Future Fish:

New and innovative ready to use seafood products by the use of 3D printing

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Report summary

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Ágrip á íslensku:	Í þessari skýrslu er lýst niðurstöðum vinnu við þróun nýrra sjávarafurða með byltingarkenndri tækni, þrívíddar matvælaprentun. Markmiðið var að þróa nýjar og frumlegar sjávarafurðir úr verðlitlu aukahráefni til notkunar í 3D matvælaprenturum. Helstu niðurstöður voru: (a) þróun á uppskriftum og ferlum til að þrívíddarprenta mismunandi sjávarfang, (b) tilbúnar grunnformúlur fyrir 3D prenthylki, (c) sýningaruppskriftir og hönnun til að kynna þrívíddarprentun og sjávarfang fyrir framtíðarnotendum, (d) námsefni / fræðsluefni til að fræða fólk um notkun þrívíddarprentunar á vannýttum sjávarafurðum. Niðurstöður þessarar vinnu er hægt að nýta í frekari rannsóknir t.a.m. hvernig hægt er að aðlaga nýja tækni að flóknum hráefnum eins og aukaafurðum úr sjávarfangi. Niðurstöðurnar geta einnig verið notaðar í veitingarekstri þar sem hægt er að búa til aðlaðandi og næringargóða sérsmíðaða 3D prentaða skammta og rétti úr verðlitlum sjávarafurðum. Þá er hægt að yfirfæra aðferðirnar sem voru þróaðar í verkefninu á önnur flókin og/eða nýstárleg hráefni (t.d. þörunga, einfrumuprótein, skordýr osfrv.) til að útbúa neytendavænar vörur á formi sem höfðar til neytenda.		
Lykilorð á íslensku:	*þrívíddar matvælaprentun, vöruþróun, fiskur, sjávarfang, aukahráefni*		
Summary in English:	In this report the results of work on development of new and innovative ready to use seafood products using a revolutionary technology, 3D food printing, are described. The aim of the work was to develop quality, safe and stable ready-to-use seafood products for 3D food printers and additional applications from low value byproducts. Key results included: (a) development of 3D printed seafood formulations, including parameters to make quality product, (b) ready to use base formulations for 3D food print cartridge applications, (c) showcase recipes and designs for introductions of 3D food printing and seafood to future end users, (d) course/ educational material to educate people in the use of 3D printing of underutilized seafood sources. The outcome of this work can be applied to further research areas such as how new innovative processing and preparation appliances can be adapted to complex raw materials like byproducts from seafoods. The findings can as well be applied in HORECA environments where appealing and nutritious custom-made 3D printed portions and dishes can be created from low value byproduct seafood raw materials. The methods and procedures developed and the learning from the work can be applied to other complex raw materials and new innovative emerging food raw materials (e.g. algae, single cell protein, insects etc) to make consumer friendly products in a format that is appealing to consumers.		
English keywords:	*3D food printing, product development, fish, seafood, byproducts*		

1 Contents

Executive Summary

In this report the results of work on development of new and innovative ready to use seafood products using a revolutionary technology, 3D food printing, are described. The aim of the work was to develop quality, safe and stable ready to use seafood products for 3D food printers and additional applications from low value, nutritious, byproducts. Through a collaboration between companies in the seafood industry, chefs, a leading producer of 3D food printers, Matís, and the University of Iceland, significant outcomes and key research resulted in development of a) formulations and processes for 3D printing food products from seafood raw materials and ingredients, b) ready to use 3D food printing formulas that can be prefilled into 3D food printing cartridges and containing seafood raw materials and ingredients, and c) innovative seafood creations and products produced from the formulations and processes.

From this research, various other key objectives were successfully completed. Processing parameters for raw materials, formulations, and prototypes of 3D printed seafood products have been developed. Additionally, printing and cooking parameters for 3D printing of seafood products were applied and tested. Seafood raw materials and ingredients for a wide range of novel seafood products, using the 3D printing technology, were created and from this development work, innovative formulas and printed final forms were created. Learnings from working with raw materials and prototype development formed the base for optimization of 3D printed products, development of ready to print filled cartridges, a 3D printing app, and an educational module. There were also videos (2D and virtual reality videos) created in collaboration with another project led by Matís, the Future Kitchen project, that heavily disseminate the important of seafood sustainable and value add of seafood products in a food tech, seafood processing, and future kitchen 3D food printing environment. Additionally, working with the Icelandic chef team various formulas were tested and key showcase recipes were developed.

We successfully fulfilled the following aims and milestones:

- *Key optimized formulas to make seafood products.*
- *3D printed seafood formulations, including parameters to make quality product.*
- *Key ready to use base formulations for 3D food print cartridge applications.*
- *Showcase recipe(s) and/ or design for introductions of 3D food printing and seafood to future end users (for example: events, classrooms, conferences).*
- *Course/ educational material to educate people in the use of 3D printing relating to seafood in general and with the utilization of underutilized seafood sources.*

The outcome of this work can be applied to further research areas such as how new innovative processing and preparation appliances can be adapted to complex raw materials like byproducts from seafoods. The findings can be applied in HORECA (Hotel, Restaurant, Café industries) environments where appealing and nutritious custom-made 3D printed portions and dishes can be created from low value byproduct seafood raw materials. Furthermore, the results can be used if applied on an industrial level for mass scale production of ready to print formulas. In addition, the work has brought about significant educational opportunities for seafood products and the seafood industry in the future. The methods and procedures developed and the learning from the work can be applied to other complex raw materials and new innovative emerging food raw materials (e.g. algae, single cell protein, insects etc) to make consumer friendly products in a format that is appealing to consumers.

The outcomes of this work have received significant attention due to publications and dissemination globally, emphasizing that Iceland is on the forefront of Food Tech and 3D seafood printing and how to better utilize seafood products and byproducts.

The work described in the report was supported by Tækniþróunarsjóður through the project *Future fish (Fiskur framtíðarinnar*) and AVS through the project *New and innovative ready to use seafood products (Nýjar tækniumbyltandi sjávarafurðir)*.

1. Introduction

1.1 3D printing of food

The market for smart kitchen appliances will soon be a billion-dollar industry, effecting how the seafood industry processes raw materials and how HORECAs buy, prepare, and cook their seafood into the future. The technology 3D food printing, also known as additive manufacturing, creates products based on a X-Y-Z three axis stage (Sun et al., 2015), layer by layer into three dimensional forms with computer assisted design (CAD). Key components of a 3D food printing include a robotic arm, nozzles, powder or a variety of homogenized ingredients, cartridges, and 3D software/ hardware and engineering to create products (Figure 1.1.1). Using various ingredients, flavours, textures, cooking, and processing, etc. we can investigate and create real product possibilities.

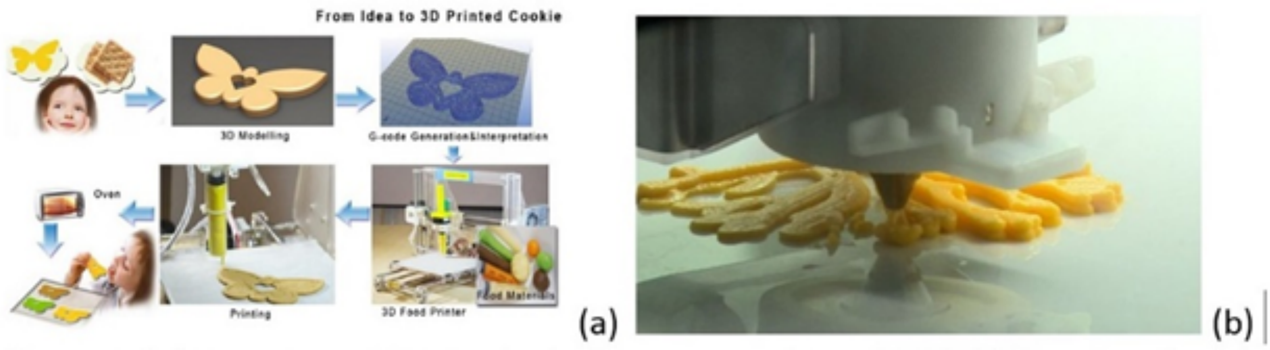


Figure 1.1.1. *(a) Overview of 3D food printing process (Sun et al., 2015) (b) 'Sea Coral' made from seafood puree, made by world acclaimed Spanish Chef Paco Perez, impossible to make by hand (Natural Machines 2017).*

Figure 1.1.2*. A pair of Foodini 3D printers from Natural Machines, which extrude food from a system of refillable capsules, meaning you're free to print with practically any ingredients you choose (Photo: Natural Machines).*

In the vast area of modern food manufacturing the digital technology of using 3D printing as a way of customizing traditional material into shapes of different color, texture and taste has made an impression on the way the future kitchen is portrayed (Sun et al., 2015). Even though attention for this technology has mostly been centered on molding and layering of artificial material the potential for Food Layered Manufacture or FLM has for long been established (Wegrzyn et al., 2012). 3D food printing has the potential to benefit both consumers and producers. For instance modification of nutritional needs as well as innovative shape constructions might help engage children to eat healthier (Hamilton et al., 2018). In a world that moves towards automation there is also a significant economical benefit for producers to integrate precise manufacturing processes from the hands of special artisans to machines (Dankar et al. 2018).

Additionally, the 3D food printing technology might be a way to reduce food waste in certain fields of manufacturing where byproducts that sometimes have high nutritional value can be transformed into shapes with flavor and texture that pleases customers. It might also be a way to present new ingredients such as algae or insects to people in an appeling way (Wiggers, 2017). Commercial food printers construct pre-programmed forms or patterns with extrusion. This extrusion resembles the use of a confectionery bag. The limitations of using different foods extends to their processing requirements, shelf-life and printing parameters which demand a soft paste-like substance or puree (Godoi et al., 2016). To properly print a food or ingredient, the printer must be calibrated/ optimized for that ingredient, including the height of the nozzle, printing speed and force, and proper extrusion rate with a given nozzle size (Pallottino et al., 2016).

Rabid development of low-cost food printers invites researchers to be ready with pre-packaged products for commercial use. Three-dimensional food printing is an innovative method that could meet the demands of future consumers for sustainability and give personalized options of flavour and presentation designs that are visually appealing.

Many institutions and companies are working on developments in the 3D printed food industry with various types of 3D food printers, including and not limited to TNO, Culinary Institute of America (CIA), International Culinary Center (ICC), Barilla, NASA, Hershey´s, PepsiCo, Cargill, Nestle, the U.S. military. All these businesses are collaborating with culinary experts, including Natural Machines. Barilla, for example, has worked with the research institute TNO in the Netherlands to develop a pasta printing machine. Bocusini, is another start-up, that has developed a 3D food printer, mainly for confections. To date, very limited work has been done with seafoods or seafood-based ingredients with this technology. This opens major opportunities for Iceland to take a lead in this area.

1.2 3D printing and seafood

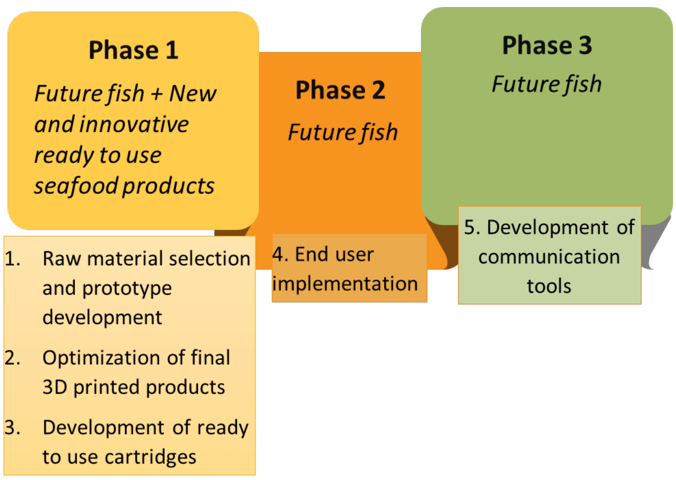
The utilization of byproducts in the fish industry has grown over the years as technological developments of material processing increase. Co-products from fisheries such as fish trimmings are a rich resource of high quality protein and bioactive compounds (Villamil et al., 2017), that can be refined and isolated. There is an increasing competition in the byproduct market and value of these byproducts are also increasing. Iceland can develop more innovative ways to process byproducts for improved utilization and increased market value through the cooperation of Icelandic fish processors, institutions, universities, chefs and consumers.

Many thousands of tons of various low value cod and haddock byproducts are created each year and exported. Low value byproducts can be further processed in Iceland and sold as high value ready to make/use products in different markets. These food products could be successful in new and emerging markets, where customized and appealing seafood presentations are sought after, selling for a significant margin. North America and Europe are top markets for Icelandic seafood, with cod and haddock being top Icelandic species consumed in the US and UK (Wright, 2016). The United States is a market where the consumption of seafood has been gradually declining and where 90% of seafood imported into the US is fresh or frozen imports (Anonymous, 2016; Alieva, 2017). Western Europe is a significant seafood export market for Iceland and there is an expected decline in future consumption.

Key barriers to seafood consumption in foodservice and retail, have been identifed as limited availability and unwillingness to prepare seafood due to raw handling and general lack of cooking skills. The projected decline is a major concern for Icelandic fisheries and can be reversed with new innovative products, technologies and markets.

The main aim of the work described in this report was to develop new innovative Icelandic seafood formulations and products using a 3D printing food technology from low value byproducts. To fulfill this aim focus was put on developing a ready-to-use product formulation using trimmings from Atlantic Cod that is considered as byproduct from the fish industy. The work was supported by Tækniþróunarsjóður through the project *Future fish (Fiskur framtíðarinnar*) and AVS through the project *New and innovative ready to use seafood products (Nýjar tækniumbyltandi sjávarafurðir)*. These two projects overlapped partly and are in the report described as one large project.

The project was divided into three main phases: Phase 1 was the largest part, focusing on research and product development to produce a range of formulations and products. In Phase 2 the 3D printing technology, formulation and products developed in Phase 1 were implemented with the end users. In Phase 3 the goal was to develop communication tools for the 3D food printing technology with seafoods and the products developed in the project. The phases overlapped as the product development process got feedback from the other phases where the outcome of product development was tested in real settings with end users. This feedback loop was to ensure that optimal products would come out of the project. To accomplish these phases, the work was organised into five main stages:



In the following chapters the process and outcome of the work is described.

2 Development of formulations /products (phase 1)

Among the the main challenges of 3D printing with fish as ingredient is its connective tissue and limitations in nozzle sizes that can be used pending the fish raw material. The beginning raw materials, pre-processing, and mix of ingredients can affect the overall printability and quality of the food form. The food material to be printed should be as homogenous as possible and flowable and with printing should remain in the shape/ food form designated prior to printing (Godoi et al., 2016).

When setting out to print a food, such as seafood, key factors should be considered: a) printability and maintenance of shape post-printing and b) application and post processing of printed material.

a) Printability

Various parameters can affect printability including formulation and preparation, temperature, texture, ingredients, rheological and viscous properties of the ingredients and food. The printability would translate to the ability of the printer, with optimized printing parameters, to extrude a food material into a well-defined structure. The food material should be extrudable without excessive air pockets, such that a stable food form is printed with minimal gaps in well defined, stable layers. Food safety is also a consideration and like with any food, particularly raw, safe handling practices should be practiced like manual handling. Regarding applications and post processing, the material should have the same applications (Lipton et al., 2010).

b) Application and post processing of printed material

The printed food form should uphold shape and height, generated by printing layer upon layer, with chosen cooking parameters. Once cooked, the product should have typical rheological properties expected of the food product itself. This involves detailed research and planning and starts with the raw materials and ingredients themselves. To add, the printing itself will not impact the flavour of the food. The properties of the food material must be considered for proper formulation relating to the physical, mechanical, and rheological properties (Lipton et al., 2015).

In phase 1 of the work focus was put on raw material selection, prototype development, optimization of 3D printed products/formulation and development of ready to use cartridges.

2.1 Raw material and ingredient selection

Several pre-tests were run on printing different raw materials including mince from haddock, cod and halibut. With the future consumer in mind, salmon was also tested, that is the utilization of the trimming from salmon cut-offs from home cooking (see Salmon and Avocado Galaxy appetiser, section 2.4.3).

The main raw material ingredient focus was however on cod and haddock being the most fished groundfish species in Iceland. Haddock and cod byproduct mince from trimmings, frames, skin, etc. was identified as having the greatest potential for value addition (based on communication with seafood producers Icefish and Thorfish). Fresh, salted and frozen mince was obtained from producers and fish stores.

When using the traditional raw material sources (fresh, frozen, salted fillets made into mince), straining was required, and a larger size nozzle was needed (4 mm or greater). It was therefore suggested that straining should be used as a quality precaution for all formulas. Working further with the mince it was decided to produce surimi as it was hypothesized that less straining would be required. Two main experiments were executed. In the first one different salt concentrations were tested in two different surimi types, (1) prepared with conventional washing and (2) pH shift process (see figures 7.1.1 and 7.1.2 in appendix). In the second experiment the two different surimi types were tested with other ingredients with the aim of making formulas for ready-to use cartridges. In chapter 2.2 and 2.3 the experiments are described.

Functional ingredients tested in the project included astaxanthin, fish oil, seaweed and salt (see section 2.4). The astaxanthin and oils were well incorporated and left negligible aftertaste. Fish oil, for example, was well incorporated into cod surimi and improved the printability of the surimi in addition to adding nutritional value (see section 2.4.7). The flavour was not significantly impacted by the addition of oil and with flavoured oil it was significantly improved, which could prove to be a very important nutritional ingredient for development of further formalized formulas and prototypes.

2.2 Study on model surimi formulations and affect on 3D food printing

The objective of the study was to develop fish protein-based products from Atlantic cod byproducts and investigate the effects of starting raw material, cold storage, and addition of salt on various quality characteristics and properties of surimi and surimi gels when 3D food printed. The study was performed in collaboration of Matís, UNU-FTP and Háskóli Islands, executed by Phd student Romauli Napitupulu. Cod mince was used to make surimi with two different methods, (1) conventional washing (CW) and (2) protein isolate, pH shift process (PS). The surimi was frozen for 7 days and then thawed. It was then analysed and used to make surimi gels through 3D printing at 0, 4 and 7 days of storage (after thawing) at 4°C. The printed gels were cooked and referigerated overnight for optimal setting. Printability, microbial levels, color, total volatile nitrogen bases (TVB-N), water holding capacity (WHC), texture profile (TPA), near infrared spectroscopy (NIR) and nuclear magnetic resonance (NMR) were all studied (figure 2.2.1).

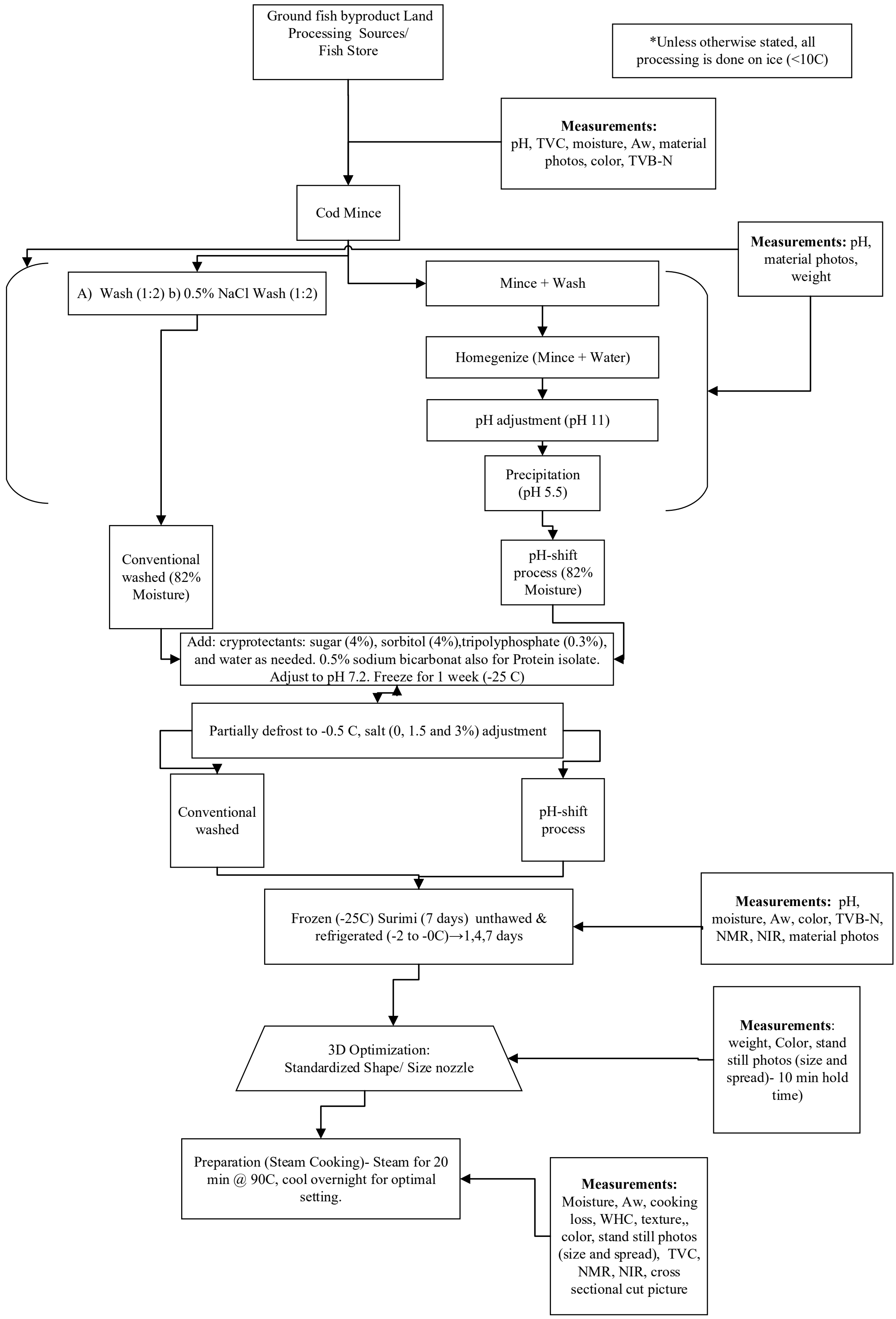


Figure 2.2.1. *Experimental design, preparation of cod surimi and 3D printing.*

Key conclusions for base formulations were as follows: a) Surimi made from two washing methods was successfully printed without and with increasing salt concentration at different points of cold storage. It cannot be concluded that one surimi preparation method was better than the other b) as various factors affect overall gel formation of surimi pastes (further research was conducted to optimize formulas to develop ready to print surimi product formulations, see chapter 1.3), c) fresh, higher quality starting byproduct mince material is recommended. Safe and high-quality 3D printed surimi products made from seafood byproducts can be achieved through conventional and pH-shift processing, proper handling, and proper cooking instructions. d) The addition of binders, cryoprotectants, and other ingredients will be key to developing formulations that are stable with freezing and refrigeration, optimal gelation, and consumer acceptability. In figure 2.2.2, examples of 3D cod surimi gels after steam cooking are shown.

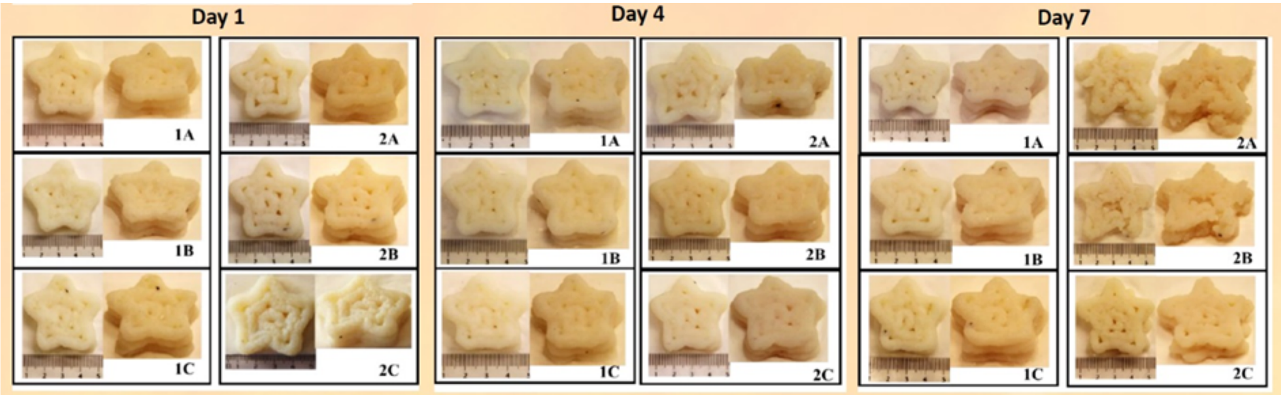


Figure 2.2.2. *Pictures of 3D cod surimi gels after steam cooking and 1, 4 and 7 days of storage. Conventional surimi (CW) and protein isolate surimi (PS) with different salt concentrations (1A = CW 0% salt, 1B = CW 1.5% salt, 1C = CW 3% salt; 2A = PS 0% salt, 2B = PS 1.5% salt, 2C = PS 3% salt).*

With the surimi ingredients, the 4 mm and 1.5 mm nozzle can work without straining as the material has already been pre-processed from the byproduct mince to remove significant amounts of connective tissue (see figure 2.2.3). This affords greater flexibility in shapes that can be printed.

Figure 2.2.3*. Pictures of mince (left), protein isolate surimi (middle) and conventional surimi (right).*

More details on the study can be found in published scientific article (Guðjónsdóttir et al., 2018) and UNU-FTP report (Napitupulu R., 2018) (see appendix, 6.2).

2.3 Ready to use 3D printing formulas for cartridges

Commercial food printers construct pre-programmed forms or patterns with extrusion. This extrusion resembles the use of a confectionery bag but with significant control and ability to create very appealing shapes for the consumer. The limitations of using different foods extends to their processing requirements, shelf-life and printing parameters which demand a soft paste-like substance or puree-fitting well for surimi which is made from paste like texture formulations. Based on information from consumer focus groups (see chapter 3.1), the user would like a prefilled cartridge with ready to print seafood formulas that can then be cooked. Ready to print formula in a prefilled cartridge that can either be stored in the fridge for 5 days or frozen for several months could be a solution with significant applications for retails, restaurants, HORECA´s and in the home.

Figure 2.3.1. *Cartridge for 3D food printer Foodini (left), printing with Foodini (right).*

The aim of this study was to produce ready-to-print raw seafood formulation from byproducts in white fish (cod and haddock) Icelandic fish industry processing. For obtaining material that could serve as a main ingredient in formulation of product, surimi was made from cod mince using conventional washing (CW) and the protein isolate, pH shift process (PS). The resulting formulations from these raw materials were compared regarding functionality, physical and chemical properties and shelf life (see figure 2.3.2) after refrigerated storage as well as after cooking. Storage studies were conducted in plastic packaging that is practical for bulk filling in the restaurants, retail, or at home, etc. Formulations were developed and tested in collaboration with Háskóli Islands, UNU-FTP, and Matís. A master's student, Ólafur Tryggvi Pálsson, and Phd student, Romauli Napitupulu, participated in the research.

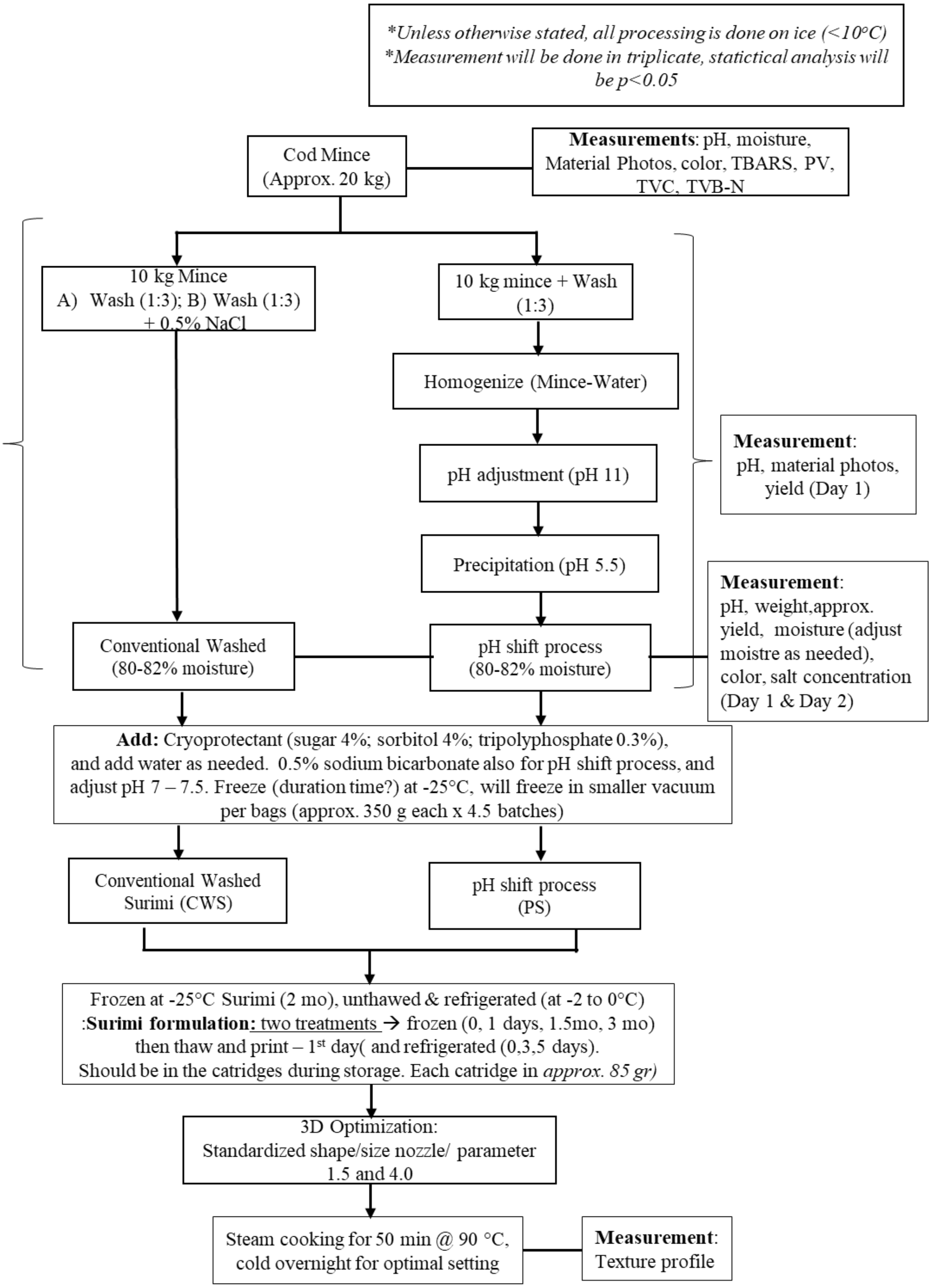


Figure 2.3.2. *Schematic of the experimental testing*

Recipe development

Two major factors were observed in the selection of additional ingredients and their proportions to the recipe: Prolonged gelation and shelf-life refrigeration. Recipe formulation development was done in a stepwise manner, looking at how to reduce gelation of the surimi paste (protein isolate surimi or conventional surimi with added ingredients). Formulation development started with traditional formulas that were modified to make them gluten free. Generally from readings and known formulas from industry, wheat starch is a key component. However, in the case of our developments, gluten free starches to help in the setting process were utilizied. From these ideal recipes that are meant to be made the day of mixing with ingredients, the formula was adjusted so that it could be ready to print over 5 days. Salt, oil, starch, egg, water and xanthan gum (to reduce/ inhibit gelation and increase flowability) in various levels were tested. Salt and xanthan gum, were the key ingredients in the final adjustment due to the significant impact they had on gelation with refrigerated storage, printing, and cooking. Table 2.3.1 shows the final formula with the ability to print without gelation at refrigerated storage.

Table 2.3.1. *Recipe for ready-to-print raw seafood formula which has the ability to print without gelation with refrigerated storage.*

Ingredient	Proportion (%)
starch, corn	6.1
potato flour	6.1
salt, table	2.0
water	16.1
egg white, liquid	5.3
surimi (CW or PS)	62.3
vegetable oil	1.1
gum, xanthan	1.0
Total	100.0

Printing parameters (mm)
Lead time: 1.6
Printing speed: 2200
Distance between layers: 1.8
Jump height: 2.2

Formulas that were not suitable for being ready-to-print with refrigeration gelled within 1-2 days. The formula printed well upon mixing and printing the same day (see figure 2.3.3). The optimized surimi formula was a good formula to work from with both the protein isolate (pH shift) surimi raw material in addition to the conventional surimi raw material.

Figure 2.3.3. *Example of optimized surimi formulation, coventional (left) and protein isolate (pH shift) (right), for printing right after mixing.*

Parameters studied

The printability of the formula over 5 days of refrigerated storage was studied in various shape applications with a 1.5 mm cartridge, allowing for innate printing of shapes of different heights and widths to test for accuracy in addition for the ability of the printed shapes to set. Other key testing parameters of the fresh formula included water holding capacity (WHC), texture analysis, colour, microbial analysis and total volatile basic nitrogen (TVBN) for spolage indication. Through processing of material it is important to understand the gain or loss of water in the surimi paste with cooking to understand how well the gel held water and the functionality of the gelled proteins themselves.

Three created prints were tested, a layered cylander, triangles, and rectangles. This was to study the accuracy, printability, flowability, and ability of the paste to hold shape before cooking (see figures 2.3.4-6).

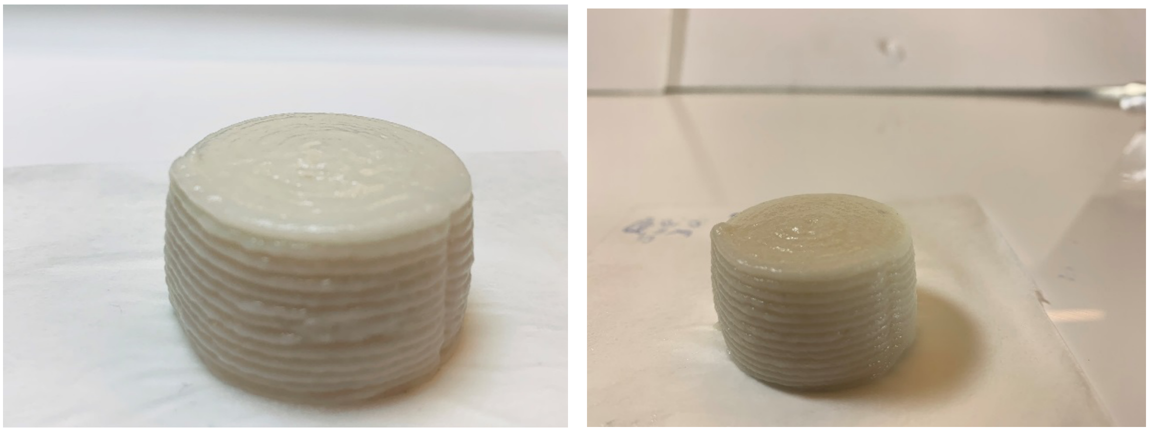


Figure 2.3.4*. Example of cylander print: D0 PS paste (left), D0 CWS paste print (right).*

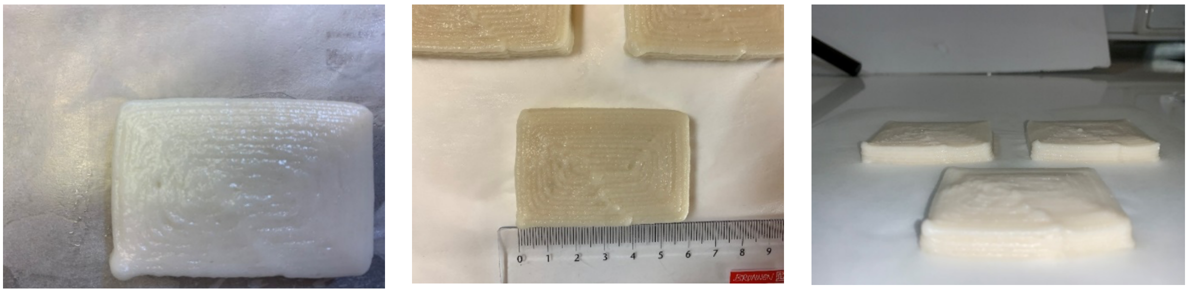


Figure 2.3.5. *Example of rectangular print, D0 conventional surimi print (left), D5 pH shift print (middle), D5 (right).*

Figure 2.3.6. *Example of steam cooking in lab testing to imitate typical water bath cooking of surimi in industry (left). Cooked and gelled surimi product, pH shift paste after 5 days of storage (right).*

Storage stability with freezing of the surimi and thawing with frozen shelf life were studied before and after cooking for texture, microbial levels, color, NIR, printability, functionality, etc. with different levels of salt addition.

Main results

Height and width and shapes of the pH shift (PS) and conventional (CWS) surimi pastes were consistant. The shapes were tested for setting ability, accuracy, flowability, and quality. Printed gels from PS was more sticky and there was gapped in the side and wider compared to CWS printed gels. CWS printed gels structure was softer and evenly created layer. No change in diameter was observed in top or bottom with cooking, the hight rose by 2-3 mm. After 5 days (D5) of 17efrigerated storage the cooked shapes seemed to not be as precise in layering and slightly more irregularities in precision relative to D0 and D2, however still acceptable. The protein isolate surimi paste after cooking seemed to have a slightly better ability to hold water (WHC) and thus a slightly better gel formation with cooking. There was not a significant difference in colour amongst the treatments. TVBN of cooked samples rose within the storage time. After cooking all samples had low microbial counts, however after 5 days the microbial counts had risen, and the samples were on the borderline of sufficient quality (see more details appendix 7.3). It is therefore suggested that storage up to approximately 4 days would be reasonable for refrigerated storage prior to printing. Also looking ahead, a natural preservative that is allowed in seafood products is something to investigate.

Storage stability of surimi pastes after 6 months at frozen storage were tested by microbial count and fesability of printing. The printing was successful without significant gelling. However, total plate count of the surimi was not acceptable after 6 months of storage. Note that the surimi paste was frozen after 2 days of refrigerated storage, the result might have been different had the surimi paste been frozen the same day it was made (DO). Cooking reduced the microbial count significantly (<200 Cfu). The product was sampled for tasting by a small group and it was found that the taste did not significantly change with cooking however the texture was slightly more granular like in taste. In the future, with more research, formal sensory panels would further help in testing and feasibility with frozen shelf life.

Both a plastic (prototype) cartridge and metal cartridge were used for the storage testing. The plastic cartridge broke with freezing expansion and therefore was not suitable for storage (figure 2.3.7).

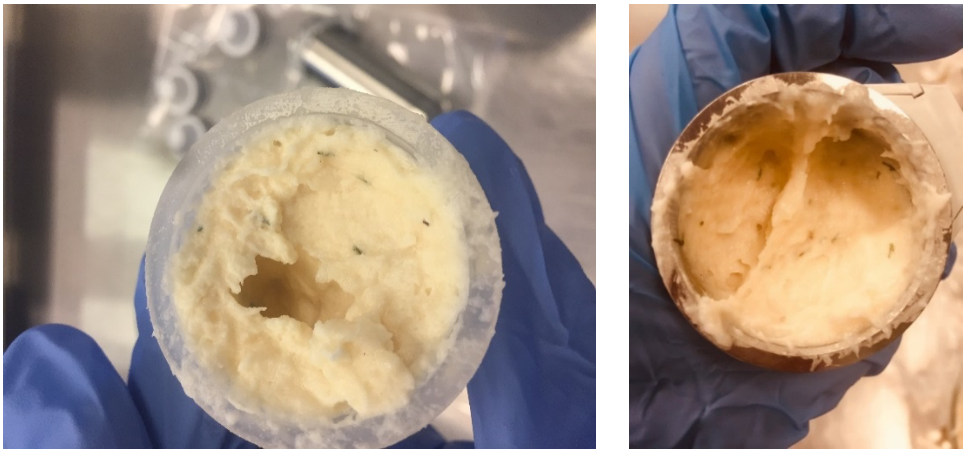


Figure 2.3.7. *Formulas after frozen storage, plastic (left) and meal (right) cartridge.*

Subtitutions for sugar in the surimi was further sought after to make the ready to print formulas more healthy as sugar is a key component in surimi ready to eat products currently made in the seafood industry, functioning as cryoprotectant. Inlign with the ready to print formula developed and tested, a reduced sugar formula was also developed. Cod protein hydrolysate and allulose were tested as a subtitute for sugar in the initial raw surimi and also in the final raw surimi paste. Preliminary results indicate that using allulose in the formulation, physicohemical properties (i.e. gel strength and hardness) are close to the commercial cryoprotectant (sorbitol). Using cod protein hydrolysate resulted softer in gel strength and lower value in hardness. It will therefore be interesting to investigate further on the optimal concentration of the allulose (with or without sorbitol).

Conclusion

Results indicated that it is possible to produce ready-to-print (RTP) raw formula products utilizing seperation and washing techniques, using both pH shift protein isolate processing and surimi protein from surimi conventional processing. This also emphasizes the possibilities for byproduct mince in 3D food printing applications and that there is significant impact and potential for these formulations for industry, the home consumer, and HORECA. This is particularily the case when the 3D food printer can not only print, but cook as well. Such a printer is expected to be on the market in early 2021.

2.4 Development of prototypes

Formulas were developed for specific shapes and designs and nozzle shape. The utilization and order of ingredients and pre-processing all can make an affect on the formulation.

Optimized seafood meals and formulations were created utilizing 3D food printing, featuring both traditional and nontraditional formulations to appeal to consumers. For example, rather than the traditional Icelandic cod and potatoes, a 3D printed Icelandic cod volcano with potatoes and “lava” sauce was created. Based on result from testing of different raw materials (chaper 2.1-2.3) a key focus was put on surimi based raw material formulations. Seven recipes were developed: Cod and potatoes volcano, Twisted star (Fish and potatoes with butter), Salmon and Avocado Galaxy, Fish Mousseline (with mince and with protein isolate made from pH shift process), Pasta (made with conventionally washed surimi raw material), Artistic triangles with astaxanthin, Fish protein isolate chips (pretzels) and pizza.

The optimized diverse formulas and shapes developed can reach various consumer populations and end users (restaurants, catering, and home consumers). In development of these products, challenges, and complexities for the end user of the formula were realized and thus, certain formulas, may be more appealing to the HORECAs and/or the consumer.

2.4.1 Cod and potatoes volcano

Figure 2.4.1.1. *Cod and potatoes volcano variant (ingredients: volcano (cooked cod mince, potato, butter, salt, pepper, etc), potato base (spinach powder, butter, salt), lava (red pasta sauce).*

The schematic below shows the process of making the shape with salted cod (figure 2.4.1.2). This could also be made with cod mince. The volcano ingredients and potato base required straining. All ingredients were precooked, set over night with cold storage and then printed cold (4.0 mm nozzle, 1.5 mm nozzle for red sauce). Other shapes can be made with this recipe. Recipe and labelling information is shown in table 2.4.1 and figure 2.4.1.4.

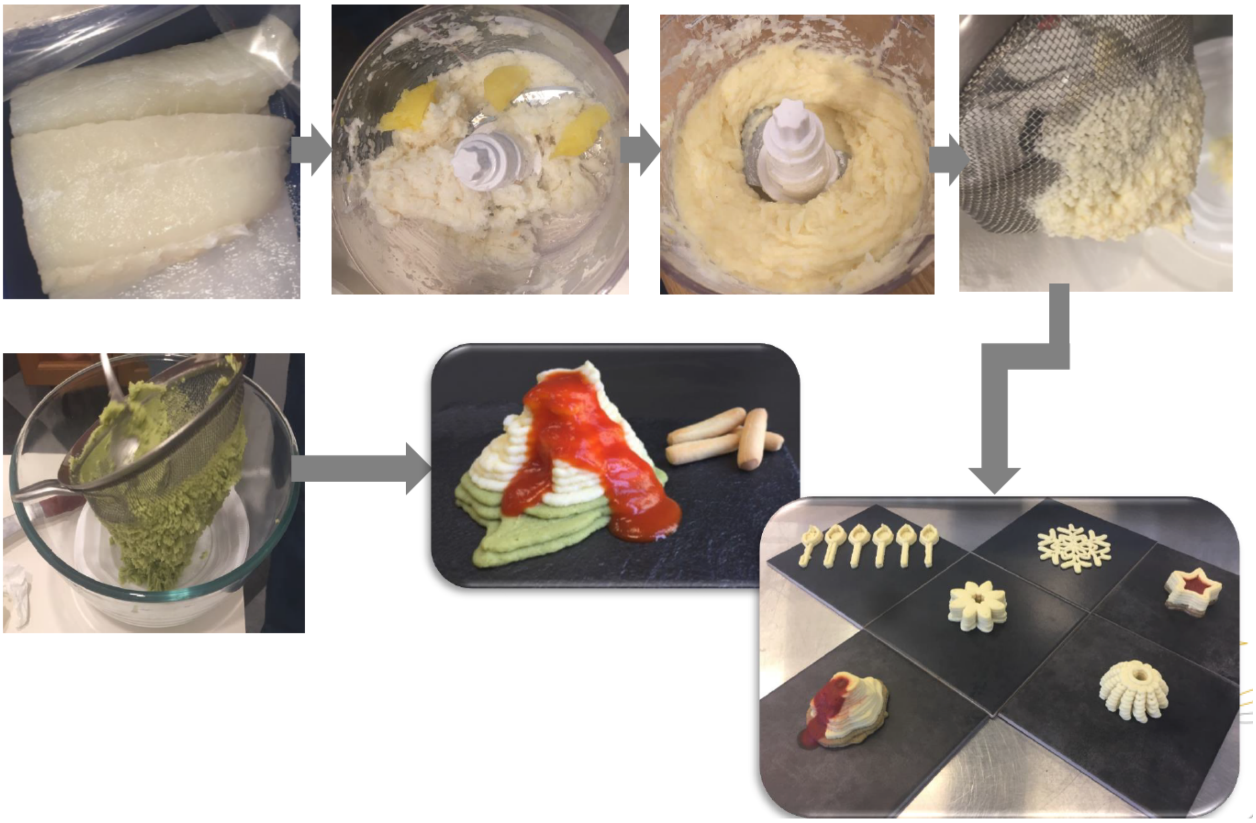


Figure 2.4.1.2. *Scematic showing the making of the cod and potato volcano.*

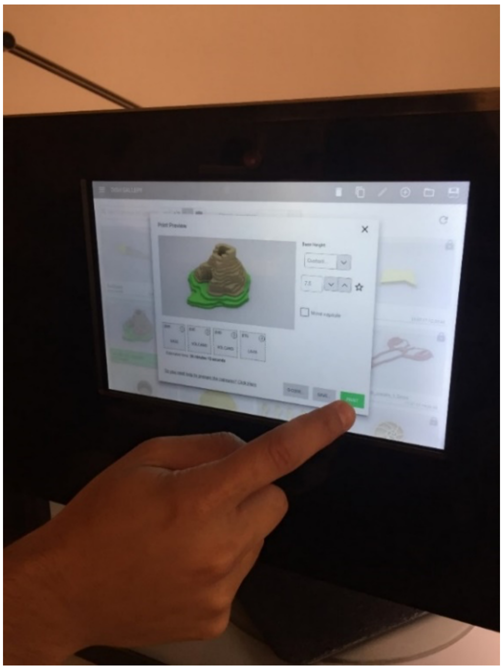


Figure 2.4.1.3. *Printing of the Cod and potato volcano in the Foodini printer (Natural Machines).*

Table 2.4.1*. Recipe for cod and potatoes volcano, list of ingredients in fish base (left) and cartridge use (see more details on the recipe, appendix 6.4)*

Fish base		
Amount	**Measure**	**Ingredient**
560	g	salted cod loin
186	g	potato powder
17	g	butter
1,25	tsps	salt

Cartridge		
Amount	**Size nozzle**	**Ingredient**
1	4.0 mm	potatoes and spinach powder
2	4.0 mm	fish base
1	1.5 mm	tomato sauce

Ingredients: Cod (**fish**), potatoes, salted butter, salt.

Nutrition Information

	Per 100 g	Per portion of 75 g
Energy	415 kJ / 98 kcal	300 kJ / 71 kcal
Fat	2.3 g	1.7 g
Saturates	1.2 g	0.9 g
Carbohydrate	5.3 g	3.9 g
Sugars	0 g	0 g
Protein	14 g	10 g
Salt	0.56 g	0.42 g

Reference intake of an average adult (8,400 kJ / 2,000 kcal)

Figure 2.4.1.4. *Cod and potato volcano labelling information. Ingredient list and nutritional information*

2.4.2 Twisted star (Fish and potatoes with butter)

Figure 2.4.2.1. *Twisted star made from haddock, potatoes and butter.*

The 3D printed haddock twisted star is a modern presentation of haddock, potatoes, and butter that must be cooked (figure 2.4.2.1) This is unlike the volcano recipe, which is already cooked before printing.

Table 2.4.2. *Recipe for twisted star made with haddock, potatoes, and butter.*

Amount	Measure	Ingredient
979.00	g	haddock, raw, fillet
30.00	g	cream, whipping, classic heavy, ultra paste
40.50	g	butter, salted
3.50	g	salt, table
439.00	g	potato, microwaved, in skin, peeled, 2 1/3' 3/4"

Nutrition Information

	Per 100 g	Per portion of 75 g
Energy	422 kJ / 100 kcal	322 kJ / 76 kcal
Fat	3.3 g	2.5 g
Saturates	1.9 g	1.4 g
Carbohydrate	6.5 g	4.9 g
Sugars	0 g	0 g
Protein	11 g	8.5 g
Salt	0.63 g	0.47 g

Reference intake of an average adult (8,400 kJ / 2,000 kcal)

INGREDIENTS: Haddock Fish (**Fish**), Potatoes, butter, salted (**Milk**), Heavy Whipping Cream (**Milk**), Salt

Figure 2.4.2.2. *Twisted star labelling information. Ingredient list and nutritional information.*

The formula did require straining of both the potatoes and the fish, prior to printing (4 mm nozzle). The formulation was printed and cooked at 150˚C for 15 minutes, followed by 15 minutes at 100˚C. Microbial levels with cooking were successfully reduced to an aerobic plate count of less than 10 ppm). The twisted star was presented to consumers in a focus group (see chaper 3.1).

Figure 2.4.2.3. *Twisted star. After printing and before cooking, cross section (left) and after cooking (right),*

2.4.3 Salmon and Avocado Galaxy

Showcase recipe was made with salmon crème and avocado crème using spiral shape provided in the Foodini food printer (4 mm nozzle). See figure 2.4.3.1 and 2.4.3.2. The „galaxy" serves approximately 6 people on a medium size circular flatbread or tortilla. Garnish ideas: small greens, dill, cucumber.

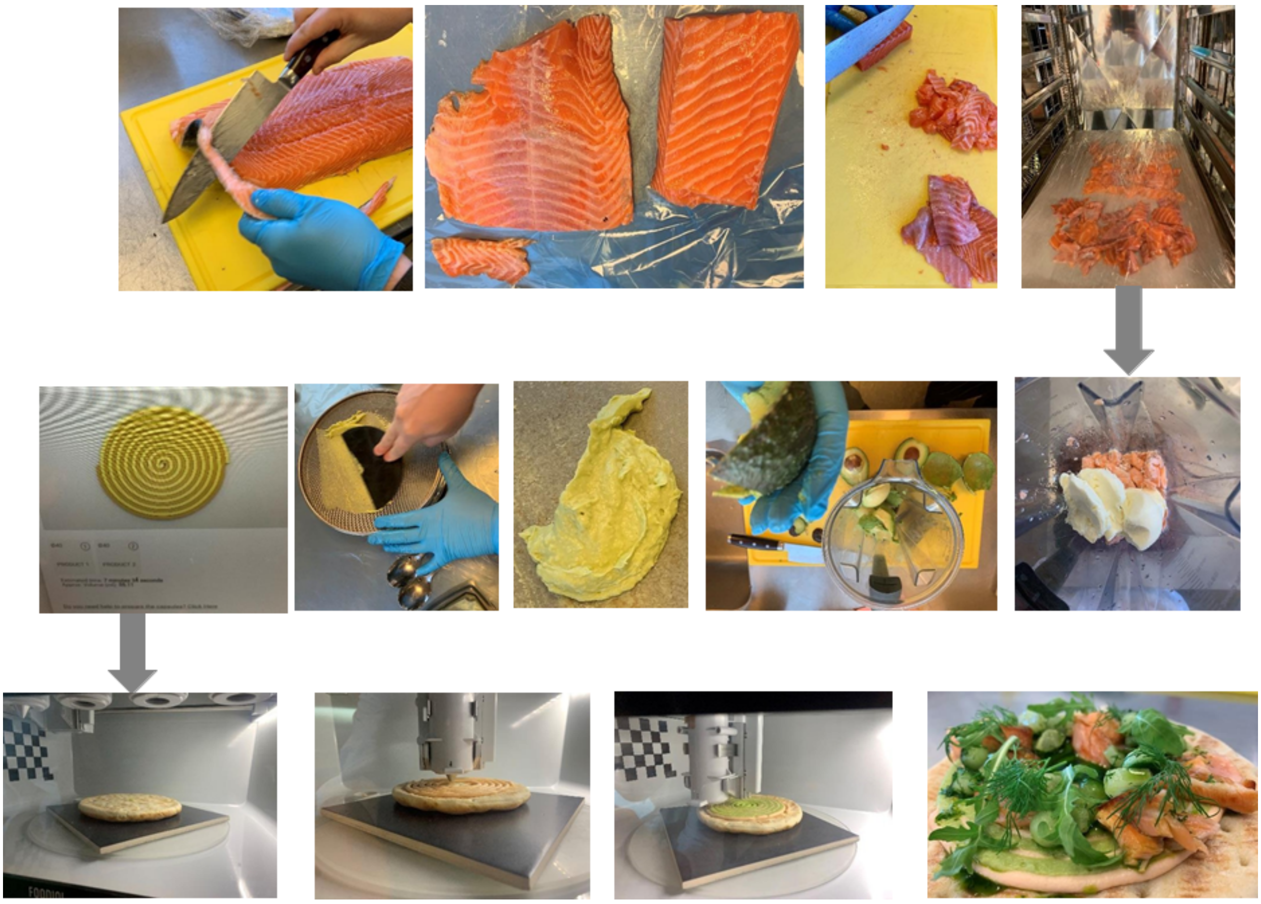


Figure 2.4.3.1. *Salmon and Avocado Galaxy Cold Appetizer showcase recipe process schematic.*

Figure 2.4.3.2. *Another version of the salmon mousse with a salmon fillet, broccoli, and fish broth foam garnished with caviar and herb and also with white root vegetable.*

2.4.4 Fish Mousseline (with mince and with protein isolate made from pH shift process)

The fish mousseline formulation was investigated and tested as the Icelandic chef team suggested that this is a common fish dish in Iceland and also globally that utilizes mince from fish processing and additionally does require some type of mold to create a shape. Thus, this dish was highly fitting for testing of underutilized fish mince (in this case haddock) and protein isolate made from fish mince. The fish dish had a great deal of taste appeal and had a light fish flavor with a quiche type texture and flavor with a creamy note.

Optimised recipes for the mousseline made with haddock mince and haddock protein isolate is listed in table 2.4.4.

Table 2.4.4. *Mousseline recipe with haddock mince (left) and haddock protein isolate (right).*

Amount	Measure	Ingredient
400.00	g	haddock, raw, fillet
0.75	cup	cream, whipping, heavy
1.00	tsp	egg white, raw

Amount	Measure	Ingredient
1.50	cup	cream, whipping, heavy
1.00	tsp	egg white, raw
400.00	g	Fish Protein Isolate

The minced haddock version was sieved as needed (figure 2.4.4.1) and the sieved fish meat was collected into a glass bowl over ice. The protein isolate version did not require sieving prior to printing. This is due to the preparation of the protein isolate prior to use in the recipe. You can season too as you like, for example with dill or Italian seasoning. The egg white is to be whipped prior to adding to the fish meat, either fish mince or fish protein isolate. The créme should be added gradually, 2 tablespoons at a time. This involved constant folding/whipping of the crème into the fish protein with a spatula. When done incorporating the créme, the mousseline should have the texture of mashed potatoes. The mousseline paste is to be set overnight (chilled overnight in glass bowl) prior to cooking. The next day, the paste was filled into a cartridge with 1.5 mm nozzle. Cooking was conducted at 180˚C at 30 minutes with steam and minimal fan.

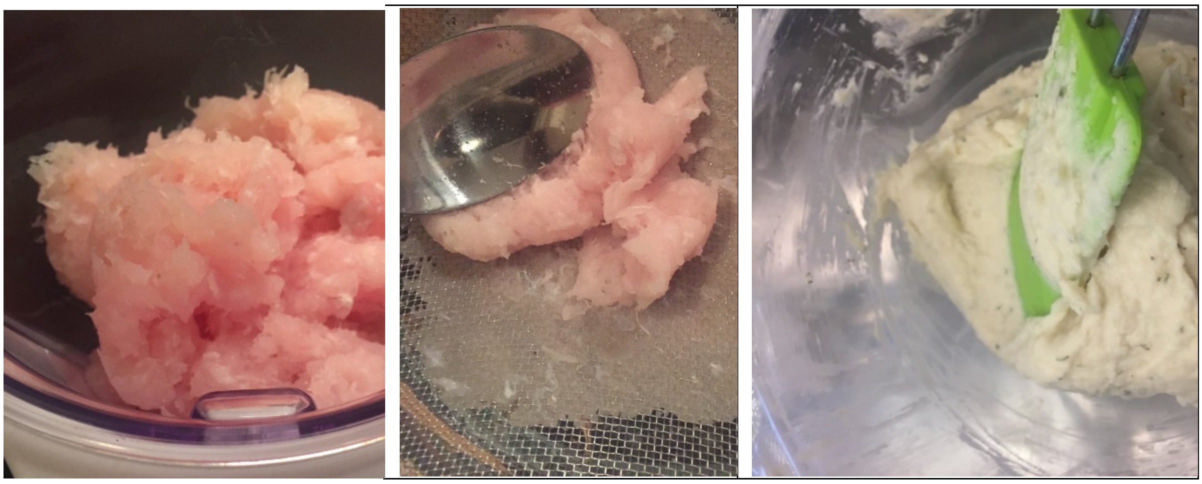


Figure 2.4.4.1. *Haddock mince sieved and mixed with other ingredients to form a mousseline paste.*

The protein isolate performed the best in formulation both for printing, protein setting and with cooking. Twice as much créme could be incorporate into the mousseline formulation with protein isolate due to its water holding capacity. Additionally, there was more browning in the protein isolate formula which is likely due to the sodium bicarbonate that is contained within the formula of the protein isolate (which is used to adjust the pH of the protein isolate). With cooking and when tested, the microbial count was acceptable (less than 200 CFU/g at 30°C).

Nutrition Information

	Per 100 g
Energy	625 kJ / 150 kcal
Fat	11 g
Saturates	7.1 g
Carbohydrate	0.8 g
Sugars	0.8 g
Protein	12 g
Salt	0.39 g

Reference intake of an average adult (8,400 kJ / 2,000 kcal)

INGREDIENTS: Haddock Fish (**Fish**), Heavy Whipping Cream (**Milk**), **Egg** Whites (**Egg**)

Nutrition Information

	Per 100 g
Energy	782 kJ / 189 kcal
Fat	17 g
Saturates	11 g
Carbohydrate	1.3 g
Sugars	1.3 g
Protein	7.7 g
Salt	0.03 g

Reference intake of an average adult (8,400 kJ / 2,000 kcal)

INGREDIENTS: Haddock protein isolate (Haddock (**Fish**), sucrose, sorbitol, sodium tripolyphosphate, sodium bicarbonate) Heavy Whipping Cream (**Milk**), Egg Whites (**Egg**).

Figure 2.4.4.2. *Haddock mousseline labelling information. Ingredient list and Nutritional information. Mousseline made with mince (left) and protein isolate (right).*

Figure 2.4.4.3. *Haddock mince mousseline, printing (left), ready after printing (middle), after cooking (right).*

Figure 2.4.4.3. *Haddock protein isolate mousseline, ready after printing (left), after cooking (right).*

The protein isolate and fish mince formulations were stored for 2 days. There was significant liquid loss with freezing and cooking, particularly for the fish mince formulation (figure 2.4.4.4). The formulas required remixing prior to printing.

Figure 2.4.4.4. *Printed formulas (top is mousseline made with fish mince) and bottom is fish mousseline made with protein isolate after 2 days of storage.*

2.4.5 Pasta (made with conventionally washed surimi raw material)

Cod surimi pasta with pesto filling was made (see figure 2.4.5.2). Raw surimi was mixed with flour and egg folded into. Water and oil added and then sieved. A pre-ready pesto sauce is suitable for the filling. Parmesan cheese can be added, finely grated to the sauce. Sieve as needed. The pasta was printed with a 1.5 mm nozzle and was boiled for 5 minutes.

Amount	Measure	Ingredient
66.00	g	Icelandic Surimi- Matis
11.00	g	water, tap
58.00	g	egg, raw
58.00	g	flour, baking, gluten free
28.00	g	oil, vegetable

INGREDIENTS: **Icelandic cod surimi** (**cod mince (fish)**, sucrose, sucralose, sodium tripolyphosphate, salt), **eggs**, gluten free flour, vegetable oil, water.

Figure 2.4.5.1. *Cod surimi pasta recipe and ingredient list for labelling.*

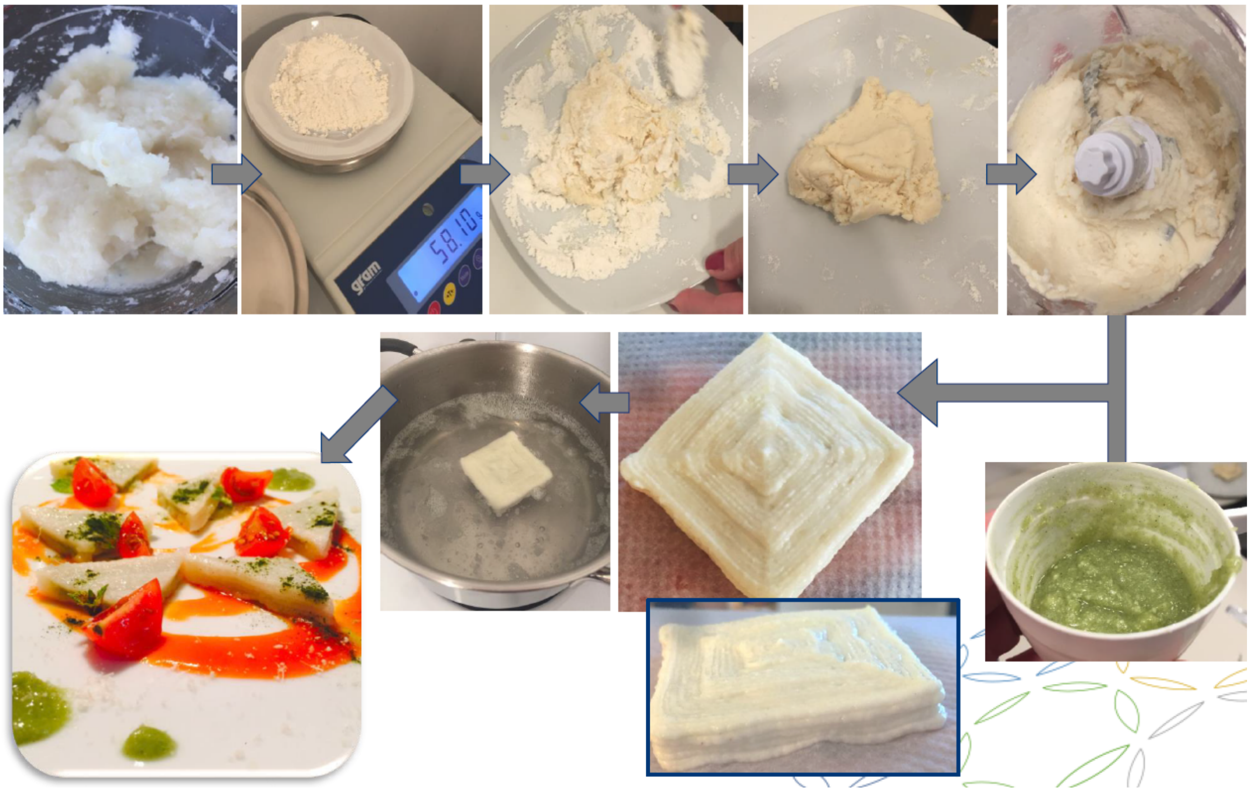


Figure 2.4.5.2. *Schematic flow for the making of cod surimi pasta.*

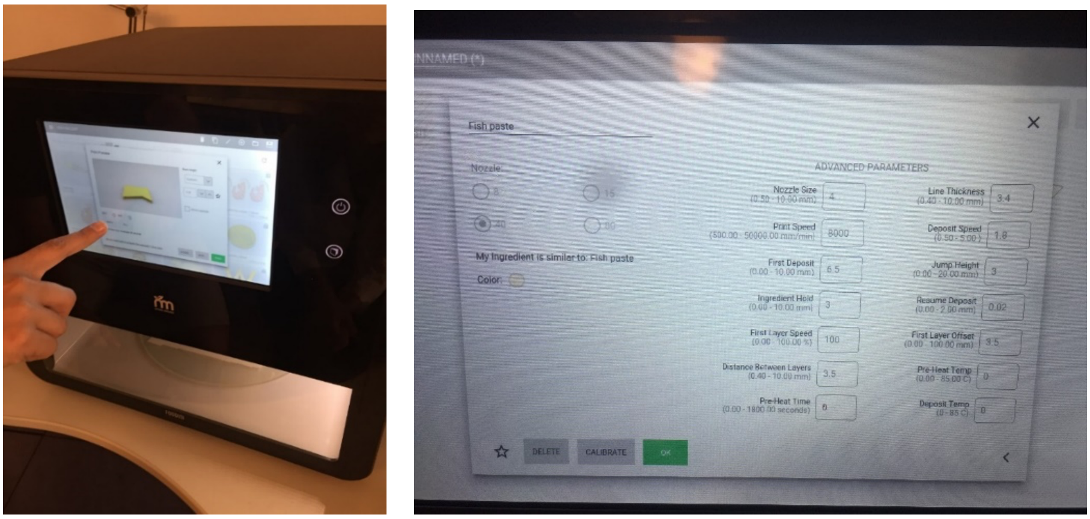


Figure 2.4.5.3. *Printing of the cod surimi pasta with the Foodini printer (Natural Machines).*

2.4.6 Fish protein isolate chips (pretzels) and pizza.

Protein isolate fish pretzel and pizza were made with cod protein isolate (pH 6.9), gluten free flour, water, yeast, oil, sugar and salt (to flavor or as desired) (recipe figure 2.4.6.1).

Amount	Measure	Ingredient
160.00	g	Fish Protein Isolate
40.00	g	water, tap
200.00	g	flour, baking, gluten free
2.00	g	sugar
3.00	g	yeast, bakers, active, dry

Figure 2.4.6.1*. Fish protein isolate pretzels and pizza recipe.*

The yeast was activated with water (30 minutes at ambient temperature) followed by addition of other formulation batter ingredients and incorporation of the protein isolate. The batter was then strained to remove fish connective tissue in the formulation and then printing followed. The pretzel was printed with a 4 mm nozzle. The 3D printed pretzel was fried until reaching a puffed texture and a golden-brown hue. 2 cartridges are needed for the pizza optimized formula, one cartridge for dough (4 mm) and the second for the sauce (1.5 m or 0.8 mm). Sieving may be needed for the red sauce if it is chunky, thick or if it contains higher mesh sized herbs. The pizza was cooked at 200°C for 10 minutes.

Figure 2.4.6.2. *Fish protein isolate pretzels and pizza. Schematic diagram of the process.*

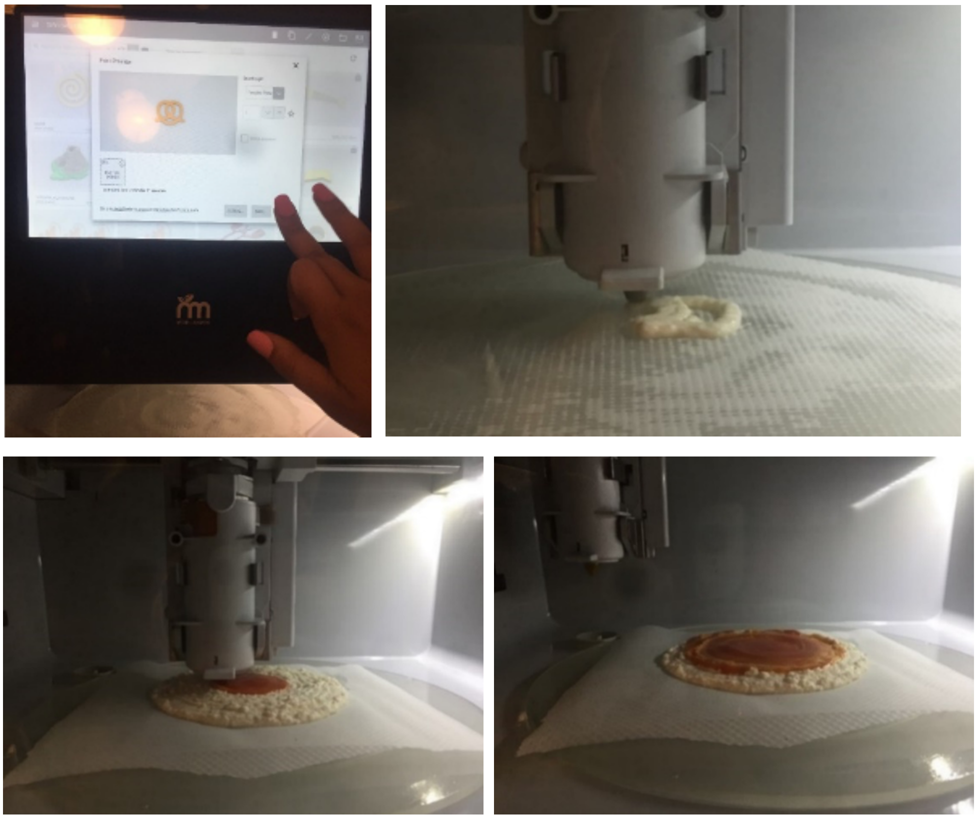


Figure 6.2.5.3. *Printing the pretzels (above) and pizza (below.*

Nutrition Information	
	Per 100 g
Energy	806 kJ / 190 kcal
Fat	0 g
Saturates	0 g
Carbohydrate	39 g
Sugars	3.4 g
Protein	7.7 g
Salt	0.04 g
Reference intake of an average adult (8,400 kJ / 2,000 kcal)	

Ingredients: Gluten free baking flours, **Icelandic fish Protein isolate** (sucrose, sorbitol, sodium tripolyphosphate, baking soda), water, Bakers Yeast, sugar.

Figure 6.2.5.4. *Fish protein pretzels/ pizza dough labelling information. Ingredient list and Nutritional information.*

2.4.7 Artistic triangles with astaxanthin with prototype packaging:

Triangles with astaxanthin were made using surimi and protein isolate surimi (see figure 2.4.7.1). The experiment and formulation for the artisic triangles was conducted by Rebekka Egilsdóttir, student at the Icelandic University of Arts.

On ice, surimi is first minced with the salt and then water and ice are added followed by the other liquid ingredients and then the starches and sugar (see recipe table 2.4.7). All preparation is done on ice and the formula does not reach over 10°C. Printed into triangle shape using one cartridge, 1,5 mm nozzle. Steam cooked at 90°C until gel is fully set with heat.

Table 2.4.7. *Triangle recipe.*

Ingredient	amount (g)
Raw conventional surimi or protein isolate surimi (g)	47
salt	1.5
water	20
oil	1.5
sugar	5
cornstarch	12.5
potato starch	12.5

Figure 2.4.7.1. *Schematic of process. Cooked surimi paste product (orange colored triangles (1.5 mm nozzle) mixed with astaxanthin omega 3-fatty acid oil). The grayish purple hue triangles are made with Icelandic volcanic salt.*

Figure 2.4.7.2. *Raw surimi material mixed with astaxanthin and omega-3 fatty acid fish oil (orange flavored) made by SagaNatura.*

Packaging prototype and a video was also created to compliment the cooked surimi paste creations (figure 2.4.7.3).

Figure 2.4.7.3. *Prototype of packaging for surimi triangles.*

Feedback from teachers and fellow students at the Icelandic Academy of the Arts: The printed shapes paired with the student´s packaging. The teachers and the students liked the form because it was not a normal food shape. They reported that they would eat the fish in that form and said they would snack on it like that. They did not have a preference on where it could be sold. They did like the packaging but did not mention if they would buy it like that. The professors where very excited about this project regarding printing of seafood and surimi products. They liked the product very much as it was sweet and tasted like a pancake. In a blind tasting, they at first did not know it was fish until they were told it was so.

2.5 Adapted Flavor formulas from Ready to print (RTP) base formula

Ready to print (RTP) adapted forms and formulation were developed with chef Viktor Örn Andrésson from the Icelandic Chef team. From the base RTP formula developed, various flavor versions were created, formulated, and printed**.** The chef felt most comfortable using the conventional surimi paste formulation versus the protein isolate (pH shift) surimi paste as it tasted and smelled closest to haddock or cod fish mince.

Initial examples include the langoustine formula (see table 2.5.1) printed in various shapes, see figure 2.5.1: a) and b) pasta shape c) beehive pattern d) salamander shape appealing to children. The raw printed shapes were allowed to set for 20 minutes followed by 20-30 minutes of cooking at 100°C with steam. We found it was best to cook in a covered dish to prevent water touching the printed form. The forms were printed with a 1.5 mm nozzle cartridge. Straining was required prior to printing.

Table 2.5.1. *Langostine dish recipe (adapted from ready to print base formula).*

Ingredient	Amount (g)
starch, corn	20
potato flour	20
salt, table	6.75
egg white, liquid	35
surimi	92
gum, xanthan	3.25
langustine	85
cream	150

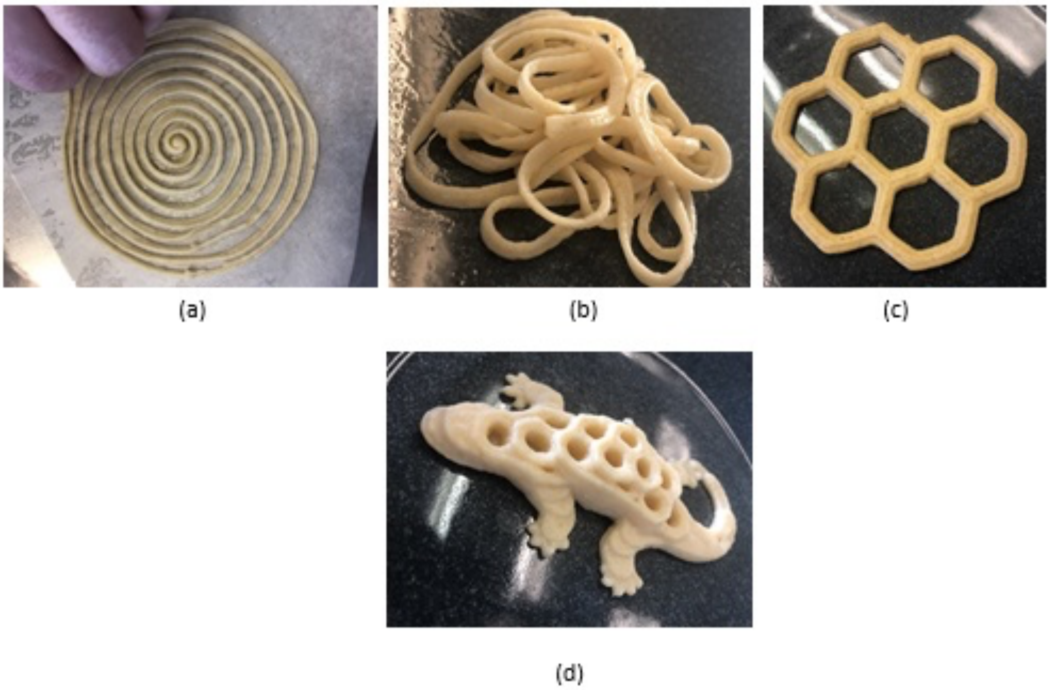


Figure 2.5.1. *a) and b) pasta shape c) beehive pattern d) salamander shape appealing to children.*

Examples of ready to print (RTP) adapted forms and formulation developed include yellow curry, tomato basil and dulse (see recipes in appendix 7.2.5). In figure 2.5.2 the several examples are shown.

Figure 2.5.2. *Dulce adapted ready to print raw formula prior to printing and cooking (left top), mixing of adapted ready to print base formula with curry and other ingredients (bottom left). Left photo: yellow curry (left top), dulse flower (middle top), cod surimi scallop shape (middle bottom), tomato basil cone for soup (right).*

Sieving is required for the tomato basil formula; this is better suited for HORECA and restaurants in which the base ready to print (RTP) product could be delivered in bulk. The base formula could then be adapted, and the formulas developed by chef and Matís applied. The same applies for the other formulas, however, they could have more applications for in home use as you do not always need to sieve. Sieving is important to reduce clogging of the nozzle (1.5 mm). These formulas do not require sieving for 4.0 mm nozzle shapes. Also, it is important to note, that salt can be added after cooking. This would enable for a realistic ready to print recipe, should it be delivered in prefilled cartridges. It is important to note that additional salt to the ready to print base formula may increase chances of gelation with storage and thus affect the printability.

The langustine formula was printed in langostine shape and made to a dish decorated with dill sauce walnuts, cucumbers and apples, butter milk, dill oil and dill as a garnish, and finally toped off with crispy barley and quinoa, video was made showing how to prepare (see figure 2.5.3). Other versions of the langustine dish are show in figure 2.5.5. By using haddock mince or surimi as well as langoustine, you can make a very balanced, appealing, and delicious dish.

Figure 2.5.3. *Langustine formulation printed into langoustie shape. Parameters and designed langoustine shape in collaboration with Matís and NaturalMachines (producer for 3D food printer).*

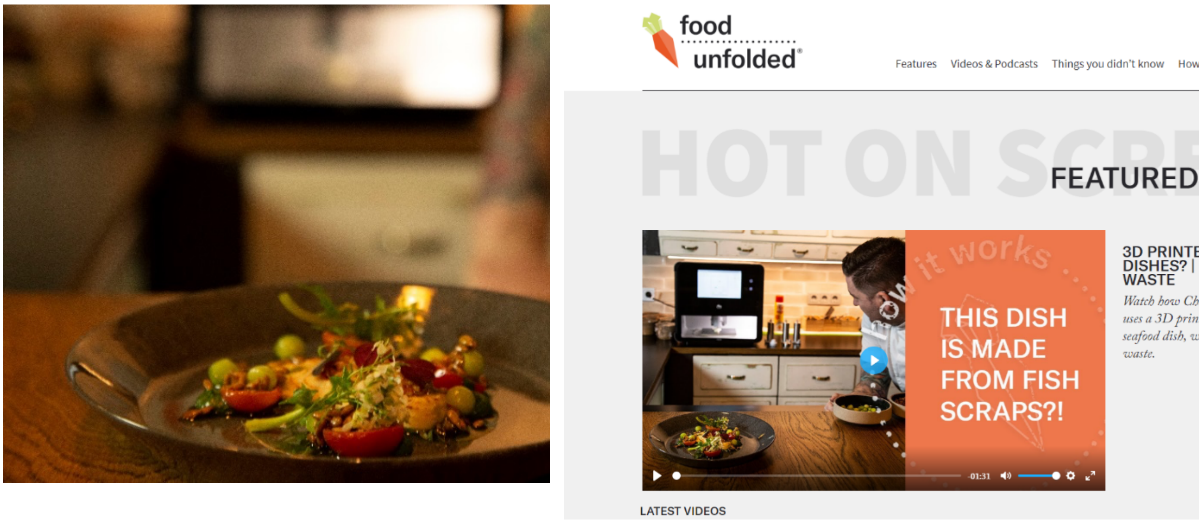


Figure 2.5.4. *Langoustine dish presented in Future kitchen video at the website of Food Unfolded https://www.foodunfolded.com/videos/3d-printed-culinary-dishes-reducing-food-waste*

Figure 2.5.5. *Other versions of the langustine dish.*

3 End user implementation (phase 2)

In Phase 2 of the project the 3D printing technology, formulation and products developed in Phase 1 were implemented with the end users. This phase included consumer testing and showcasing recipe and/or design for introductions of 3D food printing and seafood.

3.1 Consumer testing

In development and optimization for formulas throughout the project, consumer testing was key to understanding the consumer. Consumers in two age groups (years 18-24 and 35-50) were tested regarding perceptions of 3D printed fish via focus group. The aim of the focus groups was threefold. Firstly, to bring forward ideas and attitudes of consumers towards 3D printed food, before and after introduction to 3D printing and 3D printed food. Secondly, to investigate consumers´ attitudes and ideas towards sustainability and sustainable use of fish and other food and thirdly to understand if and then how 3D printing can increase seafood consumption.

Execution

The focus groups were held at Matís, Vínlandsleið 12 in March and April 2018. A random selection from the population was bought from the registration office and recruiting was done by calling people from the list. The aim was to recruit people for each group with even gender ratios and age distribution. The focus group discussions were controlled by a moderator who followed a list of questions and made sure all relevant topics were discussed and that all panellists participated. One trial focus group was carried out with a group of students, to test the question list and setup. Four focus groups were held, two with people 18 to 24 years of age (iGeneration) and two with people 35 to 50 years of age, 15 male and 11 women. In each focus group five to seven people took part. The gender ratios were quite even. Most participants in the younger groups were single, with no children in their care, and all except two were living with their parents. The majority was students, but a few were working. However, most of the students were also working part time jobs. Most participants in the older groups were cohabiting or married, were living independently and had one to four children.

No information was given to the participants on 3D printing in general, 3D printing of food or sustainability prior to the discussions, and fish was not mentioned. The aim was to bring forward unaffected ideas at the beginning of the discussion topics. 3D food printing was then introduced with a power point show where photos of different 3D printed food was shown. Afterwards the group was escorted to an inhouse kitchen where the 3D printer was on display. They were given all general information on the 3D printer, how it works and its limitations. A small star shaped form out of dough from fish and potatoes, was printed out during the introduction. Discussions were allowed during the introduction. After the introductions, the participants were asked about their opinion on the printer and if they would want to purchase one. Then a consumer survey on a 3D printed fish cake was carried out. Each participant evaluated one warm fish cake and a photo of traditional boiled cod with potatoes and butter (Figure 3.1.1). They were told that the ingredients on the photo and in the cake were the same and in similar ratios. First, the appearance of the dish was evaluated on a 9-point scale (figure 3.1.2 (left)). The 3D printed dish was then tasted, and participants evaluated liking (figure 3.1.2 (right)). The participants evaluated the traditional dish from a photo and were asked how much they would like or dislike this dish, given that the ingredients were fresh, and the dish was cooked according to their taste. After the consumer survey the experience was discussed, and the 3D printed dish compared to the traditional dish. The participants were then asked about their fish consumption and questions on ideas and views on sustainability asked. After discussion on sustainability, the definition on sustainability was explained and participants were asked their view on using the 3D printer for underutilised materials. At the end of the discussions, participants were asked to write down at least three ideas on dishes or products with raw materials from fish where 3D printing is used in some way. They were instructed to think of a target group for the product and reasons for use. They were also asked to rate their three best ideas from one to three. After the discussion was finished, participants were thanked for their contribution and handed gift certificates.

Figure 3.1.1. *Dishes used in survey for participants during focus group discussions. The 3D printed fish (haddock/ cod and potatoes with butter printed as twisted star) was tasted by participants, but the traditional dish was evaluated from a photo.*

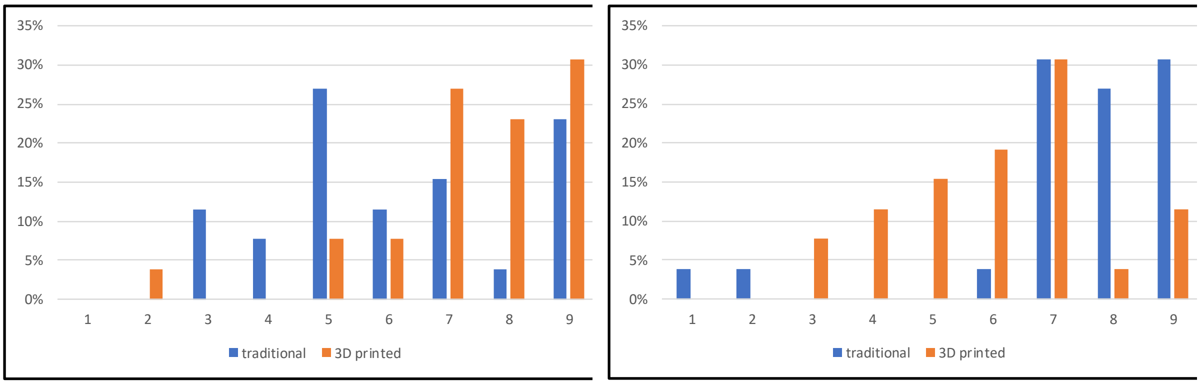


Figure 3.1.2. *Results from consumer survey. Questions: How much do you dislike or like the appearance of the dish? (left). How much do you dislike or like the dish? (right). X-axis: scores, 1=dislike very much, 5 =neither like nor dislike, 9=like very much. Y-axis: frequency of scores. Total number of participants = 26.*

Main results

The consumer group in general had experience of cooking but the level of experience and interest in cooking varied from no interest to a professional level and a passion for cooking. Most participants had, or tried to have, regular meals, especially dinner but eating habits varied. All participants ate fish, but the consumption varied much, from eating fish very rarely up to three times a week or more.

Attitudes towards the 3D food printer:

- Most saw the current version on the 3D food printer as a prototype version, and that a lot more development needed to be done to make it practical for home use. Most participants would like to own a 3D food printer if it were very cheap or free, but they saw a limited use for it at the moment.

- The key features that are needed, are cooking and cooling of the materials, but other faults in the current version are that it takes a long time to print and that very little can be printed at a time. Another feature needed, mentioned in the younger groups, was to be able to control the printer with a smartphone, so that you can have the meal ready at a certain time, e.g. when home from school or work. Most of the participants thought it was too much work to prepare the ingredients. Some said that they would probably not use it, and that it would end up in storage.
- Many agreed that with more development of the printer, especially when it will cook and cool, it could become the microwave of the future. Not much difference was seen between age groups.

Several ideas were set forward for potential use of the 3D food printer throughout the focus group discussion:

- Most participants saw the best use for the printer in making ornate shapes and decorations, e.g. for bakeries, canteens and restaurants, but then the 3D printer would have to be much more efficient. For home use it was mostly seen as a fun equipment to make cake decorations, fun and funny shapes, and to show off for friends or parents in law.
- Elderly people were mentioned but some had the concern that older people can be conservative and not open to new types of food. Children were however often mentioned by the group as potential users of the 3D printed food, printing healthy food like fish, in fun shapes e.g. dinosaurs, to encourage children to eat.
- Use for printing food according to individual needs was seen in hospitals. Specialised food for people that suffer from allergy, people with Parkinson´s disease and other that do not have strength in their hands to cook, was also mentioned.
- Another option for the printer was for people who eat alone, such as people working nightshifts, or instead of vending machines where no canteen food is available.

Different views were detected on using fish as an ingredient for the 3D food printer:

- Many connected the printer more with decorative use, like for chocolate and desserts, and did not see the use for fish as an ingredient since the fish loses its texture when mixed and it would be better to eat the fish as it is. It also seemed to be an important feature for use of fish, that the printer cooks.
- Results on survey on attitudes on the 3D printed dish compared to the traditional dish, indicate that people who generally like boiled haddock disliked the 3D printed dish and vice versa. This seems to be mostly due to the difference in textures. The younger group was generally more positive towards the 3D printed dish than the older groups, but different views were seen within both age groups. In one of the older groups, ideas relating to the image of eating and cooking came forward.
- They can be interpreted so that the 3D printer removes the physical connection with the ingredients and therefore cuts out the experience of cooking. In one of the older groups it was stated that the 3D printer was marketed for food enthusiasts but had only functional value for people not interested in food.

The concept of sustainability was not very clear to participants in this study although many had ideas in the right direction.

- Before discussing sustainable use of food, ideas came forward in the older groups, on using the printer for cheaper fish, or underutilised materials and leftovers. It was by many, in both age groups, considered a waste to use food which is good as it is, as printing ingredients.

- All participants agreed that it would be a good idea to use cut-offs and fish proteins from underutilized materials as ingredients for the 3D food printer. In one of the younger groups (1A) it was stated that this would be interesting for their age group due to its presumed environmental awareness. It was however important that this would not be marketed as "leftovers" or second-class materials since that would be negative. The younger age group did not have much preference on cut-offs or protein, if the product was of a good quality. It was also stated that it was important that the fish protein would not have fish flavour. For the older groups, cut-offs seem to be preferred since that is the original raw material.
- It was important for all groups that this material would be sold in ready-made cartridges, but some were concerned about the environmental impact of using plastic cartridges. It was as well discussed if the material in the cartridges would be of reduced quality.
- Some thought the 3D printing would not be much different from making fish cakes by hand, but many said that it was important that the meal looks good and for that the 3D printer would be useful.
- Other underutilized materials were mentioned as potential ingredients for 3D printing, such as other proteins and insects.

Number of product ideas came from participants after introduction to the 3D printed fish and sustainable use of fish.

- Different types of fish cakes in different shapes and with different types of flavourings and food colours came forward. Fish meals targeted for children were very often mentioned e.g. dinosaur shaped fish cakes, to increase children´s fish consumption.
- Another popular idea was printing for individual needs such as protein bars for athletes, food with the correct ingredients and nutritional value for patients or people with eating disorders, and shapes which make eating easier for elderly or disabled people.
- Decorative use was also popular, to create beautiful, fun, or surprising shapes and pictures. Some mentioned that this was the real advantage of the 3D printer, to create something complicated which is difficult or time consuming to do by hand. Decorative dishes such as sushi or salmon pate which reveals a pattern or picture when cut was mentioned. Fish snacks or chips were also mentioned a few times, e.g. out of dried fish, shaped like puffins, Iceland or Hallgrímskirkja (church) and targeted for tourists.
- Ideas on edible cutleries and plates were seen, e.g. edible lobster shells.

The presentation provoked not only discussion around 3D food printing, but seafood and seafood sustainability. Consumers may not be ready for it right now, but with advancements (ability to cook, catridges, etc.) there will be improved acceptability of 3D food printing. For the future of seafood sustainability and 3D food printing, it will be important to educate and engage.

From the focus group findings key factors for future acceptability of 3D printed seafood are thus awareness and outreach, convenience, and the option to buy ready to print cartridges.

3.2 Showcase recipe and/or design for introductions of 3D food printing and seafood

Several recipes and designs were developed to showcase the potential of using 3D food printing for seafood dishes to future end users.

Avocado and Salmon galaxy appetizer (see also chapter 2.4.3). This is a formulation that can be applied to different fish species and allows the HORECAs as well as at home consumers to be able to utilize the whole fillet of the fish, including the trimmings. This is also a very appealing dish that can be shown and served in educational settings and workshops. This is a fun and colourful dish that allows the user to print on top of a tortilla or piece of bread. The showcase recipe was successfully disseminated through Instagram (figure 3.2.1).

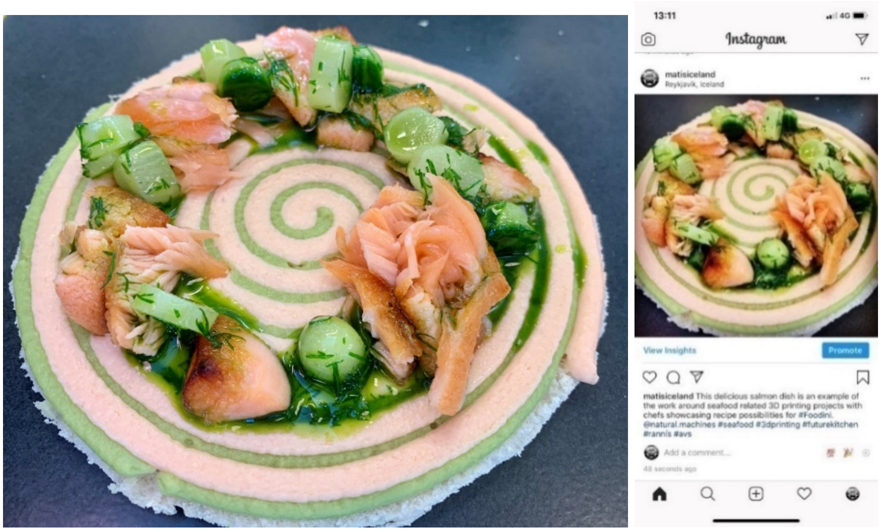


Figure 3.2.1. *Showcase recipe, Salmon & Avocado Galaxy Cold appetizer posted on Instagram.*

The recipe for the Avocado and Salmon galaxy appetiser is available on Foodini World, app with online recipes for Foodini 3D printer from Natural Machines (see figure 3.2.2).

Figure 3.2.2. *Recipe of the Salmon and Avocado Galaxy Cold Appetizer featured in Foodini world app with online recipes for the 3D printer Foodini.*

Another shape was developed in partnership with Natural Machine. The design has flexibility regarding utilization of seafood and other ingredients and is in the shape of a "fish in water" (see figure 3.2.3).

Figure 3.2.3. *„Fish in water" shape printed in Foodini 3D printer. Three capsules are needed, fish ingredients and other ingredients with different colors can be utilized (left). „Fish in water" shape with dulce showcased (right).*

Four designs/recipes developed in the project are featured in Natural Machine´s dish -gallery (figures 3.2.4-5): Salmon and avocado appetizer, Langoustine dish hexagon, Langoustine dish shrimp, Langoustine dish langoustines, see also on webpage https://www.naturalmachines.com/dish-gallery.

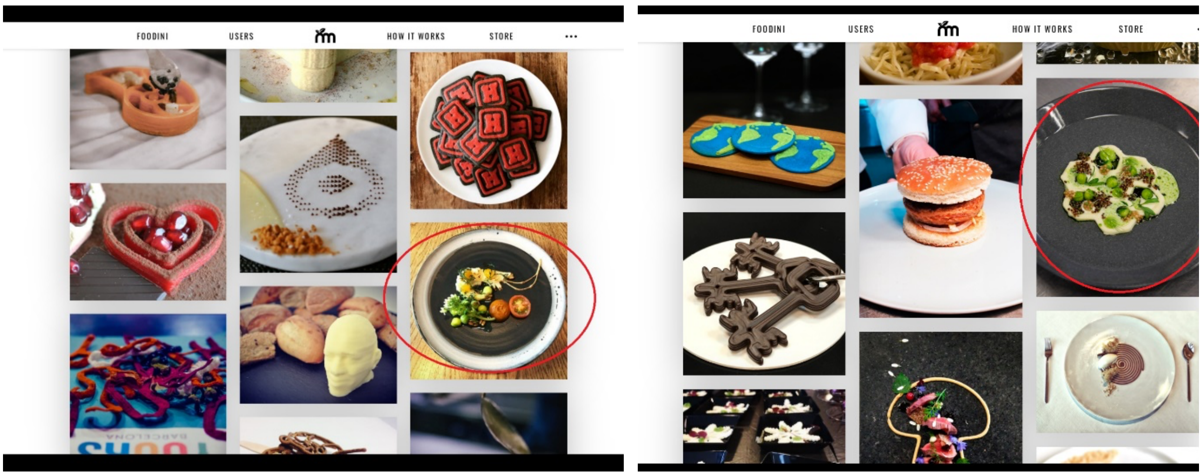


Figure 3.2.4. *Natural Machine´s dish -gallery. Langoustine dish featured, from adapted RTP base formula and printed in shape of a shrimp (left) and hexagon (right).*

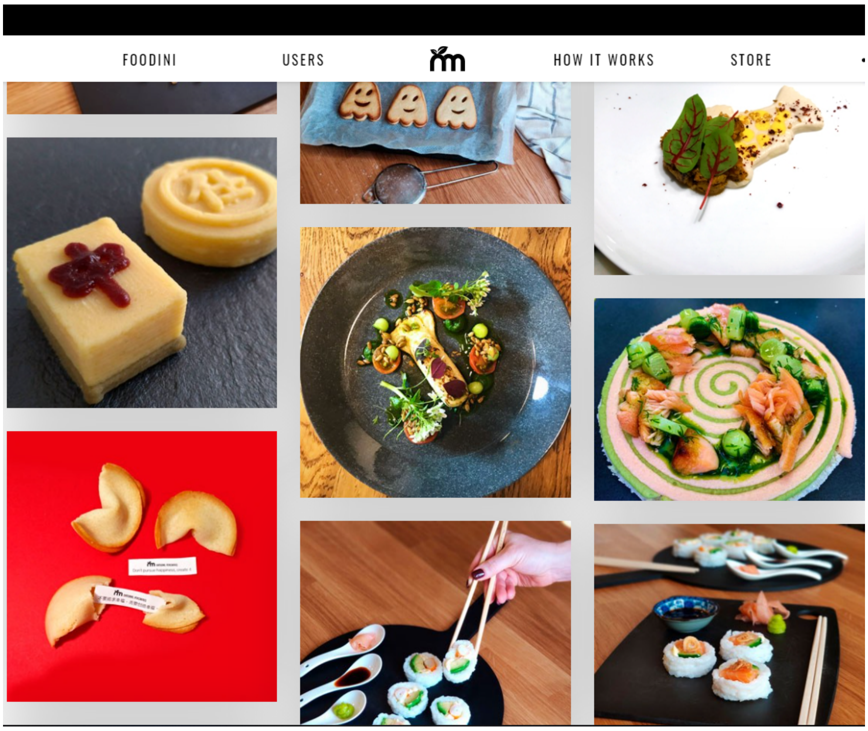


Figure 3.2.5. *Natural Machine´s dish -gallery. Avocado and Salmon galaxy appetizer featured (right) and Langoustine dish from adapted RTP base formula printed in shape of a langustine (middle).*

4 Communication and education tools (phase 3)

In Phase 3 of the project the goal was to develop communication tools for the 3D food printing technology with seafoods and the products developed in the project. This included creating videos, brochure, course, and webinar.

4.1 Videos

3D food printing videos featuring and showing 3D food printing of sustainable sources of seafood in Iceland were created in collaboration with another project coordinated by Matís, Future Kitchen infotainment series, funded by EIT Food. Tækniþróunarsjóður and AVS were given credit in these videos as well. Future Kitchen are series of videos made to engage especially young generations in a conversation about food tech by making them an on-site viewer of how food science, technology and innovation can advance sustainability. The videos are available to watch on www.foodunfolded.com, EIT Food's platform for public outreach and communication. FoodUnfolded® is a global digital platform that creates and shares its content on the latest food and agriculture innovations. Strong and significant interest in the videos relating to the 3D food printing and sustainable sources of seafood were further featured in Iceland and global news from Europe to the USA (i.e. Fiskifrettir, EITFood, Waste360).

Two videos were made. The first one, *3D printed seafood. Look inside*, is a VR video featuring 3D printing based on the research done in this project (figure 4.1.1). The second video, *3D printed culinary dishes? Reducing food waste*, is a 2D video featuring chef Viktor Örn Andrésson making one of the dishes created in the project (figure 4.1.2).

Figure 4.1.1. *VR Video: 3D Printed Seafood. Look Inside (360 Video). Snapshots of the Virtual Reality Video featuring 3D printing from the research done in this project. https://www.foodunfolded.com/videos/3d-printed-seafood-look-inside-360-video*

Figure 4.1.2. *2D Video: 3D Printed Culinary Dishes? Reducing Food Waste. Showcase Dish featured..* *https://www.foodunfolded.com/videos/3d-printed-culinary-dishes-reducing-food-waste*

4.2 Brochure on Future fish

Natural Machines and Matís cooperated in creating a brochure: Foodini in lowering food waste. The aim of the brochure is to tell about the project and showcase how 3D printing can be used to make appeling seafood dishes can be made from underutilized sources of seafood. The brochure is available on Natural Machines webpage: *https://static.naturalmachines.com/images/Foodini-Brochure-Helping-Promote-Seafood-Sustainability-And-Lowering-Food-Waste.pdf*

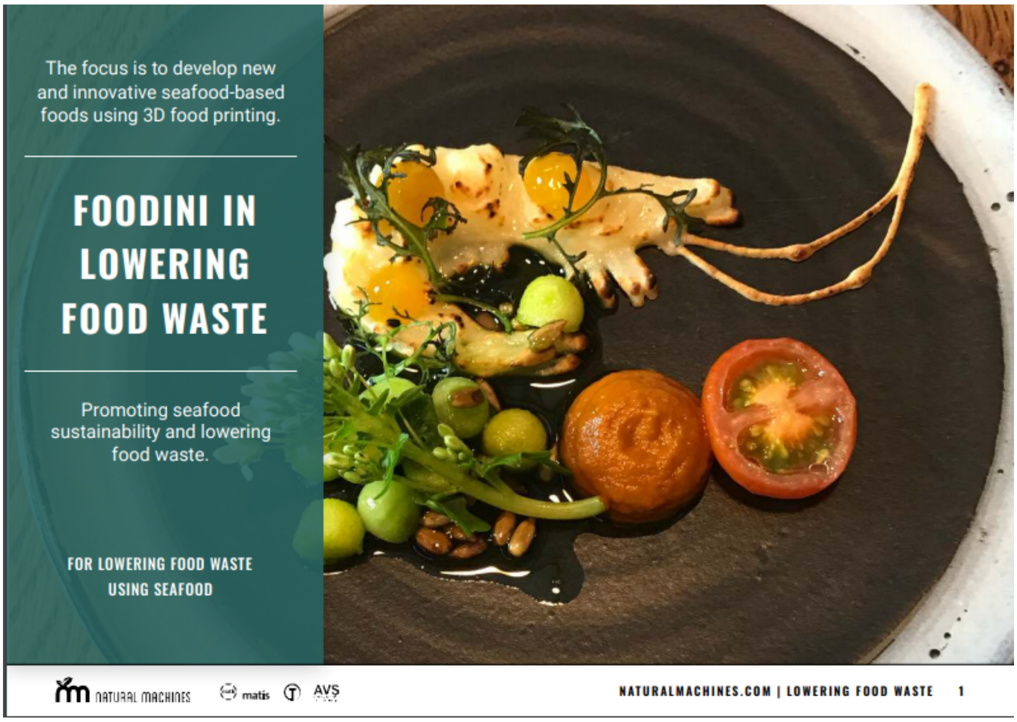


Figure 4.2.1. *Foodini in lowering food waste. Brochure front page.*

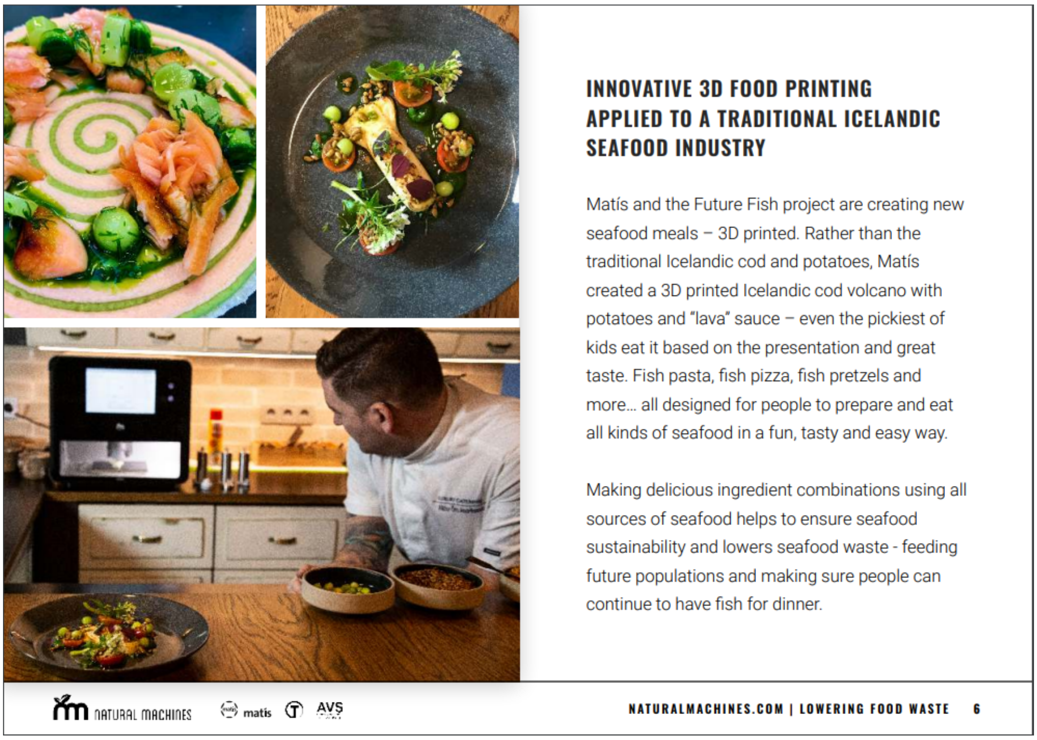


Figure 4.2.2*. Foodini in lowering food waste brochure. Examples given on how 3D printing can be used to make great looking seafood dishes.*

4.3 Future Fish Course

Course/ education material was created to to expose future consumers to 3D food printing of seafood and educate people in the use of 3D printing relating to seafood in general and with the utilization of underutilized seafood sources. The course was based on the learnings, data and expertise gained through the project including working with chefs. The course was held two times in which the education material was implemented, on February 5th 2020 and February 26th 2020, for students in Food Science at the University of Iceland. The course took place at Matís. 18 students participated in the two courses.

Figure 4.3.1*. Students waching 3D printing in action.*

The Future fish course was a ≈3 hour presentation designed to give participants an idea of how technological advances, such as new 3D printing, can be used to increase sustainability in seafood consumption, along with other uses. Participants got to know how entertaining using virtual reality can be, and how it is used to reach consumers to increase their awareness and interest in innovation and technological advancements related to food and food consumption. The course was divided into four parts:

1. A slide presentation to sustainable seafood and 3D food printing. The participants received an introduction to how seafood consumption can be made more sustainable by using a 3D food printer. The transition of seafood cuts and trimmings into a form that is usable for the 3D food printer was presented. The origin and function of the 3D food printer was also discussed, as well as other possible and current uses for it. Informal discussions following the presentation.

2. Participants watched virtual reality infotainment videos in VR goggles on food origin, innovation, technological advances and sustainability in food production and consumption. The videos are available to watch on www.foodunfolded.com, EIT Food's platform for public outreach and communication.

3. A short survey regarding the experience of watching the VR videos was presented to the participants, and they asked to answer it (by choice). The survey was a part of the EIT Food Future Kitchen project, gathering information on the effectiveness of using VR infotainment for consumer education and engagement.

4. The Foodini 3D Food Printer in action was presented to the participants with a hands-on experience where participants viewed the printing of real food into 3 dimensional shapes and tried out the printer themselves (by choice). The Foodini 3D Food Printer is designed and developed by Natural Machines, a Spanish company, and one of the cooperative partners of the Future Kitchen EIT Food project.

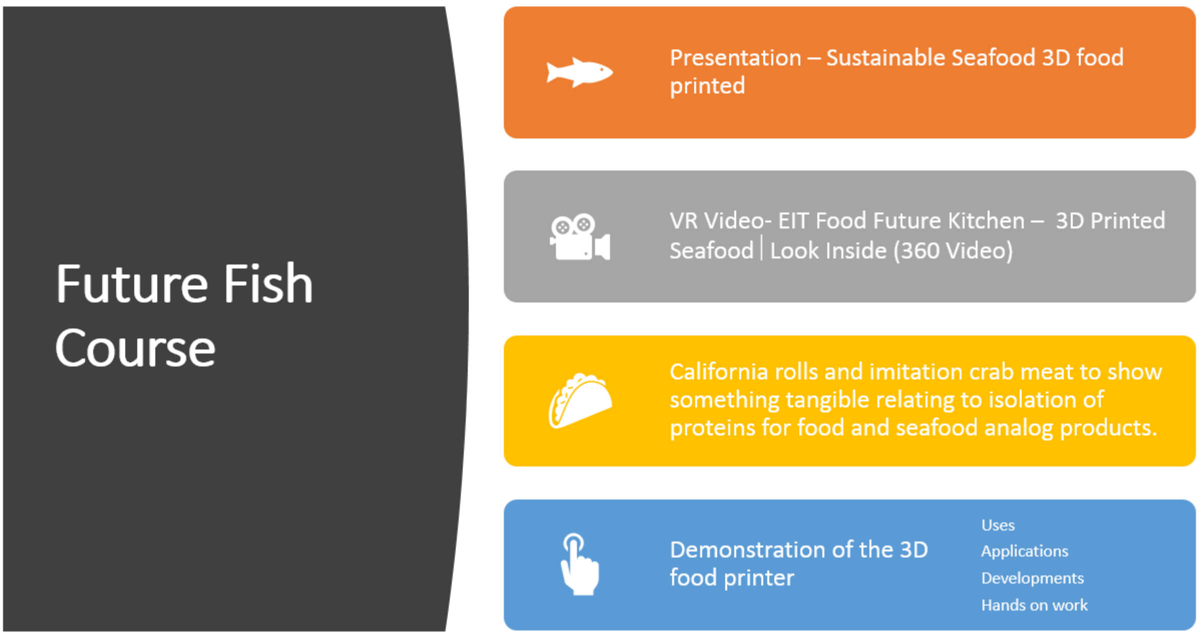


Figure 4.3.2. *Future Fish Course*

Extra reading material included *Printing on Food or Food Printing* (Pallottino, 2016), *From pixels to plate, food has become 3D printing's delicious new frontier* (Digital trends, 2017) and *Foodini in lowering food waste brochure* (see chapter 4.2).

4.4 Webinar

Two other similar courses as the ones listed above, were organized and were supposed to take place on March 25th, 2020, for students at the Agricultural University of Iceland in Hvanneyri. Eight persons had already signed up but because of Covid-19 situations the school closed before we where able to have the courses. After the school had reopend in May, a webinar version of the course was made and a flyer was sent out to everyone currently studying at the university, offering them to sign up to the webinar (if interested) (see figure 4.4.1). Not a single person signed up or asked about the webinar, so it was unfortunately canceled.

Figure 4.4.1. *Flyer advertising webinar on 3D printing and seafood.*

The programme for the webinar was tested on friends and family members before it was supposed to be launched in May. It was a total success, everyone was very interested, and the programme worked well, the webinar is thus ready for launch (see programme in appendix 7.7).

5 Looking Ahead

According to focus group results, key factors for future acceptability of 3D printed seafood among consumers are awareness and outreach, convenience, and the option to buy ready to print cartridges.

From traditional raw materials including haddock, cod, halibut, we have evaluated performance of fish muscle in various formulations with different cooking and printing parameters as well as starting raw material (fresh and frozen). Processing parameters, raw materials, pre-processing, and and utilization of different fish ingredients (pre-frozen, fresh, raw, cooked), and other ingredients all affected the outcomes of the final printed formulation. The utilization and order of ingredients and pre-processing all can make an affect on the formulation.

- When using traditional raw material sources (fresh, frozen, salted fillets made into mince), straining is required, and a larger size nozzle is needed (4 mm or greater). It is therefore suggested that straining should be used as a quality precaution for all formulas. As straining of this kind of material is needed to remove connective tissue, there is opportunity to develop a kitchen strainer for raw fish 3D food printing applications. This is a development outside the scope of the proposal but is a development that can be made later.
- Cod protein hydrolysate and allulose were tested as a subtitute for sugar in the initial raw surimi and also in the final raw surimi paste. Preliminary results indicate that using allulose in the formulation, physicohemical properties (i.e. gel strength and hardness) are close to the commercial cryoprotectant (sorbitol). Using cod protein hydrolysate surimi resulted in softer gel strength and lower hardness. It will therefore be interesting to investigate further on the optimal concentration of the allulose (with or without sorbitol).

Based on information from consumer focus groups the user would like a prefilled cartridge with ready to print seafood formulas that can then be cooked. Results indicate that it is possible to produce ready-to-print (RTP) raw formula products utilizing seperation and washing techniques, using both pH shift protein isolate processing and surimi protein from surimi conventional processing.

- According to our findings, refrigerated storage of raw formula up to approximately 4 days would be reasonable for refrigerated storage prior to printing. Looking ahead, a natural preservative that is allowed in seafood products is something to investigate to exend the shelf life further.
- Surimi pastes could be printed without significant gelling after 6 months at frozen storage but microbial counts were high. This should be further investigated.
- Both a plastic (prototype) cartridge and metal cartridge were used for the storage testing. The plastic cartridge broke with freezing expansion and therefore was not suitable for storage. Different types of cartridges for RTP sould be investigated.
- Test on scale up filling revealed that lubrication for pumping product is needed (i.e. oil added to formula. The RTP formula works well for bulk packaging.

Response to designs and show case recipes developed in the project have been very positive and can in the future be used for further introductions of 3D food printing and seafood to future end users (for example: events, classrooms, conferences). The same applies for the educational material developed aiming to educate people in the use of 3D printing relating to seafood in general and with the utilization of underutilized seafood sources.

The project has demonstrated that there are possibilities for byproduct mince in 3D food printing applications by utilizing seperation and washing techniques and potential for these formulations for industry, the home consumer, and HORECA. This is particularily the case when the 3D food printer can not only print, but cook as well. Such a printer is expected to be on the market in early 2021.

The outcomes of this project can be applied to further research areas such as how new innovative processing and preparation appliances can be adapted to complex raw materials like byproducts from seafoods. The findings from this project can be applied in HORECA environments where appealing and nutritious custom-made 3D printed portions and dishes can be created from low value byproduct seafood raw materials. Furthermore, the results of the project, can be used if applied at an industrial level for mass scale production of ready to print formulas. In addition, the project, has brought about significant educational opportunities for seafood products and the seafood industry in the future. The methods and procedures developed in the project and the learning from the project can be applied to other complex raw materials and new innovative emerging food raw materials (e.g. algae, single cell protein, insects etc) to make consumer friendly products in a format that is appealing to consumers.

3D food printing enables chefs to expand their creativity and have even more control in precision of their food presentations. They provide as well a way for restaurants to reduce their food waste as demonstrated by 2 Michelin-starred Cocina Hermanos Torres in Barcelona in the video *3D printing transforming fine dining* (created within the Future kitchen project mentioned earlier), were the chefs mention the use of i.e. fish cut offs, bones and skins. 3D food printing can also improve the quality of life for Dysphagia patents, as shown in the video *Making soft food more exciting*. These are two examples on possibilities of 3D food printing that would be interesting to explore further within Iceland.

3D food printing is one of the top emerging technologies in the food industry and is part of the fourth industrial revolution. It might be a key appliance in the kitchen of the future and become as common as the microwave in a few years. The report of the Prime minister committee on the fourth revolution, Iceland and the Foruth Industrial revolution (Huginn Freyr Þorsteisson et al., 2019) highlights a need for Iceland to prepare itself for the major upcoming technological disruptions, food being one of the top areas being disrupted. This technology fits well into the greater demand from consumers for convenience, portion control and customization. Analysis shows that the convenience food market will continue to show healthy growth. Implementing the technology of 3D food printing creates a truly significant opportunity for Icelandic seafood products as it can meet these needs and create the next generation of seafood products.

3D fish creations are untapped. Iceland has paved the way and set a precedent for the investigation of printing of seafood raw materials resulting in formulas and prototypes that can lead to consumer customization and ease of preparation, increased consumption of seafood and seafood ingredients, and products with novel textures, detailed shapes not possible before, and of good nutritional value with seafood protein and omega-3 fatty acids, and importantly the reduction in food waste and improved utilization of underutilized byproducts.

Project partners thank Tækniþróunarsjóður and AVS for the funding provided, making the work described in this report possible, and paving the way for future research and discoveries in this area.

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Foodini in lowering food waste (brochure). Natural Machines and Matís brochure. https://static.naturalmachines.com/images/Foodini-Brochure-Helping-Promote-Seafood-Sustainability-And-Lowering-Food-Waste.pdf

7 Appendix

7.1 Surimi processing in the project.

Figure 7.1.1 shows schematic describing convential surimi processing from mince and figure 6.1.2 shows surimi processing with pH shift process used in the project.

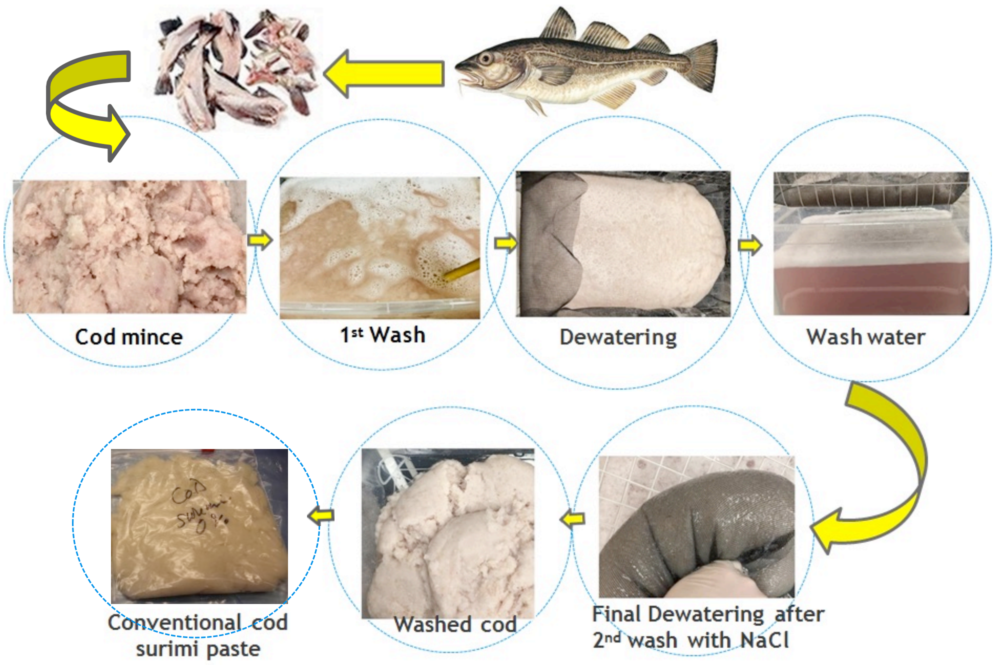

Figure 7.1.1. *Conventional surimi processing from byproduct mince.*

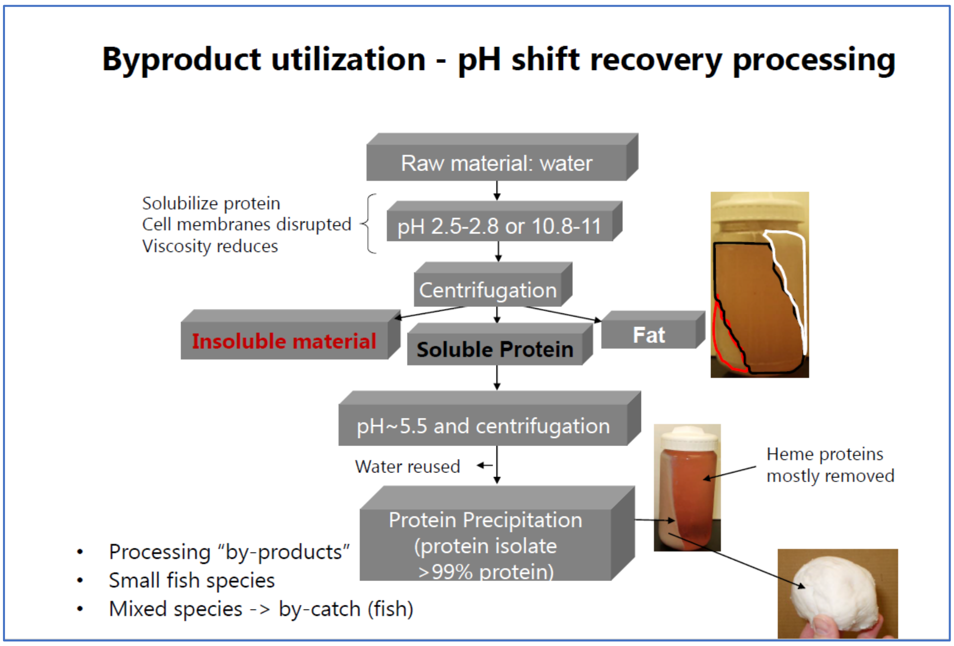

Figure 7.1.2. *pH shift method for processing of protein isolate from byproduct mince.*

7.2 Study on model surimi formulations and affect on 3D food printing.

More details on the study can be found in published UNUFTP report of Romauli Juliana Napitupulu and publication in scientific journal, Magnetic Resonance in Chemistry, see reference and links to the publications below. The results were as well presented in a poster at the Institute of Food Technologist (IFT).

UNITED NATIONS UNIVERSITY
Fisheries Training Programme

unuftp.is   Final Project 2017

INVESTIGATION OF COD SURIMI MADE ACCORDING TO THE pH-SHIFT PROCESS OR CONVENTIONAL WASHING AS CANDIDATE OF FOOD MATERIAL FOR 3D PRINTING

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ABSTRACT

Developing countries generate over 60% of global fish trade and understanding how byproduct utilisation and 3D food printing impact the seafood industry in Indonesia and globally is critical. It is important to be forward-thinking and that starts with the research we are conducting. Byproduct utilisation can occur through surimi processing and in this study, we tested both conventional and pH shift surimi processing. With the implementation of 3D food printing there can be reduction in food waste and utilisation of seafood byproducts. This research is the first of its kind evaluating how printability of surimi paste and cooked gels in star form are affected by different surimi processing methods, source and quality of byproduct starting material, the addition of salt, and cold storage.

Figure 7.2.1. *Napitupulu, R. 2018. Investigation of Cod Surimi made according to the ph-shift process or conventional washing as candidate of food material for 3D printing. United Nations University Fisheries Training Programme, Iceland. Final project.*

https://www.grocentre.is/static/gro/publication/497/document/Romauli_final%20project_2018.pdf

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SPECIAL ISSUE RESEARCH ARTICLE

WILEY

Low field NMR for quality monitoring of 3D printed surimi from cod by-products: Effects of the pH-shift method compared with conventional washing

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Abstract

Implementation of three-dimensional (3D) food printing and novel analytics can reduce food waste and increase utilization of seafood by-products. Low field nuclear magnetic resonance (LF-NMR) and chemometrics were used to investigate the printability and characteristics of surimi pastes from cod by-products as affected by different processing methods (the pH-shift method vs. conventional washing), addition of salt (0, 1.5, and 3%), length of cold storage (0, 4, and 7 days) until 3D printing, and steam cooking. The analysis revealed two to three water populations in the 3D printed samples. Increasing the salt concentration induced myofibrillar swelling in the conventionally prepared surimi, whereas a more salt-induced gelling effect was observed in the pH-shift processed surimi. Cooking had a decreasing effect on the T_{21} relaxation time and its corresponding apparent population (A_{21}), corresponding to protein denaturation and water loss during cooking. Increasing the salt concentration to 3% had a protective effect towards water exchange between the A_{21} and A_{23} populations in the conventionally washed samples but more subtly in the pH-shift samples. Similar

Figure 7.2.2. *Guðjónsdóttir M., Napitupulu R.J., Kristinsson H.T.P, 2019. Low field NMR for quality monitoring of 3D printed surimi from cod byproducts: Effects of the pH-shift method compared to conventional washing. Magnetic Resonance in Chemistry. Volume57, Issue9. Special Issue: Latest Developments and Applications of magnetic resonance in food science. September 2019. Pages 638-648. John Wiley & Sons, Inc.* https://onlinelibrary.wiley.com/doi/abs/10.1002/mrc.4855

Figure 7.2.3. *Novel 3D printed surimi and protein isolate products made from Atlantic cod byproducts. Poster presented at IFT, July 2018.*

7.3 Ready to use 3D printing formulas for cartridges

Finalized Mixing Protocol and printing

Mixing instructions (Stephan, speed 13.5). Make sure Ice is added to the bucket prior.

- 1 Min. to break up particularly thawed surimi (-7°C) Mix with Spatual
- 1 Min. with water added. Mix with spatula
- 1.25 min (add salt + xanthan gum) (-7°C) Mix with spatula
- Mix 3 more min. (-5°C) Mix with spatula
- Mix. 1.5 more minutes. Mix with spatula. Mix in egg and oil.
- 1 min Mix with spatula
- 1.25 min. Mix with spatula. Mix in starch- tapioca and potato flour
- 1.30 min. Mix with spatula check temp (0-2°C)
- 1.30 min. (Temp should be approx.2°C)

Sieve and combine all material together, material should remain below 10°C. Separate into 3 X 3 zip lock bags for day 2 and day 5. Material for day 0 is immediately tested for the protein and surimi testing. Spoonfuls put in capsule for printing.

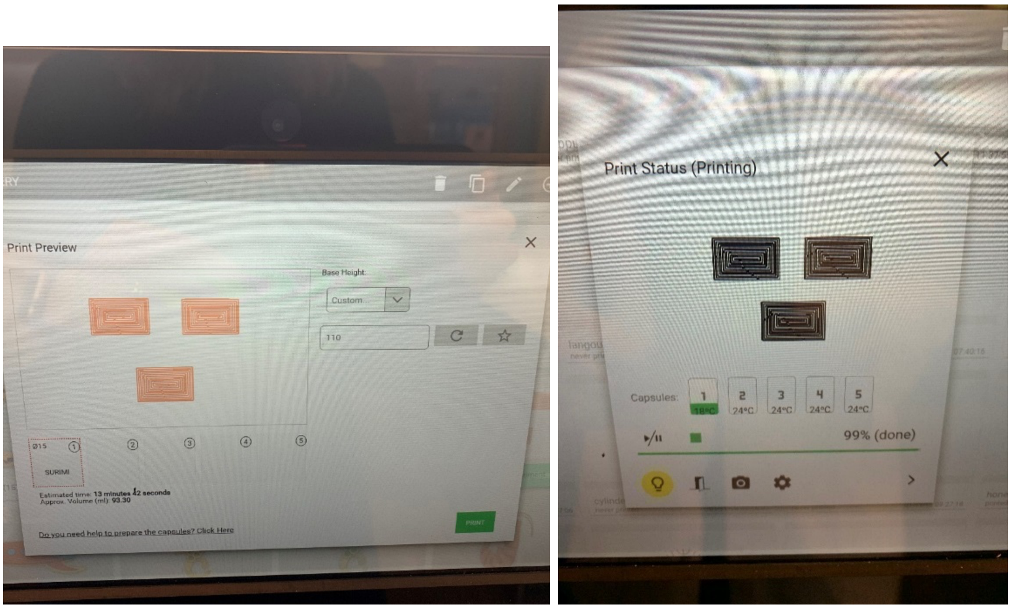


Figure 7.3.1. *Pictures of the screen in 3D food printer Foodini showing print preview.*

Results of analysis of raw material and final product

<u>Microbial sample results (Total colony forming units in 1 g at 30°C (ÖMA3)):</u>

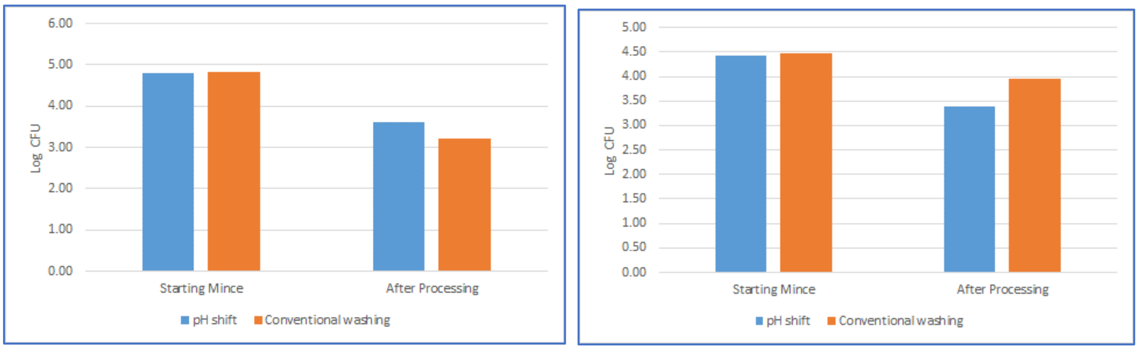


Figure 7.3.2. *Microbial counts of starting mince and after processing for pH shift and surimi. There were significant log reductions with processing, thus leading to higher quality product. (batch 1 (left)) and (batch 2 (right)). Total count in 1 g at 30°C (ÖMA3).*

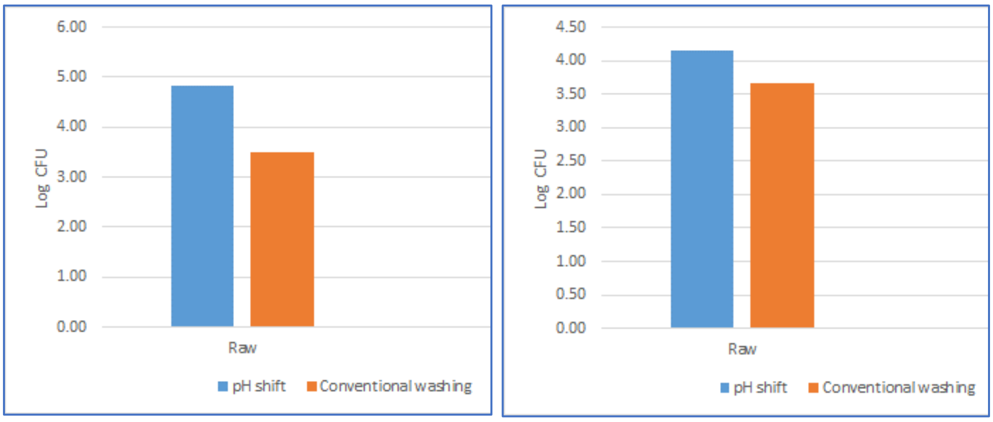


Figure 7.3.3. *Raw surimi was frozen for approximately 6 months before conducting the printing experiments. Microbial counts (CFU) of raw surimi after 6 months frozen storage, prior to making into a surimi paste. Batch 1(left), batch 2 (right). Total count in 1 g at 30°C (ÖMA3).*

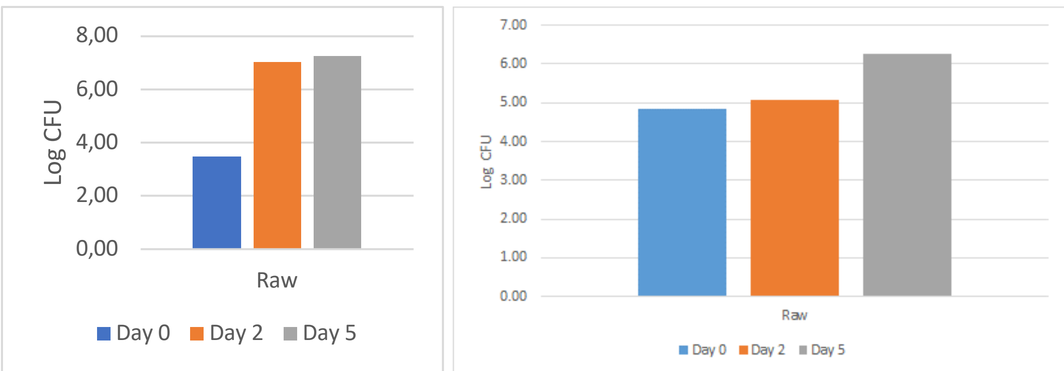


Figure 7.3.4. *Microbial counts (CFU) with cold storage for conventional surimi paste (left) and pH shift surimi paste (right). Total count in 1 g at 30°C (ÖMA3).*

<u>Total volatile base nitrogen (TVBN) results:</u>

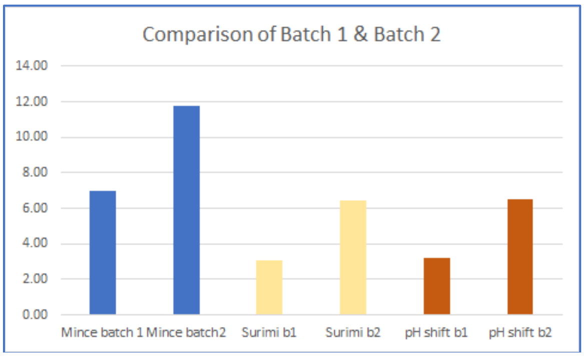


Figure 7.3.5. *TVBN results. Comparison of batch1 and bach2 of mince (blue), coventional surimi (yellow) and pH surimi made from the mince (red).*

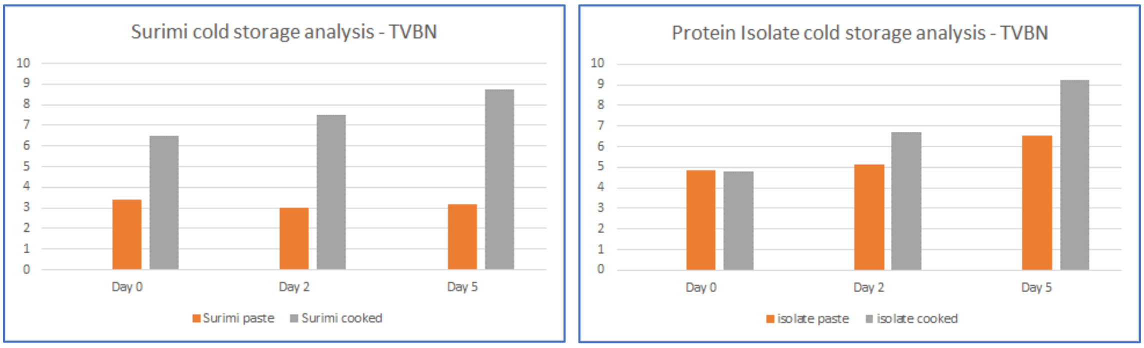


Figure 7.3.6. *Changes in TVBN during cold storage of conventional surimi (left) and pH shift surimi (right). Measurement of raw sample (orange) and cooked (gray) on of printing (D0) and after 2 (D2) and 5 days of storage (D5).*

<u>Water holding capacity results (WHC):</u>

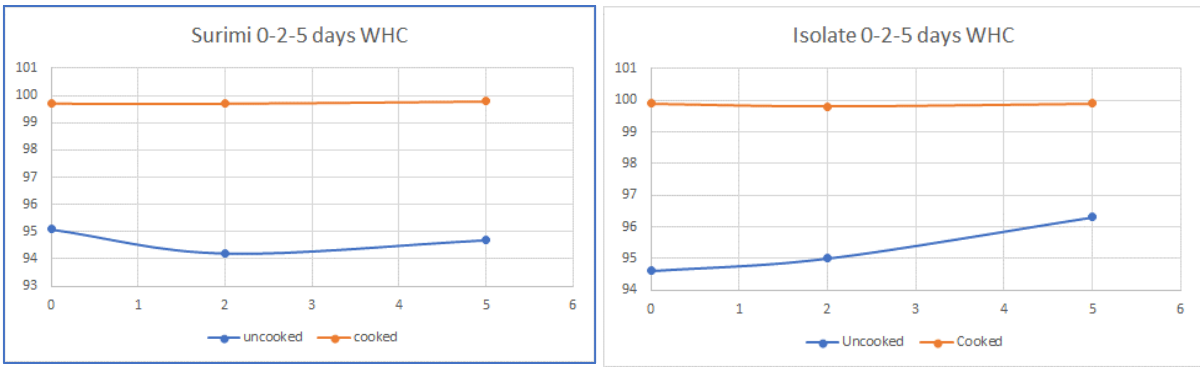


Figure 7.3.7. *Changes in water holding capacity (WHC) durinng cold storage of conventional surimi (left) and pH shift surimi (right). Measurement of raw sample (orange) and cooked (gray) on of printing (D0) and after 2 (D2) and 5 days of storage (D5).*

There was little difference in WHC; however, the pH shift surimi paste after cooking (the cylander shape was tested) seemed to have a slightly better ability to hold water and thus a slightly better gel formation with cooking.

Water content results:

Table 7.3.1. *Changes in water content (%) with cooking of conventional surimi and pH shift surimi paste. Moistures were consistant amongst both batches. These are specific moistures from Batch 2.*

% Water			
	Day 0	**Day 2**	**Day 5**
Conventional Surimi before Cooked	71.62	70.6	70.73
pH shift surimi paste before cooked	71.9	71.51	71.83
Conventional Surimi after Cooked	72.14	71.55	71.55
pH shift surimi paste after cooked	72.41	71.39	71.83

The water content recorded were consistant with the WHC values as there was not significant change in the water content across the treatments and with refrigerated storage. The WHC capacity and ability to hold moisture were good with both formulas. In fact, there may have been slight moisture gain in some instances with the steam cooking.

Table 7.3.2. *Average proximates for pH shift surimi and conventionally made surimi.*

Measuremet	**pH shift surimi**	**conventional surimi**
Moisture % (±5%)	79.9	79.4
Protein % (±3%)	12.1	12.9
Fat %	<0,01	<0,04
Ash % (±2%)	0.7	0.8

Color measurements:

Amongst the treatments, there was not a significant difference with high L values for the final surimi pastes as well as cooked product (figures 6.3.8-9).

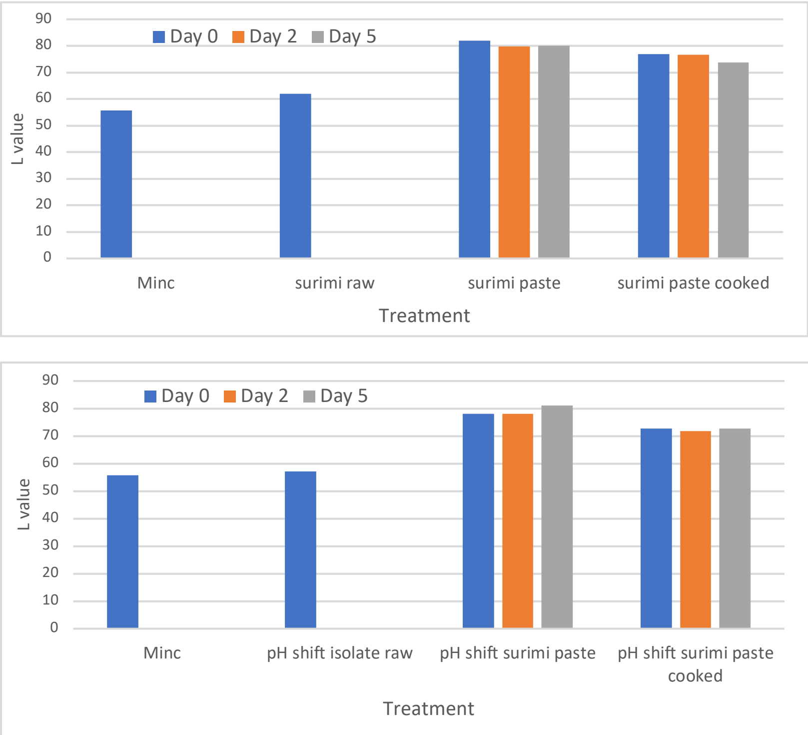


Figure 7.3.8. *Colour measurement (L values (ligtness) of batch 1 of mince and surimi made of it, raw, after printing (surimi paste) and cooking (surimi paste cooked) on day 0 and after 2 and 5 days of cold storage. The picture above shows results for conventional surimi and surimi made with pH shift proccess.*

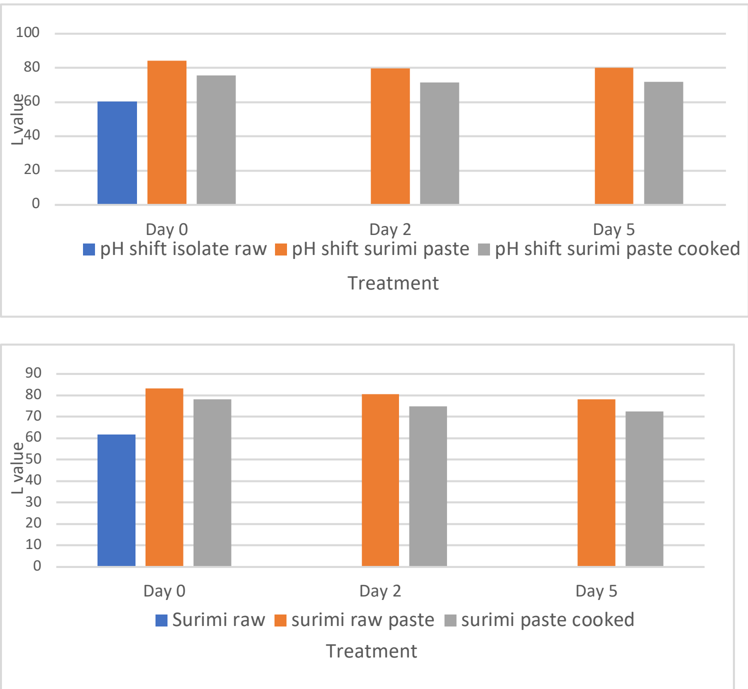


Figure 7.3.9. *Colour measurement (L values (ligtness) of batch 2 of mince and surimi made of it, raw, after printing (surimi paste) and cooking (surimi paste cooked) on day 0 and after 2 and 5 days of cold storage. The picture above shows results for conventional surimi and surimi made with pH shift proccess.*

7.4 Recipes for 3D printing formulations

Cod volcano

Mixture made the night before and then refrigerated mixture for use the next day.

283 g (+/- skin) salted Cod, if not salted, add at least two tablespoons of salt to water. Bring to boil. Add fish and boil for 7-10 minutes until meat begins to flake and break apart. Let product stand for 3-5 minutes in the hot water. Strain the fish from the water using a skimmer, some residual water is okay. Remove any residual skin if possible. The remainder should be later removed through straining.

To mixture, in a small kitchen aid mincer/ blender add: 1 tbsp of butter, 1 tsp of oil (you could try a mild tasting fish oil here....), add salt and pepper to taste. Use moderate speed. Mix the ingredients until the product resembles a well mixed, slightly flakey homogenous texture. Then add yukon (microwaved) potato (better to sieve the product prior to adding). Add creme (1 tablespoon if too dry or needs more moisture). Mix in until smooth, do not overmix. Sieve to ensure that there are not irregular or large pieces of fish, skin, or potato. All of the product should be strained. Place into a bowl and chill overnight.

Further Notes:

- Product should be sieved out by pressing a spoon to the formulation through the sieve with moderate/ heavy pressure. Product should come out looking fluffy, but not runny. If there is some residual moisture in the beginning, this is okay and can be mixed in later.
- The formulation should look like a looser sugar cookie dough as it sets and over night with chilling will become firmer.
- The blender will get hot. If the process is taking some time in larger batches, cool the product as soon as possible after completed with mixing to keep microbially safe.
- Mix the fish/ ingredients in batches as needed, make sure the mixer is only ¾ full.

Product can be tested the following day, but should remain somewhat chilled, including the cartridges, if serving to consumers. This product is served cold. Further stabilization ingredient testing will be needed to maintain shape with cooking (collagen may be good to start as it is marine-centric).

***Table 7.4**. Recipe for cod volcano, with frozen or salted cod (left) and raw cod (right).*

Frozen/ salted cod	**Raw Cod**
560 g of cod loin	92x2 potatos
93 x2 potato	10 g of butter
17 g butter	1.25 tsp salt
1.25 tsps. Butter	Mix, should then be chilled. Then add:
	500 g fish cut into small cubes
Homogenize until smooth with stick blender until it looks like mashed potatoes.	

The volcano ingredients and potato base required straining. All ingredients are precooked, set over night with cold storage and were then printed. If there is challenge in flowability of the product or it is too thick, add oil in step wise amounts until more flowable.

Printing Parameters:

Total of 4 catridges (there was also a smaller print designed that only requires 3 cartridges (2 for fish base and one for the tomato sauce)):

- Cartridge 1: for base (potatoes and spinach powder) (4.0 mm nozzle)
- Cartridges 2+3: with Fish Base (4.0 mm nozzle)
- Cartridge 4: with tomato sauce (0.8 mm nozzle)

Twisted star

Printing Parameters:

- 4 mm nozzle for printing.
- Add butter, creme, and salt to microwaved potatoes (scooped out from skin), then homogenized the meat (minced prior), then homogenize everything together until it looks like mashed potatoes.
- Final cooking instructions: 150 C for 15 minutes and then down to 100 C for another 15 minutes, no steam and no air blowing if possible.

Pasta

Parameters:

- Catridge 1 Fish Paste dough (1.5 mm nozzle)
- Catrtidge 2: Pesto sauce (1.5 mm)

Salmon and avocado galaxy

- Cartridge 1: Avocado crème
- Cartridge 2: Salmon crème

Adjust nozzle to flat bread or tortilla height.

Figure 7.4.1. *Salmon and Avocado Galaxy appetizer. Printing (above) and final product on thick flatbread (left) and thin tortilla (right).*

7.5 Adapted flavour formulas

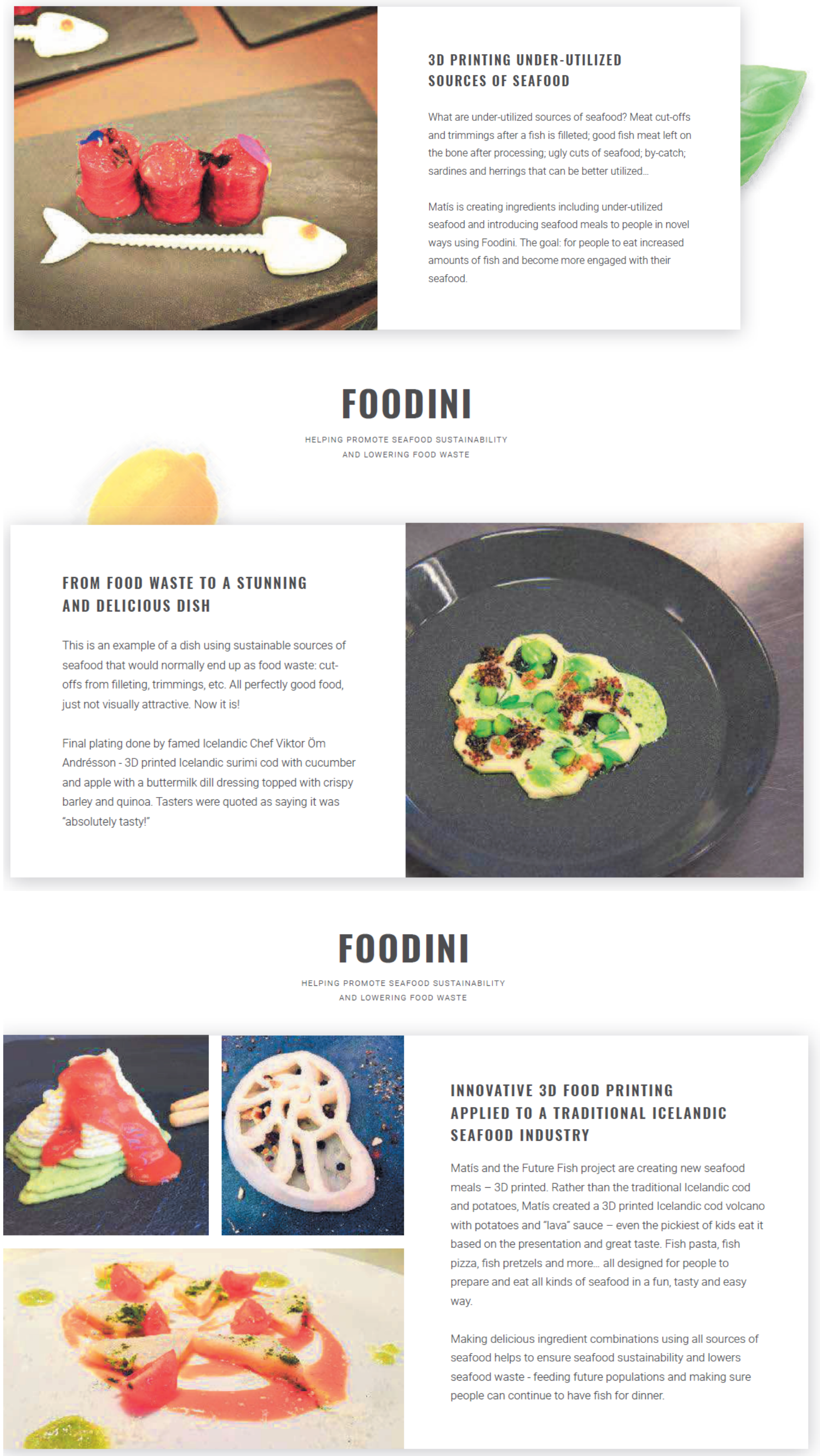
Table 7.5. *Recipes for adapted flavour formulas. Curry, tomato basil and dulse.*

Curry Recipes (adapted from ready to print formula) (g)	Recipe 1	Recipe 2
starch, corn	8	8
potato flour	8	8
salt, table	2.7	2.7
water, municipal tap	21.26	21.26
egg white, liquid	7	7
Surimi	82.37	82.37
oil, fish, cod liver	1.5	1.5
gum, xanthan	1.3	1.3
Curry	5	5
Yellow curry	3	2
Additional salt	2	2

Tomato basil (adapted from ready to print base formula) (g)	Recipe 1	Recipe 2
starch, corn	8	8
potato flour	8	8
salt, table	2.7	2.7
water, municipal tap	21.26	21.26
egg white, liquid	7	7
Surimi	82.37	82.37
oil, fish, cod liver	1.5	1.5
gum, xanthan	1.3	1.3
Paprika	1	1
tomato paste	4.9	4.9
Basil	0.54	0.54
Garlic	0.39	0.39
Onion	1.04	1.04
apple vinegar		2.4
Additional salt		2

Dulse Recipe (adapted from ready to print base formula) (g)	
starch, corn	8
potato flour	8
salt, table	2.7
water, municipal tap	21.26
egg white, liquid	7
Surimi	82.37
oil, fish, cod liver	1.5
gum, xanthan	1.3
Dulse (chopped up finely)	2
Additionally salt (Icelandic salt)	1
Additionally xanthan gum for thickening and flowability	2.7
Coconut (finely chopped)	1

7.6 Brochure: Foodini in lowering food waste



3D PRINTING UNDER-UTILIZED SOURCES OF SEAFOOD

What are under-utilized sources of seafood? Meat cut-offs and trimmings after a fish is filleted; good fish meat left on the bone after processing; ugly cuts of seafood; by-catch; sardines and herrings that can be better utilized…

Matís is creating ingredients including under-utilized seafood and introducing seafood meals to people in novel ways using Foodini. The goal: for people to eat increased amounts of fish and become more engaged with their seafood.

FOODINI

HELPING PROMOTE SEAFOOD SUSTAINABILITY AND LOWERING FOOD WASTE

FROM FOOD WASTE TO A STUNNING AND DELICIOUS DISH

This is an example of a dish using sustainable sources of seafood that would normally end up as food waste: cut-offs from filleting, trimmings, etc. All perfectly good food, just not visually attractive. Now it is!

Final plating done by famed Icelandic Chef Viktor Örn Andrésson - 3D printed Icelandic surimi cod with cucumber and apple with a buttermilk dill dressing topped with crispy barley and quinoa. Tasters were quoted as saying it was "absolutely tasty!"

FOODINI

HELPING PROMOTE SEAFOOD SUSTAINABILITY AND LOWERING FOOD WASTE

INNOVATIVE 3D FOOD PRINTING APPLIED TO A TRADITIONAL ICELANDIC SEAFOOD INDUSTRY

Matís and the Future Fish project are creating new seafood meals – 3D printed. Rather than the traditional Icelandic cod and potatoes, Matís created a 3D printed Icelandic cod volcano with potatoes and "lava" sauce – even the pickiest of kids eat it based on the presentation and great taste. Fish pasta, fish pizza, fish pretzels and more… all designed for people to prepare and eat all kinds of seafood in a fun, tasty and easy way.

Making delicious ingredient combinations using all sources of seafood helps to ensure seafood sustainability and lowers seafood waste - feeding future populations and making sure people can continue to have fish for dinner.

Figure 7.6.1. *Pictures from the brochure Foodini in lowering food waste.*

7.7 Webinar

Description of the webinar set up:

1. Module – 15-20 min

Students are given a brief introduction of the 3D food printer and its future possibilities with increasing utilization and sustainability.

A slide presentation to sustainable seafood and 3D food printing. The participants receive an introduction to how seafood consumption can be made more sustainable by using a 3D food printer. The transition of seafood cuts and trimmings into a form that is usable for the 3D food printer is presented. The origin and function of the 3D food printer is also discussed, as well as other possible and current uses for it. Informal discussions following the presentation. https://padlet.com/evamargret/spurningar

2. Module – 20 min

Students will watch educational 3D video about seafood byproduct printing, food origin, innovation, technological advances and sustainability in food production and consumption. https://padlet.com/evamargret/myndskeid

The videos are made by Matís as a part of an EIT Food supported project called Future Kitchen, in cooperation with other European food innovation and public outreach companies, organizations and Universities. The videos are available to watch on www.foodunfolded.com, EIT Food's platform for public outreach and communication. https://www.youtube.com/watch?v=0_bXX-1NAUM&feature=emb_title

3. Module – 5 min

Students are asked to fill out a short survey about their experience of the webinar experience.

A short survey regarding the experience of watching the VR videos is presented to the participants, and they asked to answer it (by choice). The survey is a part of the EIT Food Future Kitchen project, gathering information on the effectiveness of using VR infotainment for consumer education and engagement.

4. Module – 5-15 min

Discussions, chat and questions. https://padlet.com/evamargret/umraedur

The Extra reading material was the same as in the courses.