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'Edible seaweeds' as an alternative to animal-based proteins in the UK: Identifying product beliefs and consumer traits as drivers of consumer acceptability for macroalgae

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ABSTRACT

Edible macroalgae (i.e., 'seaweeds') are a nutritious and sustainable alternative to animal-based proteins. However, consumption of seaweeds in Western countries remains low, and little is known about individual drivers of acceptance. The aim of this study was to further explore the consumer acceptability of seaweed-based food products in the UK. In an online study (N = 476), participants were presented with a general description of edible seaweeds, and descriptions of seaweed-based food products (e.g., 'seaweed burger'). Participants were asked to rate beliefs about product attributes, and reported acceptance in terms of liking, willingness to try, willingness to buy, and readiness to adopt as a meat alternative. It was predicted that positive beliefs about seaweed-based products would be significantly associated with greater acceptance, and that seaweed-based products would be more favourable than a general description of seaweeds. Supporting study hypotheses, structural equation modelling showed that positive beliefs about taste/ edibility and familiarity significantly predicted acceptance ($p < .01$). Taste/ edibility was higher for seaweed-based products compared to a general description of seaweeds ($p < .001$), and perceiving foods to be tasty and familiar mediated the negative effect of food neophobia on consumer acceptance ($p < .05$). Other product beliefs – including cost, healthiness, and sustainability – were relatively poor predictors of acceptance ($p > .05$). These results support the consumer acceptance of seaweeds, and identify scope for utilising specific attributes of seaweeds (as drivers of acceptance) in future product development.

1. Background

Dietary intake of protein is a long-standing recommendation in nutritional guidelines (Mozaffarian & Ludwig, 2010). In recent years, the consumption of animal-based proteins (including meat and dairy products) has substantially increased worldwide, such that the intake of animal-based proteins now exceeds recommended amounts in developed countries (Godfray et al., 2018; Stoll-Kleemann & O'Riordan, 2015). The overconsumption of meat is known to negatively impact the environment and food security, as well as consumer health (Godfray et al., 2018; Rust et al., 2020; Stoll-Kleemann & O'Riordan, 2015). To combat these effects, nudging consumers towards choosing plant-based (e.g., soy-based substitutes) and other alternative proteins (e.g., single cell proteins) as part of a 'plant-forward diet' is one strategy that has been recommended to reduce the consumption of animal-based proteins (Rust et al., 2020).

Edible macroalgae – more commonly known as 'seaweeds' – have been identified as a promising alternative to animal-based proteins. As a nutritious food source, seaweeds are generally high in dietary fibres, vitamins, and minerals, and low in dietary fat content (Cherry et al., 2019; Circuncisão et al., 2018; Fleurence et al., 2012). Across species, the protein content of green seaweeds is estimated to be 10 – 25% of its dry weight, increasing to up to 47% for red seaweeds (Cherry et al., 2019). Harvesting seaweeds is also considered to be a sustainable practice, as seaweeds can be farmed in large quantities without resources required for other plant-based alternatives, such as fertiliser,

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freshwater, and expanses of agricultural land (Mahadevan, 2015). From a product development perspective, seaweeds benefit from having an already well-established consumer market as a food source, particularly in Asia (Fleurence et al., 2012). However, despite some evidence of traditional use, seaweeds remain a food item with relatively low present-day consumption rates in most Western countries (Birch et al., 2019; Chapman et al., 2015; Fleurence et al., 2012; Labbe et al., 2019; Losada-Lopez et al., 2021; Palmieri & Forleo, 2020).

In addition to other Western countries, there appears to be an emerging market for seaweeds and seaweed-containing products in the UK (Adams, 2016; Birch et al., 2019; Bouga & Combet, 2015). In some parts of the country, consuming seaweeds in traditional recipes has continued to the present day. For example, in Wales, purple laver (*Porphyra umbilicalis*) is used to make 'laverbread', a seaweed-based puree that is often served with other seafoods or meat (Adams, 2016; Mahadevan, 2015). A growing range of seaweeds and seaweed-based food products – including sushi, seaweed sheets, breads, confectionary, condiments, pasta, soups, snacks, and drinks – have also been made available to consumers in both large supermarkets and specialist retailers, with the majority of products being UK-sourced (Bouga & Combet, 2015).

Despite the increasing availability of seaweeds and its potential use as a nutritious and sustainable food source, to our knowledge, little is known about the acceptability of seaweeds for UK consumers. Therefore, we invited consumers to complete an online survey about their beliefs regarding seaweeds and seaweed-based food products, and asked them to rate acceptability in terms of liking, willingness to try, willingness to buy, and readiness to adopt as a meat alternative. The aim of this study was to further explore the consumer acceptability of seaweed-based food products in the UK, and help identify specific drivers of acceptance for seaweeds relating to both product beliefs and consumer traits.

2. Hypotheses and supporting theoretical framework

2.1. The influence of product beliefs on consumer acceptability

Previous research has generally reported a high willingness to try/ eat seaweeds among consumers in Western countries (Birch et al., 2019; Losada-Lopez et al., 2021; Palmieri & Forleo, 2020, 2021; Wendin & Undeland, 2020). In turn, this acceptability of seaweeds is often accompanied by positive evaluations of product attributes. For example, after taste-testing sample dishes, consumers tended to report a moderate-to-strong liking of seaweeds, with positive descriptions of the flavour and texture (e.g. 'nutty' and 'soft') (Chapman et al., 2015; Lamont & McSweeney, 2021). Consumers have also perceived seaweeds to be 'tasty', 'healthy' and 'good for the environment' when evaluating potential food products (Wendin & Undeland, 2020). As a collective construct, such dimensions have been identified as having a considerable effect on acceptability of 'novel' meat substitutes, including insects and blended meat/ plant-based products (de Koning et al., 2020; Lang, 2020). However, the relative importance of *individual* product attributes to consumer acceptability for seaweeds warrants further exploration, as 'taste' and 'healthiness' in particular have recently been highlighted as key product-related drivers of acceptance for other alternatives to animal-based proteins (Onwezen et al., 2021). Therefore, it was predicted that more positive perceptions of seaweed-based food products would be significantly associated with greater acceptance ratings for these foods as individual predictors of acceptability (H1).

2.2. The influence of a 'product' context on consumer acceptability

Rather than presenting seaweeds as an edible food in general or in isolation, using seaweeds as an additional ingredient in other *well-known* products can benefit consumer acceptance (Birch et al., 2019; Chapman et al., 2015). This is particularly important to consider given that less familiarity with eating seaweeds, and greater trait levels of food neophobia and food technology neophobia (avoidance of novel foods and foods produced with novel food technologies, respectively), have been identified as significant barriers to consumers accepting seaweeds as a food source (Birch et al., 2019; Losada-Lopez et al., 2021; Palmieri & Forleo, 2020).

We also note that consideration of the meal/ product context can be helpful to further product development and placement of a particular food source within a consumer market. Framing a food source as a component within a specific meal/ product context has been shown to enhance acceptability for other alternatives to animal-based proteins relative to presenting the food source 'individually' (e.g., 'chickpea burger' vs. 'chickpeas') (Possidónio et al., 2021). Acceptance can even differ across prospective meals/ items for the same food source (Elzerman et al., 2011, 2015; Grahl et al., 2018; Possidónio et al., 2021), as consumers may perceive some product contexts to be more appropriate for consumption than others (Elzerman et al., 2011, 2015). However, noticeably fewer studies have explored the acceptability of specific seaweed-based food products relative to 'seaweeds' more generally (Chapman et al., 2015; Lamont & McSweeney, 2021; Wendin & Undeland, 2020), and preference for items appears to differ considerably between consumer segments (Chapman et al., 2015; Wendin & Undeland, 2020).

For these reasons, it was predicted that food ratings would be significantly higher (or more positive) when responding to hypothetical seaweed-based food products compared to a general text description of seaweeds as a food source (H2).

2.3. The influence of consumer traits and food-related attitudes on consumer acceptability

There is evidence that acceptability for alternatives to animal-based proteins – including seaweeds – differs across consumer profiles (Onwezen et al., 2021). In addition to considering effects of food neophobia and food technology neophobia (see section 2.2 above), studies within this area of research typically explore the role of other food-related attitudes in promoting consumer acceptance, such as attitudes towards the healthiness, convenience, and environmental impact of food, as well as the importance that consumers place on nutritional and sensory qualities of meat (Gómez-Luciano et al., 2019; Verbeke, 2015). Applying such an approach to the consumption of seaweeds, Birch and colleagues (Birch et al., 2019) found that consumers had a greater likelihood of eating seaweeds in the future if they were more health conscious and had a tendency toward 'convenient' snacking behaviour, whereas concerns about food safety and ethics (including sustainability) had little impact on acceptance. However, research also suggests that the impact of these attitudes on consumer acceptance can differ across consumer profiles that incorporate *perceptions* of consuming seaweed, particularly according to whether these beliefs are positive or negative (Palmieri & Forleo, 2020). Therefore, considering the influence of consumer traits on acceptance, in conjunction with the role of product beliefs, can provide further insight into potential drivers for seaweeds in a specific sample. In this study, consumer traits and food-related attitudes were then explored as factors that interact with food ratings (for product attributes) to predict consumer acceptance (H3).

3. Method

3.1. Study design

Using a cross-sectional design, this study examined associations between beliefs about seaweed-based food products (measured across 10 dimensions), and four acceptability ratings (liking, willingness to try, willingness to buy, and readiness to adopt as a meat alternative). Food ratings were first collected in response to a general text description of seaweed as a food source, followed by text descriptions/ photographs of

six hypothetical seaweed-based food products presented in a randomised order determined by the survey software 'Qualtrics' (Qualtrics, Provo, UT) (see section 3.4 for details). Three questions were included as attention checks throughout the survey (on two occasions, participants were asked to "please select 'not at all' by dragging the slider all the way to the left", and on the third occasion they were asked to "please select 'strongly agree'" on a Likert scale). Questionnaire measures used to assess general eating-related traits and beliefs were collected after participants had responded to all food descriptions (see section 3.5 for details). Study methods and planned data analyses were preregistered on the Open Science Framework (OSF) before data collection had begun, and structural equation modelling procedures were preregistered before the proposed model was conducted (https://osf.io/jy897/).

3.2. Participants

Participants were recruited to complete the study in March 2021 via 'Prolific' (https://www.prolific.co). Participants were directed to the survey using an anonymous link to 'Qualtrics'. Before completing a consent form (to provide informed written consent), participants were presented with an information sheet and informed that the aim of the research was to "explore consumer beliefs about a potential new food product". Participants completed the study in approximately 20 min, and were compensated for their time with a payment of £2.50 on Prolific (following the platform's guidelines on fair pay). The study was approved by the Department of Psychology Research Ethics Committee at Swansea University.

Following Fritz and MacKinnon (2007), it was estimated that 462 participants were required to detect a mediated 'small' effect using bias-corrected bootstrap approaches ($1 - \beta = 0.80$). Data collection was then stopped when 535 responses to the survey had been recorded to account for unusable data (e.g., duplicate responses from the same participant ID, participants who did not finish the survey). Participants were eligible to be included in the study if they were currently living within the UK, and if they self-identified as having normal or corrected-to-normal vision. All participants were 18 years old or older. Participants were excluded from the study if they reported having a current or history of eating disorders, if they reported any food allergies or intolerances that might limit the applicability of food descriptions used in the study, and if they failed multiple attention checks. After removing ineligible responses, 476 participants were included in the sample.

3.3. 'Seaweed' and 'seaweed-based' food descriptions

Participants were presented with seven food descriptions (see Table 1). Each product description framed seaweeds as a 'protein-rich' food source. In the first description, participants were provided with examples of different edible seaweeds. For each of the six remaining descriptions, participants were provided with an example of a hypothetical seaweed-based food product containing seaweeds as a complimentary ingredient to other identifiable food components. Hypothetical food products were chosen to represent different uses of seaweeds as a food source (i.e., as an ingredient in snacks, main dishes, beverages, and sweet foods). An example photograph of each item was included for hypothetical food products to demonstrate a potential serving. Photographs did not contain any identifiable product labels or additional information about the product, with the exception of flavourings included on juice drinks (see Supplementary methods A.1. for alt-text image descriptions).

Table 1
Descriptions of 'seaweed' and 'seaweed-based' food products provided to participants.

Product	Description
Algae/ seaweeds	"Algae" are a type of low-energy aquatic plant that has been found to be high in protein, vitamins, minerals, fibre, and fatty acid. There are many types of algae that can be included in food products. This includes 'laver', 'kelp', 'wakame', 'ogo', 'sea grapes', and 'mozuku'. A more common name for algae is 'seaweeds'.
Energy bar	A "Kelp and nut energy bar" is a protein-rich food product that contains kelp (a type of algae or seaweed). It also contains ingredients like oats, mixed nuts, and dried fruits.
Burger	A "Seaweed burger" is a protein-rich food product that contains seaweed (or algae). It is a meat-free patty, and can also contain ingredients like soy.
Pasta	"Kelp noodles" is a protein-rich food product that contains kelp (a type of algae or seaweed). As it is typically made with only seaweed-derived substances and water, it is also low in calories and high in vitamins and minerals.
Sushi	"Wakame sushi rolls" is a protein-rich food product that contains nori and wakame (types of algae or seaweed). Nori is used as a wrap, and wakame is used in a filling that also contains sushi rice and vegetables.
Juice drink	"Seaweed juice drink" is a protein-rich beverage that contains seaweeds (or algae). These drinks are typically high in vitamins and minerals, and also often contain additional fruits, vegetables, and flavourings.
Baby sugar kelp	"Baby sugar kelp" is a type of algae or seaweed that is harvested when it is small. It is high in vitamins and minerals, retains its sweetness and is not too salty. You can use it as a garnish, or as an ingredient in desserts.

3.4. Food ratings

3.4.1. Beliefs about 'seaweed' and 'seaweed-based' food products

Following Possidónio et al. (2021), participants rated their beliefs about seaweed and seaweed-based food products along 10 characteristic dimensions; taste, edibility, healthiness, caloric content, naturalness, degree of processing, expensiveness, ethics, sustainability, and familiarity. All ratings were provided in response to food descriptions using a series of 100-mm visual analogue scales anchored 'Not at all'– 'Extremely', with the characteristic of interest included in the anchor label (e.g., 'Not at all appetising'– 'Extremely appetising' for taste). A 'neutral' label was included at the midpoint of each scale to guide responding.

3.4.2. Consumer acceptability

In line with previous studies on the acceptance of alternatives to animal-based proteins (Gómez-Luciano et al., 2019; Verbeke, 2015), participants were asked to rate their readiness to adopt as a substitute for meat ("I would be prepared to eat… as a substitute for meat"), willingness to try ("Would you personally be willing to try…?"), and willingness to buy ("Would you personally be willing to purchase…?"). They were also asked to rate their expected liking ("I expect to like…"). Ratings were provided in response to each food description using a series of 100-mm visual analogue scales, with the anchors 'Not at all – Extremely'/ 'Definitely not – Definitely yes'. A neutral label was included at the midpoint of each scale to guide responding ('Neither agree nor disagree'/ 'Might or might not').

3.5. Consumer traits and demographics

In line with previous studies on the acceptance of alternatives to animal-based proteins (Gómez-Luciano et al., 2019; Verbeke, 2015), participants completed six short questionnaires to assess general attitudes and beliefs about foods. Participants completed the 'Food Neophobia Scale' (FNS; 10 items) (Pliner & Hobden, 1992) as presented in Gómez-Luciano et al. (2019), 'Food Technology Neophobia Scale' (FTNS; 13 items) (Cox & Evans, 2008), 'General Health Interest' subscale (8 items) to assess interest in health benefits of foods (Roininen et al., 1999), the 'CONVOR scale' (as reported in the 'final' version; 6 items) to assess convenience orientation relating to food choices (Candel, 2001), beliefs regarding the environmental impact of foods (5 items) (Gómez-Luciano et al., 2019), and beliefs about the benefits of

consuming meat (6 items) (Gómez-Luciano et al., 2019). To check for potential social-desirability bias in participant responses, participants also completed the 'impression management' subscale (8 items) from the 'Balanced Inventory of Desirable Responding Short Form' (BIDR-16) (Hart et al., 2015). Across all questionnaires, participants provided responses on a 5- or 7-point Likert-scale ranging from "Strongly disagree" to "Strongly agree". Higher scores indicated greater levels of the respective trait (e.g., increased food neophobia, increased interest in the health of foods).

Participants were asked to provide demographic information including their age, gender, country of residence, highest completed qualification, and employment status. Participants were also asked to report details about their current diet. This included the type of diet followed (i.e., whether or not their diet included meat and animal products), the length of time spent following their current diet, and reasons for following their current diet in an optional open-text field. At the end of the study, participants self-reported their height and weight using drop-down lists to enable calculations of body mass index (BMI). They were asked to describe their beliefs about the aim of the study in an open-text field before they were presented with a debrief form.

3.6. Data analysis

When providing food ratings, 189 participants rated 5 instead of 6 hypothetical foods due to a function error (selection was randomised). No significant outliers were detected for product beliefs or consumer acceptability variables (3 × IQR). Though it did not warrant exclusion from the study, 23 participants failed a single attention check. Unless otherwise stated, all food ratings (relating to product beliefs and consumer acceptance) were collapsed across hypothetical seaweed-based food products by calculating the mean.

To check associations between identified predictors and consumer acceptance for hypothetical seaweed-based food products, all food ratings were entered into a bivariate correlation matrix. As the Shapiro-Wilk test showed that data for food ratings were not normally distributed ($p < .005$), an appropriate non-parametric test was used to calculate coefficients (Spearman's Rho). These analyses showed that 'Taste' and 'edibility' ($r_s = 0.768$, $p < .001$), and 'ethics' and 'sustainability' ($r_s = 0.822$, $p < .001$), were highly correlated. As such, composite scores for these beliefs were included in data analyses (mean score across variables). See Supplementary Table A.1. for all correlations between predictors, and Supplementary Fig. A.1 for correlations between predictors and consumer acceptance.

A one-way repeated measures MANOVA was used to test the hypothesis that product beliefs would be significantly higher (or more positive) when responding to hypothetical seaweed-based food products compared to a general text description of seaweeds as a food source (H2). 'Food description' was entered as a within-subjects factor with 7 levels (descriptions of algae/ seaweeds, energy bar, burger, pasta, sushi, juice drink, and baby sugar kelp), and ratings for product beliefs were entered as dependent variables. A one-way repeated measures MANOVA was also used to explore differences between individual hypothetical food products in terms of acceptability. 'Food product' was entered as a within-subjects factor with 6 levels (energy bar, burger, pasta, sushi, juice drink, and baby sugar kelp), and acceptability outcome measures were entered as dependent variables. Across analyses, Mauchly's test of sphericity was significant ($p < .001$), and the Greenhouse-Geisser correction was applied to within-subjects effects. Bonferroni-corrected pairwise comparisons were used as follow-up tests.

A two-step structural equation modelling analysis was used to identify product-related attributes as predictors of acceptability for hypothetical seaweed-based food products (H1), and explore potential interactions with consumer demographics and food-related attitudes (H3). Following a recent theoretical framework of acceptability for meat substitutes and 'plant-forward' diets (Lang, 2020), consumer demographics and consumer values/ attitudes towards foods, food technologies, and relevant behaviours, were included as antecedent predictors of acceptability for seaweed-based food products. Consumer evaluations of product attributes were included as key mediating factors influencing acceptability for seaweeds. As such, both direct and indirect effects (via beliefs about product-related attributes) of consumer profiles on acceptability were explored (see Fig. 1). For results of multiple linear regression analyses with each individual measure of acceptability as the outcome variable, see Supplementary methods A.2. and Tables A.2 - 5.

In line with recommendations and suggested cut-off values reported by Hair and colleagues (Hair et al., 2014; Hair et al., 2017), the reliability (Cronbach's alpha, McDonald's omega, composite reliability) and validity (average variance extracted [AVE], Fornell-Larcker criterion, heterotrait-monotrait ratios) of latent constructs was checked in step 1, and overall model fit indices were reported in step 2 (CFI [comparative fit index] and RMSEA [root mean square error of approximation]). Model parameters and item weights were estimated using the Maximum Likelihood (ML) estimator and adjusted using bias-corrected bootstrapping approaches (1000 samples). In step 1, up to 20% of items were dropped from analyses if factor loadings were < 0.50. In step 2, exogenous variables and intervening endogenous variables, that did not significantly influence endogenous variables, were removed as part of exploratory model trimming, and modification indices were used to explore post-hoc improvements to model fit by accounting for residual covariances within included factors ($mi > 10$). Indirect effects were deemed significant if $p < .05$, and if 95% confidence intervals did not cross zero.

Structural equation modelling was conducted using the 'Lavaan' syntax (Rosseel, 2012) in JASP v0.15. All other data analyses were conducted in IBM SPSS v26.

4. Results

4.1. Participant characteristics

Participants included 325 females (68.3%), 150 males (31.5%), and one participant who identified their gender as non-binary. One participant reported that their identified gender was not assigned at birth, and one participant preferred not to say. Almost all participants followed a diet that contained meat or fish (93.3%), including 8.2% who had a flexitarian diet (i.e., mostly consumed a vegetarian diet but occasionally consumed meat/ fish), and 77.1% of participants reported that their current diet was lifelong. Most participants were resident in England (85.7%), followed by Scotland (7.8%), Wales (4.6%), and Northern Ireland respectively (1.9%). Most participants had received education to high-school (37.2%) or university-degree level (60.3%), with < 1% reporting no formal qualifications. The majority of participants reported being in full-time or part-time employment (58.0%), being self-employed (8.2%), retired (5.7%), or a student (12.4%). See Table 2 for all other participant characteristics.

4.2. Differences in beliefs between descriptions of 'algae/ seaweed' and hypothetical seaweed-based food products

There was a significant MANOVA effect for food description (Pillai's Trace = 0.868, $F(48, 237) = 32.35$, $p < .001$, partial $\eta^2 = 0.868$), and significant differences were observed between food descriptions for all product beliefs (Greenhouse-Geisser corrected p's < 0.05). Bonferroni-corrected pairwise comparisons showed that algae/ seaweed was believed to be significantly less appetising than the energy bar, burger, pasta and sushi ($p < .001$); healthier than the energy bar, burger, sushi, and baby sugar kelp ($p < .05$); less calorific than the energy bar, burger, sushi, juice drink, and baby sugar kelp ($p < .001$); more natural than the energy bar, burger, pasta, sushi, and juice drink ($p < .001$); less processed than the energy bar, burger, pasta, sushi, and juice drink ($p < .001$); less expensive than the energy bar, burger, pasta, sushi, juice drink, and baby sugar kelp ($p < .001$); less familiar than the energy bar

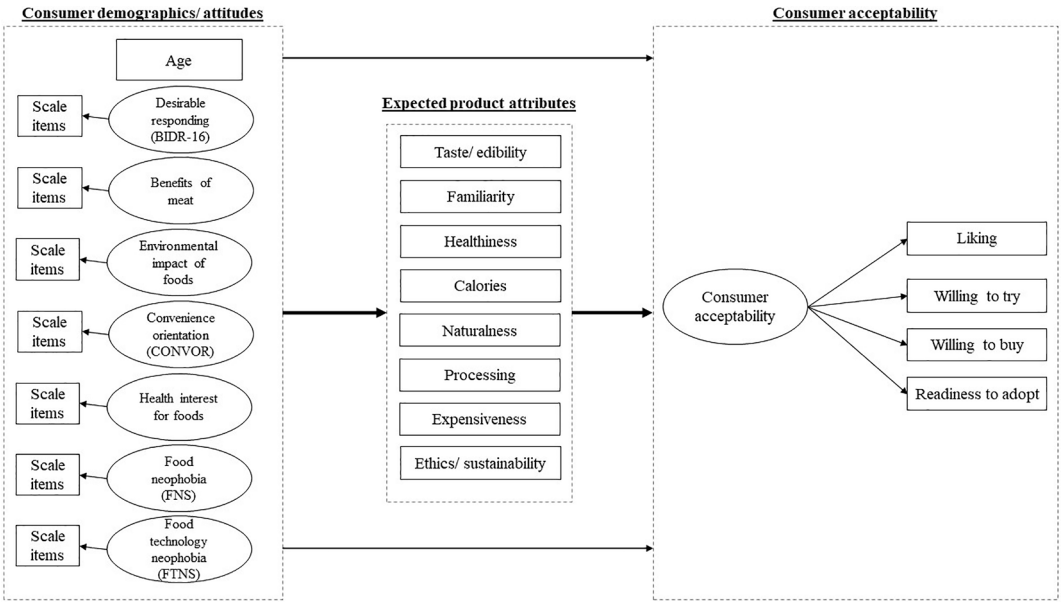

Fig. 1. Adapted from (Lang, 2020), proposed structural equation model for the acceptance of seaweed-based food products, with consumer traits and beliefs about product attributes as predictors of acceptability in this study.

Table 2
Sample characteristics ($N = 476$).

Consumer trait	Range	M (SD)
Age (years)	18.0 – 76.0	37.1 (13.7)
BMI (kg/m^2)	14.9 – 55.3	25.7 (5.8)
Food neophobia (FNS) [1]	10 – 47	23.8 (7.1)
Food technology neophobia (FTNS) [1]	20 – 82	49.4 (10.9)
Health interest for foods [2]	1.4 – 6.9	4.2 (1.0)
Convenience orientation (CONVOR-scale) [1]	6 – 42	24.1 (8.1)
Environmental impact of food [1]	7 – 25	18.6 (3.4)
Benefits of meat [1]	6 – 30	19.2 (6.2)
Desirable responding (BIDR-16) [2]	1 – 7	4.3 (1.0)

[1] Sum of item scores in scale.
[2] Mean scale score calculated across items.

and sushi ($p < .001$); and more familiar than the baby sugar kelp ($p < .001$). There were no significant differences between algae/ seaweed and seaweed-based food products in terms of ethics/ sustainability ($p > .05$). See Table 3 for descriptive statistics for food ratings.

4.3. Differences in acceptability between hypothetical seaweed-based food products

There was a significant MANOVA effect for hypothetical product type (Pillai's Trace = 0.633, $F(20, 265) = 22.830$, $p < .001$, partial $\eta^2 = 0.633$), and significant differences were observed between product descriptions for all acceptability measures (Greenhouse-Geisser corrected p's < 0.001). Bonferroni-corrected pairwise comparisons showed that readiness to adopt the burger and sushi as meat substitutes was significantly higher than readiness to adopt for all other foods ($p < .001$); and readiness to adopt the baby sugar kelp and juice drink was significantly lower ($p < .001$). Willingness to try and willingness to buy the juice drink and baby sugar kelp was significantly lower than for all other foods ($p < .001$). Expected liking for the sushi was significantly higher than for all other foods ($p < .001$), and significantly lower for the juice drink ($p < .001$). See Supplementary Table A.6. for all other comparisons between individual foods.

4.4. Identifying drivers of acceptability for hypothetical seaweed-based food products

4.4.1. Construct validity and reliability of latent variables

Table 4 displays results for step 1 of the model testing latent

Table 3
Descriptive statistics for beliefs about foods and consumer acceptance ratings, measured using 100-mm VAS. Mean (SD) is reported.

Variable	Algae/ seaweeds	Energy bar	Burger	Pasta	Sushi	Juice drink	Baby sugar kelp	Across foods [1]
Product belief								
Taste/ edibility	52 (24)	63 (24)	61 (24)	66 (22)	75 (26)	47 (26)	51 (25)	61 (17)
Healthiness	82 (15)	75 (17)	71 (18)	82 (14)	78 (17)	80 (17)	73 (18)	77 (12)
Calories	29 (19)	58 (20)	49 (20)	28 (22)	43 (22)	42 (23)	34 (21)	42 (14)
Naturalness	86 (19)	69 (18)	64 (22)	73 (19)	73 (19)	73 (21)	82 (19)	72 (14)
Processing	27 (24)	51 (22)	57 (24)	47 (24)	43 (22)	47 (23)	26 (22)	45 (17)
Expensiveness	56 (20)	63 (17)	64 (15)	63 (19)	71 (17)	73 (17)	63 (22)	66 (13)
Ethics/ Sustainability	74 (18)	71 (16)	72 (16)	73 (17)	71 (17)	72 (17)	72 (19)	72 (14)
Familiarity	34 (27)	44 (28)	36 (29)	32 (26)	64 (28)	33 (27)	21 (23)	38 (19)
Acceptability								
Readiness to adopt	42 (32)	37 (33)	53 (35)	44 (33)	55 (36)	25 (30)	29 (30)	41 (26)
Willingness to try	76 (27)	75 (28)	73 (29)	79 (24)	78 (29)	63 (31)	68 (29)	73 (22)
Willingness to buy	62 (28)	59 (30)	57 (31)	64 (27)	68 (32)	45 (31)	50 (29)	57 (23)
Liking	49 (27)	57 (30)	53 (28)	60 (25)	68 (33)	39 (28)	48 (27)	54 (20)

[1] Collapsed across hypothetical seaweed-based food products by averaging scores for individual items (excluding the general description of algae/ seaweeds).

Table 4
CFA standardised factor loadings, reliability, construct validity, and discriminant validity of latent variables. For each individual construct, SQRT of AVE is displayed along the diagonal in bold. For each pairwise comparison, the factor covariance and heterotrait-monotrait (HTMT) ratio of correlation is presented.

Construct	Factor loadings	Cronbach α	McDonald ω	CR	AVE	Factor covariances, HTMT ratio							
						1	2	3	4	5	6	7	8
1. Desirable responding (BIDR-16)	0.471 – 0.639 (8 items)	0.781	0.782	0.782	0.311	**0.558**							
2. Benefits of meat	0.657 – 0.928 (5 items)	0.905	0.908	0.905	0.661	−0.073, 0.111	**0.813**						
3. Environmental impact of foods	0.601 – 0.879 (3 items)	0.749	0.775	0.774	0.539	0.073, 0.106	−0.230, 0.307	**0.734**					
4. Convenience orientation (CONVOR-scale)	0.553 – 0.934 (6 items)	0.907	0.911	0.911	0.637	−0.225, 0.234	0.001, 0.072	−0.114, 0.142	**0.798**				
5. Health interest for foods	0.502 – 0.786 (7 items)	0.841	0.845	0.846	0.444	0.169, 0.215	−0.232, 0.218	0.263, 0.341	−0.190, 0.198	**0.666**			
6. Food neophobia (FNS)	0.512 – 0.754 (10 items)	0.885	0.893	0.893	0.460	−0.034, 0.123	0.085, 0.157	−0.194, 0.212	0.271, 0.279	−0.211, 0.225	**0.678**		
7. Food technology neophobia (FTNS)	0.519 – 0.781 (9 items)	0.880	0.881	0.880	0.453	< -0.001, 0.112	0.111, 0.177	−0.167, 0.222	0.176, 0.197	−0.062, 0.131	0.378, 0.367	**0.673**	
8. Consumer acceptance	0.594 – 0.928 (4 items)	0.885	0.904	0.905	0.709	0.089, 0.128	−0.307, 0.431	0.379, 0.429	−0.181, 0.200	0.283, 0.306	−0.567, 0.533	−0.326, 0.341	**0.842**

variables. Where appropriate, scale items with standardised factor loadings < 0.50 were removed from the analysis for latent constructs; FTNS (4 items), Health interest (1 item), environmental impact (2 items), benefits of meat (1 item). For the BIDR-16 scale, 2 items with factor loadings < 0.50 were not removed, as doing so decreased reliability for the measure. Cronbach's alpha, McDonald's omega, and composite reliability values were > 0.70 for all measures, indicating adequate reliability across constructs.

Supporting convergent validity, AVE was > 0.50 for benefits of meat, environmental impact of foods, convenience orientation, and consumer acceptance. AVE was lower for desirable responding, health interest for foods, food neophobia, and food technology neophobia. However, discriminant validity of all constructs was supported, as the SQRT of the AVE along the diagonal was higher than the covariances for each corresponding pair (satisfying the Fornell-Larcker criterion). Heterotrait-monotrait (HTMT) ratios were acceptable across comparisons, as all values were < 0.85 (Henseler et al., 2014).

4.4.2. Direct and indirect effects on consumer acceptance

In step 2 of the analysis, the full structural model was approaching acceptable fit across indices overall (CFI = 0.810, RMSEA = 0.060, X^2 = 4503.28, df = 1677, p <.001), and accounted for 84.7% (R^2 = 0.847) of the variance in consumer acceptance. As shown in Table 5, having greater food neophobia and stronger beliefs about the benefits of meat significantly predicted decreased acceptance for hypothetical seaweed-based food products, whereas perceiving foods to be more tasty/ edible and familiar significantly predicted increased acceptance. Of these significant predictors, taste/ edibility appeared to have the largest influence on consumer acceptance. All other consumer traits and product beliefs were comparatively poor predictors of acceptability, and direct paths failed to reach significance.

When exploring indirect paths predicting consumer acceptance, the model showed that each consumer trait significantly predicted at least one product belief. However, food neophobia was the only trait to have significant indirect effects on consumer acceptance via both taste/ edibility and familiarity, indicating partial mediation (given the significant direct effect of food neophobia on consumer acceptance). For all other indirect effects containing taste/ edibility and familiarity, p >.05 and/ or confidence intervals crossed zero (see Table 6).

To explore the development of a more parsimonious model of consumer acceptance, product beliefs that did not significantly predict consumer acceptance, and consumer traits that did not significantly predict consumer acceptance via direct or indirect paths, were removed from the model. This meant that food neophobia and beliefs about the benefits of meat were included as antecedent predictors of acceptance, and taste/ edibility and familiarity were included as intervening endogenous constructs.

Though model trimming alone appeared to have little influence on the model fit (CFI = 0.872, RMSEA = 0.099, X^2 = 1028.91, df = 182, p <.001), this noticeably improved when covariances between items within the FNS and benefits of meat were accounted for after checking modification indices (CFI = 0.953, RMSEA = 0.063, X^2 = 472.36, df = 162, p <.001). Consistent with the full model, the revised model explained 83.9% (R^2 = 0.839) of the variance in consumer acceptance. Direct paths predicting consumer acceptance remained significant for food neophobia (β = -0.20, p <.001, 95% CI = -5.64 – −2.98), benefits of meat (β = -0.10, p <.001, 95% CI = -3.24 – −0.97), taste/ edibility (β = 0.76, p <.001, 95% CI = 0.58 – 0.76), and familiarity (β = 0.05, p =.025, 95% CI = 0.00 – 0.09). Indirect effects of food neophobia on consumer acceptance via taste/ edibility (β = -0.35, p <.001, 95% CI = -9.26 – −5.79) and familiarity (β = -0.01, p =.038, 95% CI = -0.62 – −0.02) also remained significant. There was no significant indirect effect of beliefs about the benefits of meat on consumer acceptance via familiarity (β = 0.00, p =.153, 95% CI = -0.29 – 0.00), but contrasting with the full model, the indirect effect via taste/ edibility was significant (β = -0.16, p <.001, 95% CI = -4.61 – −1.67). For this reason, the full model was accepted as a more conservative 'final' fit.

Table 5
Coefficients for all direct paths predicting consumer acceptance in the structural model.

Predictor	B	SE	β	95% LLCI, ULCI	z	p
Consumer traits						
Age (yrs)	0.05	0.03	0.04	−0.07, 0.26	1.90	0.058
Desirable responding (BIDR-16)	−0.31	0.53	−0.02	−23.26, 24.83	−0.58	0.560
Benefits of meat	−1.69	0.46	−0.09	−16.27, 25.39	−3.66	**< 0.001**
Environmental impact of foods	0.58	0.62	0.03	−50.96, 118.91	0.95	0.344
Convenience orientation (CONVOR-scale)	−0.39	0.28	−0.04	−7.07, 7.82	−1.40	0.161
Health interest for foods	0.17	0.39	0.01	−62.47, 13.35	0.44	0.662
Food neophobia (FNS)	−4.04	0.73	−0.19	−10.35, 16.09	−5.55	**< 0.001**
Food technology neophobia (FTNS)	0.09	0.36	0.01	−7.82, 8.36	0.25	0.807
Expected product attributes						
Taste/ edibility	0.66	0.05	0.75	0.54, 0.77	13.47	**< 0.001**
Familiarity	0.06	0.02	0.07	0.01, 0.10	2.93	**0.003**
Healthiness	0.04	0.03	0.03	−0.57, 0.55	1.34	0.182
Calories	−0.05	0.03	−0.04	−0.14, 0.06	−1.75	0.080
Naturalness	0.01	0.03	0.01	−0.58, 0.33	0.30	0.768
Processing	0.02	0.02	0.02	−0.06, 0.14	0.88	0.377
Expensiveness	0.02	0.03	0.02	−0.04, 0.08	0.91	0.362
Sustainability/ ethics	−0.02	0.03	−0.02	−0.34, 0.17	−0.70	0.483

5. Discussion

This online study aimed to further explore the consumer acceptability of seaweed-based food products in the UK, and help identify specific drivers of acceptance for seaweeds. First and foremost, it was predicted that positive perceptions of seaweed-based food products (including seaweed as a complimentary ingredient) would be significantly related to consumer acceptance for seaweed-based food products. In this study, taste/ edibility and familiarity were the only product attributes to significantly predict acceptability, and taste/ edibility in particular was identified as the stronger driver of consumer acceptance. Previous research has shown that willingness to try is lower when consumers generally perceive seaweeds to be less tasty and appealing (Palmieri & Forleo, 2020; Wendin & Undeland, 2020), and that consumers are more likely to eat seaweeds when they are familiar with its use as an ingredient in dishes such as sushi (Birch et al., 2019). Our study extends these results to specific examples of potential seaweed-based food products, and further delineates the importance of taste/ edibility and familiarity for acceptance of seaweeds from the influence of other product-related attributes, such as health and sustainability (Birch et al., 2019; Losada-Lopez et al., 2021; Palmieri & Forleo, 2020; Wendin & Undeland, 2020).

Second, it was predicted that hypothetical seaweed-based food products would be perceived more favourably than a general description of edible seaweeds, as this has been recognised as a method to improve the palatability of seaweeds for Western consumers (Birch et al., 2019; Chapman et al., 2015). In support of this, we found some evidence that hypothetical seaweed-based products were rated more favourably in terms of taste/ edibility (4 of 6 products), as well as familiarity (2 of 6 products). Given that both attributes were identified as strong predictors of acceptance across models, results further emphasise the importance of exploring consumer perceptions of seaweeds in a product-focussed context. Indeed, this study has particular implications for guiding future product development, as results highlight potential food products that may successfully incorporate seaweeds to enhance acceptance for UK consumers.

Importantly, by contrasting a range of hypothetical food products, this study helps identify differences in acceptability between potential food items. Overall, participants were most accepting of the seaweed-based sushi and burger, and least accepting of the juice drink and baby sugar kelp. Similar findings have been reported in past research, as consumers favourably rate seaweeds when framed for use in main dishes, and often give lower ratings for seaweeds when presented in sweet foods and beverages (Chapman et al., 2015; Wendin & Undeland, 2020). One explanation for this is that consumers, particularly in the UK, are most likely to be familiar with use of seaweeds in savoury items. Sushi, soups, and snacks (e.g., crackers) are the most common seaweed-based food products currently available in UK supermarkets (Bouga & Combet, 2015), and traditional recipes in the UK often make use of seaweeds as a main dish (e.g., 'laverbread') (Adams, 2016; Mahadevan, 2015). More generally, meat-free burger patties are also a common example of products incorporating alternatives to animal-based proteins that are widely available to consumers, such as plant-based and myco-protein options (Onwezen et al., 2021). However, there is some evidence that seaweeds can be successfully introduced into other products, as 'chocolate ice cream with sugar kelp' was the highest rated item in one of the few studies where participants actually consumed real foods (Chapman et al., 2015). This suggests that, for less familiar (or expected) product contexts, allowing consumers the opportunity to taste products could help improve acceptability.

It is generally well-documented that acceptance for alternatives to animal-based proteins differs between consumers (Onwezen et al., 2021). For seaweeds in particular, previous studies have highlighted food neophobia as a crucial barrier to consumer acceptance (Birch et al., 2019; Losada-Lopez et al., 2021; Palmieri & Forleo, 2020). Though it should be acknowledged that the FNS may not be the most appropriate measure of food neophobia in other populations and food contexts (Damsbo-Svendsen et al., 2017), food neophobia (in conjunction with beliefs about the benefits of meat) was one of the only traits to significantly predict acceptability in this study. This further differentiates effects from the influence of other food-related attitudes that are typically investigated within this domain (e.g., global beliefs about the environmental impact of food, health interest, and convenience orientation for food). However, we also found evidence that the effect of food neophobia in particular was partially mediated by beliefs about the taste/ edibility and familiarity of products, suggesting that these attributes may potentially mitigate the negative effect of food neophobia on consumer acceptance. Palmieri and Forleo (Palmieri & Forleo, 2020) found similar effects in Italian consumers, reporting that perceptions of seaweed attributes and the option to taste-test a product could improve acceptability in neophobic consumers. Though familiarity had a relatively small effect compared to taste/ edibility, these findings highlight the perception of both taste/ edibility and familiarity as specific factors that may combat potential barriers to consumer acceptance for seaweeds.

Measuring consumer acceptance in response to food descriptions can be particularly useful to identify initial interest in novel products (as developing and testing *real* food items can be costly in terms of time and resources). However, one concern with this approach is that information provided to consumers can prime responding. In this study, contrasting with our prediction that hypothetical seaweed-based food products would be rated more positively across dimensions, the general description of seaweeds as a food source was perceived to be healthier, less

Table 6
Coefficients for indirect paths predicting consumer acceptance.[1]

Consumer traits	Mediating variable	Indirect effect						Total effect					
		B	SE	95% LLCI, ULCI	β	z	p	B	SE	95% LLCI, ULCI	β	z	p
Age (yrs)	Taste/ edibility	−0.01	0.03	−0.08, 0.06	−0.01	−0.41	0.680	0.04	0.04	−0.10, 0.25	0.03	0.89	0.375
	Familiarity	−0.01	0.01	−0.03, 0.00	−0.01	−2.39	0.017	0.04	0.03	−0.08, 0.22	0.03	1.38	0.168
Desirable responding (BIDR-16)	Taste/ edibility	1.50	0.55	−1.73, 10.46	0.09	2.70	0.007	1.19	0.76	–23.30, 24.52	0.07	1.56	0.118
	Familiarity	−0.02	0.06	−0.27, 0.15	0.00	−0.27	0.786	−0.32	0.53	−21.16, 26.10	−0.02	−0.61	0.544
Benefits of meat	Taste/ edibility	−1.41	0.57	−14.66, 7.10	−0.08	−2.48	0.013	−3.10	0.76	−18.04, 34.14	−0.17	−4.08	< 0.001
	Familiarity	−0.06	0.06	−0.47, 0.09	0.00	−1.00	0.316	−1.75	0.47	−14.68, 28.42	−0.10	−3.75	< 0.001
Environmental impact of foods	Taste/ edibility	4.29	0.84	−37.48, 35.25	0.20	5.10	< 0.001	4.87	1.04	−37.71, 162.46	0.23	4.69	< 0.001
	Familiarity	0.15	0.09	−0.33, 1.41	0.01	1.64	0.101	0.74	0.62	−52.90, 110.14	0.03	1.19	0.234
Convenience orientation (CONVOR-scale)	Taste/ edibility	0.69	0.34	−1.50, 2.79	0.06	2.00	0.046	0.30	0.44	−7.24, 7.08	0.03	0.67	0.503
	Familiarity	−0.01	0.04	−0.10, 0.09	0.00	−0.16	0.874	−0.40	0.28	−7.04, 8.13	−0.04	−1.41	0.159
Health interest for foods	Taste/ edibility	0.69	0.50	−9.23, 17.74	0.05	1.38	0.168	0.86	0.64	−45.22, 19.84	0.06	1.34	0.181
	Familiarity	0.06	0.06	−0.19, 0.48	0.00	1.08	0.280	0.23	0.40	−57.45, 13.71	0.02	0.59	0.556
Food neophobia (FNS)	Taste/ edibility	−5.76	0.87	−15.74, −0.41	−0.27	−6.61	**< 0.001**	−9.80	1.23	−24.07, 9.73	−0.47	−7.96	< 0.001
	Familiarity	−0.24	0.11	−0.67, −0.05	−0.01	−2.19	**0.029**	−4.28	0.74	−10.45, 15.89	−0.20	−5.82	< 0.001
Food technology neophobia (FTNS)	Taste/ edibility	−1.45	0.44	−7.11, 2.53	−0.11	−3.31	< 0.001	−1.37	0.56	−11.00, 7.94	−0.11	−2.43	0.015
	Familiarity	−0.02	0.05	−0.19, 0.08	0.00	−0.49	0.628	0.07	0.36	−7.82, 8.19	0.01	0.18	0.856

[1] Indirect effects are indicated as significant (in bold) if p <.05, and 95% confidence intervals do not cross zero.

calorific, more natural, less processed, and less expensive than hypothetical seaweed-based food products. This was likely (at least in part) influenced by the nutritional information provided to participants in the food description (e.g., they were specifically informed that seaweeds are low-energy and high in vitamins and minerals, and presented with examples of 'natural' seaweeds). Indeed, there was some evidence that a ceiling effect may have occurred for beliefs about healthiness, naturalness, expensiveness, and sustainability/ ethics, as the 25th percentile for ratings of seaweed-based food products was ≥ 59 (above the midpoint of the scale), indicating a potential bias towards higher ratings. We do note that responses still varied among participants, with few selecting maximum scale scores (≤1.3% for each variable). Nevertheless, it remains unclear whether participants' beliefs accurately reflect their current knowledge and experience of consuming seaweeds as a food source, and future qualitative research on the consumer understanding of edible seaweeds would be beneficial.

As previously suggested, there remains a need to further explore consumer acceptance in response to taste-tests for seaweeds. This is particularly important given that some research has shown that participants often overestimated their expected liking (and acceptance) for similar products (foods containing the microalgae 'spirulina'), and actual liking of foods led to participants feeling disappointed (Grahl et al., 2020). There is also some evidence to suggest that acceptance for seaweeds may be lower than for other products available to consumers, and further research is needed to compare acceptance for seaweed-based foods with other products. For example, compared to fish and other seafoods, US consumers gave lower average liking scores to seaweeds (Labbe et al., 2019), and were often willing to pay less of a price premium for products (Brayden et al., 2018). In a study on consumers in the Netherlands, only 12% of participants selected a product made from seaweed as their preferred choice for a hypothetical snack, compared to 54% who selected a hybrid meat/ meat substitute, and 30% who selected a snack made from lentils or beans (de Boer et al., 2013). In such studies, it would be useful to further explore *why* consumers would choose one alternative over another (Onwezen et al., 2021).

It should be noted that additional challenges in the development of seaweed-based food products have been identified in the literature, particularly as this relates to intensity/ volume of consumption. First, one potential concern is that frequently consuming seaweeds in large amounts may increase dietary intake above recommended levels for some micronutrients (e.g., iodine), and some species/ cultivation environments may be associated with increased toxicity (Cherry et al., 2019; Circuncisão et al., 2018). Regulations to guide seaweed farming and product development require greater clarity in several countries, including the UK (Bouga & Combet, 2015; Cherry et al., 2019; Circuncisão et al., 2018). Second, it may be difficult to produce high-protein foods using seaweeds alone given that reports of protein content widely vary across species (Cherry et al., 2019; Circuncisão et al., 2018; Fleurence et al., 2012), and large quantities may be less acceptable to consumers (Grahl et al., 2020; Lamont & McSweeney, 2021). However, use of seaweeds as an additional ingredient within other foods (as described in hypothetical contexts used in this study) that may fortify nutritional qualities – such as protein content – remains a promising avenue to explore (e.g., (Bouga & Combet, 2015)).

Limitations of the sample should also be addressed. First, this sample predominantly included participants who self-identified as meat and/ or fish consumers, and few participants reported following a vegan or vegetarian diet (7%). Though we found little evidence of an effect of the consumer diet on acceptance in supplementary analyses (see Tables A.3 - 4), the role of the consumer's current diet in predicting acceptance for seaweed-based food products may have been underestimated in this sample, and future research should consider whether there are specific

between-group differences. For instance, it has previously been reported that consumers with a preference for meat, and vegetarians/ vegans, differ in their likelihood of eating seaweeds in the future (Birch et al., 2019), as well as their beliefs about meat and alternatives to animal-based proteins more generally in terms of taste, texture, price, ease of preparation, nutritional content, and environmental benefits (Michel et al., 2021). Second, the majority of participants were well-educated, with 60% of participants having completed education at a university-level, and a further 12% reporting being current students. As previous research has suggested that higher education levels can increase acceptability for seaweeds and other alternatives to animal-based proteins (Birch et al., 2019; de Boer et al., 2013; Palmieri & Forleo, 2020), the generalisability of results should be treated with caution, and greater interest may be given to the role of education level in future work as a key consumer demographic.

6. Conclusions

To the best of our knowledge, this is one of the first studies to directly explore the consumer acceptability of seaweed-based food products in the UK. Results indicate that consumers perceived hypothetical seaweed-based products to be tastier/ more edible than a general description of seaweeds as a food source. Taste/ edibility and familiarity were highlighted as strong drivers of acceptability, with taste/ edibility in particular identified as an attribute that could further enhance acceptance in consumers, and potentially mitigate the effects of food neophobia as a barrier to acceptance. Results suggest that consumers in the UK are accepting of seaweeds, and this study identifies scope for future research to further explore product development strategies for seaweed-based foods.

7. Availability of data and materials

The datasets generated and analysed during the current study are available in the Open Science Framework repository, https://osf.io/jy897/.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2022.104613.

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