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The Potential of Algae As Food: A Norwegian Survey On The Willingness of Consumers To Try Algae-Made Food

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Abstract

Since the world's population is increasing, alternative food sources must be tapped. Although algae have a high potential to become a part of our diets due to their favorable nutritional properties, there is a little information on the willingness of consumers in Norway to try algae-made foods. In this paper we used a Norwegian survey to address this question. We constructed an order logistic regression model and predicted conditional probabilities to try algae food. The results show that among the most important aspect for willingness to try food with algae is age, health conscientiousness, and environmental attitudes.

Keywords: Seaweeds; Consumers; Willingness to try; food.

Introduction

Algae, both microalgae and seaweeds (or marine macroalgae), play a vital role of the water ecosystems and ecosystem services. For example, they can serve as nutrition for fish and sea animals, mitigate eutrophication, sequester carbon from the atmosphere etc. There is a growing consensus that algae may contribute to the growing demand of food in the world because it is among the most sustainable food we can eat. Many types of algae contain a lot of protein, vitamin D and Omega 3. In addition, the production of algae needs no land and no freshwater.

There are two groups of algae, microalgae and macroalgae. Macroalgae, or seaweed, are mostly used for food. They are classified into three groups according to their color: brown seaweed, red seaweed, and green seaweed. Most of the seaweeds are produced and consumed in Asia, where China is the largest producer with 57 percent of the world production (Cai et al, 2021). In Europe, however, the production of seaweed, which consist of both harvest from wild-stocks and aquaculture, is at a considerably smaller scale. Norway, as the largest producer in Europe has 0.5 percent of the world production of seaweed (Cai et al, 2021).

Although there is a growing interest in the use of seaweeds as food in Europe, one of the main contemporary challenges is to introduce it in the diet. So far, little is known about the consumers' acceptance of algae as a healthy food alternatives, supplements, and ingredients. The aim of this paper was to understand more about the acceptance of alga as food in the Norwegian diet. This was performed by using a Norwegian survey that contains a question about willingness to try algae as food. We used an ordered logistic regression model to find differences in willingness to try algae among different socioeconomic groups, and individuals with different personalities and different attitudes.

The first section of this paper presents algae as food and the different groups of algae, the next section presents the focus variable, willingness to try algae as food. Then we present the covariates. After that we write about the estimation procedure and present the results from the model. Then the model is used to predict differences among the different groups. Finally, the results are discussed, and we conclude.

Algae as food

Both seaweeds and microalgae have long history of being a part of the human dietary worldwide. Recent archaeological findings revealed the use of numerous seaweeds can be dated back to 14,000 years ago (Dillehay et al., 2008). Back then coastal communities on the south-eastern Pacific coast of present-day Chile (near the present city of Puerto Montt) collected and used the brown seaweeds *Durvillaea antarctica* (Southern bull kelp, cochayuyo) and *Macrocystis pyrifera* (Giant or Bladder kelp) as well as the red macroalgae *Porphyra columbina* (luche), *Sarcothalia crispata (luga negra)* , *Mazzaella* sp. and *Gigartina* sp. as food and for medicinal purposes. These and closely related seaweed species still economically important macroalgae and used for human consumption in Chile (Camus et al., 2018; Astorga-España et al., 2017) In many Asian countries, seaweeds have been integrated into the local cuisine for centuries and are characterized by their nutritional properties and *umami* flavors (Pereira, 2016). Nori sheets as product from the two red macroalgae *Porphyra yezoensis* and *Porphyra tenera* are used for sushi and onigiri. Kombu (Japan), dasima (Korea) and haidai (China) refer to edible seaweeds of the family Laminariacea (e.g. *Saccharina japonica*) and is commonly used as food in East Asia, e.g. to prepare "dashi". Wakame (*Undaria pinnatifida*), which has a subtly sweet, but distinctive and strong flavor, is often served in soups and salads. Hijiki (*Sargassum fusiforme*) is consumed in Japan as appetizer and garnish together with rice, vegetables, in soups, salads and sushi.

In Europe, seaweeds also have a long tradition to be used as food, feed, and agricultural fertilizer in coastal areas. Dwellings along the entire Atlantic coastline have traditionally harvested seaweeds for human consumption and as animal feed for centuries. Seaweeds often served as alternatives to missing food and feed sources when agricultural crops were not available during hardships such as famine or simply in winter (Mouritsen et al., 2021). Seaweeds were also collected from European shores to fertilize soil used for agriculture. In coastal England, Scotland, and Ireland, *Palmaria palmata* (dulse), a red seaweed that is rich in protein, iron, and vitamins, is for example eaten raw, toasted, cooked together with porridge, or fried as crisps due to its notably umami flavor deriving from the glutamate content. The red macroalga *Porphyra umbilicalis* and other closely related *Porphyra* and *Pyropia* species are traditionally boiled and minced to make Welsh laverbread as part of a breakfast.

Although traditional seaweed-based cuisines still play an important in some European countries, seaweeds are mainly sourced for industrial purposes today. In Norway, 130,000-180,000 tons of the brown seaweeds *Laminaria hyperborea* and *Ascophyllum nodosum* are annually harvested (FAO, 2021). The harvested biomass is used to extract alginate from the cell walls of the seaweeds' stipes and blades as well as to produce fine powders that is sold as mineral, vitamin and trace element supplements to food and feed. *Saccharina latissima* (Sugar kelp) and *Alaria esculenta* are another alginate-rich kelp species that are commercially produced through aquaculture in Europe, mainly in Norway (Directorate of Fisheries, 2022). Food-grade alginate is provided as a fine powder to the food industry because its water-absorbing properties makes it useful as thickening and gelling agents as well as stabilizer in numerous products such as drinks, ice cream, cosmetics, and jellies (McHugh, 2003). Different types of alginates can be recognized by the codes E400 to E405 on the list of ingredients of a product. Red seaweeds such as *Chondrus crispus* (Irish moss) and the morphologically similar *Mastocarpus stellatus* (false Irish moss) are harvested by hand from rocky coastal shores in Britany and Normandy, France, as well as in western Ireland. These macroalgae are rich in the polysaccharide carrageenan. After the carrageenan-powder (E407) was boiled in water, the resulting gel can be used as emulsifier, stabilizer, gelling and thickening agent in e.g. soups, ice cream, body lotion and toothpaste. The gelling properties of carrageenan also allow the production of biodegradable and edible films as potential alternatives to plastic for food preservation (McHugh, 2003). Traditionally, carrageenan is boiled with milk and sugar or honey, and used as medicine for respiratory diseases. Recent research showed that carrageenan also has antimicrobial, antitumor, antiviral and antioxidant properties. So-called agarophytes are red macroalgae (e.g. *Gelidium corneum* and *Pterocladiella capillacea*) contain the carbohydrate agar in their cell walls. Since agar or agar-agar (E406) only derives from algae, it is a vegan alternative to animal-based gelatin. The thickening properties of agar, which was dissolved as powder in boiled water, is used to produce jellies, puddings, and custards. Due to high content of dietary fiber (80%), agar could have beneficial effects on the microbial gut flora, serving as an intestinal regulator (McHugh, 2003).

Microalgae and cyanobacteria such as *Nostoc* and *Spirulina* (*Arthrospira platensis*, *A. fusiformis* and *A. maxima*) are used as food and food ingredients in Asia (China, Mongolia), South America (by the Aztecs in today's Mexico) and Africa for centuries. For example, harvested and sun-dried *Spirulina* were added to meat and vegetable broths in Chad (Gantar and Svirčev, 2008). In the 1960s and 70s, however, *Spirulina* was regarded as potential food source for the rapidly growing world population because dried *Spirulina* biomass is particularly rich in protein, some B vitamins, iron and manganese (Gantar and Svirčev, 2008). Today, however, *Spirulina* products are mainly sold as food supplements in capsules, tablets and as powder as well as ingredients in the nutraceutical market worldwide. Similarly, multiple biochemical compounds extracted from microalgae are thought to have health benefits. These microalgae are grown in photobioreactors under controlled conditions mainly in Germany, France, Spain, and Portugal. After harvest and drying, the biomass is mainly sold with reference to the biochemical profile. The green microalga *Chlorella vulgaris* is characterized to be rich in proteins, carbohydrates (e.g. starch), pigments (chlorophyll), minerals and vitamins such as B_{12} (Carnovale et al., 2021). Therefore, capsules, extracts, tablets, and powders containing this green microalga are sold as dietary supplements, food additives and colorants. The red-orange colored pigment β-carotene is commercially produced by *Dunaliella salina* grown in salt ponds. Another freshwater green microalga, *Haematococcus pluvialis*, produces the highly antioxidative pigment astaxanthin when it is exposed to unfavorable growth conditions such as bright light, high salinity stress and low nutrient levels. Astaxanthin, which primarily is used as animal feed additive to impart coloration in both agriculture and aquaculture, can be used as safe food supplements with daily intake of 8 mg for adults. The green microalgae *Chlorella sorokiniana*, *Nannochloropsis oceanica* and the diatom *Phaeodactylum tricornutum* are good sources of omega-3 fatty acids such as α-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (García et al., 2017; Niccolai et al., 2019). Although these omega-3 fatty acids are suspected to reduce cardiovascular diseases and have positive effects on the brain development of newborns, humans can only obtain them through their diet because they cannot be synthesized at all or in significant amounts.

Food health and food safety issues

Seaweeds have been also recognized as sources of nutritional and functional food ingredients (Holdt and Kraan, 2011). Therefore, they have been considered as healthy or even superfood being rich in in a great variety of minerals, vitamins, essential amino acids, dietary fibers and bioactive compounds such as polyphenols (Roohinejad et al, 2017; Lomartire et al, 2021). Brown et al (2014) reported that bioactive compounds from seaweeds might be beneficial against cancer, obesity, and gut health. For example, there is emerging evidence that phlorotannins extracted from brown seaweeds have antidiabetic effects. Polyphenols from *Ecklonia* sp., *Sargassum* sp. and *Fucus* sp. were shown to decrease blood glucose levels and improving insulin resistance in animals, supporting promising potential clinical benefits for diabetes treatment (Zhao et al., 2018; Murray et al., 2018). Polyphenol-rich extracts form the seaweed *Lessonia trabeculata* had a positive effect on regulating the microbial gut flora in diabetic rats (Yuan et al., 2019).

Despite seaweeds and microalgae are regarded to as a food source with great potential for the future, it is important to consider the food safety implications of their increased consumption. Numerous factors can affect the presence of hazards in seaweeds such as the species, the physiology, the season they were produced and harvested, the production waters, the methods of harvesting and processing afterwards (FAO and WHO, 2022). High contents of heavy metals (e.g. cadmium, inorganic arsenic, lead and mercury) in the seaweed biomass are toxic to humans. Since recent studies showed that the concentrations of these potentially toxic elements are species-specific and variable between seasons and different locations, seaweed products could require a close monitoring of heavy metals for food-safety (Roleda et al., 2019). Some kelps such as *Saccharina latissima*, which is commercially produced in Norway, usually high levels of the trace element iodine (Roleda et al., 2018). This is an essential nutrient for the functioning of the human thyroid metabolism and the neurological development. While the massive deficiency of dietary iodine results in metabolic problems such as goiter, its excessive intake inhibits the function of these hormones. Due to this relatively small window for an optimal dietary intake, there is a huge uncertainty amongst seaweed farmers producing kelp biomass as food product or ingredients. Therefore, iodine is usually destroyed by through blanching or short boiling of the harvested kelp biomass before it is further processed for long-term storage and packed (Lüning and Mortensen, 2015). On the other hand, iodine is added to certain food products in many developed countries to counteract domestic iodine deficiency. In Norway, iodine is added to the fodder of cows. Hence, milk and other dairy products serve as good iodine sources for the country's population (Aakre et al, 2020).

Data

We use the data from the Norwegian Monitor survey for 2019. This is a representative survey of the Norwegian population and contained 3,681 participants. The participants answered questions about food consumption, health, morality, attitudes about the environment, political questions and other questions related to the society. All the questions were multiple choices, resulting in nominal data. Although the individuals that participated in the survey were 15 years and older, we restricted the data sample to individuals 20 years or older.

The focus variable

Our focus variable for this study was the survey's participants' willingness to try food made with algae. Table 1 shows that 17.3% out of the 3,535 respondents in the survey were "unwilling" to try food made with algae, while 32.9% responded to the question by "may be willing" and 47.1% were "willing" to try food made with algae.

Table 1: Answers to the question in the survey: "Assume that the food is approved by the health authorities and taste as good as other food and is as healthy and nutritious as other food. How willing or unwilling will you be to try the following types of food."

		Unwilling	**May be willing**	**Willing**	**Impossible to answer**	**N**
Food made with algae	n	596	1,130	1,621	92	3,535
	%	17.3	32.9	47.1	2.7	100

The covariates

As covariates, we used socio-demographic variables, variables describing individual's personality, and variables describing attitudes. The age of the individual ranged between 20 and 89 years, where the average age was 47.4 years. As income variable we used gross household income before tax per consumer unit. Household income per consumer unit is defined by OECD (2008) as household income dived by the square root of number of individuals in the household. Centrality is an index variable constructed by Statistics Norway (2020) and it is based on the number of workplaces and services individuals can reach in each of Norway's counties within 90 minutes of commuting. Each municipality is assigned a value between 0 and 1,000, where 1,000 is the highest degree of centrality. This value is assigned to Oslo, the capital of Norway. The lowest value of the index is 295, which is assigned to the island of Utsira in the North Sea, Norway's smallest municipality with a population of 188 in 2022. The average individual in our sample lives in a county with centrality index 832, indicating a small city or a suburb.

Further, Table 2 indicates that 61% in our sample have university education, 50% are female, 64% are married or cohabit, and 24% have children below an age of 15 years living in the same household.

The personality variables are latent variables constructed from the Big Five taxonomy (MacRae and Costa, 2003) with the graded response model (Samejima, 1969). The Norwegian version of the Big Five questionnaire (Engvik and Claussen, 2011) was used. The Big Five taxonomy and the estimation of these variables are explained in Gustavsen and Hegnes (2020).

The attitude variables consist of two latent variables describing attitudes toward the environment, one dummy variable indicating if the individual is vegetarian or vegan, and one dummy variable indicating if health or taste is the most important when choosing which food to consume. The environmental intention variable is constructed based on four questions regarding how engaged individuals are supporting the environment. The environmental behavior variable is constructed based on five questions regarding what individuals do to improve the environment. The last two variables in Table 2 shows that six percent of the individuals in the sample is vegetarians or vegans, and 35% of the individuals think that the health aspect of the food is more important than the taste of the food.

Table 2: The covariates, N=3,267

Socioeconomic variables	**Explanation**	**Mean**	**Standard deviation**
Age	= The age of the individual	47.44	17.74
Income	= Household income per consumer unit (in NOK 1,000)	574.80	300.10
Centrality	= Index (Oslo=1,000)	832.76	127.13
University	=1 if the individual has university education, 0 otherwise	0.61	0.49
Woman	=1 if the individual is a woman, 0 otherwise	0.50	0.50
Married	= 1 if the individual is married or cohabit, 0 otherwise	0.64	0.48
Children	= 1 if there are children below 15 years in the household, 0 otherwise	0.24	0.43
Personality variables			
Extraversion	Index	–0.01	0.89
Agreeableness	Index	–0.02	0.80
Conscientiousness	Index	–0.01	0.79
Emotional stability	Index	0.00	0.88
Openness to experience	Index	–0.01	0.88
Attitudes			
Environmental intention	Index	–0.01	0.86
Environmental behavior	Index	0.00	0.79
Vegetarian	= 1 if the individual is vegetarian or vegan, 0 otherwise	0.06	0.25
Health	=1 if the individual thinks nutritional value is more important than the taste of the food, 0 otherwise	0.35	0.48

The modelling procedure

First, we constructed the latent variables for attitudes and personality with the graded response model using the grm package in the statistical software package *R*. Secondly, all the continuous variables were standardized (to have zero mean and variance equal to 1). Then all variables in Table 2 were inserted into the ordered logistic regression model (Agresti, 2002) and estimated with the package polr in *R*. The parameter estimates using all the variables from Table 2 are called the full model in Table 3.

To find a model with more precision and less variance, we deleted insignificant variables at 10 percent level one by one starting out with the least significant and re-estimating the model. We used the AIC and BIC to compare the models. We stopped the process when AIC and/or BIC did not show improvement in the model. All the personality variables were kept despite some of them were insignificant. The estimated parameters in the two rightmost columns in Table 3 are the results from the reduced model.

The reduced model was then used to predict the probabilities of willingness to try conditional on values of the covariates. First, we predicted the probability of being willing to try food with algae at the 90th quantile of the age (a 71-year old individual) keeping all the other covariates at their mean. Then we predicted the probability of being willing to try food with algae at the 10th quantile of the age (a 23-year-old individual) keeping all the other covariates on their mean. We applied the same procedure for the other sociodemographic variables and attitudes in the reduced model. In order to test for the differences in probability, the model was bootstrapped with 500 iterations and t-tests were performed.

Results

The results from the full ordered logistic regression model and the reduced ordered logistic regression models are shown in Table 3. Except for the sign, the magnitude and the significance, the estimated parameters have no logical meaning. We see that the reduced model is better than the full model in terms of variance and precision, since AIC and BIC are smaller in the reduced model than in the full model. But the sign and the magnitude of the parameters are quite similar.

Table 3: Estimated parameters from the ordered logit models.

	Full model		**Reduced model**	
	Coefficient	**Standard deviation**	**Coefficient**	**Standard deviation**
Socioeconomics				
Age	– 0.40*	0.04	–0.39*	0.04
Income	0.05	0.04		
Centrality	0.14*	0.04	0.15*	0.04
University	0.28*	0.08	0.29*	0.08
Woman	–0.32*	0.08	–0.33*	0.08
Married	– 0.04	0.08		
Children	–0.06	0.09		
Personalities				
Extraversion	–0.01	0.04	0.00	0.04
Agreeableness	– 0.09*	0.04	–0.09*	0.04
Conscientiousness	– 0.18*	0.04	–0.17*	0.04
Emotional stability	0.06	0.04	0.06	0.04
Openness to experience	0.25*	0.04	0.25*	0.04
Attitudes				
Environmental intention	0.51*	0.04	0.51*	0.04
Environmental behavior	0.17*	0.04	0.17*	0.04
Vegetarian	– 0.10	0.16		
Health	0.33*	0.08	0.32*	0.08
Cut points				
Intercept (unwilling, may be willing)	–1.77*	0.09	–1.66	0.08
Intercept (may be willing, willing)	0.07	0.09	0.18	0.07
Information criterium	AIC=5975.27 BIC=6084.67		AIC=5969.69 BIC=6054.77	

Note: The numbers marked with asterisk are significantly different from zero at 5% level.

From the reduced model, we see that higher age affects the probability to try algae food negatively while lower age affects the probability positively. Individuals living in central areas have higher probability than individuals living in more rural areas, *ceteris paribus*. University education affects it positively, while being a woman affects it negatively. Some of the personality traits also have effects on the probability to try algae with Openness to experience having the highest positive effect. Both environmental variables have positive effects, meaning that individuals with more positive attitudes towards the environment have higher probability to try food with algae. Individuals who put more emphasis on health than the taste of food have higher probability to try food with algae than individuals who valuate taste more, *ceteris paribus*. The attitude toward the environment has the largest positive effect on the probability to try food with algae.

Since the estimated parameters are difficult to interpret, we used the estimated model to predict probabilities to try food with algae for different values of sociodemographic covariates and the attitudes, one by one, holding the other covariates fixed at their means. This is shown in Table 4.

Table 4: Willingness to try foods made with algae in upper 90 quantiles and lower 10 quantiles of different covariates.

Tests	High	Low	Difference
Age: High vs Low	0.35* (26.27)	0.62* (40.75)	–0.26* (–11.65)
Centrality: Oslo vs Rural area	0.54* (33.51)	0.44* (27.41)	0.10* (3.78)
Woman vs Man	0.45* (31.45)	0.53* (39.94)	–0.08* (–4.13)
University vs non-university education	0.52* (45.51)	0.45* (28.69)	0.07* (3.97)
Environmental attitude: High vs Low	0.67* (37.78)	0.33* (22.26)	0.33* (12.03)
Environmental practice: High vs Low	0.55* (32.14)	0.43* (24.49)	0.12* (3.98)
Healthy food: Important vs Not important	0.54* (34.54)	0.46* (39.26)	0.08* (4.21)

[a] t-values in parentheses. The numbers marked with asterisks are significantly different from zero at 5% level.

Table 4 shows that an average individual of high age (71 years) has 35% probability of trying food with algae, while an average individual with low age (23 years) has 62% probability. The difference is 26% and significantly different from zero at 5% level. An average individual living in Oslo has 54% probability of trying algae-made food, while the probability of an average individual living in a rural area to do so is reduced to 44%. The largest difference in probability is between individual with high interest in the environment and individuals with low interest in the environment (Table 4).

Discussion and conclusion

Seaweeds and microalgae are potential food sources for humankind in the frame of the rising population worldwide due to their promising nutritional composition and properties. While seaweeds are either harvested from wild-stock in their coastal marine ecosystems or produced through aquaculture on in-, near- and off-shore facilities, microalgae are produced in photobioreactors. In 2019 the global seaweed production was 35.76 million tons of fresh biomass with 97% of seaweeds being cultivated. China, Indonesia, South-Korea, The Philippines, and North-Korea were the top 5 countries produced 98% of all seaweeds worldwide (Cai et al., 2021). These and other Asian countries, predominantly Japan, have a strong tradition of integrating seaweeds into their cuisine and diets, resulting in the great variety food products made of numerous macroalgal species. Kombu, wakame and nori are common food products in East Asia and consumed for example as soup ingredients, salads, sushi wraps, snacks.

In Europe, however, the consumption of seaweeds is very low, although populations along the Atlantic shores traditionally used seaweeds as food. Nevertheless, there is an increasing interest in using macroalgae as food in Europe, including Norway. This can be ascribed to the introduction and growing popularity of Asian cuisine to Western countries. Depending on the preparation methods, numerous seaweeds can be tasty by for example having a distinct *umami* flavor due to high levels of monosodium glutamate (Mouritsen et al., 2012). Recent approaches try to integrate native macroalgae into the New Nordic cuisine, which is supported by numerous research projects to enhance the flavor (Mouritsen et al., 2013). However, there is a general lack in understanding on how far the Norwegian population is willing to try algae-made food.

The model used in the present study predicts that the highest probability (89%) to try food with algae is among young males, living in Oslo, having a university education, are interested in the environment and care about healthy foods. On the opposite side of the probability distribution are elderly females without any university education that live rurally and do not show any interested in the environment or healthy food. For these individuals the probability to try algae-made foods is just 11%.

These results indicates that when food safety issues are resolved, algae producers should target primarily young people in the most densely populated areas to sell their products. Marketers should emphasis the environmental aspect and the healthy aspects of algae. This is in line with Moons et al (2018) who investigated the drivers and barriers for food based on micro algae. They concluded that the major motivational driver of adaption of food based on micro algae was health consciousness and the willingness to compromise on taste.

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