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Sensory attributes of seaweed
Effects of fat and cultivation

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Title

Sensory attributes of seaweed – Effects of fat and cultivation

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Abstract

The world's population is increasing drastically and thus, an increase in environmentally friendly and sustainably produced protein sources are needed to feed the entire population. Incorporation of new protein sources, with smaller impact on the environment, in the diet may be a way of solving this problem. Seaweed is a possible future protein source that may be a part of the solution. The objective of this study is to investigate how different fat contents in emulsions, which are commonly occurring in the food industry, affect the sensory attributes of seaweeds. Further, the study will examine how different cultivation conditions designed to enhance the protein content of seaweeds may affect their sensory attributes. The test design consisted of four cultivation conditions and four different fat contents in emulsions that were assessed by a trained sensory panel using Quantitative Descriptive Analysis. Attributes assessed included appearance, odour, texture, taste and flavour. The appearance as well as odour attributes are affected by both cultivation conditions and fat content of the emulsions. Texture attributes are affected by the fat content, but not by cultivation. Tastes and flavours are neither affected by cultivation nor by fat content of the emulsions, indicating that these attributes are dependent on the seaweed itself.

Keywords

Seaweed, *Ulva fenestrata*, Fat, Cultivation conditions, Sensory evaluation

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Titel

Sensoriska attribut hos havssallat – Påverkan av fett och odling

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Sammanfattning

Världens befolkning ökar drastiskt och därför behövs en ökning av miljövänliga och hållbart producerade proteinkällor för att kunna försörja hela befolkningen med näringsriktig mat. Integrering av nya proteinkällor, med mindre påverkan på miljön, i kosten kan vara ett sätt att lösa detta problem. Havssallat är en möjlig framtida proteinkälla som kan vara en del av lösningen. Syftet med denna studie är att undersöka hur olika fetthalter i emulsioner, vilka är vanligt förekommande i livsmedelsindustrin, påverkar havssallatens sensoriska egenskaper. Vidare kommer studien att undersöka hur olika odlingsförhållanden utformade för att öka proteinhalten i havssallat kan påverka dess sensoriska egenskaper. Testdesignen bestod av fyra odlingsförhållanden och fyra olika fetthalter i emulsioner som bedömdes av en tränad sensorisk panel med hjälp av Quantitative Descriptive Analysis. Attribut som bedömdes var bland annat utseende, doft, textur och smak. Såväl utseende som dofter påverkas av både odlingsförhållanden och fetthalt i emulsionerna. Texturegenskaper påverkas av fetthalten, men inte av odling. Smaker påverkas varken av odlingen eller av fetthalten i emulsionerna, vilket tyder på att dessa egenskaper är beroende av själva havssallaten.

Ämnesord

Havssallat, *Ulva fenestrata*, Fett, Odlingsförhållanden, Sensorisk analys

Content

Preface

My interest in food and especially the fascination for the fantastic diversity of flavours and aromas that can be found in a well-prepared meal came early to me. In early years I was determined to work with food, this led me into the restaurant business and work as a chef were tastes and flavours are essential to an appealing meal. When I started my study of Food and Meal Science, the discipline of Sensory evaluation appealed to me and pointed me in a new direction. To study food using the human senses as an instrument is very appealing and I like to explore this field further.

I would like to thank my supervisor Karin Wendin for all the valuable input that has helped me forward in the work with this thesis. I would also like to thank Kristoffer Stedt and Ingrid Undeland for letting me do my thesis within the Chalmers led CirkAlg-project funded by the Swedish Research Council Formas with project ID 2018-01839.

Marcus Johansson
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Introduction

The population of the world is expected to increase to 8.5 billion people by the year 2030 and almost 10 billion people by the year 2050 (United Nations, 2019). The world’s population also becomes older and the part of the population aged 65+ are expected to increase with 78% by the year 2050 compared to 2019 (United Nations, 2019). The need for food is calculated to be twice the amount in 2050 compared to 2000 to feed the world’s population (Aiking, 2014). With a rapid population growth and increase in the number of elderly people that needs to be supported by a smaller proportion of the population the burden of subsistence increases. To solve this increased demand better and more sustainable food provision solutions are needed. Increased urbanisation and incomes of the population also generates a changed consumption behaviour and an increased demand for better and more protein dense diets (Henchion, Hayes, Mullen, Fenelon, & Tiwari, 2017). United Nations (2015) have set as one of the 17 sustainability goals, to end hunger in the world by 2030 and make sufficient, safe and nutritious food available to everyone all the time. The increased demand for food as well as the goal of ending hunger in the world presents a big challenge that needs to be solved. According to Aiking (2014) the only way to meet these increased demands in a sustainable and environmentally friendly way is to decrease the demand for animal protein and shift towards other less resource intense proteins. One problem with the plant-based proteins is that they often lack some amino acids that are essential to the human diet and only consuming one sort of plant-based protein may not be enough (Mattila, et al., 2018). Because of this, a variety of protein sources need to be considered to fulfil the human needs. Some of the emerging proteins that are viable sources for the future are pulses, insects and seaweeds (Henchion, Hayes, Mullen, Fenelon, & Tiwari, 2017). Seaweeds are multicellular macroalgae that may be brown, red or green and grow wild in in the sea all over the world (Monagail, Cornish, Morrison, Araújo, & Critchley, 2017). They are interesting products that may be a part solution both to the increased need for sustainable proteins and a way to reach the agenda 2030 goal “to conserve and sustainably use the oceans” (United Nations, 2015). This study is part of the Chalmers led and FORMAS financed project CirkAlg investigating the potential of seaweed as a future protein source and how to implement it into diets where it is not present today. This study looks into how fat contents of western diets alongside cultivation conditions of the seaweed may affect sensory attributes of the seaweed.

Consumption of seaweed

Seaweed have been a part of human diet in coastal regions worldwide for a very long time. The oldest remains of human consumption of seaweed are about 14000 years old and are from both Chile and Japan (Figueroa, Farfán, & Aguilera, 2021). Findings in Europe suggests that seaweed was a part of the diet at least as early as 5500 years ago even though it only has survived as a part of the diet in very limited regions and often as a food for poorer parts of the society (Mouritsen, Rhatigan, & Pérez-Lloréns, 2018). In Asian countries such as China, Korea and Japan the consumption of seaweed has been and still is a big part of the daily food intake, while in Europe seaweed is mostly used in the form of fertilizers and animal feed (Mouritsen, Rhatigan, & Pérez-Lloréns, 2018). However, in recent years the interest in consuming seaweed has risen in Europe and America mainly by the influence of the Asian kitchen and the popularisation of dishes such as sushi (Rioux, Beaulieu, & Turgeon, 2017). Apart from the Asian gastronomical influences on the western food consumption, the nutritional values of seaweed and the search for more sustainable food has also been a contributing factor for the rising consumption in western societies (Araújo, et al., 2021). Seaweed may be a viable and sustainable protein source for the future since it often contains a high percentage of protein per dry weight (Wells, et al., 2017) and hence is an interesting food source to include in the western diets. Apart from the protein, Nagappan and Vairappan (2014) points at the potential of a high-quality fat composition of monounsaturated and polyunsaturated fatty acids in seaweed, which in turn is known to decrease low density lipoprotein cholesterol and reduce risk of heart disease. To ingest encapsulated seaweed have shown positive effects on blood glucose and insulin levels in adults (Elisdottir, et al., 2021).

Seaweed and eutrophication

Some of the main nutrients needed to cultivate seaweed are phosphorous and nitrogen (Roleda & Hurd, 2019). These nutrients are also a big part of the eutrophication problem seen around the world in coastal regions. In Europe eutrophication is a problem in both the Baltic Sea and in the North Sea alongside many other regions (Ahtiainen & Vanhatalo, 2012). The eutrophication in the coastal near regions of the world are much a result of human activity in said regions (Fei, 2004). Waters from nearby land runs of into rivers and end up around the coastal outlet of the river. With these runoffs, excess nutrients from the surrounding human activity such as agriculture and industrial activities as well as the everyday life of large amounts of humans in the regions creates an ideal environment for eutrophication (Xiao, et al., 2017). These big seepages of nutrients to the sea and the resulting eutrophication problem have since the 1970´s been generating more intense seaweed growth in affected regions resulting in green tides (Smetacek & Zingone, 2013). These green tides mainly consist of *Ulva* spp. which grows fast under the right circumstances and thus creates large amounts of biomass, when it reaches the shores they become a big problem because of the quantities (Smetacek & Zingone, 2013). Although wild growing seaweeds are a problem when large amounts drifts towards the shores, they are beneficial in counteracting eutrophication (Seghetta, Tørring, Bruhn, & Thomsen, 2016). Studies have shown that a controlled cultivation of seaweed in costal near regions have a substantial effect on the reduction of both nitrogen and phosphorus in the water (Fei, 2004; Seghetta, Tørring, Bruhn, & Thomsen, 2016; Xiao, et al., 2017; Zheng, Jin, Zhang, Wang, & Wu, 2019). With an increased availability of nitrogen, the seaweed has the opportunity to produce more amino acids and an increase in protein content is possible (Roleda & Hurd, 2019).

Cultivation of seaweed

Most of the seaweeds sold on the market is farmed and only a smaller amount is harvested from wild growing seaweeds. Between 2005 and 2015 the amount harvested seaweeds in the world more than doubled (FAO, 2018). The large increase in these ten years were almost exclusively done in the farmed amounts of seaweeds, the wild harvest remained stable at 1.1 million tonnes while farmed seaweed represented 29.4 tonnes (FAO, 2018). This increase of farmed seaweeds has almost exclusively been done in East Asia, where China and Indonesia acted as lead producers (García-Poza, et al., 2020). There are two main methods of cultivating seaweeds, “Offshore” and “Onshore” both having advantages and disadvantages (García-Poza, et al., 2020). In the offshore cultivation the advantages are that there are methods that makes the cultivation low cost and fairly easy to perform on a large scale. Disadvantages with the offshore methods is that there is a low control of the environment and negative impacts such as pollutions and storms that may destroy the harvest is impendent (Fernand, et al., 2017). Onshore cultivations disadvantage is mainly the cost of the building and maintaining the facilities needed for cultivation (García-Poza, et al., 2020). Advantages of onshore cultivation is for instance the possibility to fully control and alter the nutrient input to give the seaweeds the desired environment for optimal growth (Hafting, et al., 2015). It has also been shown in studies that it is possible to affect the nutrient contents of the seaweed by altering the cultivation conditions (Peña-Rodríguez, Mawhinney, Ricque-Marie, & Cruz-Suárez, 2011; Olsson, et al., 2020). One way of altering the cultivation conditions is by using wastewaters produced by, for instance, the aquaculture industry. Stedt, Pavia, & Toth (2022) found in their meta-study that the use of such wastewaters for cultivating seaweeds helps reducing excess nutrient outlet from the industries. Further they also found that seaweeds cultivated in wastewaters were affected in a positive way both in growth and content of nitrogen which is used as an approximation for proteins.

Seaweed and western diet

Prager (2016) argues that a way to incorporate more seaweed in the western diet may be to add it into already present western foodstuffs and in that manner gain acceptance for seaweed as a component of everyday food. This addition to foodstuffs in combination with promotion of its nutritional and sustainability benefits would help gaining acceptance for seaweed in the western diet.

To incorporate the seaweed in western cuisine in an acceptable way it is of importance to understand how the sensory aspects of the seaweed are affected by cooking traditions in this part of the world. One important difference between Western and Asian diets is the fat content of the cuisine. Asian cuisine is relatively low in fats while Western cuisine consists of higher fat contents (El-Salhy, Patcharatrakul, & Gonlachanvit, 2021). In the food industry vegetable oil is a common fat source. In the European Union the three most used oil plants are sunflower, palm and rapeseed (European Commission, 2021). According to the European Commission (2021) rapeseed which is the third most common oil plant at the moment will exceed the use of palm oil by 2031 and becoming the second most used oil plant in Europe. To understand how one of the most common fat sources in Western diets affect the sensory attributes of seaweed is of interest to further understand how to use seaweed in the diet. This investigation of how the fat contents of the cuisine affect the sensory aspects of the seaweed is a step in understanding how seaweed may be incorporated in Western diet as a healthy and sustainable alternative to traditional components.

Phenolic compounds are antioxidants that are present in seaweeds as well as other plants and are considered to be beneficial to humans as they help reducing reactive oxygen species (Karakaya, 2004). There are high amounts of phenolic compounds in seaweed, these are aromatic and have a polar structure which makes them water soluble (McGee, 2004; Rioux, Beaulieu, & Turgeon, 2017). These compounds affect both flavour and aroma of the seaweed (Cheynier, 2012). Chung et al. (2016) states that flavour from polar molecules becomes less intense as the fat content of an emulsion decreases. On the other hand, increasing the fat content intensifies the polar molecules flavour. This suggests that the fat content of the emulsions may affect the flavour profile of the seaweed added to them. Further seaweed contains many volatile compounds which are contributing to the aroma of the seaweed (Figueroa, Farfán, & Aguilera, 2021). There are both polar and non-polar volatile compounds (Sachan, Castro, Choudhary, & Feller, 2018). Depending on the polarity of the volatile compounds present in the seaweed, the fat content of the emulsions may affect the perceived aromas in different directions of intensity.

Sensory evaluation

Sensory evaluation is done by analysing products using the human senses. Sensory analysis is defined as: “science involved with the assessment of the organoleptic attributes of a product by the senses” (Swedish Institute for Standards, 2009, p. 4). It is an important tool for food scientists and product developers in the food industry (Lawless & Heymann, 2010). When performing sensory evaluation of a product it is important to specify the purpose of the evaluation. There are many different sensory methods and they are all used to answer different questions. Lawless and Heymann (2010) specifies three main categories of methods that are commonly used: Affective tests, Difference testing and Descriptive analyses. An affective test uses panels of untrained panellists, often consumers, who assess products out of feelings, perceptions and attitudes. These tests can answer the question, how well the products are liked or if one is more liked than the other. Affective tests measure opinions and attitudes towards the tested product. When performing a difference test, an analytical panel picked out for their ability to use their well-developed sensory senses as an instrument is used. The answers given in a difference test is whether the included test-products have any perceivable differences. Descriptive analyses are performed by an analytical panel with the same credentials as for the difference tests. When a descriptive analysis is performed the aim is to characterise and quantify the sensory attributes of a product. One way to create a sensory profile of a product that is well known and extensively used is the Quantitative Descriptive Analysis method (Cadot, Caillé, Samson, Barbeau, & Cheynier, 2010). With this method a panel of assessors, trained and selected according to standards developed by standardisation institutes such as ISO, CEN or ASTM, with good awareness of their sensory skills can generate a sensory vocabulary containing attributes that describe the products (Guld, Sárdy, Gere, & Rácz, 2020). The vocabulary that the assessors generate comprises attributes within the categories of texture, appearance, aroma, taste and flavour. Since the assessors are trained to assess the intensity of the different attributes, and not include their personal opinions about the products, a diagram with average values for each product can be generated to visualise the sensory profile of a product (Guld, Sárdy, Gere, & Rácz, 2020). In most sensory methods statistical evaluations of the results are possible to perform to understand the differences between each of the products in the test design.

Objective

The objective of this study is to investigate how different fat contents in emulsions affect the sensory attributes of seaweeds. Further, the study will examine how different cultivation conditions designed to enhance the protein content of seaweeds may affect their sensory attributes.

Materials and methods

For this study the seaweed *Ulva fenestrata* was used. The seaweed was cultivated under four different conditions. Three of the seaweeds were cultivated in a controlled environment where tanks for cultivation were used at Tjärnö Marine Laboratory (TML, N58.876245, E11.145867). The seaweeds labelled Process Water 1 (PW1) and Process water 2 (PW2) are both cultivated in process waters from the seafood industry. PW1 had a low salt content and PW2 had a higher salt content. The control (C) seaweed was cultivated under the same conditions as PW1 and PW2 using seawater as cultivation medium. The fourth seaweed used in this study, Seafarm, was cultivated in an off-shore seafarm (2 ha á 100 x 200 m) located in the Koster archipelago (Skagerrak), Sweden (N58.859901, E11.068660). After cultivation the seaweeds were harvested, freeze dried and milled into a powder that were mixed into emulsions for sensory evaluation.

A test design (table 1) was created with four cultivation conditions and four fat contents as variables. With this design all the different cultivation conditions were tested with all the different fat contents generating 16 samples that were assessed in the sensory evaluation.

Table 1 Test design with four cultivation conditions and four fat contents

Cultivation conditions	C (Control)	PW1	PW2	Seafarm
Fat content (%)				
0	X	X	X	X
5	X	X	X	X
10	X	X	X	X
15	X	X	X	X

In table 2 the contents and proportion between the different ingredients for the emulsions are presented. Each of the emulsions consisted of a liquid base of water and rapeseed oil (Martin & Servera Sweden AB), the water amount was dependent on the fat content of the emulsion. The total liquid weight for the emulsion was 150 grams. 2.5 grams of seaweed was mixed with 2 grams of soy lecithin (Sosa ingredients, Spain) and added to the liquid in a 500 ml dispersing vessel (Kinematica GS40, Switzerland). The solution was then homogenised at 1100 rpm for four minutes (Kinematica Polytron PT 2500 E homogeniser, Switzerland). During the first minute of homogenisation 1.3 grams of xanthan gum (Guzmán Gastronomia SL, Spain) was added simultaneously to facilitate full dispersion. Four emulsions differing in fat content, 0%, 5%, 10% and 15%, were blended for each of the four different seaweed types, generating a test design with 16 different samples. The samples where coded with three-digit blinding codes that was unique for every individual sample and for every repetition of the sample that occurred in the test design.

Table 2 Ingredients in the emulsions used in the test, total weight of all emulsions liquid base is 150 grams

Emulsion	Water (grams)	Oil (grams)	Seaweed (grams)	Soy lecithin (grams)	Xanthan gum (grams)
0%	150	0	2.5	2	1.3
5%	142.5	7.5	2.5	2	1.3
10%	135	15	2.5	2	1.3
15%	127.5	22.5	2.5	2	1.3

Sensory evaluation

The samples were evaluated using a trained analytical sensory panel at Kristianstad University using Quantitative Descriptive Analysis. Six panellists were invited to participate in the evaluation. The panel work was performed in accordance with ISO 6658:2017 (Swedish Institute for Standards, 2017). The panel generated attributes to be used in the descriptive analysis. This was done by evaluating a selection of the samples from the test design. The samples used for attribute generation were selected to represent the extremes among the samples in order to include all aspects of the test design. First the panellists generated attributes individually. When everyone had an individual sample vocabulary the panel started to discuss the attributes and finally decided upon a common vocabulary including attributes, their definitions and how to evaluate the samples. Along with the development of the vocabulary the panellists were trained to use the line scale and to reach consensus in evaluating the training samples. The line scale was 110 mm and spanned from 0 to 100 and anchored at 10 and 90. The anchor at 10 was marked “a little” and the anchor at 90 was marked “much”.

The Quantitative Descriptive Analysis was performed in a sensory laboratory equipped according to ISO 8589:2010 (Swedish Institute for Standards, 2010) and using EyeQuestion (version 4.11.68, logic8, Netherlands) software for data collection. Evaluation was performed in two two-hour sessions during two consecutive days. Each panellist evaluated all sixteen samples in duplicate. The panellists were served a single sample at a time in a randomised order with individual orders for each panellist to prevent bias from any overlapping effects within the test design.

Data analysis

Statistical analysis of the collected data was performed using IBM SPSS version 27.0. Descriptive statistics were performed calculating the mean values (M) and standard error of mean (SEM) for all the samples and evaluated attributes. SEM was used to investigate the difference between panellists in the assessments and how close to the mean the panellists were in their assessments. Two-way analysis of variance (ANOVA) with samples and assessors as fixed factors followed by a

Tuckey's post hoc test and a significance level of $p<0.05$ was used to analyse the data. Principal components analysis (PCA) was performed using EyeOpenR version 4.11.68 on the collected data to give an overview of the results.

Ethical considerations

The study did not include any of the conditions that need an ethical approval according to the Swedish Research Council (2017). The panellists that performed the sensory evaluation of the seaweed are part of an analytical panel that is employed to perform these kinds of tests. However, the panellists gave their informed consent prior to participation. They were free to leave the test at any point without need to give an explanation.

Results

The results are presented with an initial overview of all the samples using PCA to cluster the samples and to get an indication of how the different attributes affect the outcome. After this initial overview each attribute is reported individually under corresponding subheadings. The attributes are divided into four different groups corresponding to their sensory characteristic, odour, appearance, texture and taste and flavour.

In all figures the samples are colour coded to distinguish between them. Samples with a green colour indicates the control (C), pink colour indicates PW1, blue colour indicates PW2 and orange colour indicates the Seafarm seaweed. Every colour comes in four different shades indicating the fat content of the sample, a lighter shade of the colour indicates a lower fat content, and a darker shade indicates a higher fat content.

Principal Component Analysis

To give an overview of the results a PCA-plot is shown. The PCA is divided into a score plot (Figure 1a), showing were the different samples place in relation to each other, and a loadings plot (Figure 1b), showing which attributes affect the placement in the plot, to ease the interpretation. The two plots figure 1a and figure

1b can only be understood if they are read as placed one over the other creating a Bi-plot.

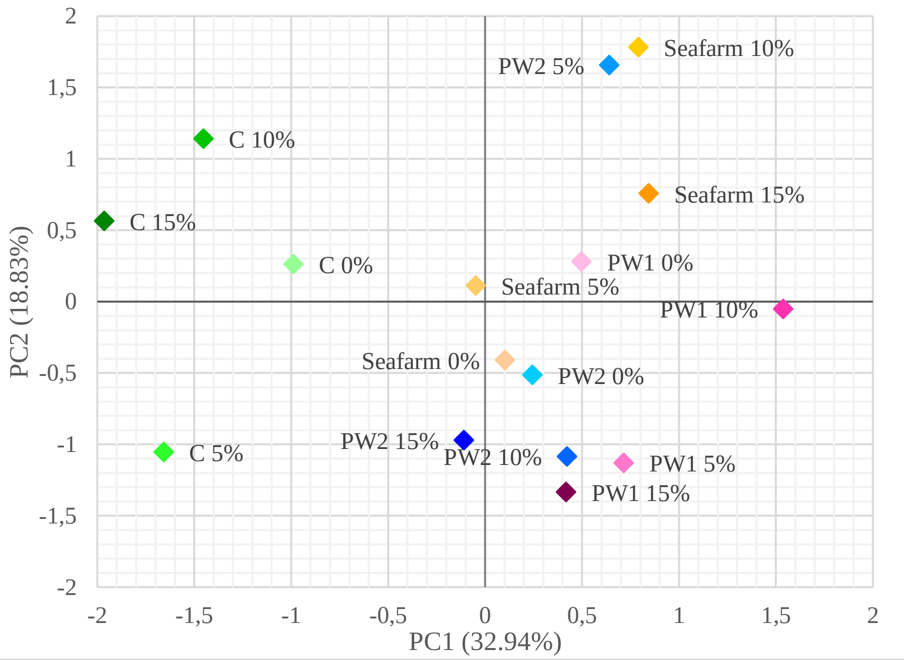

Figure 1a Score plot

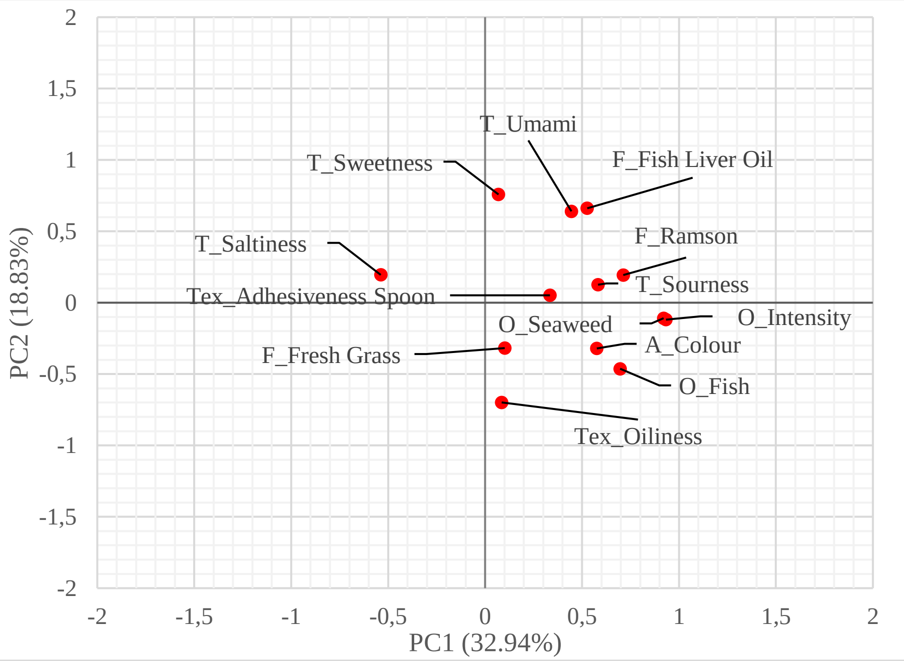

Figure 1b Loadings plot

Figure 1 Principal Component Analysis (PCA) of the sensory evaluation. Biplot divided into Score plot and Loadings plot.

The PCA plot (Figure 1) shows 51.77% of the variance in the data with 32.94% in PC1 and 18.83% in PC2. These two PC's show the two largest independent variances in the data but they only account for about half of the variance in the data indicating that there are more components that are important for the variance. The score plot (Figure 1a) shows that the C-samples cluster together. These samples are characterized by generally receiving lower scores on all the attributes assessed except on the taste of saltiness where they were assessed equal or a bit higher than the other samples. This can be seen in the loadings plot (Figure 1b) where the taste of saltines just as the C-samples can be found in the left part of the plot while the rest of the attributes are found in the right part of the plot as the other samples do in the score plot (Figure 1a). PW2 10%, PW2 15%, PW1 5% and PW1 15% form one cluster in the lower part of the plot. PW2 5% and Seafarm 10% forms a cluster in the upper right part of the plot while the rest of the samples are clustered in the middle right part of the plot. It is also possible to see that all of the samples with zero percent fat are clustered fairly close to origo of the plot and the samples with higher fat content spread out further away from the centre. Seafarm 5% is the exception of this, since it is placed almost at origo, however this position in relation to the other Seafarm samples indicates that with higher fat content the measured attributes differ in a way that moves the sample further to the upper part of the plot. It is possible to see that the addition of fat alters the positioning of all seaweeds in the plot. Different amounts of fat in the emulsions increases or decreases different sensory attributes in all the seaweeds.

Odour

The odour of the seaweed was assessed using three different attributes: intensity, fish and seaweed. The intensity of the odour was assessed by an initial whiff when the container with the emulsion was opened. As seen in figure 2a the results indicate that the intensity of the odour is higher in PW1, PW2 and Seafarm compared to the C seaweed. The seaweed C shows a significant difference to the other seaweeds at both 0%, 10% and 15% added fat. The C seaweed with 5% added fat get a higher score than the rest of the emulsions from the same seaweed and thus show significant differences only to those emulsions with the highest scores in the assessment. The fat content of the emulsions does not show any significant differences to the odour intensity even though there may be an effect on some of the seaweeds. Visible in figure 2a is that the odour intensity declines when adding 15% of fat to the emulsion for all of the seaweeds except Seafarm. The odour of fish (figure 2b) is assessed at approximately the same level in all the different emulsions and no significant differences is found. There is however a tendency that the odour of fish increases with higher fat content in the emulsions as seen especially with the PW1 and PW2 seaweeds. For the attribute odour of seaweed (figure 2c) there are some significant differences especially between the Seafarm and C seaweed with higher fat content. The seaweed Seafarm seems to behave in a different way from the rest of the seaweeds when adding fat to the emulsion. The seaweeds C, PW1 and PW2 tend to decrease in odour of seaweed while Seafarm remains stable or even increase a little in this attribute.

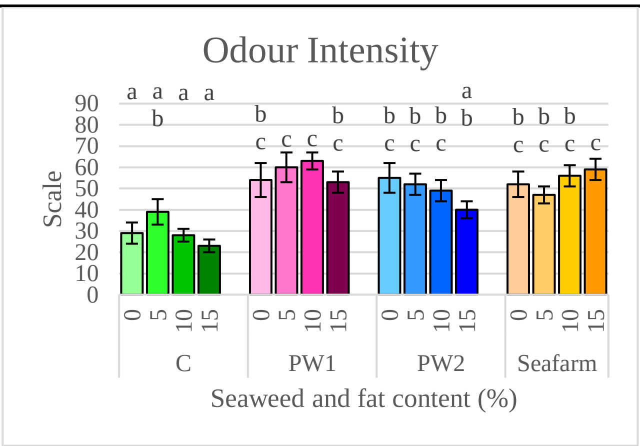

Figure 2a Odour Intensity

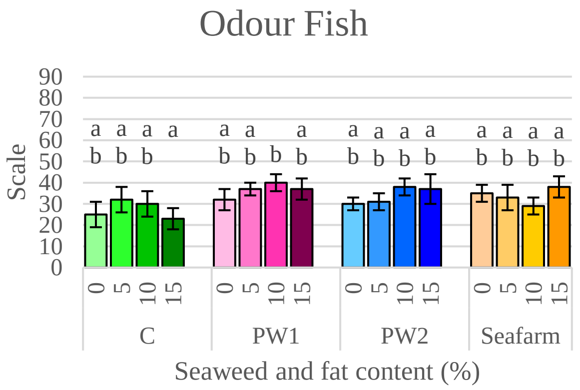

Figure 2b Odour Fish

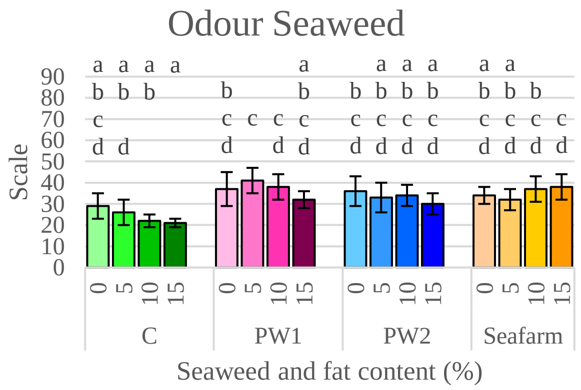

Figure 2c Odour Seaweed

Figure 2 Odour, arranged by attribute seaweed and fat content. Bars show the mean value (M), error stack show the standard error of mean (SEM). The letters over the bars indicate the significance between the samples, the significance levels apply to each attribute individually. If two bars have the same letter there is no significant (ns) difference between them. If two bars have no common letters it indicates a statistically significant difference ($p<0.05$).

In all of the assessed odour attributes the significant differences are between the different cultivation conditions. However, it is possible to see some tendencies to effect from the addition of fat. These effects are different to the different seaweeds but there is a tendency that the scores of the attributes increase with the addition of fat to the Seafarm seaweed. With the rest of the seaweeds the addition of fat tends to lower the scores of the attributes except for the odour of fish were also PW1 and PW2 get higher scores when fat is added to the emulsions.

Appearance

In the assessment of appearance, the panellists assessed the attribute colour. This attribute was assessed on a scale where a low score indicates a green colour with much yellow in it and a high score indicates a green colour with much blue in it. In figure 3 the differences between the samples in colour are visible. It is possible to see that both PW1 and PW2 have more of the blue/green colours while C and Seafarm have more of the yellow/green colour. What is also visible is the effect of added fat to the colour. PW1, PW2 and Seafarm all have significant differences in colour when comparing the 0% fat content to the 15% fat content samples. There also seems to be a difference in effect on the colour by fat depending on how much yellow the 0% sample had. For both C and Seafarm the addition of 5% fat generates approximately the same colour as the addition of 10% or 15% of fat. For PW1 and PW2 which initially has more of the blue and green colour the addition of 5% fat makes the assessed level go down a bit while the addition of 10% and 15% fat lowers the seaweed to the same level. This indicates that the addition of fat in the more blue/green seaweed may have a larger colour influence than on the seaweed with a more yellow/green colour.

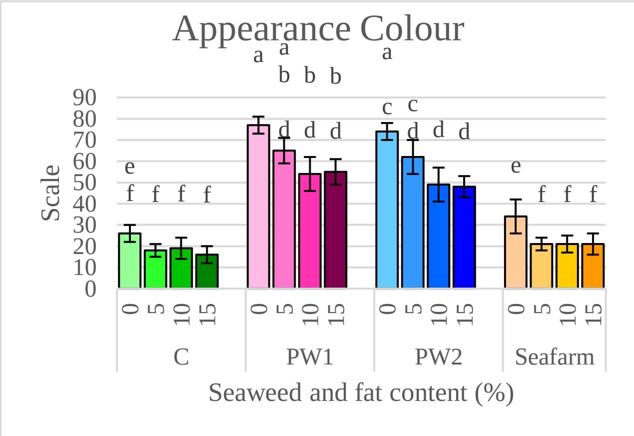

Figure 3 Appearance colour, arranged by seaweed and fat content. Bars show the mean value (M), error stack show the standard error of mean (SEM). The letters over the bars indicate the significance between the samples, if two bars have the same letter there is no significant (ns) difference between them. If two bars have no common letters it indicates a statistically significant difference (p<0.05).

Texture

The texture of the emulsions was assessed both by hand and mouthfeel. The texture in hand was assessed with the attribute adhesiveness to the spoon where a spoonful of the emulsion was tipped over and the remains on the spoon was assessed. As seen in figure 4a the adhesiveness to the spoon was increased by the addition of fat. There are significant differences between the 0% fat content and the 10% and 15% fat content emulsions for three of the four seaweeds, only PW1-samples are with no significant differences. For PW2 and Seafarm the 5% emulsion also significantly differ from the once with 0% fat content. This indicates that the addition of fat to the seaweed affect how adhesive the emulsion becomes. However, there are no significant differences between the addition of the different amounts of fat to the emulsions. To get a more adhesive emulsion 5% fat works in the same way as 15% fat content. The oiliness (figure 4b) was assessed using mouthfeel, the panellists assessed how oily the mouth felt when ingesting the emulsions. As presented in figure 4b the oiliness of the emulsions are all approximately the same level and no significant differences either between the different seaweed types nor the different fat contents of the emulsions where found.

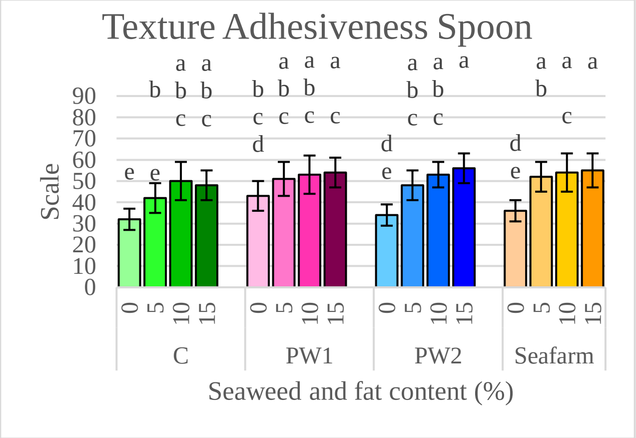

Figure 4a Texture Adhesiveness Spoon

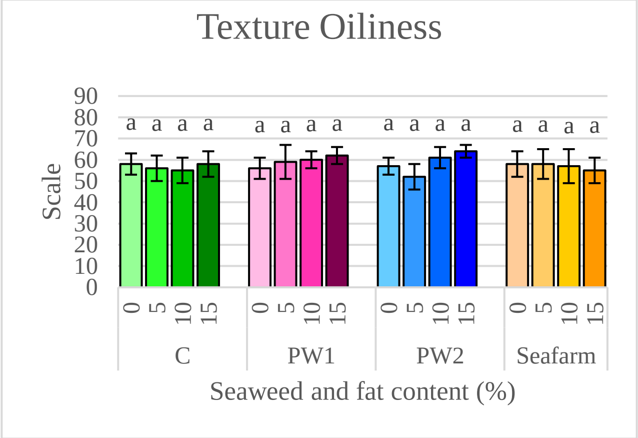

Figure 4b Texture Oiliness

Figure 4 Texture, arranged by attribute seaweed and fat content. Bars show the mean value (M), error stack show the standard error of mean (SEM). The letters over the bars indicate the significance between the samples, the significance levels apply to each attribute individually. If two bars have the same letter there is no significant (ns) difference between them. If two bars have no common letters it indicates a statistically significant difference (p<0.05).

Taste and flavour

When assessing the taste and flavours of the seaweed emulsions four basic tastes; saltiness, sourness, sweetness and umami, were assessed. In addition to these tastes, three different flavours where assessed: fish liver oil, fresh grass and ramson. Among the tastes the only one showing some significant differences between samples is the saltiness (figure 5a). This difference though significant is small and only visible in the PW2 seaweed which is assessed with a bit lower taste of saltiness than the rest of the seaweeds. This may indicate that the PW2 cultivation conditions generates a little lower level of salty taste in the seaweed.

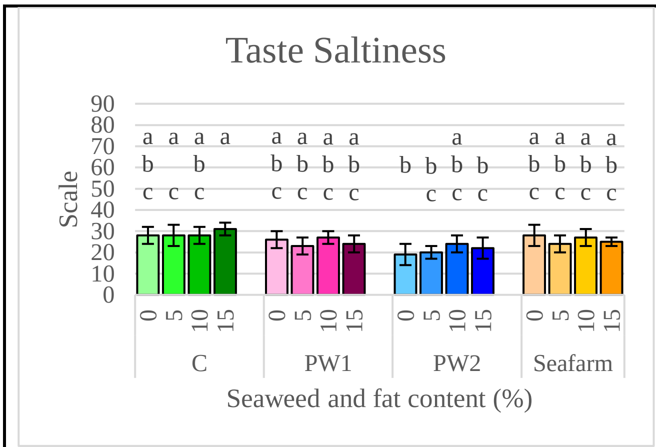

Figure 5a Taste Saltiness

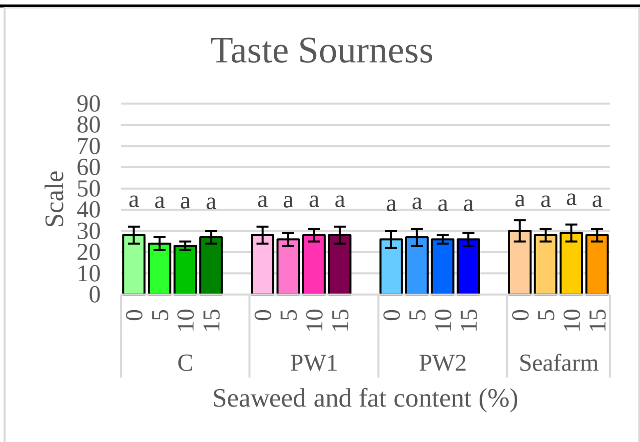

Figure 5b Taste Sourness

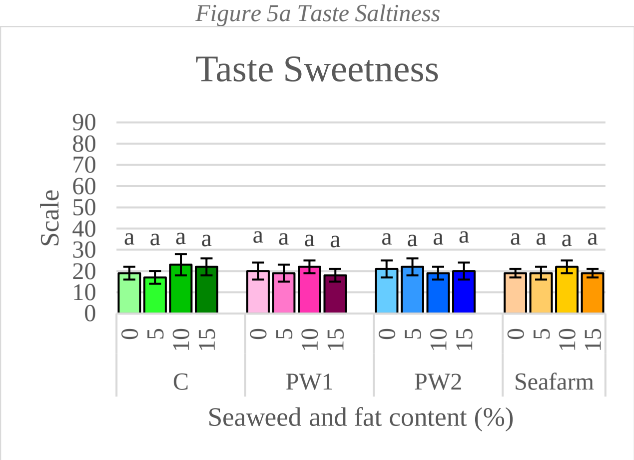

Figure 5c Taste Sweetness

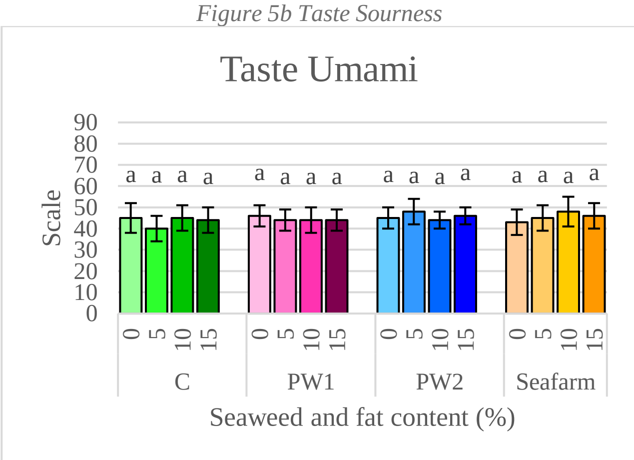

Figure 5d Taste Umami

Figure 5 Taste, arranged by attribute seaweed and fat content. Bars show the mean value (M), error stack show the standard error of mean (SEM). The letters over the bars indicate the significance between the samples, the significance levels apply to each attribute individually. If two bars have the same letter there is no significant (ns) difference between them. If two bars have no common letters it indicates a statistically significant difference ($p<0.05$).

The assessment of the sourness (figure 5b) does not generate any significant differences among the different samples. All seaweeds as well as all amounts of fat content in the emulsions are assessed with the same level of sourness. The level of sourness in the samples is assessed almost equal to the amount of saltiness (figure 5a) in the samples. The sweetness (figure 5c) in the samples is assessed at almost the same levels and no significant differences are found among the different seaweeds. The sweetness is assessed as lower than both the saltiness (figure 5a) and the sourness (figure 5b) of all the different samples. The one basic taste that stands out with higher assessed levels is the taste of umami (figure 5d). There are no significant differences seen between the samples, but the taste of umami stands out as the most intense of the basic tastes in all the seaweed samples.

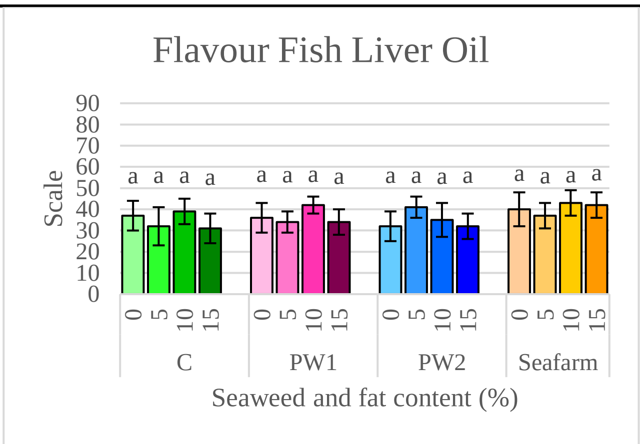

Figure 6a Flavour Fish Liver Oil

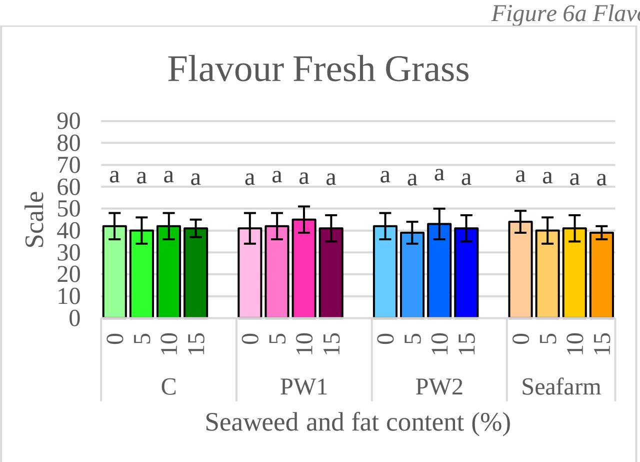

Figure 6b Flavour Fresh Grass

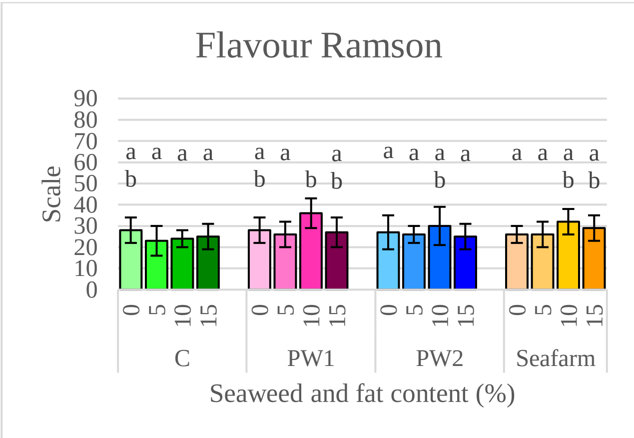

Figure 6c Flavour Ramson

Figure 6 Flavour, arranged by attribute seaweed and fat content. Bars show the mean value (M), error stack show the standard error of mean (SEM). The letters over the bars indicate the significance between the samples, the significance levels apply to each attribute individually. If two bars have the same letter there is no significant (ns) difference between them. If two bars have no common letters it indicates a statistically significant difference (p<0.05).

Among the flavours assessed the flavour of fish liver oil (figure 6a) and the flavour of fresh grass (figure 6b) are the most intense, they are both assessed at a similar level as the taste of umami (figure 5d). Neither the flavour of fish liver oil nor fresh grass show any significant differences between seaweeds or fat content in the emulsions. The flavour of ramson (figure 6c) is present in all of the different seaweeds and is assessed at approximately the same levels regardless of the cultivation method. There is however a tendency among all the different seaweeds except for C that an addition of 10% fat to the emulsion increases the intensity of ramson flavour. The tastes and flavours assessed are mostly without any significant differences between the different cultivation conditions and fat contents of the emulsions.

Discussion

The discussion section of this thesis is divided in to three sections: results discussion, methodological discussion and relevance for the subject food and meal science. Under each heading the discussion will be held in contrast to the objective to the thesis. The results and methods used will be discussed and problematised to deepen the interpretation of the findings in this thesis.

Results discussion

With an initial look at the PCA-plot (figure 1) it is possible to see that there are some differences in the assessments of both the cultivation conditions and the fat contents of the emulsions. One of the more interesting things to notice in figure 1a is that the addition of fat to the emulsions seems to increase the intensities of the attributes that differentiate the cultivation conditions from each other. This suggests that the addition of fat to the seaweeds may be a way to alter the effects of cultivation conditions on the attributes of the seaweeds assessed in this test. The effects of cultivation are seen in the odour attributes (figure 2) and in the appearance attribute of colour (figure 3). The most differentiated odour attribute is that of odour intensity (figure 2a). In this attribute a significant difference is found between the Control seaweed and the rest of the cultivation conditions. The effect on odour by cultivation conditions have previously been studied by Yamamoto et al (2014). Their findings suggest that the place of cultivation have an impact on the aromatic compounds of the seaweed. Considering the different cultivation conditions as different places of growth this may be an explanation to why the odour intensity (figure 2a) was assessed different in this test. The results of the test indicates that more intense volatile compounds are present in the seaweeds cultivated in the two process waters PW1 and PW2 as well as in the Seafarm cultivation while the Control seaweed have less intense volatile compounds. This suggests that the controlled cultivation of seaweed in seawater tanks may have a reducing effect on the volatile compound's intensity. The cultivation of seaweed in tanks of wastewaters (PW1, PW2) seems to result in an odour intensity more in line with seaweeds cultivated in the Seafarm. The Appearance attribute of colour (figure 3) shows a significant difference between the different cultivation conditions as well as by the addition of fat to the emulsions. The two seaweeds cultivated in wastewaters, PW1 and PW2, are both assessed to have a more blue tone to their green colour while the two seaweeds cultivated in seawater, C and Seafarm, have a more yellow tone to their green colour. This difference in colour may be a result of the concentration of nitrogen and phosphorus in the seaweeds as suggested by Yu and Yang (2008). More nitrogen intense cultivation conditions have the impact of producing more compounds consisting of nitrogen tissue in the seaweeds such as chlorophyll and amino acids (Roleda & Hurd, 2019). An increase in chlorophyll due to a more nitrogen intense cultivation environment may be the reason for the darker and more blue/green colour in the PW1 and PW2 seaweeds. The adhesiveness to the spoon (figure 4a) that was assessed as a measurement of the texture in hand does not show any significant differences between the cultivation conditions. The difference in adhesiveness occurs with the addition of fat to the emulsions. With the addition of as much as 10% of fat there are significant differences for three out of the four seaweeds tested. This indicates that only 5% differences in fat content are too little to make significant differences in adhesiveness in this test. The oiliness in mouth (figure 4b) was assessed at approximately the same levels for all cultivation conditions and fat contents in the emulsions. This indicates that the oily feel to the emulsions is not due to the fat content but to some other part of the emulsions. A perceived oiliness in the mouth can be a result of the interaction between the emulsifier and thickener in the emulsion (Wendin & Hall, 2001). Riquelme, Laguna, Tárrega, Robert and Arancibia (2021) has shown that it is the droplet size in the emulsion more than the actual fat content that creates the oily residue in the mouth. Since it is the oily feel in the mouth that is assessed in this test it is likely that the results of this attribute is due to the way that the emulsions were made more than the actual composition of them. With the same procedure used for all of the emulsions it is reasonable to think that the droplet sizes were fairly equal in size in all of the emulsions and thus creating the same residue and oily feel in the mouth. Taste and flavours in the emulsions are affected neither by the cultivation conditions nor the fat content of the emulsions. This indicates that the taste and flavour profile of the seaweed remains stable even if different cultivation conditions are used. The one basic taste that stands out is the taste of umami and that is commonly associated with the quantity of free glutamate content in the seaweeds (Mouritsen, Duelund, Petersen, Hartmann, & Frøst, 2019).

Methodological discussion

To make an initial description and gain an understanding about sensory attributes of a product a descriptive test such as Quantitative Descriptive Analysis is a good starting point. Murray, Delahunty and Baxter (2001) describes that one of the methods strengths is that the panellists make their own individual assessments and that the results are not derived from consensus discussions. This is an advantage since the results are equally affected by all panellists. In consensus methods there is a risk that one or two panellists with high influence over the group have a large influence on the results of the test. In the method used for this study consensus is only a part of the work with generating attributes and defining them. In this part of the work all panellists must agree on what the attributes mean to be able to assess them later on. The use of consensus is thus not the same problem in Quantitative Descriptive Analysis as it is in for example Flavour Profiling or Profile Attribute Analysis where the results are generated by consensus discussions and where the panel leader acts as an active participant (Lawless & Heymann, 2010).The fact that the panel leader takes more of a supporting role letting the panel generate the attributes and the common language around the assessed products is also perceived as beneficial to the study. How much training a sensory panel needs is dependent on their prior knowledge to both the method used and the product that is being assessed. With an adequate and sufficient training, the panel is able to go through a learning process that makes them ready for the assessment (Kreutzmann, Thybo, & Bredie, 2007). The panel used for this study have long term experience with the method of Quantitative Descriptive Analysis and are used to work together in a team. They are used to performing this kind of tests on different kinds of products and adapt to the products quite easy. Even though this was their first time assessing seaweed, their prior knowledge and experience with sensory evaluation work, the training time of two two-hour sessions was considered reasonable. The training together with the number of replicates made in a study is considered equally important to secure the reliability. Stone et al. (2021) states that replicates from each panellist is needed in order to ensure that they are consistent in their assessments. How many replicates that is needed is on the other hand not so clear. Traditionally triplicates are considered as a standard and the average of a triplicate is used as mean value in studies (Singer, Pedroso-de-Lima, Tanaka, & González-López, 2007). Peltier et al. (2018) argues that a duplicate very well may be enough in sensory evaluation since the third replicate only generates a small difference to the results when working with a well-trained panel. For this study, due to the amounts of products that were accessible, duplicate assessments were done to each sample. With more replicates the results may have been a bit improved, but the training and experience of the panel was considered enough to get reliable results even with duplicate assessments. When analysing and interpreting the results of the sensory evaluation it is important to have in mind that the results are no absolute scores of the product but only relative to the products assessed in the same test (Lawless & Heymann, 2010). The results of a sensory evaluation are thus only meant to be interpreted in relation to the other samples assessed by the same panel in the same test. If the same test would be set up with another panel the outcome of the test is depending on that panels references and the results may because of this differ even if everything else is set up identically (Canul, et al., 2011; Murray, Delahunty, & Baxter, 2001). The results of this study are to be considered as a comparison between the individual samples of the study and are not comparable to results of other studies since it is not possible to produce any absolute numbers with a descriptive sensory evaluation.

Relevance for the subject Food and Meal Science and future research

The work with supplying the world with sustainable and nutritious food is crucial to be able to reach the goals of Agenda 2030 (United Nations, 2015). However, food must be more than just sustainable and nutritious. Food must be attractive and appealing to consumers to be accepted and become a part of their diet. This study describes the sensory attributes of a novel protein source in the western diet and thus takes a first step in understanding how seaweed may be implemented as a part of the diet. To understand how novel foods can be introduced to the diet and how they differ from present diets is important to make the products accessible and acceptable to consumers. This study is a first step to describe the sensory attributes and understand how fat affects them in the seaweed. Further studies are needed to fully understand how to implement seaweed as a part of the western diet. To do consumer tests with seaweed products that are recognisable to the consumers is a possible next step towards the implementation of seaweed in the western diet.

Conclusion

The results of this study show that the colour can be affected by both cultivation conditions and fat contents applied to the seaweed. Significant differences found in texture are only dependent of the fat content of the emulsions, no difference between cultivation conditions can be found. Odour is affected by cultivation conditions while fat contents at the tested levels only show tendencies to affect the odour. Cultivation conditions and fat content does not affect the taste and flavour in any significant way.

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