardware, integration services and analytics for land based IMTA (fish and seaweed operation). There are still challenges mainly related to the automation of water flows, mechanisation of harvest, strain selection and operational management. A validated prototype for semi-automated harvesting was developed and tested in project GenialG, and now the company expects to reach a production of 100 T ww in 2023. However, the harvesting equipment needs to be adjusted for large-scale commercial operation conditions. Therefore, another aspect of SeaMark will be to further develop and demonstrate harvesting equipment for large quantities in short periods – up to 2 T ww/day.

In the following section, ALGP' production process for cultivation and processing of sea lettuce will be presented (Figure 11).

Seeding raceways

The raceways are seeded with seaweed fragments harvested on site or from excess growth from the raceways. It is left to grow for 2-3 weeks in the raceways, monitored with multiparametric sensors.

Harvesting

After the growth period, the seaweed is harvested with a harvesting pump and most of the seaweed is transported to the processing facility on site for further processing while some of the seaweed is used for reseeding the raceways.

Washing

After arriving at the processing facility, the seaweed is washed in sterilised seawater or sterilised freshwater, depending on the downstream target product. The washing is done in a washing machine, customised for several seaweed species.
Any excess water is removed from the biomass with a centrifuge.

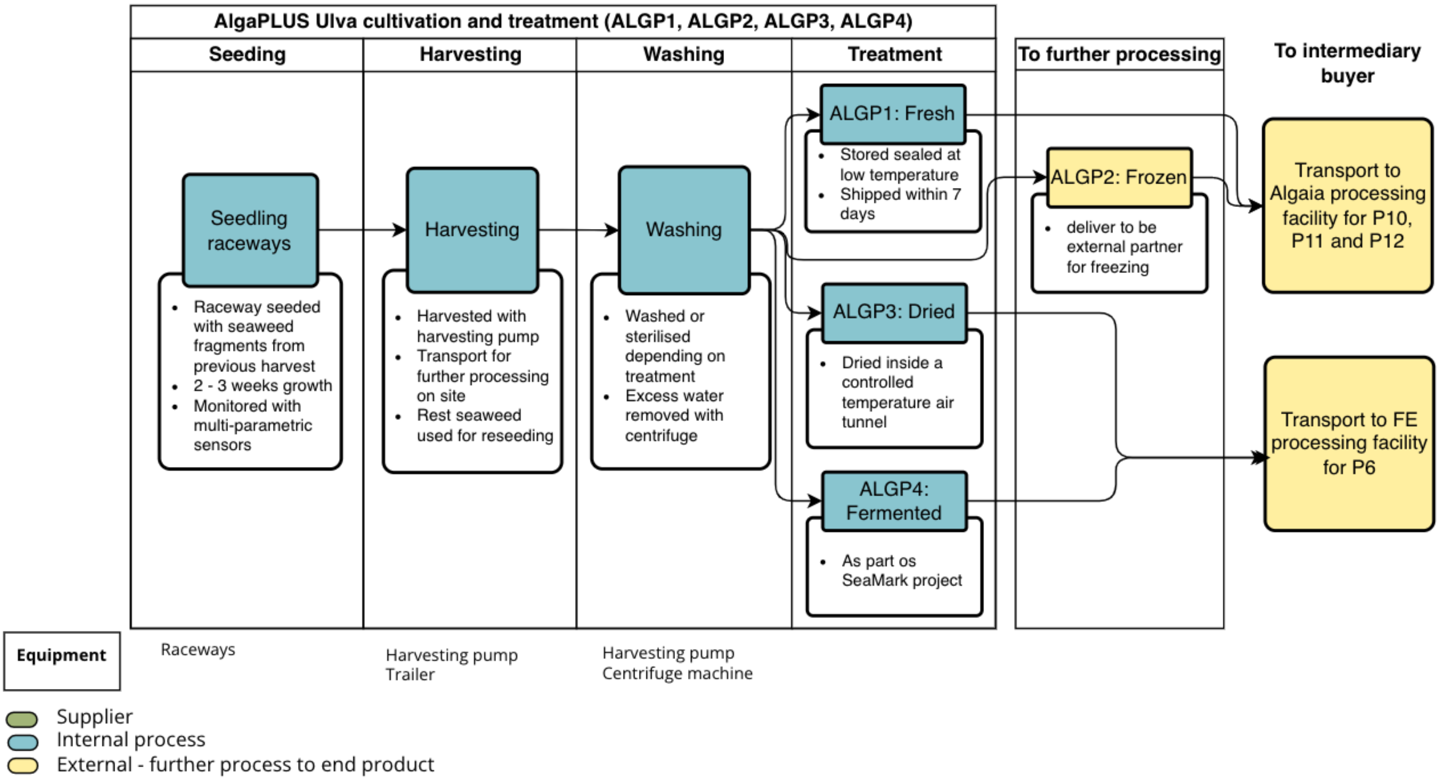

Figure 11: Flow diagram outlining the cultivation and processing of sea lettuce to be used in SeaMark products P6, P10, P11 and P12.

Processing into end-products

The end products in the SeaMark-project are wet (ALGP1) or frozen (ALGP2) sea lettuce biomass delivered to ALG in France and dried (ALGP3) or fermented (ALGP4) sea lettuce delivered to FEXP in Denmark. At the end of the project, after evaluation of each process, the company expects to be able to go up in the value chain, by incorporating new biomass processing phases and thus commercialise, biomass fractions instead of whole biomass like nowadays.

The wet biomass is stored in sealed containers in cooled conditions (<7°C) at the production facility and should be used for further processing within seven days.
The freezing of the seaweed and storage of the frozen product is performed by an external supplier. The wet or frozen seaweed is packed in plastic pallet boxes with a capacity of up to 300 kg per box.

ALGP also delivers dried seaweed. For that, the wet seaweed is placed in trays inside a controlled temperature air-tunnel where it is dried. The process takes around 16 hours, including filling and emptying the dryer. The dried biomass can be stored for 3-4 years and is packed in 100 kg big bags if the seaweed is whole and 400 kg bags if it is ground to powder.

Within the idea to further incorporate new processing/biorefinery stages on site, and after initial trials are done at FEXP and AAU, ALGP will, if trials are successful, also do small scale ensilage testing of fermented seaweed for product 'P6: Meat Replacer Product'. These tests will be performed according to the developed fermentation protocols by FEXP and AAU.

MAPPING OF PRODUCTION PROCESSES OF THE TWELVE SEAMARK PRODUCTS

Product 1-4: Biorefinery processing

Oceanium (OCE) develops several products based on their processing of seaweed from ORF. The products share much of the same inputs and processing stream, and the product form is either as dry powder or pellets.
The products (P) are:

- P1 Bioactive beta glucans
- P2 Bioactive fucoidans
- P3 Bio-packaging materials
- P4 Fibre and protein food ingredients

OCE has developed different brands for their products. Food fibre and food protein are marketed under *Ocean Health* brand. *Ocean Actives* is the nutraceutical's brand (beta-glucan and fucoidan), and there is a family of products being developed for materials applications like bio-packaging, textiles, and coatings (P3), that are based on the same fibre as food products. Within each group of products, many variants of formulations are possible, and research is in process in different areas. Some composite materials formulations are subject for a patent application. For some of the products, specific markets and potential buyers are defined, while others are at a very early stage. Optimising and upscaling of production process, verification of bioactivity effects and developing market strategies are the main innovation actions within SeaMark for these products.

All four products require the same raw material: it is either frozen or dried sugar kelp. P1, P2, P3 and P4 are co-extracted during the same production processes (Figure 15). At the first stage (extraction), the chopped seaweed is extracted with water and acid, and calcium chloride and preservatives may be added. The soluble compounds, including minerals (ash), protein and soluble carbohydrates, are then separated from fibre. After extraction, the liquid with dissolved compounds is used in the next stage, while the fibre is sent directly to the drying stage. At the second stage, micro- and ultra-filtration is used to purify the nutraceutical products. The output is two streams of liquid concentrates, one of which contains "P1: beta-glucan", and another one "P2: fucoidan". These liquids are dried using spray dryer and the fibre is dried and milled. Dried fibre is the material used in "P3: bio-packaging" and "P4: fibre and protein food ingredients". Extraction of protein and its further processing is not yet established (Figure 12).

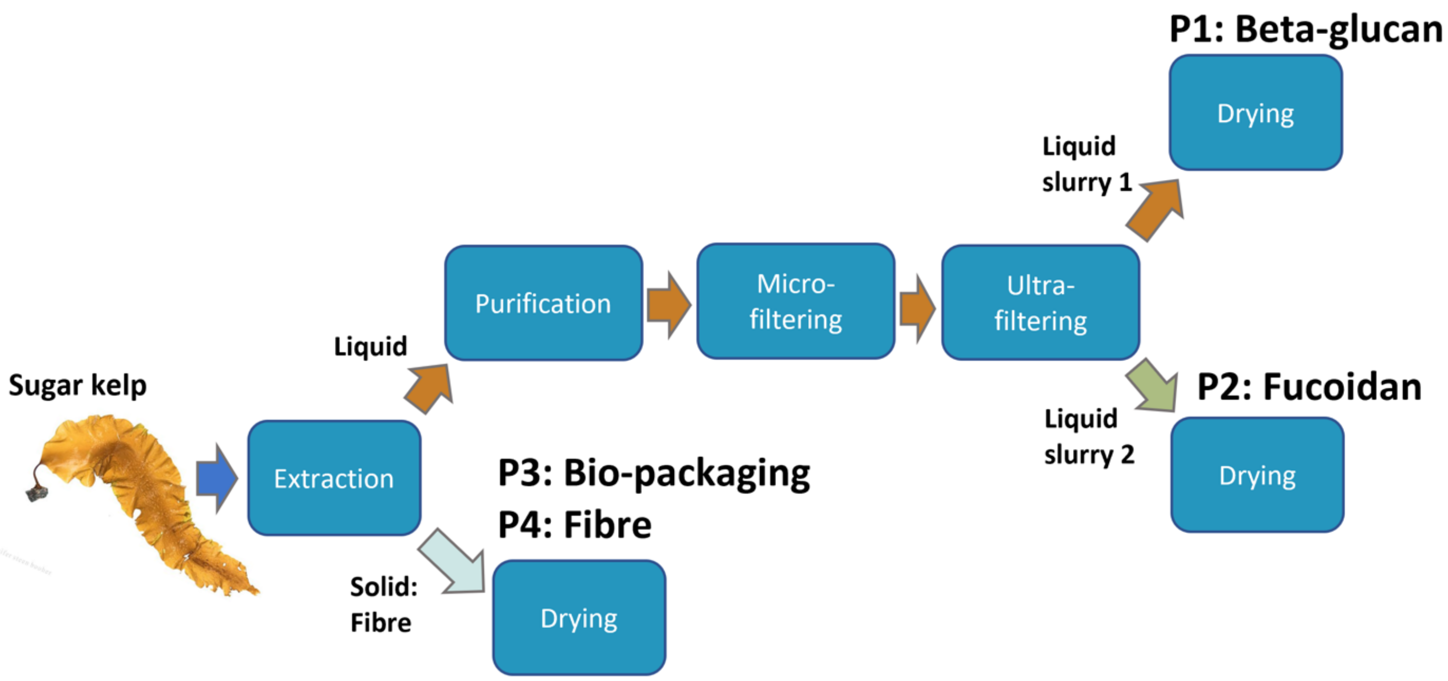

Figure 12: Common flow-chart demonstrating the production process for co-extraction of P1 - P4.

Product 1: Bioactive beta-glucans

Beta-glucan is a polysaccharide product produced as dry powder in a biorefinery (Figure 13). It can be extracted from various raw materials, including seaweed. It is used as an ingredient in cosmetic products and nutraceuticals. Beta-glucan produced by OCE in UK is extracted from seaweed from ORF.

Figure 13: Bioactive beta-glucan can be used in cosmeceuticals and nutraceuticals. Photo: Oceanium

Product description

Beta-glucan is one of well-known bioactive polysaccharides that can be isolated from the different sources such as cereal, yeasts and fungi (Figure 16). Several health benefits are documented for its application in food products (Kaur et al. 2018), while benefits as ingredient in cosmetic products are less established (Du et al. 2013). Depending on the source, the extracted beta glucan varies in chemical and functional characteristics. OCE is in the process of developing *Ocean Actives* beta-glucan extracted from seaweed. It is a water-soluble product with claimed prebiotic and immunomodulatory activity.

Sugar kelp in frozen or dry form is the raw material for this product, and it is supplied by ORF. At the biorefinery the components needed for the product are extracted from the seaweed, separated from fibre, filtered, and dried. The powder is packed and delivered in food-grade, air-tight containers to customers.

Main selling points

According to the producer, the product will be the first commercial beta-glucan extracted from seaweed. It is water-soluble and has low molecular weight, which facilitates its application in an array of final products. Validated health claims are critical for future market potential. The producer highlights the innovation, traceability and sustainability components of the raw material and "green" production technology. The product is currently targeted to cosmetic producers as ingredient in skincare formulations and nutraceutical producers as health supplements of functional-food ingredients. For a more detailed analysis on the product's competitive advantages, see the SeaMark Deliverable 7.1.

Technological readiness level

The product is currently developed to TRL 5, aiming for TRL 7 by the end of the SeaMark project. The company can produce small amount of beta-glucan, and the process is established, however, production in larger volumes needed for testing and supply to customers is not yet achieved.

Innovation action in SeaMark

Improvements of the current TRL are mainly realised in WP3 – biorefinery processing for bioactives, fibres and biomaterials and WP6 – Product application development. In the up-scaled OCE seaweed biorefinery process, consistent high-quality beta-glucan will be developed based on the pilot production of year 1 and incorporating learning from WP6. The products will be analysed to confirm safety: detailed polysaccharide compositional analysis will be carried out by partner DTU. The product will be characterised and optimised by MAT during year 1 to inform production process for year 2. The optimised product will be evaluated in human volunteer studies designed to substantiate product health claims (for the US market). A beta-glucan product dossier will be prepared to support nutraceutical marketing.

P1 is a flagship product in SeaMark, which means that value-chain, techno-economic, and life cycle assessments as well as regulatory investigations and market analysis will be conducted. Go-to-market strategies and business plans will also be developed for the product.

As the input and production processes of "P1: Bioactive beta-glucans" is identical to that of P2, a common flow chart and description of the production process are presented immediately after the P2 description.

Product 2: Bioactive fucoidans

Fucoidan is a polysaccharide that is found primarily in the cell walls of brown seaweeds (Figure 14). The product is used as a bio-active ingredient in the form of water-soluble powder in a range of cosmeceutical and nutritional applications. Fucoidan produced by OCE in UK is extracted from seaweed from ORF.

Product description

Fucoidans are polysaccharides present in brown seaweed and other marine organisms. Bio-active properties of fucoidan, such as anti-inflammatory, anti-viral and antioxidant effects are documented (Luthuli et al. 2019), however large variation is observed depending on the source material (Cumashi et al. 2007). A number of cosmetic products, foods and supplements containing fucoidans are now available on the market and regulatory approval of its clinical use is ongoing in several countries (Fitton et al. 2019). Fucoidans from selected brown seaweeds species already have novel foods and GRAS approval, which will accelerate approval of sugar kelp fucoidan. OCE is developing a process for fucoidan extraction from sugar kelp. Frozen or dried seaweed is the raw material for this product, and it is supplied by ORF. At the biorefinery the components needed for the product are extracted from the seaweed, separated from fibre, filtrated, and dried. The powder is packed and delivered in food-grade, air-tight containers to customers.

Main selling points

OCEAN ACTIVES Fucoidan is targeted primarily for cosmetic and nutritional applications. As ingredient in skin health products, its claimed key properties are skin barrier protection and reduced aging and redness. Fucoidan will also be marketed as a nutritional supplement supporting gut, immune, and cardiometabolic health, however the health claims need to be further verified in both areas of application. It is a potentially more powerful ingredient for cosmetic and supplement products, and its sustainability and traceability are thought to attract industrial buyers. Another advantage is that fucoidan may represent a comprehensive solution for several health problems instead of targeting only one. OCE is in dialogue with potential buyers in the US and UK.

P2 is an innovation product in SeaMark, which means that a market analysis and a go-to-market strategy will be developed for the product. An initial assessment of the market potential of the product will be presented in the upcoming D7.3, which will be available in January 2024.

Technological readiness level

The product is currently developed to TRL 5, aiming for TRL 7 by the end of the SeaMark project. It is one of the products that has passed lab scale stage and is already produced at high purity in large amounts at a pilot biorefinery.

Innovation actions within the SeaMark project

In the up-scaled OCE seaweed biorefinery process, consistent high-quality bioactive fucoidan will be developed based on the pilot production of year 1 and incorporating learning from WP6. The products will be analysed to confirm food safety: detailed polysaccharide compositional analysis will be carried out by partner DTU. The product will be characterised by DTU during year 1 to inform optimised production process by OCE for year 2. The optimised product will be evaluated in human volunteer studies designed to substantiate product health claims (for the US market). A fucoidan product dossier will be prepared to support nutraceutical marketing.

Mapping and description of production process of P1: Bioactive beta-glucan and P2: Bioactive fucoidan

The inputs, production, and storage of beta-glucan and fucoidan is identical. The only difference is that another concentrated liquid is used in drying stage. Due to this, the flow charts and associated description are presented together.

Figure 14: Fucoidan can be used as a bioactive ingredient in cosmeceutical and nutraceutical applications. Photo: Oceanium

The production of beta-glucan requires the following inputs:

- Sugar kelp, frozen or dried
- Fresh water
- Calcium chloride
- Preservatives
- Acid

Equipment:

- Tanks with agitator
- Pumps
- Centrifuges
- Micro- and ultra-filtration unit
- Spray dryer

Raw material

Production requires either frozen or dried sugar kelp, which is delivered in temperature-controlled (frozen seaweed only) vehicles in agreed volumes. The volume depends on the seaweed form, storage capacity and production plan of OCE.

Extraction

At the first stage (extraction), the chopped seaweed is extracted with water and acid, and calcium chloride and preservatives may be added (all standard, off-the-shelf inputs). The soluble compounds, including minerals (ash), protein and soluble carbohydrates, are then separated from fibre. Machinery used at this stage are holding tanks with agitator and centrifuges. These are standard machines, as all other equipment used in the process. After extraction, the liquid with dissolved compounds is used in the next stage, while the fibre is sent directly to the drying stage and used for other products.

Filtration

At the second stage, micro- and ultra-filtration is used to purify the nutraceutical products. The output is two streams of concentrated liquid, one of which contains "P1: beta-glucan".

Drying

These liquids are dried using spray dryer.

End products

The end-product is in the form of dry powder that can be stored at ambient temperatures. The product is packed, stored, and transported to buyers in food-grade packaging. Food-grade, air-tight containers are required to transport the products. Together all stages require a minimum of 36 hours to complete.

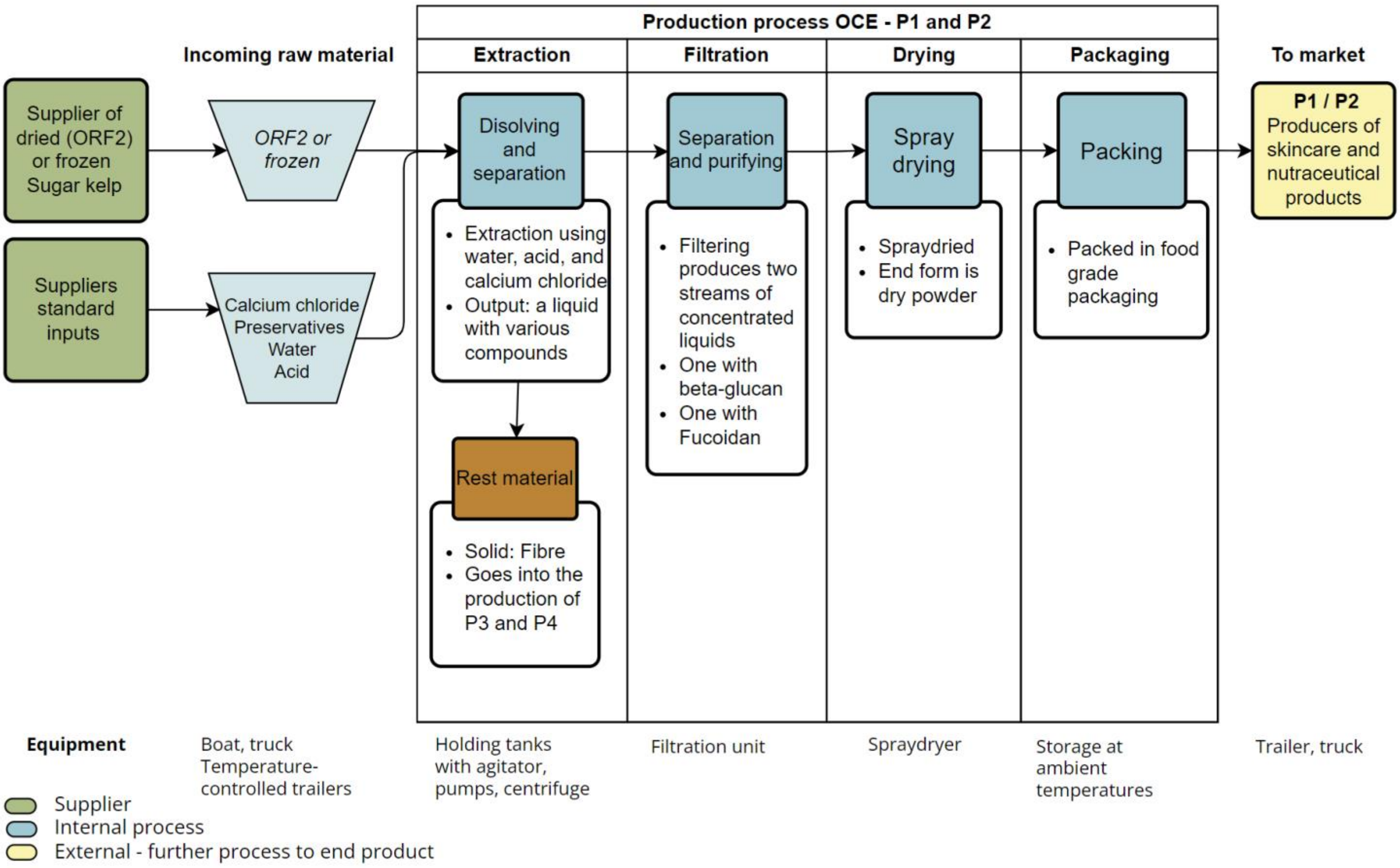

Figure 15: Flowchart of the production process of bioactive beta-glucan (P1) and fucoidan (P2).

Product 3: Bio-packaging materials

OCE will produce seaweed-based powdered or pelleted material and inks/coatings which will be sold to producers of packaging, textiles, and materials for a range of applications in those markets, including, but not limited to, film, board and coatings. ORF will supply seaweed for production.

Figure 16: The seaweed-based material can be used for producers of packaging and textiles to create film and board. Photo: Oceanium

Product description

The properties of seaweed-derived compounds make them promising candidates to produce innovative materials in packaging and textiles applications that have a potential to reduce the use of fossil-fuel derived plastic. Alginate, carrageenan, and agar are the most suitable compounds for production of biofilms and bioplastics – packaging materials that are biodegradable and renewable (Lomartire et al. 2022). OCE has demonstrated experimental proof of concept to convert seaweed-derived compounds into materials including film, board, inks, and leather-like materials. Board and film can be used as outer packaging. All these forms use the same seaweed component base, but slightly different formulations. OCE has recently finished developing these materials and processes through Innovate UK funding and currently in talks with commercial partners for further development. The company has filed a patent for their materials. As production scale develops, OCE will produce powdered or pelleted materials which will be sold to producers. The material is seaweed fibre, which needs further processing to develop functionality.

Main selling points

Fossil-fuels derived plastic replacement is the main advantage of the product. The "seaweed story" (the origin) and the wide range of functionalities are important advantages as well.

P3 is an innovation product in SeaMark, which means that a market analysis and a go-to-market strategy will be developed for the product. An initial assessment of the market potential of the product will be presented in the upcoming D7.3, which will be available in January 2024.

Technological readiness level

The product is currently developed to TRL 4/5, aiming for TRL 7 by the end of the SeaMark project. OCE emphasises that bio-packaging is on a very early R&D level and is not scaled up. The target applications and products are not finally decided on, and different options are being explored.

Innovation actions within the SeaMark project

Production process will be optimised and scaled up in year 2 based on the experience and learning outcomes of the first year. The finished products will be analysed to confirm food safety.

Product 4: Fibre and protein food ingredients

OCE is developing protein and fibre derived from kelp. The protein can be used as ingredient in functional and sport food formulations, while the fibre is suitable for many applications including gluten-free breads, plant-based meats, and beverages (Figure 17). ORF will supply raw material for these products.

Product description

OCE biorefinery develops fibre and protein ingredient products using food-safety accredited production processes. Both products are produced as dry powders suitable for formulation in a range of food products. Seaweed fibre is a texturizing ingredient used in food for its water binding and gel forming properties. The product fits into the well-established fibre market providing a sustainable and clean label alternative to terrestrial fibre products and to existing E-number products such as seaweed hydrocolloids. Seaweed protein is in the development as a sustainable plant-based protein ingredient under high demand because of the rapid growth of plant-based diets. OCE seaweed products offer amino acid composition and digestibility that according to the producer themselves compare favourably with established terrestrial plant proteins.

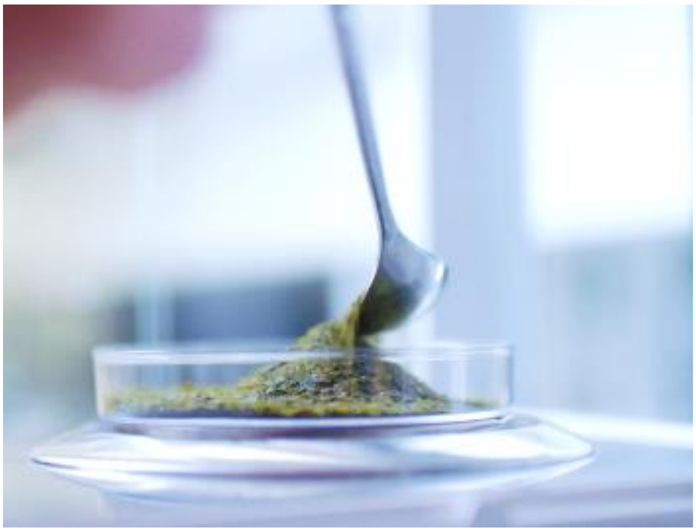

Figure 17: Protein can be used in functional and sport food formulations, while the fibres can be used for gluten-free bread, plant-based meats, and beverages. Photo: Oceanium

Main selling points

OCE highlights the versatility and sustainability of the fibre product and its potential for replacing synthetic ingredients. Several functional benefits for food application are claimed, including extending shelf life of food. The main advantage of the protein product according to OCE is that it provides the full range of amino acids. Studies also demonstrate the high quality of protein in Faroese cultivated sugar kelp, although the concentration of protein is relatively low (Bak et al. 2019).

Technological readiness level

OCE has received preliminary feedback from the UK Food Standards Agency stating that novel foods approval is not likely to be required for seaweed fibre. If this is formally confirmed by UK and European regulators this product will reach TRL 8 by the end of the project. Seaweed protein will require novel foods approval. Therefore, this product will reach TRL 7 by the end of the project. The extraction process for protein is under development.

Socio-economic assessment and market analysis will be conducted. A go-to-market strategy will also be developed for the product.

Innovation actions within the SeaMark project

Production process will be optimised and scaled up in year 2 based on the experience and learning outcomes of the first year. The finished products will be analysed to confirm food safety. Food analysis service providers will conduct analysis on nutritional profile and composition of products, as well as microbiology.

Mapping and description of production process for product 3 and 4

As the inputs and processing steps are identical for P3 and P4, a common flow-chart is presented, and description of the production process is presented below (Figure 18).
Production of "P3: bio-packaging materials" and "P4: Fibre and protein food ingredients" require the following inputs:

- Sugar kelp, frozen or dried
- Fresh water
- Calcium chloride
- Preservatives
- Acid

Equipment

- Tanks with agitator
- Pumps
- Centrifuges
- Spray dryer

Raw material

The product requires the same raw material as P1 and P2: it is either frozen or dried sugar kelp, which is delivered in temperature-controlled (frozen kelp only) vehicles in agreed volumes. The volume depends on the seaweed form and on the storage capacity and production plan of OCE.

Extraction

At the first stage (extraction), the chopped seaweed is extracted with water and acid, and calcium chloride and preservatives may be added (all standard, off-the-shelf inputs). The soluble compounds, including minerals (ash), protein and soluble carbohydrates, are then separated from fibre. Machinery used at this stage are holding tanks with agitator and centrifuges. These are standard machines with some modifications, as all other equipment used in the process.

Drying

The fibre is dried and milled into powder.

End products

The dry powder can be stored at ambient temperatures. The products are packed, stored, and transported to buyers in food-grade packaging. Food-grade, air-tight containers are required to transport the products. Together all stages require a minimum of 16 hours to complete.

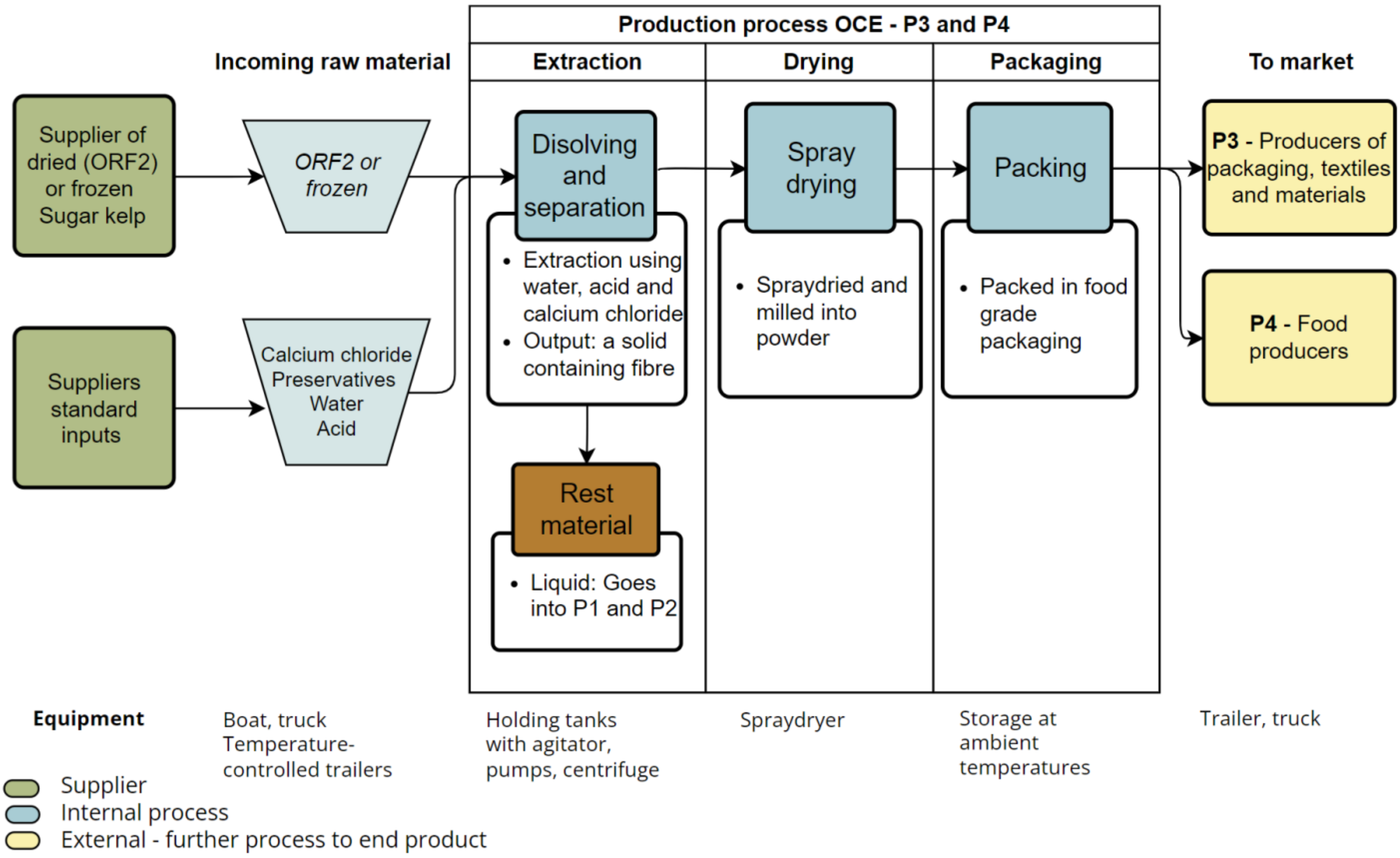

Figure 18: Flowchart of the production process of bio-packaging (P3) and fibre and protein food ingredients (P4)

Product 5: Pig feed supplement

"P5: pig feed supplement" is a fermented supplementary feed, primarily sold to pig farmers for its many vital benefits stemming from the fermentation process (Figure 19). The product is produced by the Danish company Fermentation Experts (FEXP) with seaweed from ORF.

Figure 19: The finished product as sold to feed distributors or pig farmers. Picture: Fermentation Experts

Product description

The product is a supplementary feed made from fermented seaweed and rapeseed meal, sold primarily to pig farmers in need of the multiple positive benefits on productivity and gut wellbeing benefits from the fermentation process. According to FEXP, adding fermented seaweed to the pig feed supplement adds other wellbeing benefits than feed supplements produced from fermented rapeseed meal without added seaweed. Even with the contribution of seaweed, a major part of the product is rapeseed meal (canola oil by-product), constituting around 9 percent.

Figure 20: One of the unique selling points of the product are improved wellbeing benefits, improving productivity and milk production of sows. Picture: DepositPhotos

The pig feed supplement is mixed with other feed, normally at a ratio from 0,1 to 20 percent, depending on whether it is intended for piglets or sows. It is not used for pigs ready for slaughter, since they do not require the more costly feed supplement with health benefits. Depending on the problems at a farm, for instance high bacterial pressure, different percentages of the mixture can be used. The exact dosage differs a lot from farm to farm how they are using it. If the dosage is too high, the pigs can get protein diarrhoea, in which case the dosage is lowered. It is very individual how the pigs respond to it, so it is a trial-and-error process.

The fermentation is carried by lactic acid bacteria which produce substantial lactic acid in the finished product. This has many several benefits of wellbeing and good gut balance for the animals. In addition, there are several metabolites produced during the fermentation process. Most of these metabolites are known to positively influence physiological processes both locally in the intestine and systemically when ingested by the animals thereby a huge number of beneficial components in the supplementary feed.

Main selling points

FEXP highlight that the fermentation process means that the sows produce more liveborn piglets and at the same time they also produce more milk so they can take care of their piglets (Figure 20). It has also been documented that the farmer can lower the feed usage due to the improved protein uptake.

The increased production and lower feed usage are regarded to be the main selling points of the product since the farmers see a beneficial economic gain of the product. According to Jens Legarth, CEO, FEXP farmers would not buy the product solely for the improved health or wellbeing of the pigs, there also needs to be an economic gain to compensate for the increased cost of the feed. For a more detailed analysis of the product's competitive advantages, see SeaMark D7.1.

Technological readiness level

The product is at TRL 9, which is the highest TRL-level. It means that the product is fully developed and produced routinely. Contrary to most of the products in SeaMark, the pig feed supplement is a product that already is being produced and is on the market. The producer, FEXP, already commercialises fermented rapeseed meal for sows and in weaner pig production.

In the MacroCascade project, FEXP developed the EP199 product which contains co-fermented rapeseed meal and seaweed. For the past 1½-2 years, around 50 Danish farmers have fed their sows with this product. After 9 months, preliminary data from these farms show a better feed conversion, a better utilisation of protein from the feed (5% less usage of protein in average) and a higher piglet weaning weight (approx. 8.2 %).

Innovation actions within the SeaMark project

There will be no product development for this product in the SeaMark project since the product is already in commercial production. In SeaMark the focus is to demonstrate and document the beneficial effect on production and

Figure 21: According to Fermentation Experts, one of the unique selling points is that the pig feed supplement improves feed conversion rates. During trials, there have been observed improved protein uptake, reducing the need for feed by 5 %. Picture: DepositPhotos

health/wellbeing parameters in the largest conducted pig trial to date. Focus will be on fermented seaweed's ability to promote sow wellbeing and performance by gut microbiome and immune system stimulation. Efforts are also made to investigate the reasons behind the improved feed conversion rate, and the better protein uptake, thereby reducing the need for more protein, consequently lowering feed costs (Figure 21).

The specific objectives are to:

- Demonstrate the beneficial effect of fermented seaweed on the gut microbiome and immune system maturation of sows during the physiologically stressful transition period from gestation to lactation in large scale on a practical farm
- Describe the biochemical basis for a prebiotic effect as well as the effect on the gut microbiome
- Optimise seaweed fermentation protocols for a prebiotic effect of the fermented product
- Provide a characterisation of the fermented food product

This work will be conducted in collaboration with Arhus University (AU), University of Copenhagen (UCPH) and Aalborg University

P5 is a flagship product in SeaMark, which means that value-chain, techno-economic, and life cycle assessments as well as regulatory investigations and market analysis will be conducted. Go-to-market strategies and business plans will also be developed for the product.

Mapping and description of production process

The production of Pig Feed Supplement requires the following inputs:

- Rapeseed meal
- Fermented brown sugar kelp
- Lactic Acid Bacteria
- Water
- Energy (natural gas and electricity)

Equipment

- Sealed containers
- Special dryer

Most of the inputs are standard inputs that can be bought from several sources on the market, therefore the supply chain for these inputs will not be elaborated here.

The fermented seaweed is a less standard input which is the focus of the SeaMark project. The fermented brown seaweed (*Saccharina latissima*) is supplied by ORF, and the supply chain and production process has been described on page 7.

There are three processing stages in the production of Pigs Feed Supplement: fermentation, drying and mixing. In addition, there is a stage where the product is sent to the market (Figure 22).

Raw materials

The raw material for the production is fermented seaweed, rapeseed meal and lactic acid bacteria. Rapeseed meal and lactic acid bacteria are standard inputs that are acquired from the market. The rapeseed meal is dry and can be stored in a dry warehouse at normal room temperature for up to at least a year.

The fermented seaweed, sugar kelp, is supplied by ORF. Immediately after the seaweed is harvested, it is minced, put in containers to which lactic acid bacteria are added and sealed. Thus, the fermentation process begins immediately after the seaweed is harvested and is ongoing as the seaweed is transported from ORF to FEXP.

It arrives at FEXP in shipping containers with around 24 tonnes of seaweed in a container. The seaweed can be stored for at least a year at normal temperature. The long storage time makes it possible to keep the seaweed in Faroe Islands to be able to fill a full container of 24 tonnes, thereby saving some transportation costs.

FEXP has an additional supplier of seaweed, ALGEA from Norway, who supply dried seaweed, *Ascophyllum nodosum*. As the seaweed is dry and not fermented, it must be fermented prior to production by adding water and lactic acid bacteria. This pre-processing takes about a month.
It should also be mentioned, that for a similar product, FEXP uses soybean meal instead of rapeseed meal.

Fermenting

The fermentation process involves an inoculum development step, which is the preparation of a population of microorganisms from a stock dormant culture to a state useful for inoculating a final production fermenter. Some of the raw material is added, so that the bacteria get used to the raw material. Wet fermented seaweed is then mixed with rapeseed meal and fermented again without the addition of water.

Drying

After end of the fermentation process the fermented seaweed/rapeseed meal mixture is dried in a special dryer to a water content of around 10 percent. This makes it good for storage, since it will not get mouldy or rot when the water content is lower than 15 percent.

This product is a 'concentrated' fermented and dried biomass. For seaweed/rapeseed meal, the product is called EP1199. After drying, the concentrated EP1199 is mixed/diluted with fermented rapeseed meal (EP100) resulting in the final product EP199 (Figure 26).

Mixing

Prior to final delivery to the farm, EP199 is again mixed with other feed at a ratio from 0.1 to 20 percent, depending on the needs of the costumer (Figure 23).

To Market

The EP199 is sold across Europe. A part of the product is sold directly to the farmers, while another part is sold via feed distribution companies, feed mills, where they mix it with other feed.

Figure 23: The feed supplement is sold directly to farmers or to feed distribution companies, where it is mixed with other feed. Photo: DepositPhotos

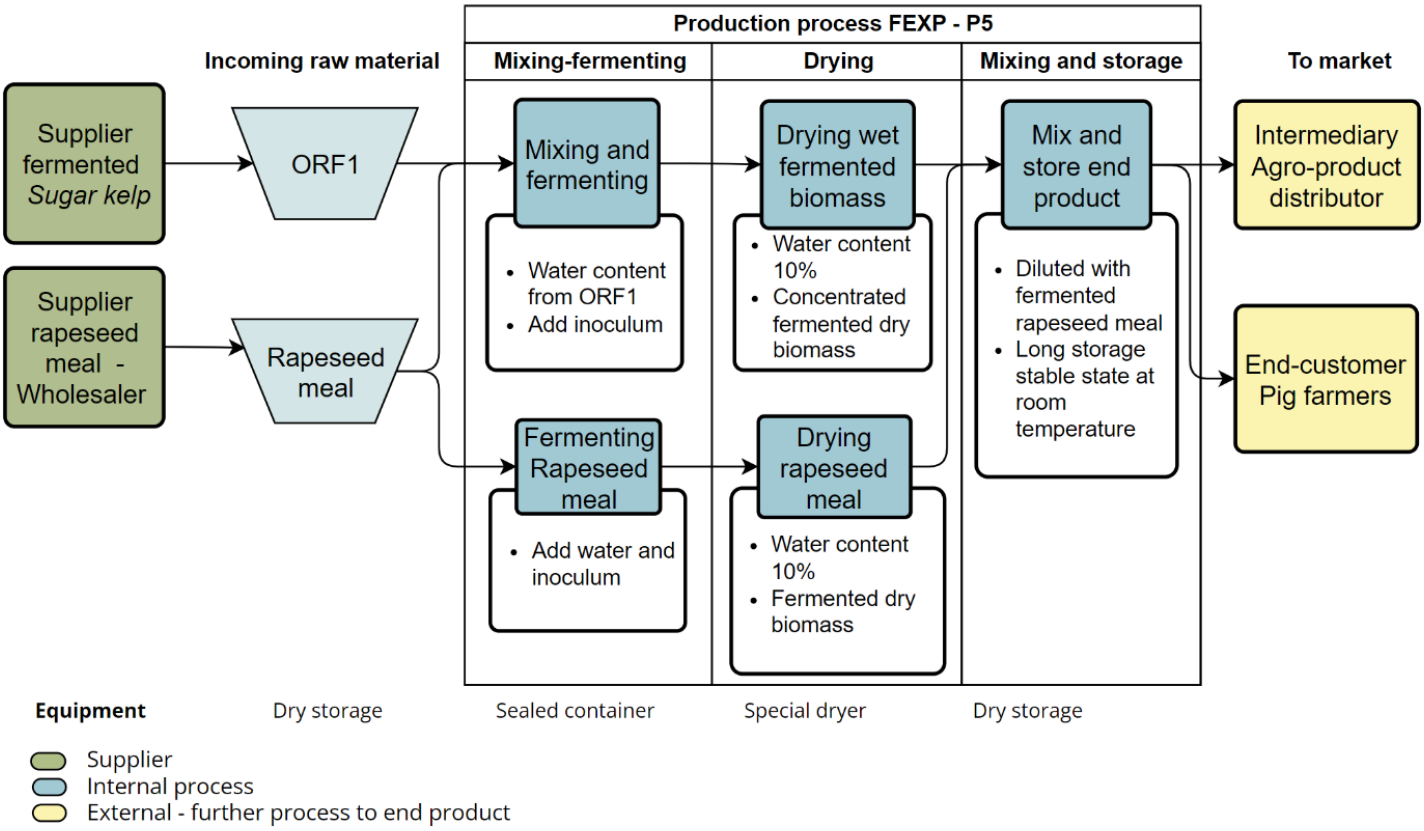

Figure 22: Flowchart of the production process of Pig Feed Supplement (P5)

Product 6: Meat replacer product

"P6: Meat Replacer Product" is a fermented mixture of seaweed and a protein source, e.g. rapeseed meal, soybean meal, fava beans, chickpeas, used either as an ingredient to prolong shelf life of meat or bread or as a meat replacement product.
The product is produced by FEXP with sugar kelp ORF or sea lettuce from ALGP in Portugal.

Product description

The product is a fermented ingredient (additive) which can be sold to food producers for various product applications.
The fermentation of the product is done by lactic acid bacteria which leave substantial lactic acid in the finished product giving many benefits of wellbeing and a good functioning gut. In addition, the metabolites produced from the fermentation process leaves a lot of beneficial components in the product. According to FEXP, the fermentation process preserves the vitamins and minerals in a much better way compared to boiling at high temperatures. Fermenting food products, like seaweed, also greatly reduces the bitterness, so they become more palatable.

The product can be used as:

- Hybrid product – half meat / half plant based
- Fully plant-based meat replacer
- An ingredient in protein bread
- Meatballs or sausages
- Pesto

The product has one potential issue with the perception of seaweeds. Some meat producers consider seaweed to be fish, which makes it impossible to add it to meat products.

Main selling points

The product has many potential product applications, making it very versatile. The product could have a potential to minimise food waste, using plant side streams. According to FEXP, the products consist of potential prebiotic fibres, lactic acid bacteria, and bioactive metabolites that have putative antioxidant, antimicrobial, and anti-inflammatory effects. In addition to the claimed benefits of wellbeing, the product is also a clean label product, with a very short list of ingredients. Such products are in increasing demand. To make a fully plant-based hamburger or sausage some fibres and vegan binder must be added, like beans or sunflower meal. This produces a vegan meat replacer with no E-numbers. To avoid E-numbers, FEXP produces natural binders themselves, replacing methylcellulose. Adding seaweed to this product also adds a lot of benefits of wellbeing.

P6 is an innovation product in SeaMark, which means that a market analysis and a go-to-market strategy will be developed for the product. An initial assessment of the market potential of the product will be presented in the upcoming D7.3, which will be available in January 2024.

Figure 24: The meat replacer product can also be used as a total meat replacer to make a plant based burger or sausage with no E-numbers. Photo: DepositPhotos

Technological readiness level

The product is at TRL 7. It means that the product prototype is demonstrated in an operational or other relevant environment. The aim for the product in SeaMark is to reach TRL 9, where the product is in full scale production in the operational environment and available on the market (Figure 27). Contrary to the "P5: Pig Feed Supplement", which also is produced by FEXP, the "P6: Meat Replacement Additive" is currently not being produced and is not on the market.

Innovation actions within the SeaMark project

Efforts will be made on scientific validation. The specific objectives relating to the product include:

1. Describe the biochemical basis for a prebiotic effect as well as the effect on the gut microbiome
2. Optimise seaweed fermentation protocols for a prebiotic effect of the fermented product
3. Provide a characterisation of the fermented food product

Efforts will be made to optimise fermentation conditions for prebiotic and antinutritional content. This will be done in collaboration between FEXP, AAU, UCPH and ORF. This process will also help establish the optimal amount of seaweed to be included. SeaMark wants to increase the level of prebiotic fibres and bioactives. In this connection, a set of descriptors will be developed to optimise the amount of seaweed that can safely be added to foods.

To conduct the pilot products in WP4, the partner FEXP needs to have the relevant accreditation for the safety and quality of food and feed production. In some cases, additional accreditations were needed at the start of SeaMark. These additional accreditations have been acquired at the time of writing this deliverable.

Mapping and description of production process

The production of Meat Replacement Additive requires the following inputs and equipment:

Input:

- A protein source, e.g. rapeseed meal or beans
- Fermented brown seaweed, sugar kelp, and green seaweed, sea lettuce
- Lactic Acid Bacteria
- Water
- Labour

Equipment:

- Tanks

Most of the inputs are standard inputs that can be bought from several sources on the market, therefore the supply chain for these inputs will not be elaborated here.

The fermented seaweed is a less standard input which is the focus of the SeaMark project. The fermented brown seaweed (sugar kelp) is supplied by ORF and the supply chain and production process are described in the ORF1 section above. The production process for sea lettuce supplied by ALGP is also described above.

There in only one processing stage in the production of Meat Replacement Additive, namely fermentation. In addition, there is a stage where the product is sent to the market.

Raw materials

The raw materials for the production are fermented seaweed, a protein source and lactic acid bacteria. The protein sources and lactic acid bacteria are standard inputs that are acquired from the market. The protein sources to be included can be rapeseed and soybean meal, Fava Beans, Soybeans or Chickpeas that are dry and can be stored in a dry warehouse at normal temperature for up to at least a year.

Some of the fermented seaweed, sugar kelp, is supplied by ORF in the same manner as for product 5, Pig Feed Supplement. Immediately after the seaweed is harvested, it is minced and put in containers which are sealed after addition of lactic acid bacteria. Thus, the fermentation process begins soon after the seaweed is harvested and is ongoing as the seaweed is transported from ORF to FEXP.

It arrives at FEXP in shipping containers with around 24 tonnes of seaweed in a container. The seaweed can be stored for at least a year at normal temperature. The long storage time makes it possible to keep the seaweed in Faroe Islands to be able to fill a full container of 24 tonnes, thereby saving some transporting costs.

FEXP has two additional suppliers of seaweed, namely ALGP from Portugal, who is supplying the species sea lettuce and ALGEA from Norway, who is supplying *Ascophyllum nodosum*. It has not yet been decided whether they will supply dry or fermented seaweed. If they supply dry seaweed, it must be fermented prior to production by adding water and lactic acid bacteria. This pre-processing takes about a month.

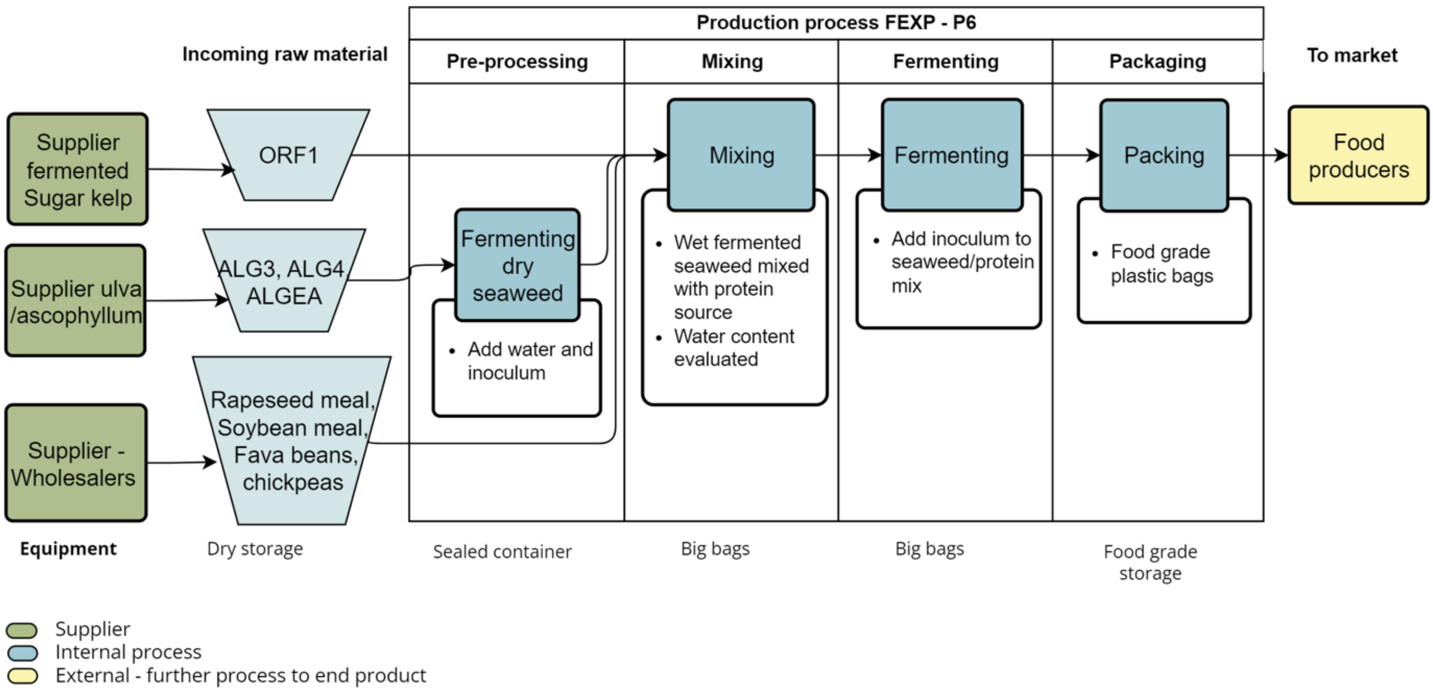

Figure 25: Flowchart of the production process of the meat replacement additive (P6).

Fermenting

The fermentation process involves an inoculum development step, which is the preparation of a population of microorganisms from a stock dormant culture to a state useful for inoculating a final production fermenter. Some of the raw material is added, so that the bacteria get use to the raw material.

Wet fermented seaweed is then mixed with the protein source until the water content of the mixed biomass is evaluated to be enough to carry out optimal fermentation. Water from the fermented seaweed goes into the process and some more water might be added. The inoculum is added, and the biomass is fermented for a few days.

To Market

The product is currently not on the market, but can be sold to various larger food suppliers, such as bakeries, meat producers, sausage producers etc.

Product 7-9: Co-extraction of alginates, designer alginates and fucoidans

ALG will develop a co-extraction process to extract alginates, designer alginates and fucoidan from fresh biomass of sugar kelp. The co-extraction process contains several steps in which the biomass through various methods is separated and processed into the respective products.

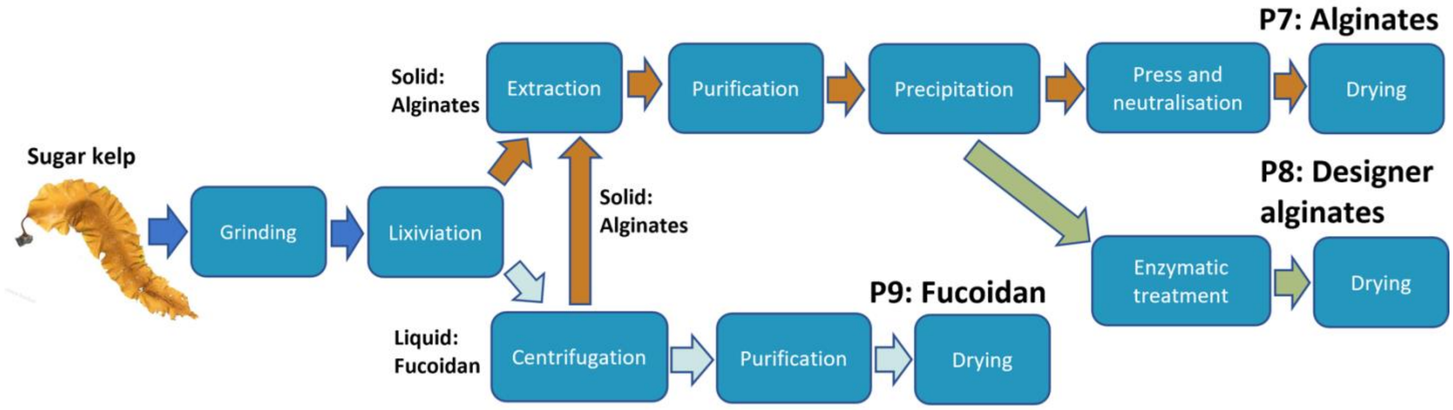

Figure 26: Flow chart demonstrating the production process for co-extraction of product 7 (alginates), 8 (designer alginates) and 9 (fucoidans).

The flowchart illustrates the sequence of the steps in the co-extraction, but since it is an ongoing project, the sequence may face some changes during the development of the process. The process starts with the grinding of the fresh sea lettuce, whereafter the biomass is separated into a liquid and a solid part. The liquid part goes further into the production of fucoidan, while the solid goes into the production of alginates. The alginates can then be enzymatically treated into designer alginates.

After the various treatments, the products are dried and in all three cases, the end-product is in powdered form. In the following sections, each of the three production sequences are described in more details.

Product 7: Green alginates

"P7: green alginates" are produced by SeaMark industry partner ALG, with head offices in Lannillis in France. ALG has more than 40 years' experience in extracting alginate from brown seaweeds. They produce natural seaweed, algae and other plant-based extracts and solutions for the food, agriculture, personal care, and nutraceutical industries. ALG will produce the biomass from sugar kelp provided by ALO and ORF. ALG will be supported by research partners LUN, MAT and DTU to develop industrial scalable production of bioactive oligosaccharides from crude alginate extracts, and RUI and CARL will test and provide feedback on the alginates.

Product description

Alginates are mainly used in the food sector for replacing fats, salt excess and carbohydrates. They can also be used to create biofilms, capsules, fibres for textiles and plasters, dental moulds, and to stabilise pigments and gels. Demand for low chemical extracted alginates is increasing, especially for cosmetic usage. Alginates are natural polysaccharides, polymers of Mannuronic and Guluronic acids representing a MG ratio. Depending on this MG ratio, alginates can be more viscosifying or gelling. Green alginates are an ingredient to be used in further processing, either in secondary processing (e.g. encapsulation systems) or by end users (cosmetics producers).

Figure 27: Alginates can be used in a wide range of applications. Alginate is commonly used as a stabilization in ice cream. Photo: DepositPhotos

Main selling points

One advantage of the product is that it is from natural plant-based source. Its capability to texture from viscous to gel at low temperature with reversibility, and its versatility through the wide range of applications. In all applications, its natural origin is a key player as well as its plant-based origin. Furthermore, the fact that it is derived from marine sources is an added value.

The comparatively mild extraction process is expected to result in alginates that have suffered less structural degradation and might therefore differ in their functional properties (e.g. higher viscosity or higher gel strength). In SeaMark, this will be tested by users of alginate. For a more detailed analysis of the product's competitive advantages, see SeaMark D7.1.

Technological readiness level

The product has a TRL 5. Alginate is already on the market as a food additive/cosmetic texturizer but produced with heavier chemical extraction charges. Through SeaMark, the green alginates will reach TRL 8, and be ready for the market.

Innovation actions within the SeaMark project

In the SeaMark project, ALG will produce and characterise green alginates with support from the partner DTU to reach commercial production.

The product will be tested in food for texturizing applications and in cosmetics for texturizing and stability purposes. Industry partners RUI and CARL will benchmark the product against the current commercial alginates provided by ALG and other sources currently used by CARL and RUI and provide feedback. From a functionality point of view, this will give indications on how the green alginate will compare to current commercially produced samples. Furthermore, research partners LUN, MAT and DTU will collaborate with ALG to develop industrial scalable production of bioactive oligosaccharides from crude alginate extracts.
P7 is a flagship product in SeaMark, which means that value-chain, techno-economic, and life cycle assessments as well as regulatory investigations and market analysis will be conducted. Go-to-market strategies and business plans will also be developed for the product.

Mapping and description of production process

The production of product 7 requires the following inputs:

- Sugar kelp
- Fresh water
- Sulfuric acid
- Sodium (or potassium) carbonate

Equipment

- Crane
- Tank
- Crushing pump
- Extraction tank and pumps
- Centrifugation and filtration systems
- Precipitation tanks and pumps
- Press and malaxing machine
- Gas flash dryer, milling and sieving system

Raw material

The raw material is fresh sugar kelp from ALO and potentially ORF. It will be sent by truck from ALO, around 3 hours transporting time. If provided by ORF, it would be air freight, which will take around 24 hours transporting time. It will arrive in quantities of some tonnes in each shipment and will be packed in bags with a few kilos in each bag.

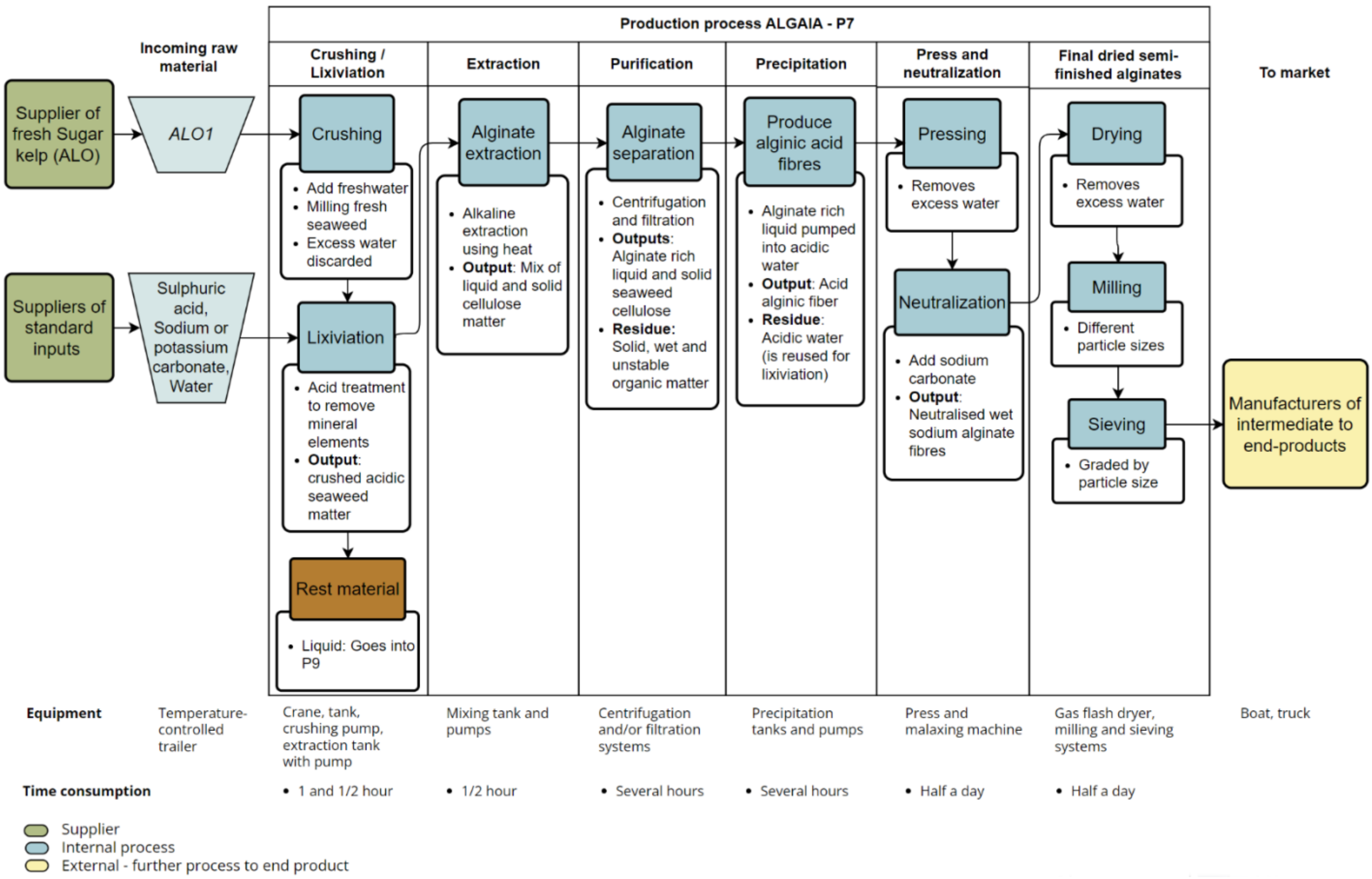

Figure 28: Flow chart demonstrating the production process for P7

Crushing

The fresh sugar kelp are taken with a crane from the delivery platform to a first tank in which freshwater is added. Milling pumps at the bottom of the tank are pumping, crushing and recycling the crushed seaweed several times. This stage is performed by one person and takes about half an hour. The final output of this stage is milled fresh seaweed, the rest is water excess which goes into the drains.

Lixiviation

During the lixiviation stage, seaweeds go through an acidic treatment to remove mineral elements and other organic compounds such as proteins, oligosaccharides. Sulfuric acid from Brenntag and an extraction tank with pumps are used in this stage. This process is performed by one person and is one hour long. The final result is crushed acidic seaweed matter containing cellulose, alginates, some other polysaccharides, lipids.

Alginate extraction

Alkaline extraction of the alginates from the seaweed raw material is performed using heat (energy) on the seaweed material and addition of sodium (or potassium) carbonate to increase pH. This process is performed by one person, using a mixing tank and pumps. After half an hour the output is a mix of liquid and solids where most of alginates are in the liquid and the solid cellulose matter is containing still some alginates.

Alginate purification

This is the new critical step for green alginate separation replacing the classical “flotation step” which involves traditionally chemical intrants. The idea is the separate the alginates from the remaining seaweed organic matter without using flocculants nor affecting the alginate structure. Centrifugation and filtration systems are used as well as pumps and mobile intermediate tanks. Two or three people perform this process, and it takes several hours to be completed. The final result is soluble alginate rich liquid for one side and solid seaweed cellulose on the other side, and the rest is solid seaweed cellulose organic matter, wet and unstable.

Precipitation

In order to produce the alginic acid fibres, the liquid is pumped into an acidic water to let the alginate precipitate as the alginate are insoluble in acid pH. For this step water, sulfuric acid, precipitation tanks and pumps are used. One person performs the work, it takes several hours to be completed. The output of this stage is acid alginic fibre which looks like wet cotton, and the rest is acidic waters which is re-used in Stage 2 lixiviation.

Press and neutralisation

This stage is combined with a pressing step to remove as much water as possible before adding salt, such as sodium carbonate, to create a sodium alginate. The inputs required are energy to press and sodium carbonate. A press and malaxing machine are used in this process. This process requires three to four people for half a day. The final output is neutralised wet sodium alginate fibres and the rest is water which runs off into drains.

Final dried semi-finished alginates

In this stage, neutralised sodium alginate fibres are dried, milled and sieved to lead to different particle sizes of particle corresponding to different grades. The inputs required are energy to feed the Gaz flash dryer, milling, and sieving systems. This stage requires three to four people for half a day. The final output is dried powder soluble and there is no rest raw material.

Figure 29: Extraction tank with temperature regulation. Photo: Algaia

Product 8: Designer alginates

"P8: designer alginates" can also be called "modified alginate for high value applications". In SeaMark, the "P7: green alginate" will also be modified to produce "P8: designer alginates", for which the target properties could be formulated based on the analytical results of the green alginate samples. This product is also produced by ALG based on sugar kelp delivered by ALO.

As P7, P8 is an ingredient to be used for further processing. The customers will use a fixed percentage of the designer alginates to produce their product. The most likely customers are manufacturers of intermediate to end products. There is then a long range of applications, from food to cosmetics, and medical devices.

Product description

P8 builds on "P7: green alginate" and aims to refine it to a higher value product. Sugar kelp alginates are high in polymers of mannuronic acids (M) compared to guluronic acids (G). High G-alginates are usually of higher market value as they bring gelling capacity and can be thus used for encapsulation and medical device applications. The objective of the designer alginates is to enzymatically modify those alginates to produce higher G-alginates.

There is a significant demand for alginates with a high ratio of G since they are very important for applications within medical devices and cosmetics, the two higher value markets for this polysaccharide. There are a limited number of species that can generate this type of high G alginate, but those species usually come from wild harvest and cannot be scaled up sustainably. This is where SeaMark can make a great impact using cultivated sugar kelp biomass.

Main selling points

The main selling points are similar as for P7. It is from natural plant-based origin; It has capability to texture from viscous to gel at low temperature with reversibility, and it can be used in a wide range of applications. These are the same selling points listed for P7 that also apply for P8, but even more so, since the product is refined into a product with a higher level of polymers of Guluronic acid, giving it higher gelling capacity.

A caveat is that the enzymatic treatment to design those alginates, has however to be studied on the regulatory frame to assess if it would not affect the image of the product.

P8 is an innovation product in SeaMark, which means that a market analysis and a go-to-market strategy will be developed for the product. An initial assessment of the market potential of the product will be presented in the upcoming D7.3, which will be available in January 2024.

Technological readiness level

The product has a TRL 5, as a successfully evaluated product, which is ready for demonstration. Through the innovation actions in SeaMark, the product will reach TRL 7, and be a ready demonstrated product.

To date, no enzymatically modified alginate exists on the market as far as is known.

Innovation actions within the SeaMark project

Alginate from cultivated sugar kelp could solve the problem of producing alginates with a high ratio of G, by "flipping" the M to G. This has been developed at lab-scale using several options of enzyme sources. However, it is challenging to identify, isolate, and produce these enzymes with sufficient degree of purity. Partners DTU and MAT have managed to produce these targeted enzymes at lab-scale, but they are limited in volume. In SeaMark, ALG will, in collaboration with DTU and MAT, produce at pilot scale several kilograms of high G alginates from sugar kelp, which will have a game changing potential for the industry.

In SeaMark the product is also going to be tested in cosmetics for texturizing and stability purposes as well as medical devices since those markets are of higher value and the concept of enzymatic treatment should not be an issue.

In collaboration, DTU and ALG will upscale an enzymatic process for designer alginates. ALG will adapt an enzymatic process protocol, established by DTU and produce batches of several kgs of speciality designer alginates. Industrial scalable production of bioactive alginate oligosaccharides will also be developed from the crude alginate extracts in collaboration with MAT, LUN and DTU.

Figure 30: Designer alginates can be used to create capsules. The SeaMark innovation process is expected to create a product of higher viscosity or gel strength. Photo: DepositPhotos

Mapping and description of production process

The production of product 8 requires the following inputs:

- Sugar kelp
- Enzymes from DTU
- Sodium carbonate
- Energy (electricity and gas)
- Fresh water

Equipment:

- Treatment tanks and separation systems
- Malaxing devise
- Gas flash dryer
- Milling and sieving system

Raw material

The raw material is green alginates from fresh sugar kelp from ALO and ORF. It will be sent by truck from ALO, around 3 hours transporting time, and by air from ORF, around 24 hours transporting time. It will arrive in quantities of some tonnes in each shipment and will be packed in bags with a few kilos in each bag.

Enzymatic treatment of green alginates

In this stage, the green alginates are used as substrate; enzymes generated by DTU will be used to orient the production of high G alginates. As of now, no specific decision has been made over 2 process options:

1. Start from dried green alginates (neutralised) produced in P7
2. Start from the process in P7, directly from the green alginic acid fibres before pressing and neutralisation.

The second option makes more sense in terms of process (costs, linearity etc.) but not tested yet where option 1 has been tested but does not make too much industrial sense since there is a need to re-dry after. At the end of this stage the product is a liquid product with high G alginates. The equipment and labour used at this stage is treatment tanks, separation systems and minimum two people for two days.

Neutralization and final dried semi-finished alginates

Sodium alginate fibres are neutralised and dried, milled and sieved to lead to different particle sizes of particle corresponding to different grades. The product is soluble dried powder. In this step, sodium carbonate is used for neutralisation and a gas flash dryer for drying and a malaxing devise. The step takes half a day.

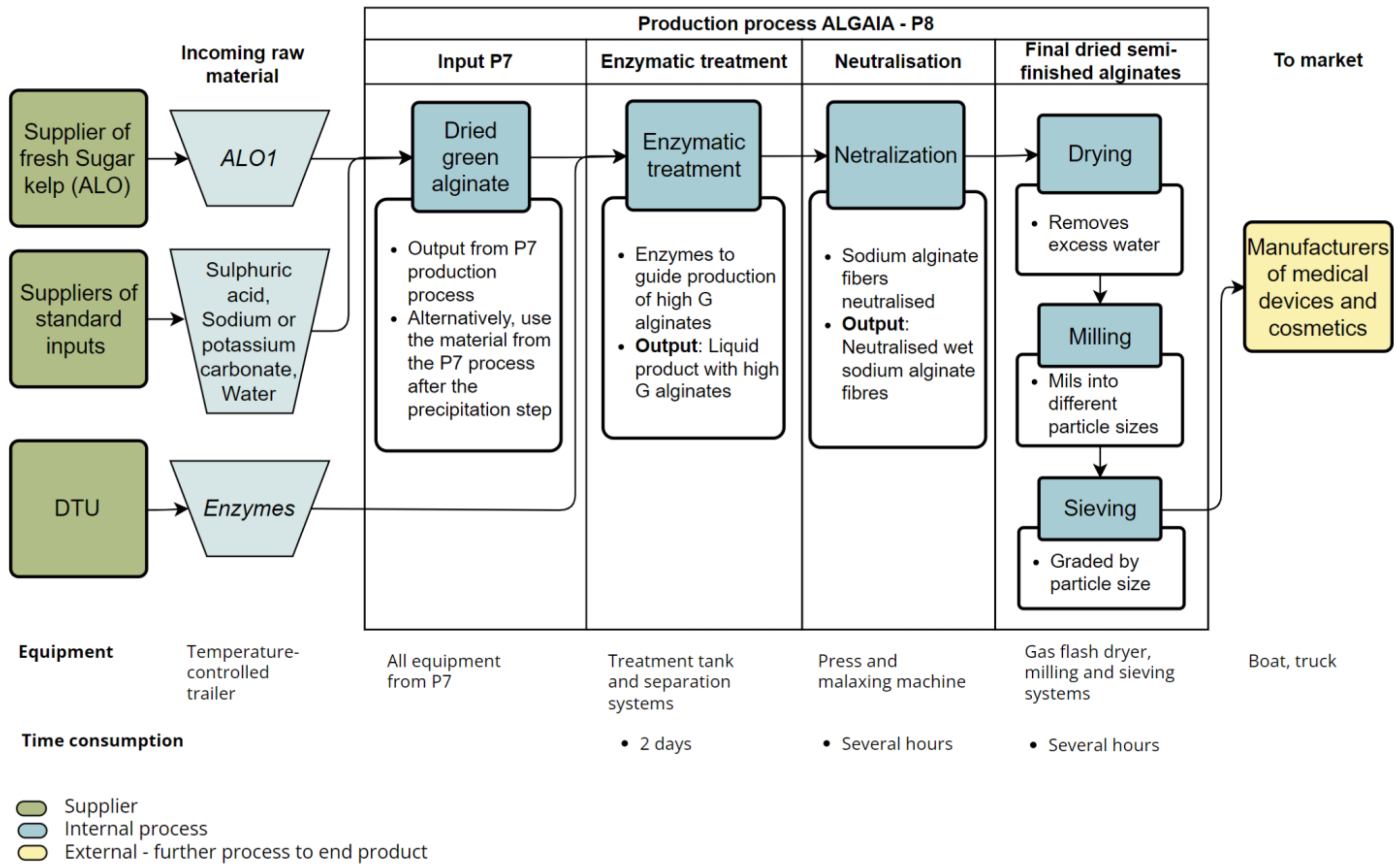

Figure 31: Flow chart demonstrating the production process for the SeaMark product 8 "designer alginates"

Product 9: Fucoidan extraction with enzymes

Product "P9: Fucoidan Extraction with Enzymes", can also be called "Enzymatically modified co-generated fucoidans". It is also produced by ALG based on sugar kelp supplied by ALO. P9 is an ingredient for further processing in formulations in the food, feed, and cosmetics.

Fucoidan fractions, more accurately known as sulphated fucose containing polysaccharides, are very versatile and have demonstrated many various bioactivities based on their molecular weight, fucose content, sulphate content, branched structure, and other monomer compositions. Users of P9 are manufacturers of intermediate and end products. It can be used for its bioactive health claims in food, feed, and cosmetics.

Product description

Fucoidans are unique brown seaweed polysaccharides based on fucose with sulphated groups attached on the fucose. Those natural compound can be different due to branching, molecular weight and sulphate group attached. This variety of composition leads to various bioactivities.
The higher the fucose content is, the higher the market value as it seems to be directly correlated to the immunostimulant activities. The current feed product is effective with a significant level of fucose that SeaMark aims to reach in co-extracting fucoidans from cultivated sugar kelp. Enzymatic treatment aims to increase fucose content, thus improving bioactivity in the feed market and targeting competitive production costs of several hundred euros per kilogram compared to several thousand euros today.

Main selling points

The fact that only brown seaweed can generate this polysaccharide makes it quite unique for a marketing positioning

Fucoidans can be used for human and animal health applications as well as antimicrobial potential applications. They also have demonstrated eliciting capacities on plants. This product is also sold on cosmetic skin applications for epiderm treatment.

This product can show various interesting commercial uses like terrestrial source polysaccharides such as heparin and it natural, marine, and plant-based origin makes it quite attractive.

Fucoidan has been demonstrated to stimulate mammalian immune systems, which makes it highly attractive as a feed additive. P9 is an innovation product in SeaMark, which means that a market analysis and a go-to-market strategy will be developed for the product. An initial assessment of the market potential of the product will be presented in the upcoming D7.3, which will be available in January 2024.

Technological readiness level

The product currently has a TRL of 5, as a successfully evaluated product, ready for demonstration.
Through SeaMark, the product will reach TRL 7, as a ready demonstrated product.

Figure 32: Fucoidan fractions have demonstrated various bioactivities and are used in food, feed, and cosmetics. Photo: DepositPhotos

Innovation actions within the SeaMark project

Market development has been limited to date due to poor standardisation in the production and purification processes, as well as source inconsistency. SeaMark aims to improve extraction yields and to standardise fraction production using enzymatic approach to enhance the use of fucoidan for feed applications. The product is a fucose rich polysaccharide with a minimum of 35% of fucose as the main monomer and sulphate group attached. In SeaMark, ALG will in collaboration with DTU to produce batches of several kg of bioactive fucoidans. DTU will provide selected enzyme cocktails for this process. The crude bioactive fucoidans will also be refined and scaled up. DTU and MAT will also define fucoidan structures using endo-active hydrolases of required specificities to provide scientifically substantiated claims for prebiotic, immune-boosting, anti-inflammatory, eye disease prevention and wound-healing activities for the cosmeceutical and nutraceutical markets.

Mapping and description of production process

The production of P9 requires the following inputs:

- Sugar kelp
- Sulfuric/hydrochloric acid from Brenntag
- Buffer solvent citrate or acetate
- Energy (electricity and gas)
- Fresh water

Equipment

- Extraction tank with pumps
- Steam producer for heating
- Pumps

- Decanter
- Ultra-filtration unit with dedicated membranes
- Concentration equipment
- Spray dryer
- Tank
- Crushing pump

Raw material

The raw material is green alginates from fresh or dried sugar kelp from ALO and ORF. It will be sent by truck from ALO, around 3 hours transporting time, and by air from ORF, around 24 hours transporting time. It will arrive in quantities of some tonnes in each shipment and will be packed in drums with 200 kilos in each drum.

Crushing

At this first stage the fresh seaweed is crushed and milled in water. The fresh sugar kelp is taken with a crane from the delivery platform to a first tank in which freshwater is added. Milling pumps at the bottom of the tank are pumping, crushing, and recycling the crushed seaweed several times. The equipment and labour used at this stage is a crane, tank, crushing pump and one person for half an hour. The product is transformed into milled fresh seaweed.

Mild acidic extraction

The next stage is a controlled acidic treatment at mild pH at 70°C to perform an extraction with high yield without destroying the structure of the fucoidan fractions. The extracted product is a liquid juice with soluble polysaccharides and oligosaccharides as well as polyols. This will also be compared to enzymatic extraction where pH (citrate or acetate buffer) and temperature (according to enzyme optimal conditions) will be controlled. At the end of the stage, temperature will be increased to inactivate the enzymes.
With this approach, alginates will not be co-extracted from the solid fractions, but will be left in the rest product, which is a crushed acidic seaweed matter containing cellulose, alginates, some other polysaccharides, and lipids. This will be processed as P7 for further extraction with sulfuric acid (from Brenntag) and heat from water steam. The equipment and labour used at this stage is an extraction tank with pumps, a steam producer for heating and one person for three hours.

Crude fucoidan fraction

The third stage is isolation of the crude fucoidan juice and first purification. This is done by centrifugation. At the end of this stage the product is a juice containing a mix of polysaccharides and some minerals and small organic compounds such as peptides. The rest raw material is a solid by-product that will be used for alginate extraction in P7. The equipment and labour used at this stage is pumps, decanter, and two persons for a minimum of two days, depending on the volumes.

Fucoidan purification

In this stage, another filtration is carried out in order to further separate other oligo- and polysaccharides from the fucoidan

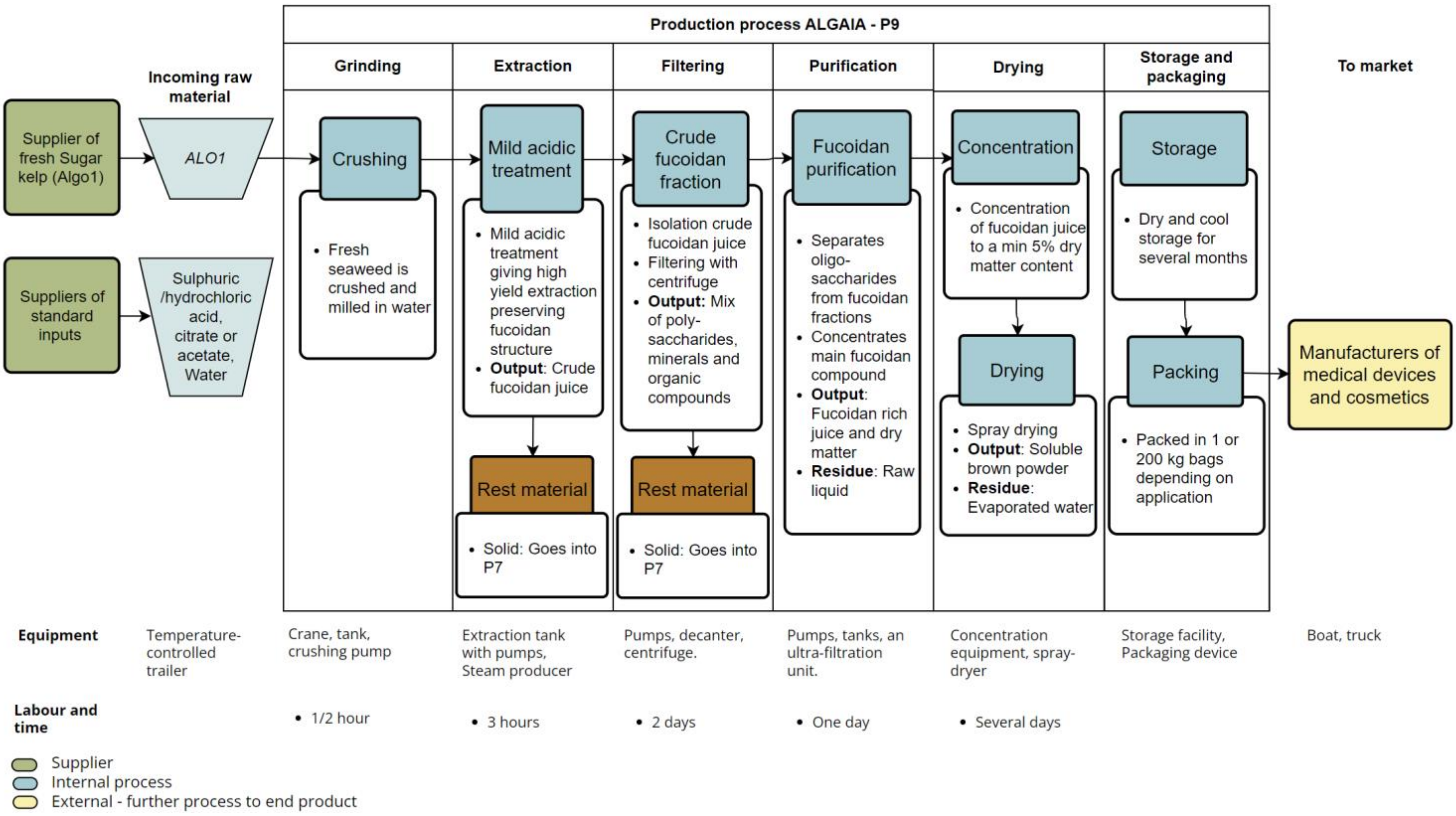

Figure 33: Flow chart demonstrating the production process for the SeaMark product 9: fucoidan extraction with enzymes

fractions and further concentrate the main fucoidan compounds. At the end of this stage the product is a liquid containing mainly fucoidan fractions with variable dry matter content depending on the batch. The rest raw material is a liquid with further oligosaccharides, some minerals and amino acids and peptides. The equipment and labour used at this stage is pumps, tanks, an ultra-filtration unit and two persons for a minimum of a day, depending on the volumes and the ultra-filtration unit's surface.

Concentration & drying

To perform the drying process at the most efficient cost, the fucoidan juice will be concentrated to a minimum of 5% dry matter content to be able to spray dry it at efficient costs. Spray dry will then occur once this product is stabilized. At the end of this stage the final product is a soluble slightly maroon powder. The rest raw material is water evaporated from the concentration. The equipment and labour used at this stage is concentration equipment that can maintain at mild temperature, a spray dryer and one person for several days, depending on the initial juice concentration and the size of the evaporator and the dryer.

Storage, packaging, and transport

The product is stored dry and cool in 1 or 200 kg bags, depending on the application. It can be stored for several months.

Product 10-12: Co-extraction of minerals, proteins and ulvans

ALG will develop a co-extraction process to extract minerals, protein and ulvans from fresh biomass of sea lettuce. The co-extraction process contains several steps in which the biomass through various methods is separated into the respective products.

The flowchart in Figure 34 illustrates the sequence of the steps in the co-extraction, but since it is an ongoing project, the sequence may face some changes during the development of the process.

The process starts with the grinding of the fresh sea lettuce, whereafter the biomass is separated into a liquid and a solid part. The solid part goes further into the production of ulvan, while the liquid is further separated through a precipitation step where the precipitate goes into the production of proteins and the liquid goes to minerals and ulvan.

After the separation and purification, the products are dried and in all three cases, the product is in powdered form. In the following sections, each of the three production sequences are described in more details.

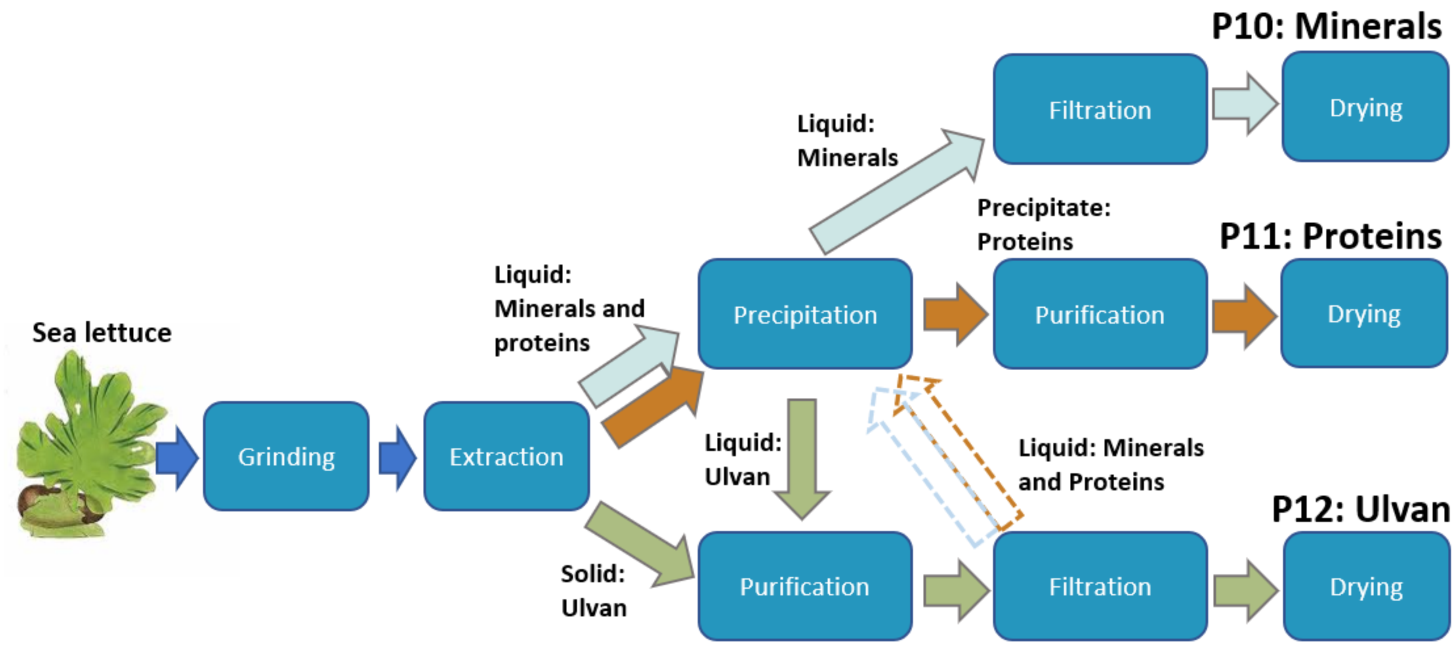

Figure 34: Flow chart demonstrating the production process for co-extraction of the SeaMark products 10-12: co-extraction of minerals, proteins and ulvans.

Product 10: Mineral concentrates

Product description

Product 10 is also produced by ALG. It is a mineral concentrate of sea lettuce minerals, either in liquid or in dry form, that can be used as a supplement for humans. Mineral concentrates can be integrated in drink mixes, sport supplements, bars, sauces, or ready foods with nutritional enriched profile. The mineral concentrates can as well be used for cosmetics and as a functional additive for horse and pet feed with 0.5-2% added. This is an ingredient, that will be incorporated into further formulation. Receiver from this primary production, are manufacturers of intermediate to end products. There is a large range of applications for mineral supplements especially in the food supplement market.

Sea lettuce farmed in ALGP has validated claims as a source of iron, magnesium, potassium, calcium and iodine. The total mineral fraction in sea lettuce is kept constant throughout time, independently of the cultivation protocols or season (results from continuous trials of 2 years).

Figure 35: There is a large range of applications for mineral concentrates especially for food supplements. Photo: DepositPhotos

Main selling points

The main advantage of the product is its marine, non-animal origin. The customer can claim (and market) the marine, non-animal origin. The food supplement/nutritional market is looking for sea mineral concentrates and this product is aiming at answering this demand. As far as known, there are no marine seaweed source of such concentrates to date.

Technological readiness level

The product has a TRL of 5, as a successfully evaluated product, ready for demonstration. Through SeaMark, the product will reach TRL 7 as a demonstrated product ready for the market.

Innovation actions within the SeaMark project

From initial fresh biomass (20 kg ww) of sea lettuce, or pre-treated biomass from a process developed in WP2 by ALGP, will ALG develop a co-extraction of protein, mineral and fibre fraction where, among other elements, batches of mineral concentrates will be produced. The results of the characterisation and production process will be validated for upscaling.

ALG will carry out a benchmarking of the mineral fractions against existing commercial mineral sources. On the mineral concentrates, targeted elements such as magnesium will be assessed for human food requirements with a particular look at its absorption performance in opposition to other classical sources.

Mapping and description of production process

Mineral concentrates (P10), Proteins (P11) and Bioactive oligosaccharides (P12) are all produced from the same biomass, sea lettuce from ALGP in Portugal, in a co-extraction process. The relevant compounds of the seaweed then feed into the different products. In what follows, the focus is on the production of P10, which requires the following inputs:

- Sea lettuce
- Fresh water
- Potassium Hydroxide
- Potassium Carbonate
- Sulfuric/oxalic acid
- Energy

Equipment:

- Ultra-filtration Unit
- Tanks
- Pumps
- Concentration equipment
- Spray dryer
- Crane
- Steam producer
- Decanter

Raw material

The raw material is sea lettuce from ALGP in Portugal. It will be delivered in 200 kg drums by truck in fresh cooled condition.

Grinding

The fresh seaweed is grinded and milled in a small amount of water. The fresh sea lettuce is then taken with a small crane from the delivery platform to a first tank in which another small amount of freshwater is added. Milling pumps at the bottom of the tank are pumping, crushing, and recycling the crushed seaweed several times. In this stage water and energy are used for the crushing pumps. This stage also requires an additional small crane and a tank. The process is carried out by one person, and it takes half an hour. The product is milled fresh

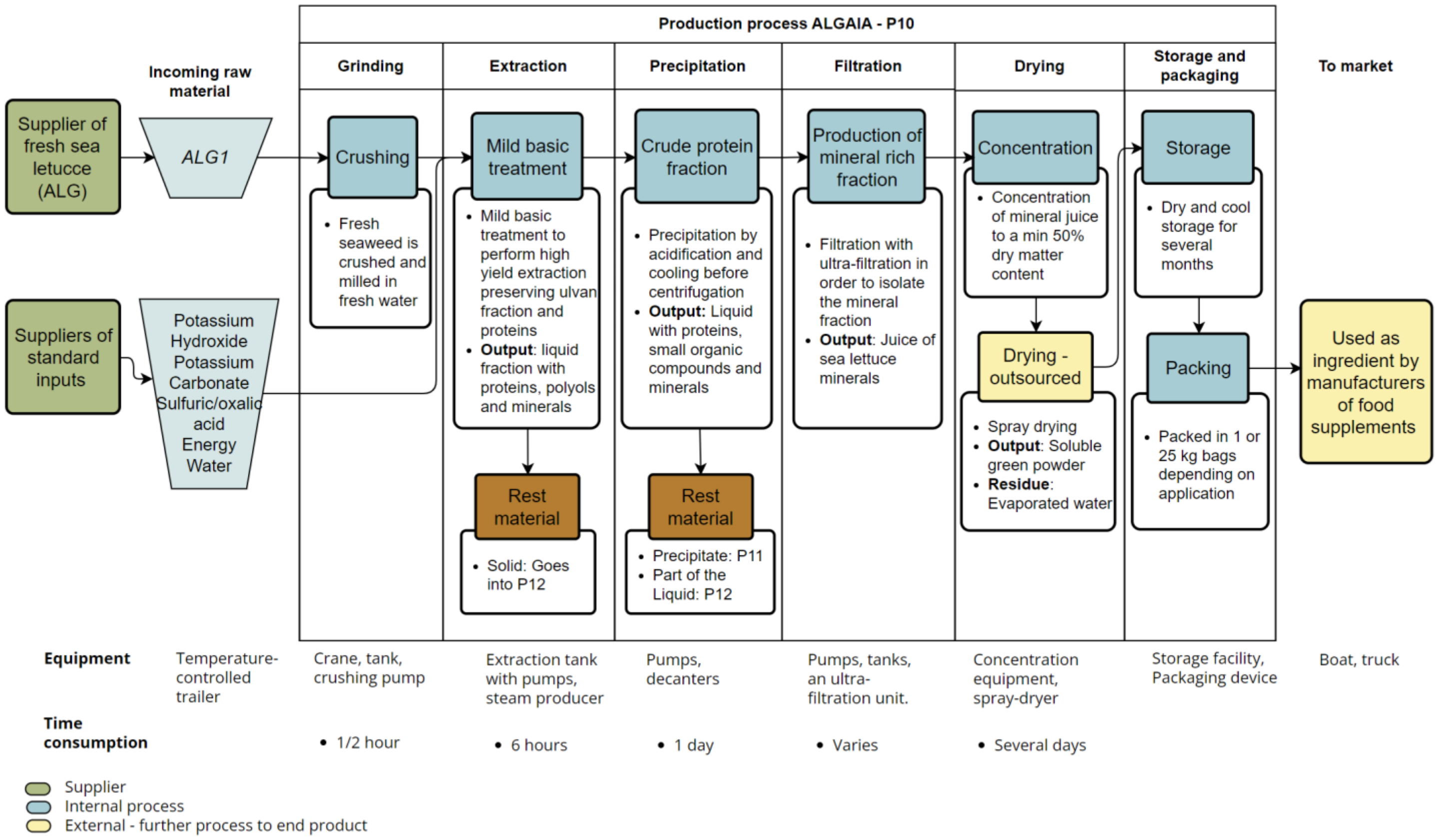

Figure 36: Flow chart demonstrating the production process for the SeaMark product 10: Mineral Concentrates. Please note this flow chart involves all the steps to bio-refine all products but the sequences of the steps may undergo some changes during the development process.

seaweed and the rest is water excess going into drains. This is limited to recover all fractions.

Mild basic extraction

This process is a basic treatment controlled at mild pH (8 to 9) at 25°C with the goal to extract with good yields but without destroying the structure of the ulvan fractions as well as the proteins. This approach is enabling to recover the proteins and within the by-product and extract Ulvan. Potassium hydroxide and potassium carbonate, water and energy are used as well as an extraction tank with pumps and steam producer for heating. The process is carried out by one person, and it takes 6 hours. The final product is a liquid fraction with proteins and polyols, as well as minerals. While the rest is an alkaline solid fraction with polysaccharides and oligosaccharides as well as lipids and pigments. This will be used then for the “P12: Ulvans” production.

Crude protein fraction

This stage entails the precipitation of the crude protein by acidification and cooling before a centrifugation. It requires Sulfuric acid and energy for separation and cooling, as well as pumps and a decanter. The process involved two persons and it has a duration of a minimum of 1 day, but that depends on the volumes to precipitate. Part of the product is a precipitate containing a mix of proteins small organic compounds such as peptides and still some minerals. The rest is a liquid by-product containing small saccharides and minerals used for ulvans (P12) and mineral production (P10).

Production of mineral rich fraction

The juice from the previous stage is filtered by ultra-filtration (UF) in order to isolate the mineral fraction. It is also possible that the juice from ‘extraction’-stage will also be used. The equipment used is tanks, pumps and an ultra-filtration system. 2 people are involved in this process. The process duration varies, as it depends on the UF surface and volume of the product. The product is concentrated juice of sea lettuce minerals. This step is however open to changes depending on the mineral outcome targeted.

Concentration & drying

In order to dry at most efficient cost, the mineral juice will be concentrated to a minimum of 50% dry matter content to be able then to spray dry it at efficient costs. Spray drying will then occur once the product is stabilised. As input for this stage, only energy for concentration and drying is needed. The equipment used is concentration equipment, which can maintain a mild temperature and a spray dryer. One person is involved at this stage. The process can take several days depending on the initial juice concentration and the size of the evaporator and the dryer. The spray drying is done externally through a service contract. The end-product is a soluble slightly green powder.

Storage, packaging, and transport

The product is stored at the production facilities in bags of 1 kg. There is no further post-processing, this ingredient will be used as it is by the customers. The end-product will be packed in 1 kg bags to 25 kg bags depending on the application and is then transported by boat or truck to the customers without need for cooling. The duration of the transportation depends on the customer, several days to months.

Product 11: Proteins

Product description

Proteins derived from sea lettuce are recovered by ALG and co-extracted together with mineral concentrates (P10) and bioactive oligosaccharides (P12) from the same biomass provided by ALGP. Seaweed protein is a good vegetable source for plant-based food and feed products. Many seaweed species have a low protein content, but sea lettuce cultivated by ALGP in land-based race-way systems has demonstrated a protein content of 20%. The partners ALG and MAT will, based on existing production and extraction protocols, further develop, and demonstrate pilot-scale co-extraction of proteins, minerals & ulvans to be defined and validated for commercial exploitation.

To utilise the proteins from the seaweed, food grade, scalable, and environmentally friendly protein extraction techniques are required. The partners ALG and MAT will, based on existing production and extraction protocols, further develop, and demonstrate pilot-scale co-extraction of proteins, minerals & ulvans to be defined and validated for commercial exploitation.

Main selling points

There is an increasing consumer health awareness and rising vegan population across regions are factors that have encouraged people to shift to alternative plant-based proteins such as seaweed protein. The issue of protein malnutrition supports the trend to find a new and cheap alternative source of protein. Seaweed could play an important role in the above-mentioned challenge and there is a demand for seaweed to be used in the industry as a source of ingredients with high nutritional quality. The main advantage of the product is its marine, non-animal origin, which is an important selling point. Many seaweed species have a low protein content, but sea lettuce cultivated by ALGP in land-based race-way systems has demonstrated a protein content of 20%.

Technological readiness level

The product is currently at a TRL 5, as a successfully evaluated product, ready for demonstration. Through SeaMark, the product will reach TRL 7 as a demonstrated product ready for the market.

Innovation actions within the SeaMark project

From initial fresh biomass (20 kg ww) of sea lettuce, or pre-treated biomass from a process developed in WP2 by ALGP, ALG will develop a co-extraction of protein, mineral and fibre fraction where, among other elements, batches of protein/peptides concentrates will be produced. The results of the characterisation and production process will be validated for upscaling.

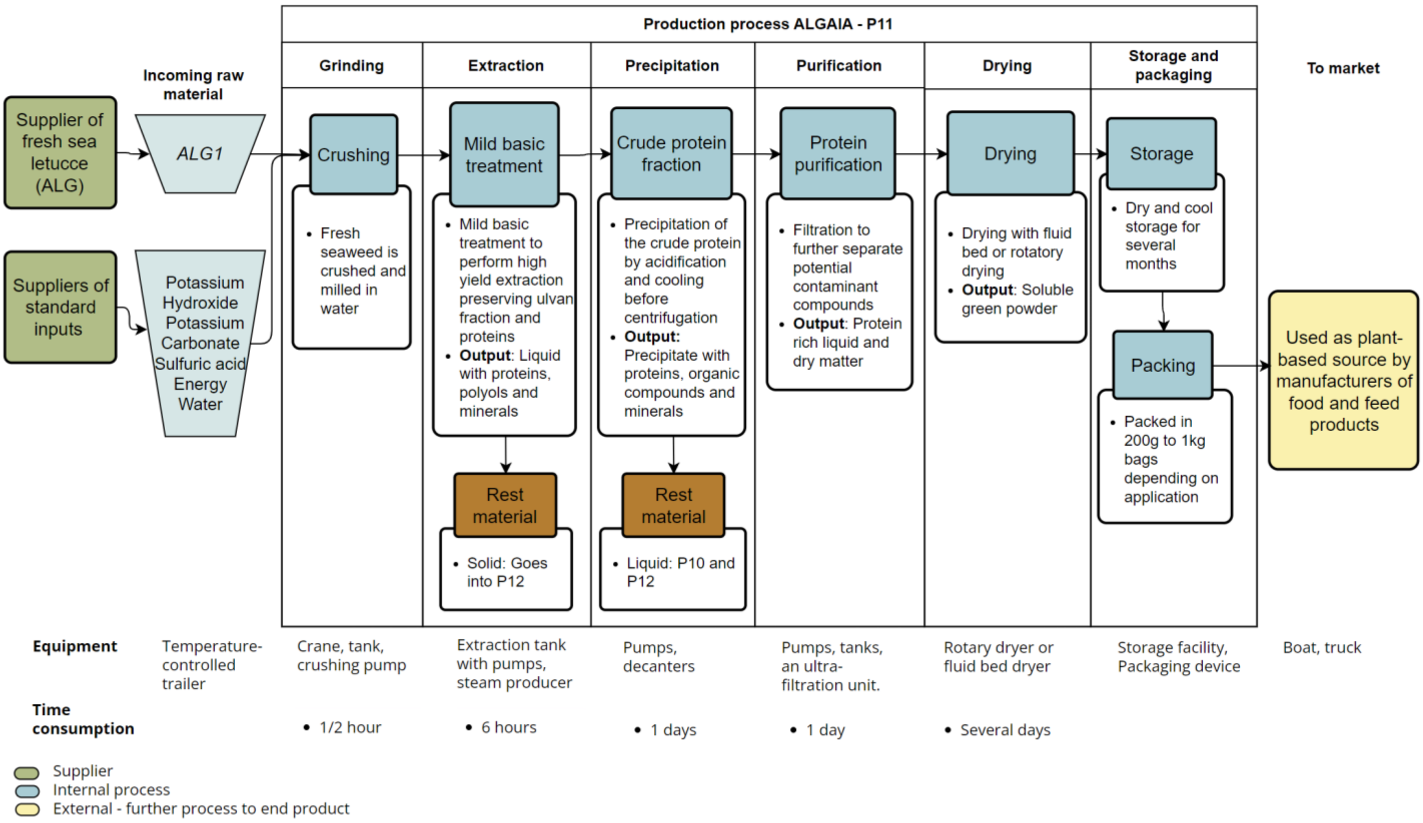

Figure 37: Flow chart demonstrating the production process for the SeaMark product 11: proteins

A benchmarking of the protein fractions will be carried out against existing commercial mineral sources and the texturizing capacity of the protein will be assessed by ALG.

Mapping and description of production process

The production of P11 requires the following inputs:

- Sea lettuce
- Sulfuric acid
- Potassium Hydroxide
- Potassium Carbonate
- Energy
- Freshwater

Equipment:

- Crane
- Tank
- Pumps
- Steam producer
- Decanter
- Ultra-filtration unit
- Rotary dryer or fluid bed dryer

Raw material

The raw material is sea lettuce from ALGP in Portugal. It will be delivered in 200 kg drums by truck in cooled condition.

Grinding

The fresh seaweed is grinded and milled in a small amount of water. The fresh sea lettuce is then taken with a small crane from the delivery platform to a first tank in which another small amount of freshwater is added. Milling pumps at the bottom of the tank are pumping, crushing, and recycling the crushed seaweed several times. In this stage water and energy are used for the crushing pumps. This stage also requires an additional small crane and a tank. The process is carried out by one person, and it takes half an hour. The product is milled fresh seaweed and the rest is water excess going into drains. This is limited to recover all fractions.

Mild basic extraction

This process is a basic treatment controlled at mild pH (8 to 9) at 25°C with the goal to extract with good yields but without destroying the structure of the ulvan fractions as well as the proteins. This approach is enabling to recover the proteins and minerals within the by-product and extract Ulvan. Potassium hydroxide and potassium carbonate, water and energy are used as well as an extraction tank with pumps and steam producer for heating. The process is carried out by one person, and it takes 6 hours. The final product is a liquid fraction with proteins and polyols, as well as minerals. While the rest is an alkaline solid fraction with polysaccharides and oligosaccharides as well as lipids and pigments. This will be used then for the product P12 (Ulvans) production.

Crude protein fraction

This stage entails the precipitation of the crude protein by acidification and cooling before a centrifugation. It requires Sulfuric acid and energy for separation and cooling, as well as pumps and a decanter. The process involved two persons and it has a duration of a minimum of 1 day, but that depends on the volumes to precipitate. The product is a precipitate containing a mix of proteins small organic compounds such as peptides and still some minerals. The rest is a liquid by-product containing small saccharides and minerals that will be used for ulvans (P12) and mineral production (P10).

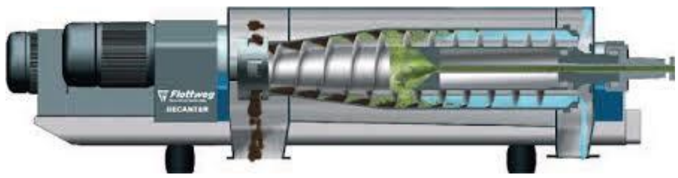

Figure 38: Decanter centrifuge for solid liquid separation. Photo: Algaia

Protein purification

In this stage, another ultra-filtration (UF), is carried out to further separate other potential contaminant compounds. The stage requires energy for the UF process as well as pumps, tanks, and an UF unit. Two people oversee carrying out the process and it takes a minimum of a day, depending on the UF unit surface. The result is a liquid containing mainly protein fractions with variable dry matter content depending on batch. The rest is liquid with further oligosaccharides, some minerals and amino acids and peptides.

Drying

In this stage, the precipitate of stage 4 is recovered to be dried in classical fluid bed or rotary dryer. Energy, a rotary dryer, or a fluid bed dryer are required for this process. This stage engages two people in addition to an external service contractor for drying a pilot scale. Depending on the drying technique this stage can take several days especially because transport in between is involved. The product is a soluble slightly green powder, and the rest raw material is water evaporate from the drying.

Storage, packaging, and transport

The product is stored at the production facilities in bags of 1 kg preferably in a dry and cool place. There is no post processing, this ingredient will be used as it is by the customers to be mixed with other compounds/ingredients. The end-product is packed in 200 g bags to 1 kg bags depending on the application. Boats or trucks are used to transport the product and there is no temperature control method used during transport. Transportation time depends on customers. It can be from several days to several months.

Product 12: Bioactive oligosaccharides

Oligosaccharides derived from sea lettuce have great potential as a highly potent bioactive source with numerous health promoting effects. Today, the processing of oligosaccharides from polysaccharides requires a lengthy synthetic procedure that could be replaced by more cost-effective production from a natural source like seaweed using fractionation and separation followed by purification. ALG will produce this product with sea lettuce biomass from ALGP, with support from MAT, LUND, DTU, and the University of Utrecht (UTR). The different bioactive oligosaccharides produced in SeaMark will be sold to end-users by the partners ALG and ALGP in the sector of nutraceuticals and medical devices.

Product description

The bioactive oligosaccharide (P12) is a product co-generated from the sea lettuce protein (P11) and mineral (P10) extraction, usable for many applications. The product aims to be a soluble powder of bioactive ulvans and oligosaccharides. Ulvans are sulphated polysaccharides unique to green algae. They are constituted of uronic acids, rhamnose and xylose with sulphate groups attached to the backbone structure. These compounds are like animal sourced current mammalian glycosaminoglycans such as heparins and dermatan sulphates. This is an ingredient, that will be incorporated into further formulation. Receiver from primary production are manufacturers of intermediate to end products. Depending on the application targeted, the range of application can be quite wide

Main selling points

The main advantage of the product is that it is a natural active biopolymer from marine, non-animal origin. Ulvan and ulvan oligosaccharides have several potentially valuable biological properties in human care like anticoagulant activities, antioxidant activities, antihyperlipidemic activities, and antitumoral activities (Seong et al., 2020; Ren et al., 2017). Ulvan can also be used for digestive health and biomedical applications, with special emphasis in tissue engineering and cosmetics.

Technological readiness level

The current TRL level is 4. SeaMark will take it to 6/7. There is no commercial production of this product to our knowledge.

Innovation actions within the SeaMark project

These saccharides have demonstrated a wide range of bioactivities from immune-stimulant, antioxidant, anticancer, antiviral, biofilm production, wound healing to plant defence potential. However, to date, as far as we know, there is no commercial development of those compounds.

ALG will develop a co-extraction of protein, mineral and fibre fraction where, among other elements, contain ulvans. The results of the characterisation and production process will be validated for upscaling. In addition, the partners LUN, DTU and MAT will develop industrial scalable production methods for bioactive ulvan oligosaccharides and define structures using combination of exo- and endo-active ulvan lyases of different specificities. The work will seek to prove scientifically substantiated claims for prebiotic, immune-boosting, anti-inflammatory and wound-healing activities of ulvans for the commercial end-users in the nutraceuticals and medical device markets. In SeaMark, a market analysis will be conducted for the Nutraceutical market, which can be useful for this product.

Figure 39: Bioactive oligosaccharides have a range of applications, particularly within the nutraceutical sector and as medical devices. Image Credit: Kseniya Tatarnikova, Shutterstock.com

Mapping of production process

The production of "P12: bioactive oligosaccharides" requires the following inputs and equipment:

Inputs:

- Sea lettuce
- Sulfuric acid
- Energy
- Potassium Hydroxide
- Potassium Carbonite
- Fresh water

Equipment:

- Pumps
- Crane
- Decanter
- Tanks
- Steam producer
- Ultra-filtration unit
- Concentration equipment
- Spray dryer

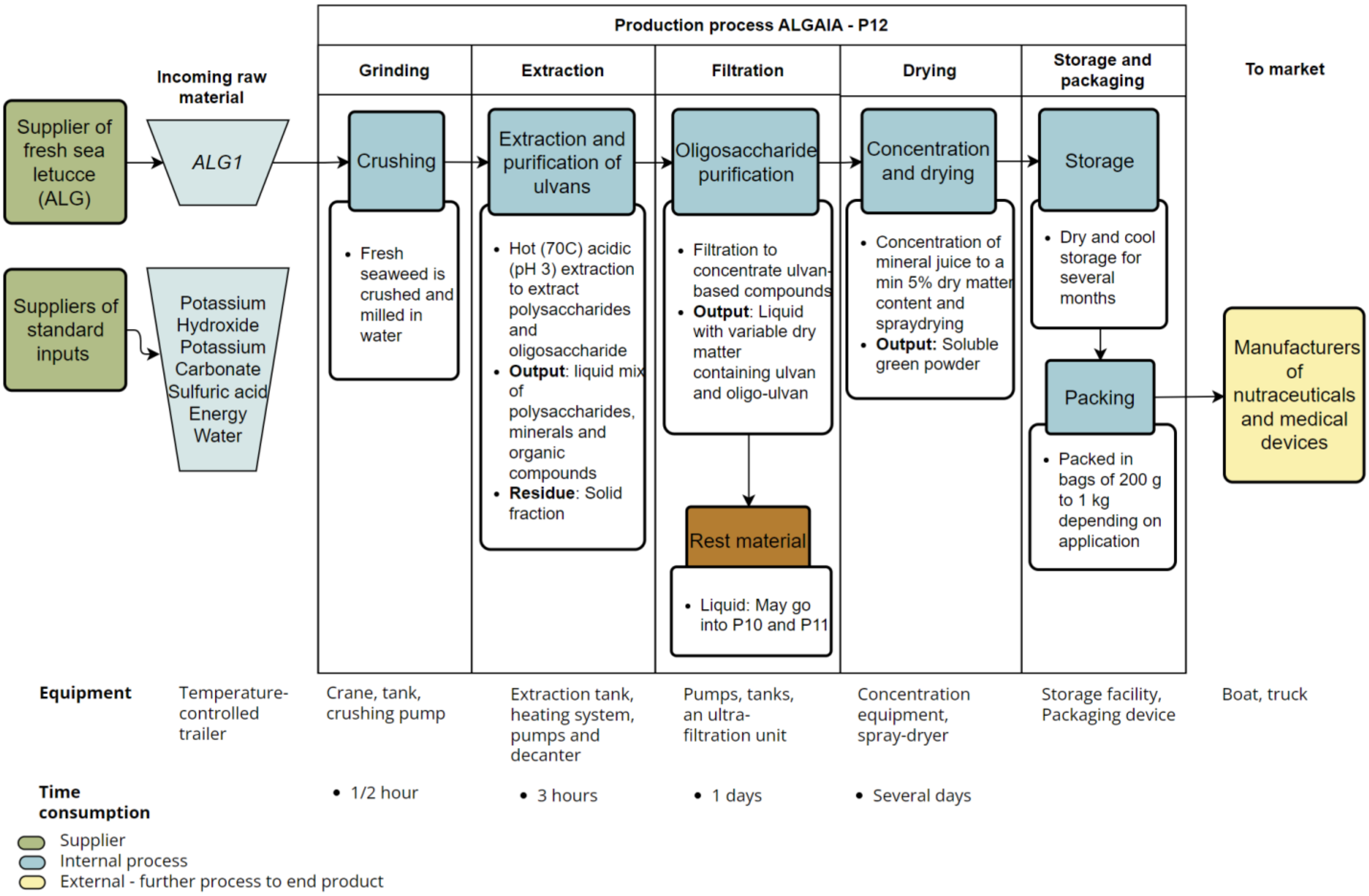

Figure 40: Flow chart demonstrating the production process for the SeaMark product 12: Bioactive Oligosaccharides.

Raw material

The raw material is sea lettuce from ALGP in Portugal. It will be delivered in 200 kg drums by truck in fresh condition.

Grinding

The fresh seaweed is grinded and milled in a small amount of water. The fresh sea lettuce is then taken with a small crane from the delivery platform to a first tank in which another small amount of freshwater is added. Milling pumps at the bottom of the tank are pumping, crushing, and recycling the crushed seaweed several times. In this stage water and energy are used for the crushing pumps. This stage also requires an additional small crane and a tank. The process is carried out by one person, and it takes half an hour. The product is milled fresh seaweed and the rest is water excess going into drains. This is limited to recover all fractions.

Extraction and purification of ulvans

From the solid product recovered in the previous stage, a hot acidic extraction is performed to extract the polysaccharides and oligosaccharides at efficient yields. As input in this stage sulfuric acid, energy for heat and separation is used as well as extraction tanks, heating system, pumps, and decanter as machinery. Two people from the company are necessary to perform this stage, it takes about 3 hours. The output is a liquid with a mix of polysaccharides, minerals, other organic compounds such as peptides. The rest is a solid fraction containing remaining elements, lipids, pigments, and cellulose. There might be a further depolymerisation step between the extraction and separation steps to generate further oligosaccharides.

Oligosaccharide purification

In this stage, an additional filtration step is carried out using UF to further separate other oligosaccharides from the other organic and mineral fraction and further concentrate the main ulvan-based compounds. As input energy for UF is needed and as machinery pumps, tanks, and UF unit. It takes two people from the company to do this stage for minimum a day, dependent on the UF surface. The output is a liquid containing mainly ulvan and oligo-ulvan fractions with variable dry matter content depending on batch. The rest is a liquid with further minerals and amino acids and peptides. Maybe to be retreated for P10 and P11 production if it does make sense.

Concentration & drying

To dry at most efficient cost, the liquid will be concentrated to a minimum of 5% dry matter content to be able then to spray dry it at efficient costs. Spray dry will then occur once this product is stabilised. Energy for the concentration and drying is needed and as machinery concentration equipment that can maintain at mild temperature and a spray dryer. This stage takes 1 person from the company and an external contracted service for the spray drying. The duration depends on the initial juice concentration and the size of the evaporator and the dryer. It could be up to several days because there is transportation in between. The output is a soluble slightly greenish powder leaving as a rest only water evaporate from the concentration and drying.

Storage, packaging, and transport

The product is stored at the production facilities in bags of 1kg preferably in a dry and cool place. There is no post-processing, this ingredient will be used as it is by the customers to be mixed with other compounds/ingredients. The end-product is packed in 200g bags to 1kg bags depending on the application. Boats or trucks are used to transport the product and there is no temperature control method used during transport. Transportation time depends on customers. It can be from several days to several months.

Figure 41: Ultra-filtration unit for compounds separation according to molecular weights. Image: Algaia.

CONCLUSION

This report has characterised the production processes of the SeaMark products. It reported on the work conducted in task 8.1 on 'characterisation of SeaMark production processes'. This task entailed mapping the key processes to produce SeaMark products. Flow charts were presented for each product and its seaweed biomass. The visualisations detailed the flow of raw materials and products, as well as the interaction, position, and function of relevant supply chain actors. The characterisation has largely been based on expert interviews with key partners in the SeaMark supply chains. Where relevant, supplementary material has also been provided by other partners involved in the development of the products.

The report serves as the foundation for assessing SeaMark innovations on market potential (WP7), techno-economic and business analyses (WP8) and life cycle assessments (WP9) and policy recommendations (WP10). The intention with the report is to provide all SeaMark partners and other interested parties with a good overview of the production processes involved in SeaMark and which actors are involved. These should facilitate understanding and collaboration within the consortium and beyond.

This document has detailed the production processes of two different species of seaweed: sugar kelp cultivated at sea in France and the Faroe Islands and sea lettuce, cultivated in a land-based IMTA system in Portugal. First the seaweed production of ORF, ALO, and ALGP were mapped, and the flow charts presented and described. Each of these seaweed products serve as input into several of the 12 products. The following sections focused on the production processes of the 12 SeaMark products produced by industry partners OCE, FEXP, and ALG. Each of the product sections outlined the characteristics of the products, their selling points, TRL and what innovation actions will be taken to advance the respective products within the SeaMark project before descriptions and flow charts of the production process for the production were presented.

This report has showcased the diversity of these production approaches, technological maturity, and products, which can be used in product applications from feed supplements to nutraceutical and medical devices. There are still many challenges to be overcome to upscale and improve economic profitability within the European seaweed industry. One of the potential ways of unlocking the success of the sector is to fully utilise the full range of compounds that this versatile resource contains. This can be achieved through the adoption of a biorefinery concept, enabling the production of a range of products (from low and high value) from the same biomass, thereby maximising the value of the resource. Ten of the SeaMark products are produced in three separate co-extraction processes for different end users. SeaMark will produce bioactive beta-glucans (P1), fucoidan (P2 and P8), oligosaccharides (P12) to be used as medical devices, and the nutraceuticals and cosmeceutical sectors. Alginates for food (P7), cosmetics (P7 & P8) and medical devices (P8); mineral concentrates (P10) and proteins (P11) for be used in food and feed; fibre and protein food ingredients (P4) and bio-packaging (P3) material to reduce the use of plastic; a co-fermented meat replacer product (P6), which can be used to partially or fully replace meat and a co-fermented feed supplement (P5) for be used for sows and piglets.

This exercise has provided a clear picture of the multifaceted nature of the SeaMark products and their different production systems. In SeaMark, strong industry partners within cultivation and processing, supported by technical research institutions and potential end users who will test and provide feedback, SeaMark aims to take the European seaweed industry to a whole new level. This requires innovations across the whole supply chain. SeaMark will innovate when it comes to breeding and genetics to improve growth rates and desired composition of the seaweed, mechanical seeding and harvesting to reduce costs, to upscaling biorefinery concepts using enzymatic and microbial processes to create novel products with many potential applications within food, feed, packaging, nutraceuticals, cosmeceuticals, and medical devices. In addition to the innovation processes within production processes and product development, significant work will also be done relating to market related challenges to increase demand and the regulatory framework to remove barriers facing the industry.

This report has provided the foundation for understanding all the production processes involved in SeaMark. In upcoming work within WP8, the focus will be on the three flagship products: "P1: Bioactive beta-glucans"; "P5: Pig feed supplement" and "P7: Green alginates". In subsequent deliverables, the attention will be on analysing the value chain of the respective flagship products (D8.5); the techno-economic feasibility of the production (D8.6) and the socio-economic impacts of upscaled seaweed production and biotransformation (D8.4). This will provide a more detailed understanding of the potential opportunities and challenges facing the production of seaweed-derived products.

DATASET

For this deliverable surveys and interviews of companies were made and compiled into a dataset called "Data for characterization of supply chains of SeaMark product ".
The description of this dataset can be found in the Data Management Plan of SeaMark openly available to Zenodo: https://doi.org/10.5281/zenodo.7261409
The dataset in itself will be only partially openly available as it contains information that are commercially sensitive for the companies and these information needs to be removed before upload.

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APPENDICES

Appendix I: Standard form for analysing production processes in seaweed cultivation

Table 1: Background information

	Answer, fill in
Place and date of interview	
Interviewed company	
Interviewed person(s) name(s) Email Phone number	
Interviewing company / institute	
Interviewers name Email Phone number	
Name of the product (E.g. Dried seaweed, fermented seaweed, wet seaweed, etc.)	
Short description of the product	
Who is the receiver of this product? (List all receivers in the table above, e.g. P1, P2, etc.)	

Table 2: Production stages (Copy this section and fill out for each stage)

		Answer, fill in	**Description or example**
	STAGE No: #		
2.#0	Stage title		
2.#1	Stage description		Describe what is happening (E.g. seeding, harvesting, etc.)
2.#2	Input used		Describe the input used, e.g. raw material, energy etc. Who is the supplier of the input? (Only needed for special inputs critical for the production process, like special seeding material, etc. Not needed if the input is a standard input, like electricity, water or 'of-the-shelf' raw material.)
2.#3	Machinery used		Describe the necessary machinery used in order to perform this stage.
2.#4	Labour involved		How many labour hours were involved in this stage (For a certain quantity seaweed, e.g. per tonne seaweed)
2.#5	External actors involved		Is there a need for external actors/providers in this stage of the production. If yes, then which actors?
2.#6	End stage of product?		Describe what the product has transformed in to at the end of this stage.
2.#7	How long time does this stage take?		Hours, Days

Remember to copy and fill out this table for all the production stages

Table 3: Packaging and transport

		Answer, fill in	**Description or example**
4.0	Where and how is the product stored?		Stored at the production facilities or at a distributor? Not stored? Stored in sealed containers, frozen, cooled, in bulk, ready packaged etc.
3.1	Is there any post-processing?		Is there anything done to the product before packaging and shipping?
3.2	Packaging		How is the product packed and in which sizes? 100 kg bags, containers, etc.
3.3	What type of transport is used?		Truck / boat / airplane etc.
3.4	Which temperature control method is being used during transport?		Cooled / frozen / none?
3.5	How long is the transporting time?		

Appendix II: Standard form for analysing production processes in seaweed processing

Table 1: Background information

	Answer, fill in
Place and date of interview	
Interviewed company	
Interviewed person(s) name(s) Email Phone number	
Interviewing company / institute	
Interviewers name Email Phone number	
Name and number of the product (Use the product name and number from the table above.) You can add an additional title, if you think it is relevant.	
How developed is the product? (Measured in *Readiness Level*) What is the status of the product now? Which status are you aiming for at the end of the SeaMark project? Look at a list of RL here (link) (Press Ctrl and click the mouse)	
Give a short description of the product Guiding questions: What is the product? What is it used for? What is the advantage of this product? Why should anyone use this product? Why is it better or different than other similar products?	
Is the product intended for end-users or for further processing? (Is the product intended to go directly to the market or will it be used as an ingredient or an input in other products.)	
If it is for further processing, then who is the receiver? If the product will be used in another product in SeaMark, then which product? (State the name and number from the table above.) If the product is going to be an input in other products, then list the products. E.g. cosmetics, plastic replacement, food, feed, etc)	

Table 2: Incoming raw material (Seaweed)

		Answer, fill in	**Description or example**
2.10	Species of seaweed		Ulva, Saccharina Latissima, Ascophyllum Nodosum
2.11	What type of raw material is used?		Wet/dried/fermented seaweed?
2.12	Who is the supplier of the seaweed?		ORF / ALO / ALGP
2.13	What type of transport is used?		Truck / boat / airplane etc.
2.14	Which temperature control method was used during transport?		Cooled / frozen / none?

2.15	How long was the transportation time?		
2.16	In which quantities does the product normally arrive?		
2.17	How is it packaged?		Card board boxes, tanks, in which units (liters, kg) ?

Table 3: Production stages (Copy this section and fill out for each stage)

		Answer, fill in	Description or example
	STAGE No: #		
3.#0	Stage title		
3.#1	Stage description		Describe what is happening
3.#2	Input used		Describe the input used, e.g. raw material, energy, enzymes etc. Who is the supplier of the input? (Only needed for special inputs critical for the production process, like special enzymes, special bacteria, etc. Not needed if the input is a standard input, like electricity, water or 'of-the-shelf' bacteria and enzymes.)
3.#3	Machinery used		Describe the necessary machinery used in order to perform this stage.
3.#4	Labour involved		How many labour hours were involved in this stage? (For a certain quantity seaweed, e.g. per tonne seaweed)
3.#5	External actors involved		Is there a need for external actors/providers in this stage of the production. If yes, then which actors?
3.#6	What is the product/output at the end of this stage		Describe what the product has transformed in to at the end of this stage.
3.#7	Rest raw material		Is there any rest raw material from this production stage that do not enter the next stages of the production process? If yes, describe them.
3.#8	How long time does this stage take?		Hours, Days

Remember to copy and fill out this table for all the production stages

Table 4: Storage, packaging and transport

		Answer, fill in	Description or example
4.1	Where and how is the product stored?		Stored at the production facilities or at a distributor? Not stored? Stored in sealed containers, frozen, cooled, in bulk, ready packaged etc.
4.2	Is there any post-processing?		Is there anything done to the product before packaging?

			E.g. mixed with other products, adjust concentration etc.
4.3	Packaging		How is the product packed and in which sizes? 100 kg bags, sealed containers, bulk, etc.
4.4	What type of transport is used?		Truck / boat / airplane etc.
4.5	Which temperature control method is being used during transport?		Cooled / frozen / none?
4.6	How long is the transportation time?		