

Perception and acceptance of high seaweed content novel foods (*Ulva* spp. and *Undaria pinnatifida*) across New Zealand and Singaporean consumers

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ARTICLE INFO

Keywords:

Ulva spp.
Undaria pinnatifida
Consumer study
Cultural differences
New Zealand
Singapore
Product acceptance
Emotional response
Sensory evaluation

ABSTRACT

Edible seaweeds are gaining global popularity as nutritious and sustainable food sources, extending beyond Asian into Western diets. To investigate consumer perception and acceptance of high seaweed content foods, two novel products, seaweed dumplings and pasta, were developed using the mixture of *Ulva* spp. and *Undaria pinnatifida* as a primary ingredient. Consumer evaluations were conducted in New Zealand (NZ, $n = 157$) and Singapore (SG, $n = 176$). Results showed low overall liking and willingness to purchase for both products in each country, though NZ consumers rated them more positively in terms of liking, healthiness and sustainability than SG consumers. Willingness to purchase was positively correlated with ratings of liking, healthiness, and sustainability. Emotional responses differed by country and product, with more NZ participants reporting positive emotions (e.g., pleased, happy, hopeful and loving) and dumplings evoking more activate emotions (e.g., energetic, shocked and amazed). Umami taste enhanced overall liking in both countries, while slimy texture (NZ) and fish-like flavour (SG) decreased overall liking. These results underscore the current challenges in consumer acceptance of high seaweed content novel foods, but also highlight cross-cultural differences that can guide the development of seaweed-based foods in global markets.

1. Introduction

Marine macroalgae, or seaweeds, are plant-like organisms that generally live attached to hard substrata in coastal areas (Kılınc et al., 2013). *Undaria pinnatifida* (brown seaweed, trading name: Wakame) is the most common and widely distributed species in the genus *Undaria*. It is native to the northwestern Pacific coast, but, as an invasive species, it occurs widely around the world and can now be found in New Zealand due to accidental introduction and cultivation (Tiwari and Troy, 2015).

Ulva spp. (green seaweed, trading name: Sea lettuce) is prevalent in Singapore (Lee et al., 2015). Seasonally, *Ulva* spp. experience explosive growth, forming a thick soft 'green carpet' that blankets shores in Singapore (Wild Singapore, 2013). Due to its health benefits and environmental advantages, seaweeds are gaining attention as a sustainable and nutritious food source (Mahadevan, 2015).

Nutritionally, seaweeds are known for their richness in polysaccharides, minerals and certain vitamins (Ito and Hori, 1989; Mabeau and Fleurence, 1993; Rajapakse and Kim, 2011). Additionally, lipid

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<https://doi.org/10.1016/j.fufo.2024.100511>

Received 31 October 2024; Received in revised form 24 November 2024; Accepted 26 November 2024

Available online 28 November 2024

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content is very low for all seaweed species, making it a low-calorie food option (Fleurence, 2016). Despite variation in protein content across seaweed species and seasons, the protein levels in *Ulva* and *Undaria* species are comparable to those of common vegetables (Fleurence et al., 2018; Murata and Nakazoe, 2001). Environmentally, seaweed farming is more sustainable than land-based agriculture, requiring fewer resources like water, fertilizer, and land (Mahadevan, 2015; Tiwari and Troy, 2015), though it is recognised as having some social and environmental impacts globally (Spillias et al., 2023).

Asian countries, including China, Korea, and Japan, have a long history of seaweed application as a food providing valuable nutrition for over 2000 years (Rajapakse and Kim, 2011; Tiwari and Troy, 2015). In New Zealand, prior to the arrival of European immigrants in the early 1800s, the traditional Māori diet has incorporated seaweeds, both as food and medicine, e.g. *Ulva* spp., *Porphyra* spp., *Gigartina* spp. and *Durvillaea antarctica* (Smith et al., 2010). In most European countries, however, no tradition of eating seaweeds existed (Ito and Hori, 1989) and the use of seaweed as a vegetable remained marginal (Fleurence, 2016; Wendin and Undeland, 2020). During the past few decades, the popularity of traditional Asian seaweed-containing dishes, such as sushi and ramen, has increased worldwide, introducing seaweeds to new consumers (Blikra et al., 2021). The consumption of seaweed products has increased in European countries (Kılınç et al., 2013) and a growing range of seaweed containing food products is available in the European grocery market (Bouga and Combet, 2015). Since seaweed exhibits distinct sensory characteristics (Figueroa et al., 2021; Mabeau and Fleurence, 1993), several studies have focused on sensory acceptance and purchase-intent of seaweed foods in Western countries (Bhattarai et al., 2024; Birch et al., 2019; Chapman et al., 2015; Losada-Lopez et al., 2021; Moss and McSweeney, 2021; Palmieri and Forleo, 2022; Wendin and Undeland, 2020). However, to date, no studies have evaluated the acceptance and sensory perceptions of high seaweed content novel foods using *Ulva* spp. and *Undaria pinnatifida* as the primary ingredients. Increased seaweed concentration would amplify the nutritional and sustainability benefits of such novel foods, filling a gap in seaweed-based food product development.

Food globalisation has made diverse foods more accessible across the world and hence understanding food acceptance across cultures is crucial when introducing new products in today's diverse and competitive markets (Lee and Lopetcharat, 2017). Cross-cultural differences in food preference and sensory perception play a significant role in how foods are perceived and accepted in different cultures for a variety of reasons including genetic variation (Doty, 1986; Feeney et al., 2021), social values (Birch, 1999; Meyer-Rochow and Jung, 2020; Olivadese and Dindo, 2023), cognitive styles (Beekman et al., 2022; Nisbett et al., 2001), and historical food practices (Hong et al., 2014; Jeong and Lee, 2021; Torrico et al., 2019). Additionally, a healthy and environmentally sustainable diet cannot be universally defined, as dietary practices are deeply influenced by local climate, geography, economics, and cultural identity (Biesbroek et al., 2023). In the context of novel foods, cultural backgrounds shape concepts of novelty and familiarity depending on food variety and availability (Kudo, 2008), hence influencing how consumers from different cultures respond to foods.

The objectives of this study were to investigate the perceived sensory profiles, acceptance, and emotional responses to two high seaweed content novel foods, using a mixture of *Ulva* spp. and *Undaria pinnatifida* as a primary ingredient, across two different cultures: New Zealand, representing a Western culture and Singapore, often referred to as the gateway to Southeast Asian food markets (Ko, 2013).

2. Methods

Ethics approvals were obtained from Massey Human Ethics Committee (reference OM1 23/26) on 11 September 2023, and A*STAR Institutional Review Board (reference 2023-106) on 30 August 2023 for data collection in New Zealand (NZ) and Singapore (SG), respectively.

All procedures were performed in compliance with relevant laws and institutional guidelines.

2.1. Participants

Participants were recruited in NZ via the Food Experience and Sensory Testing laboratory's consumer database, and in SG via the Singapore Institute of Food and Biotechnology Innovation's consumer database, the National University of Singapore notice boards and word of mouth. The following inclusion criteria were set and assessed through a screening survey: i) aged between 18 and 55 years in NZ and between 21 and 55 in SG, ii) able to communicate effectively in English, iii) not allergic or intolerant to any of the sample ingredients, iv) not pregnant nor lactating, and v) willing to try samples containing seaweed. The latter criterion was to exclude participants who may not wish to consume seaweed. Each participant took part in a 30 min session. Participants gave written informed consent and were offered either a supermarket voucher (NZ), or cash reimbursement (SG), upon session completion to compensate for their time.

2.2. Product development and preparation

Two novel food products using a mixture of *Ulva* spp. and *Undaria pinnatifida* as a primary ingredient were developed by a professional chef partnering on the project in a commercial food-grade kitchen (The Development Kitchen, Wellington, New Zealand), which met WHO food safety and NZ Food safety requirements (FAO and WHO, 2021; Ministry for Primary Industries, 2023). Asian style dumplings and Western style pesto-pasta were developed with seaweed comprising at least one-third of their wet weight. For seaweed dumplings, seaweed was processed into the casing and the stuffing, and for seaweed pasta, seaweed was processed into the pasta and the pesto. Seaweed made up 40.4 % and 53.6 % of the total wet weight of seaweed dumplings and pasta, respectively. Images of the products and ingredient lists are presented in supplementary material S1 and S2. All uncooked materials were stored frozen at -20°C for up to 6 weeks prior to cooking for the sensory evaluation.

The seaweed ingredient was a mix of commercially available *Ulva* spp. (Chlorophyta) and *Undaria pinnatifida* (Phaeophyceae), harvested from NZ coastal areas (AgriSea NZ Ltd, New Zealand), and wild-harvested *Ulva* spp. from Chek Jawa, Pulau Ubin, and Changi Beach in SG. Wild harvesting was conducted under a research collection license and in consultation of a marine biologist from the National University of Singapore. To reduce the heavy metal content, the seaweed was prepared by soaking in water for 1 min, followed by boiling for 20 min. The boiled seaweed was subsequently strained through a muslin cloth and then pressed for 3 h in a chiller maintained at 4°C to remove excess moisture and any contaminants. The samples were tested for microbial, iodine and heavy metal contents (aluminium, antimony, inorganic arsenic, total arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver, tin, thallium, zinc) to ensure they met safety requirements established for seaweed products (FAO and WHO, 2021; Ministry for Primary Industries, 2023).

A trial study was conducted to confirm cooking times of the samples. Dumplings were steamed from frozen for 8 min using a Thermomix in NZ and a steaming basket over a pot of boiling water for 10 min in SG. Pesto was defrosted for ~ 60 min prior to sample preparation. Pasta was boiled for 8 min and mixed with the defrosted pesto prior to serving at a ratio of 60 g pesto per 100 g of boiled pasta. To bind the pasta and pesto, 7.5 g of salted boiling water was added. All samples were prepared just prior to the session, covered with aluminium foil and coded with a random three-digit code, and held in a food warmer heated to $50 \pm 5^{\circ}\text{C}$.

2.3. Sensory attribute selection

Sensory attributes to describe the developed seaweed products were

compiled from the literature (Sánchez-García et al., 2021; Figueroa et al., 2022). Furthermore, attributes related to the other ingredients were added to the flavour modality of the lexicon, as well as terms deemed appropriate by the researchers based on sample tastings prior to the session. Internal bench testing sessions were conducted in NZ and SG to evaluate attribute and identify any missing attributes. Researchers assessed samples monadically, selecting terms relevant to each product using a check-all-that-apply (CATA) approach. Researchers were asked to note additional and redundant sensory attributes they perceived for each product. As a result, ‘chunky’ appearance and texture were added, and rough appearance, crispy, crunchy, gritty and rough texture were removed since they were irrelevant to the products. A consensus was reached across NZ and SG. The final list included 34 attributes (Table 1) covering appearance (4 attributes), taste (5 attributes), flavour (16 attributes), and texture (9 attributes) modalities.

2.4. Emotion term selection

An emotion lexicon to assess emotional response to meat alternatives (Orr et al., 2023) was used to measure emotional response in the current study. Although the lexicon was not developed specifically for seaweed-based foods, it was employed due to its relevance to wider alternative food categories (Giezenaar et al., 2024). This lexicon also included terms missing from other generic lexicons but relevant to novel foods, such as ‘amazed’, ‘deceived’ and ‘suspicious’ (Table 1). During the internal bench testing sessions with NZ and SG researchers, emotion terms were checked for applicability and relevance. ‘Shocked’ and ‘surprised’ were deemed relevant and were added to the existing lexicon, making a full list of 26 emotions (Table 1).

2.5. Study session and questionnaire

All participants evaluated the seaweed dumplings and seaweed pasta samples for: 1) overall liking and liking of appearance, flavour, and texture; 2) emotional response; and 3) sensory characterisation of appearance, taste, flavour, and texture. Samples were presented monadically according to a balanced design in both NZ and SG. Participants were not informed what the products were designed to resemble

Table 1

Appearance, taste, flavour and texture sensory attributes, and emotional terms present in CATA lexicons.

Appearance	Taste	Flavour	Texture	Emotion
Chunky	Bitter	Basil	Chewy	Adventurous
Green colour	Salty	Cabbage	Chunky	Afraid
Oily	Sour	Cheese	Elastic	Amazed
Soft	Sweet	Chilli	Firm	Angry
	Umami	Coriander	Holds together	Anxious
		Fish-like	Oily	Bored
		Garlic	Slimy	Calm
		Ginger	Soft	Curious
		Mushroom	Sticky	Deceived
		Nutty		Disappointed
		Ocean-like		Disgusted
		Off-flavour		Dissatisfied
		Sesame		Energetic
		Soy sauce		Happy
		Vinegar		Hopeful
		Wheat		Hungry
				Loving
				Neutral
				Nostalgic
				Pleasant
				Satisfied
				Shocked
				Surprised
				Suspicious
				Uncertain
				Unhappy

(i.e. dumplings or pasta) to avoid expectation bias, rather that they were going to be tasting two seaweed-based products.

Each participant was served two half dumplings and two 10 g dishes of pasta pesto. One portion of each product was used to evaluate affective response, the rest to evaluate sensory characteristics. During the session, filtered water and plain crackers were provided as palate cleansers. In between products, a minimum 1-minute break was enforced for palate cleansing, minimising carry over effects.

Study sessions took place in ISO standard (ISO 8589:2007) sensory booths under white light. Data was collected using Compusense Cloud® Software (Compusense Inc., Ontario, Canada) via iPads. Sensory and emotional terms were considered with participants prior to evaluating to ensure term understanding. For each product, participants first assessed appearance, flavour, texture and overall liking as well as healthiness, sustainability and willingness to purchase (WTP) on a continuous 100-point scale ranging from 0 (representing ‘dislike extremely’, ‘not healthy at all’, ‘not sustainable at all’ or ‘not willing at all’) to 100 (representing ‘like extremely’, ‘extremely healthy’, ‘extremely sustainable’ or ‘extremely willing’), with a midpoint (representing ‘neither like nor dislike’, ‘neither healthy nor unhealthy’, ‘neither sustainable nor unsustainable’ or ‘neither willing nor unwilling’). Participants then evaluated the emotional responses and sensory profile of the product, using CATA. Participants were instructed to “Select the emotion terms that describe how the sample makes you feel”, and “Select the sensory attributes that describe the sample”. The order of emotion terms and sensory attributes was presented according to a Williams Latin Square across participants but was fixed for each participant for both products. Finally, participants completed a survey asking demographics (age and gender), attitude towards new foods and seaweed consumption frequency. To measure attitudes towards new foods, four items from each of the Variety Seeking Behaviour (Van Trijp and Steenkamp, 1992) and the Food Neophobia Scale (Pliner and Hobden, 1992) were included as described by Sheen et al. (2023). All questions are listed in supplementary material S3.

2.6. Data analyses

All statistical analyses were performed in R version 4.3.3 using R Studio software version 2023.12.1 (R Core Team, 2024) at an α risk of 0.05.

2.6.1. Variations in perceived sensory attributes, emotional responses and their associated relationships

To determine whether each CATA term (i.e. the sensory attribute or emotional response) within a country differed between products, a Cochran’s Q test was performed, using the nonpar package (Sweet, 2020). A Chi-square test was performed to compare the CATA term

Table 2

Participant numbers, demographic characteristics and food-related measures by country.

	New Zealand	Singapore
Number of participants	157	176
Age (mean \pm sd)	35.4 \pm 9.27	28.7 \pm 6.22
Gender (%)		
Female	72.0 %	54.0 %
Male	26.7 %	46.0 %
Non-binary	1.3 %	0.0 %
FNS ¹ (mean \pm sd)	7.0 \pm 2.16	8.7 \pm 2.95
VARSEEK ² (mean \pm sd)	15.8 \pm 2.33	15.4 \pm 2.58
Seaweed consumption frequency (%)		
Never	9.6 %	5.1 %
\leq once per month	43.3 %	43.8 %
$>$ once per month	29.9 %	35.2 %
\geq once per week	17.2 %	15.9 %

¹ FNS = Food Neophobia Scale score, ranging from 4 to 20.

² VARSEEK = Variety Seeking Behaviour score, ranging from 4 to 20.

within a product between countries. Alternatively, Fisher’s exact test was used when one or more cells had expected counts less than five.

Additionally, a correspondence analysis was performed on emotional responses of the four product/country combinations, using citation proportions of emotional responses and sensory attributes. with sensory attributes as supplementary variables

2.6.2. Variations in liking, healthiness, sustainability and WTP ratings

To determine product and country differences in appearance, flavour, texture and overall liking as well as perceived healthiness, sustainability and WTP ratings, a linear model, with participant

responses as the response variables; product and country as the fixed factors, allowing for their interaction, was performed using the lm() function. When a significant main effect or interaction was found, post hoc Tukey tests with adjustments for multiple comparisons were conducted using the emmeans package (Lenth, 2024).

2.6.3. Correlations among liking, healthiness, sustainability and WTP ratings

Combining data from seaweed dumplings and pasta, Pearson’s correlations between liking scores, healthiness, sustainability, and WTP ratings, as well as Variety Seeking Behaviour score (VARSEEK) and Food

Table 3

Sensory attribute citation proportions by country for each product, Cochran’s Q test for comparing responses between products within countries, and Chi-square test for comparing products between countries.

	New Zealand			Singapore		
	Dumpling	Pasta	Q test <i>p</i> value	Dumpling	Pasta	Q test <i>p</i> value
Appearance						
Green colour	0.962	0.987	0.102	0.932	0.989	0.004
Soft	0.860	0.662	< 0.001	0.920	0.722	< 0.001
Oily	0.191	0.777	< 0.001	0.216	0.670	< 0.001
Chunky	0.433	0.516	0.128	0.307	0.472	< 0.001
Taste						
Umami	0.611	0.541	0.152	0.636	0.438	< 0.001
Salty	0.618	0.490	0.011	0.676	0.307	< 0.001
Sour	0.376	0.025	< 0.001	0.438	0.028	< 0.001
Bitter	0.127	0.032	0.002	0.108	0.142	0.303
Sweet	0.096	0.108	0.655	0.091	0.034	0.033
Flavour						
Mushroom	0.522	0.261	< 0.001	0.534	0.545	0.819
Garlic	0.427	0.554	0.010	0.460	0.398	0.166
Basil	0.121	0.720	< 0.001	0.216	0.636	< 0.001
Chili	0.758	0.038	< 0.001	0.835	0.023	< 0.001
Ocean-like	0.580	0.306	< 0.001	0.358	0.256	0.020
Soy sauce	0.465	0.210	< 0.001	0.483	0.131	< 0.001
Nutty	0.153	0.471	< 0.001	0.091	0.347	< 0.001
Wheat	0.140	0.312	< 0.001	0.108	0.483	< 0.001
Vinegar	0.382	0.045	< 0.001	0.545	0.034	< 0.001
Fish-like	0.363	0.159	< 0.001	0.216	0.136	0.031
Sesame	0.140	0.318	< 0.001	0.148	0.233	0.047
Coriander	0.108	0.153	0.223	0.278	0.176	0.022
Ginger	0.236	0.057	< 0.001	0.335	0.034	< 0.001
Cabbage	0.153	0.096	0.095	0.210	0.136	0.063
Cheese	0.070	0.178	0.001	0.045	0.091	0.059
Off-flavour	0.006	0.032	0.102	0.023	0.045	0.157
Texture						
Soft	0.892	0.822	0.071	0.920	0.909	0.637
Sticky	0.662	0.350	< 0.001	0.710	0.591	0.013
Slimy	0.427	0.401	0.593	0.489	0.722	< 0.001
Holds together	0.465	0.414	0.310	0.301	0.278	0.564
Oily	0.121	0.631	< 0.001	0.142	0.540	< 0.001
Chewy	0.312	0.287	0.579	0.426	0.352	0.085
Chunky	0.318	0.408	0.061	0.256	0.256	1.000
Elastic	0.204	0.070	< 0.001	0.114	0.068	0.088
Firm	0.089	0.134	0.178	0.034	0.068	0.134

Shading indicates significant differences between countries within seaweed dumplings (light shades) or seaweed pasta (dark shades) according to Chi-square test (*p* < 0.05).

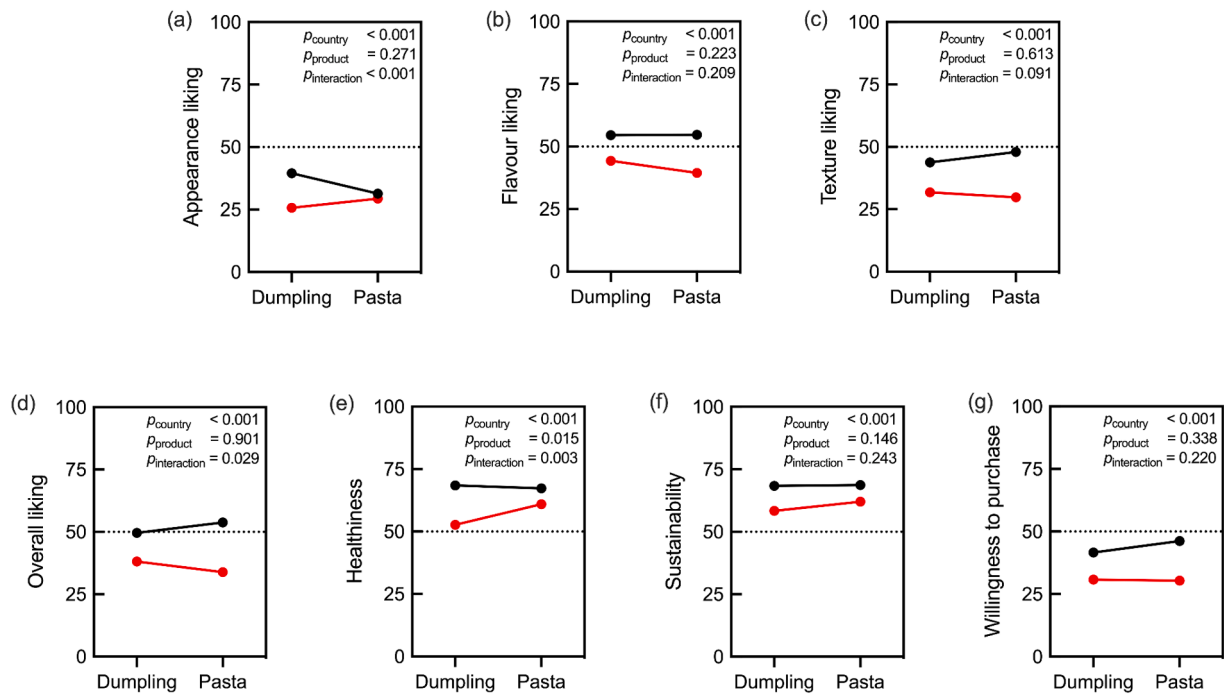


Fig. 1. Appearance liking (a), flavour liking (b), texture liking (c), overall liking (d), healthiness (e), sustainability (f) and willingness to purchase (g) ratings of the products evaluated by New Zealand (black) and Singapore (red) participants.

Neophobia Scales score (FNS) were determined for NZ and SG, respectively.

2.6.4. Sensory drivers of overall liking

Penalty-lift analysis was performed to determine the mean impact of sensory attributes on overall liking with a minimum of 10 % citation proportion (Meyners et al., 2013)

3. Results

3.1. Participants

Table 2 presents the participant characteristics. In general, NZ participants were older ($p < 0.001$) and comprised more females ($p < 0.001$). SG participants scored significantly higher on FNS ($p < 0.001$) but have similar VARSEEK as NZ participants ($p = 0.116$). Cronbach's alpha was 0.69 and 0.73 for FNS and VARSEEK, respectively. Seaweed consumption frequency was not significantly different across countries ($p = 0.381$) with about 50 % of the participants consuming seaweed

Table 4
Pearson's correlation matrix of New Zealand and Singapore participants evaluating the products.

	Appearance liking	Flavour liking	Texture liking	Overall liking	Healthiness	Sustainability	WTP	FNS
New Zealand								
Flavour liking	0.36***							
Texture liking	0.42***	0.69***						
Overall liking	0.41***	0.87***	0.80***					
Healthiness	0.15**	0.31***	0.32***	0.34***				
Sustainability	0.20***	0.34***	0.30***	0.37***	0.64***			
WTP ¹	0.42***	0.78***	0.75***	0.85***	0.31***	0.34***		
FNS ²	-0.03ns	-0.09ns	0.01ns	-0.10ns	0.04ns	-0.04ns	-0.08ns	
VARSEEK ³	0.15**	0.18**	0.04ns	0.18**	0.02ns	0.10ns	0.17**	-0.58***
Singapore								
Flavour liking	0.30***							
Texture liking	0.36***	0.59***						
Overall liking	0.35***	0.88***	0.73***					
Healthiness	0.19***	0.31***	0.29***	0.37***				
Sustainability	0.21***	0.29***	0.25***	0.32***	0.59***			
WTP	0.42***	0.79***	0.70***	0.88***	0.40***	0.34***		
FNS	-0.21***	-0.20***	-0.15**	-0.22***	-0.21***	-0.27***	-0.23***	
VARSEEK	0.16**	0.22***	0.09ns	0.19***	0.12*	0.26***	0.19***	-0.65***

ns : $p \geq 0.05$;
 * : $p < 0.05$;
 ** : $p < 0.01$;
 *** : $p < 0.001$.

¹ WTP = Willingness to purchase.

² FNS = Food Neophobia Scale score.

³ VARSEEK = Variety Seeking Behaviour score.

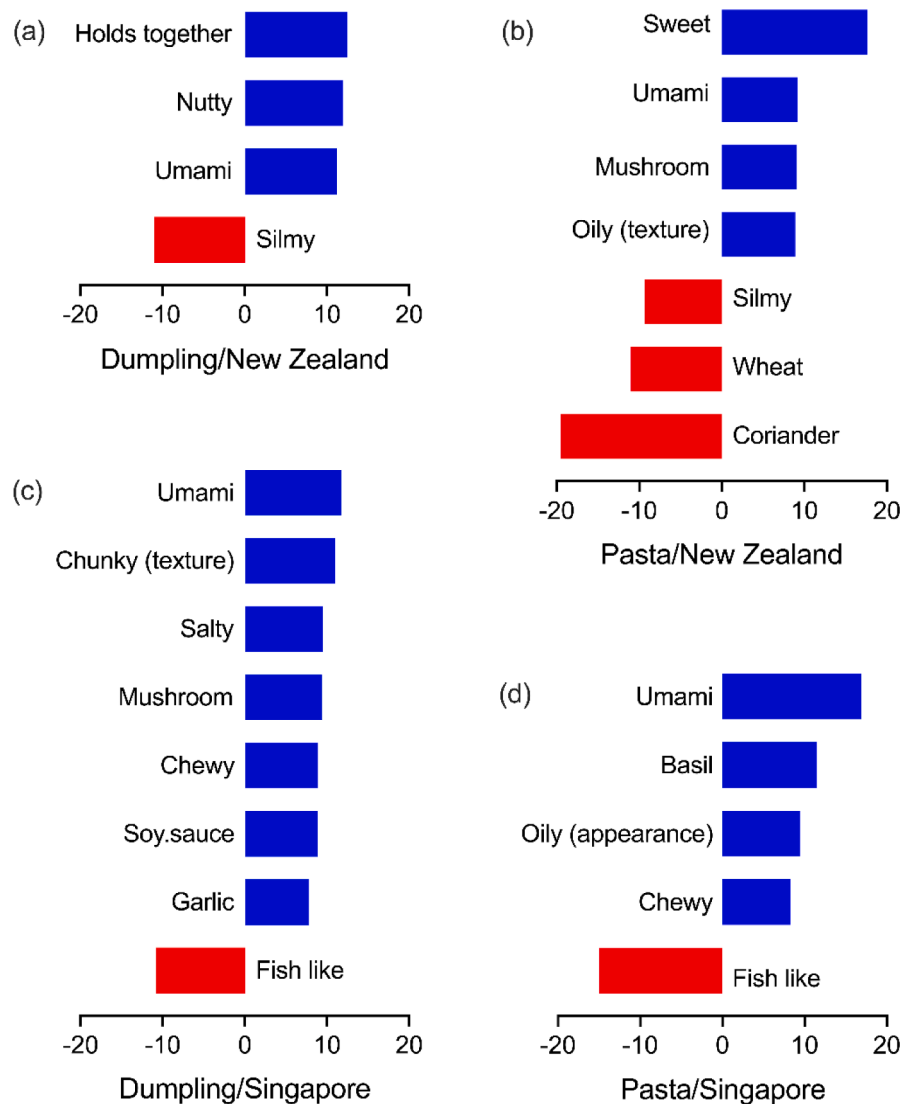


Fig. 2. Sensory attributes, with citation proportion > 10 %, significantly impacting overall liking (100-point scale) of the products in New Zealand and Singapore from Penalty-Lift analysis ($p < 0.05$).

more than once per month.

3.2. Sensory characterisation

Substantial sensory differences existed between the products (Table 3). In both countries, more participants perceived soft appearance, salty and sour tastes, chili, ocean-like, soy sauce, vinegar, fish-like and ginger flavours, and sticky texture in the dumplings than in the pasta; more participants perceived oily appearance, basil, nutty, wheat and sesame flavour, and slimy and oily texture in the pasta than in the dumpling. Additionally, significant differences existed between countries, although these were generally product dependent. For example, for pasta, significantly more NZ participants perceived an oily appearance ($p = 0.041$) and sweet taste ($p = 0.014$), whilst more SG participants perceived mushroom flavour ($p < 0.001$). For the dumpling, more NZ participants perceived ocean-like ($p < 0.001$) and fish-like flavour ($p = 0.004$) and more SG participants perceived basil ($p = 0.032$), vinegar ($p = 0.004$) and coriander flavours ($p < 0.001$). NZ participants were more likely to check 'holds together' texture in both dumplings ($p = 0.003$) and pasta ($p = 0.013$).

3.3. Liking, healthiness, sustainability and WTP ratings

Liking scores for both products were generally low (Fig. 1). NZ participants scored higher than SG participants for all likings except for pasta appearance where no significant difference existed between countries (Fig. 1a, $p_{interaction} < 0.001$). A significant interaction between country and product indicated that the difference in overall liking between countries was greater for pasta than for the dumplings (Fig. 1d, $p_{interaction} < 0.001$). Demographic factors, such as gender and seaweed consumption frequency had no significant effects on liking scores.

On average, participants rated product healthiness and sustainability positively for both products, but WTP was low. NZ participants rated dumplings and pasta similarly and significantly higher than SG counterparts for these three aspects. The interaction between country and product on healthiness was significant, suggesting a greater difference between countries in perceived healthiness of dumplings compared to pasta (Fig. 1e, $p_{interaction} = 0.003$).

Pearson's correlation coefficients amongst the above measurements and their associated significance levels are presented in Table 4. The liking of flavour, texture and overall as well as WTP were highly correlated within NZ ($r \geq 0.69$, $p < 0.001$) and SG ($r \geq 0.59$, $p < 0.001$), respectively. Perceived healthiness and sustainability were also

positively correlated with overall liking and WTP, although coefficients were low: ≥ 0.31 in NZ and $r \geq 0.32$ in SG, all $p < 0.001$. Notably, FNS was negatively correlated with likings, healthiness, sustainability and WTP ratings in SG, but not in NZ.

3.4. Sensory drivers of liking

Penalty/Lift analyses on seaweed dumplings and pasta by NZ and SG participants are presented in Fig. 2. Generally, umami taste positively drove overall liking of both products in both countries. For the dumplings, 'holds together' texture and nutty flavour drove overall liking up in NZ (Fig. 2a), whilst chunky and chewy texture, salty taste, and mushroom, soy sauce and garlic flavour drove overall liking up in SG (Fig. 2c). For the pasta, sweet taste, mushroom flavour and oily texture had positive impacts on overall liking in NZ (Fig. 2b), whilst basil flavour, oily appearance and chewy texture had positive impacts in SG (Fig. 2d). Slimy texture negatively impacted overall liking of both products in NZ (Fig. 2a&b) and fish-like flavour impacted overall liking negatively for both products in SG (Fig. 2c&d). Additionally, wheat and coriander flavour drove overall liking of pasta down significantly in NZ.

3.5. Emotional responses

Emotional responses were categorised into positive, negative and 'undefined' categories, and are presented in descending order of overall citation proportions within each category in Table 5. In NZ, the pasta evoked more positive emotions (e.g. calm) and the dumplings evoked more negative emotions (e.g. unhappy). By contrast, in SG, the pasta evoked more negative emotions (e.g. disappointed), whilst the dumplings evoked more positive emotions (e.g. adventure). The number of positive emotions that were significantly different between countries was greater for the pasta than the dumplings.

3.6. Correspondence analysis

Fig. 3 shows the emotion correspondence analysis biplot, illustrating the space spanned by the first and second dimensions which accounted for 93.0 % of the inertia in the data. Dimension 1 (56.6 %) represented emotion valence (feeling of pleasure or displeasure) and Dimension 2 (36.4 %) represented emotion arousal (feeling of activation or deactivation). In general, positive emotions (e.g. loving, hopeful, pleasant, happy and satisfied) were positioned closer to NZ responses (upper and lower right quadrants), whilst negative emotions (e.g. disgusted, deceived, dissatisfied and disappointed) were positioned close to SG responses (upper and lower left quadrants). The lower quadrants indicated that the dumplings evoked more activated emotions (e.g. energetic, amazed, shocked and surprised). Conversely, the upper quadrants showed that the pasta evoked deactivated emotions (e.g. bored, calm and neutral). Sensory attributes mapped mainly along the y-axis, highlighting the differences between the dumplings (characterised by chili, vinegar, ginger flavour, sour taste, etc.) and pasta (characterised by oily texture, basil flavour, oily appearance, etc.). Along the x-axis, NZ responses were positioned close to comparatively more pleasant attributes, including firm texture, sweet taste and cheese flavour, compared to off-flavour, bitter taste and slimy texture, which were positioned closer to SG responses.

4. Discussion

Edible seaweed is an alternative food source rich in essential nutrients and bioactive compounds, making it a promising addition to human diets (Brown et al., 2014; Holdt and Kraan, 2011; Rajapakse and Kim, 2011). Common products incorporating seaweed are snacks, bread, soups, seasonings, but at a relatively low addition (Nova et al., 2020). Here, with a view to increase the products' nutrition and sustainability credentials, two high seaweed content novel food products were

developed using *Ulva* spp. and *Undaria pinnatifida* and evaluated. Cross-cultural differences in response to the products were observed with NZ participants demonstrating higher acceptance than those from SG. However, neither country rated the products highly in terms of liking or WTP, indicating that further optimisation of the sensory characteristics is needed to successfully incorporate higher levels of seaweed into novel foods.

4.1. Seaweed consumption

In previous studies, the proportions of consumers have ever consumed seaweed were 36 % in Spain, (Losada-Lopez et al., 2021), 57 % in Italy (Palmieri and Forleo, 2020) and 75 % in Australia (Birch et al., 2019). In this study, 93 % of the participants had consumed seaweed (90 % in NZ and 95 % in SG) but this high figure is likely due to the study only recruiting participants 'willing to try samples containing seaweed' as opposed from a general population where rates may be lower. Additionally, similar seaweed consumption frequencies were found in NZ and SG, even though Asian consumers are generally more familiar with seaweed as a food than Western consumers (Ito and Hori, 1989; Merkel et al., 2021).

4.2. Acceptability

Previous studies have reported positive attitudes towards seaweed food consumption and its purchase as a novel food (Moss and McSweeney, 2021; Palmieri and Forleo, 2020; Wendin and Undeland, 2020). Notably, those studies were survey-based with no sensory evaluation (i.e. sample tastings) conducted. In the present study, however, low overall liking of both seaweed dumplings and pasta were observed. In line with past studies (Embling et al., 2022; Wendin and Undeland, 2020; Young et al., 2022), sensory properties of seaweed were not particularly liked, and their substantial impacts on emotional responses likely contributed to the observed low WTP. Other sensory studies involving inclusion of seaweed in cookies, pasta and fishcakes reported no negative effect on sensory acceptability, but their seaweed concentrations were much lower (2 % ~ 5 % w/w) (Batista et al., 2017; Chapman et al., 2015; Prabhasankar et al., 2009). Overall liking dropped significantly with increasing seaweed content (Prabhasankar et al., 2009), supporting findings in the present study that higher seaweed concentrations are less acceptable. In this study, the seaweed products were purposely developed using *Ulva* spp. and *Undaria pinnatifida* as the main ingredient (40.4 % w/w in dumplings and 53.6 % w/w in pasta), but low overall liking and WTP confirmed that incorporating seaweed into foods is challenging due to its sensory impact (Roohinejad et al., 2017).

Results suggested that acceptability of the products was higher in NZ than SG, which may be linked to NZ participants' higher perceived healthiness and sustainability ratings. Losada-Lopez et al. (2021) suggested that seaweed's credence attributes such as its health and natural properties potentially encouraged consumers to undertake new experiences. The higher acceptance in NZ could also reflect the higher biospheric concerns in Western consumers as opposed to Asian consumers (Govaerts and Ottar Olsen, 2023; Milfont, 2012).

Previous studies have reported negative impacts of food neophobia on consumer intention to eat edible seaweed, thereby affecting their satisfaction and willingness to consume (Al-Thawadi, 2018; Birch et al., 2019; Losada-Lopez et al., 2021). However, in this study, FNS were considerably low in both NZ and SG, potentially due to the recruitment criterion that participants must be willing to try seaweed containing samples. In this study, likings, perceived healthiness, sustainability and WTP ratings were negatively correlated with FNS in SG, but not in NZ. This discrepancy may be due to the products' higher perceived healthiness and sustainability credentials amongst NZ participants, which may offset any remaining effects of food neophobia. Similarly, Blikra et al. (2021) suggested that society can overcome food neophobia by realising

other benefits of a food. Also, Moss and McSweeney (2021) found no significant effects of food neophobia on edible seaweed purchase-intent of Canadian consumers, who also associated seaweed with many health benefits.

Familiarity is reported to be a driving factor for seaweed foods acceptance (Birch et al., 2019; Embling et al., 2022; Palmieri and Forleo, 2020). Familiarity was not explicitly assessed in this study, but the selection of the dumplings and pasta was carried out to represent familiar food formats in SG and NZ, respectively. However, the products evaluated in this study were novel due to their high seaweed contents. It appeared that the expected food format familiarity effect on acceptance was minimal in this study. Neither the dumplings nor pasta format led to a significantly higher likings in either country. It is postulated that the high seaweed content impacted the sensory experience to such an extent that the unfamiliarity of the appearance, texture and flavour outweighed any impact of the food format familiarity.

4.3. Emotional responses

Consumer food choice has an emotional component that significantly influences preference and purchasing decisions (Ferrarini et al., 2010; Ng et al., 2013; Samant and Seo, 2020). Past studies suggested that consumer hedonic liking and emotional responses to foods are highly related (King and Meiselman, 2010; Ng et al., 2013). Similarly, in this study, NZ participants, who had higher likings scores than their SG counterparts, evoked greater positive and lower negative emotions. Additionally, even though product differences in overall liking were not significant within each country, significant product differences in emotional response were occasionally observed within countries, providing additional information beyond liking (Ng et al., 2013). Specifically, within the country, pasta in NZ and dumplings in SG evoked more positive emotions, such as calm and adventure respectively, whereas dumplings in NZ and pasta in SG caused more negative emotions, such as unhappy and disappointed respectively. These observations likely reflect the respective familiarity of the food format in their own culture (Jeong and Lee, 2021), even though participants were not familiar with the novelty of the seaweed's presence.

In agreement with previous studies (Dupas de Matos et al., 2025; Ng et al., 2013), correspondence analysis resulted in two dimensions representing emotion valence and arousal, respectively. Dimension 1 mainly separated countries, with NZ situated closer to positive emotions, and it is in line with findings of the overall liking. Dimension 2 mainly separated products with the seaweed dumplings positioned closer to activated emotions. Activated emotions have previously been associated with intense and spicy flavours (Giezenaar et al., 2024). Similarly, in this study, the flavours of chili, ginger and vinegar as ingredients in the dumplings, were likely responsible for evoking activated emotions.

4.4. Sensory attributes

Not surprisingly, substantial sensory differences were found between the products as they used different ingredients in addition to seaweed. Perceived sensory attributes also differed between countries but were product dependent. Specifically, except 'holds together', significant country differences in sensory perceptions were found in either dumplings or pasta, but never both, likely reflecting different levels of product format familiarity and/or their expectations (Jeong and Lee, 2021).

Despite more SG participants perceiving umami in the dumplings than pasta, umami was a driver of overall liking for both products in both countries. Seaweed is a rich source of glutamic acid perceived as umami and enhances food palatability (Figueroa et al., 2021). Mushroom flavour positively impacted overall liking of the pasta in NZ and dumplings in SG. This effect could be attributed to consumer expectations and familiarity with mushroom pasta in NZ (Spoonable Recipes, 2024; Thomas et al., 2022) and mushroom dumplings in SG (Gallani,

2015). The intense colour and fish-like flavour of seaweeds has been reported as a known challenge when incorporating it as a food ingredient (Camacho et al., 2019). In this study, fish-like flavour was less frequently selected by SG participants compared to those in NZ. However, it negatively impacted the overall liking of both products in SG, but not in NZ. This could be due to cross-cultural differences in conceptualisation of the sensory term as reported in other cross-cultural studies. For example, Kim et al. (2018) reported different conceptualisations of the term nuttiness across Asian and Western cultures. In the present study, SG participants may have associated fish-like flavour to the objectionable flavour of fish degradation (e.g. trimethylamine (Wu and Bechtel, 2008)), causing the low overall liking. NZ participants did not indicate a negative impact of fish-like flavour despite selecting it more often. Slimy texture, however, was less frequently selected by NZ participants compared to those in SG. But in NZ, unlike SG, slimy texture significantly reduced the overall liking. This may reflect cross-cultural differences in the perception and acceptance of slimy texture. Generally, slimy textures are considered as one of the most common aversive food textures (Pellegrino and Luckett, 2020) and are more frequently reported as disliked, for example, by US consumers compared to SG consumers (Pellegrino, 2020). In Asian countries, slimy texture in foods is more common and widely accepted. For example, natto from Japan is valued for its sliminess (Freedman, 2016), whilst okra (Sorapong, 2012) and raw Chinese yam (Boateng et al., 2019) are also commonly used slimy food ingredients in Asian cuisine.

4.5. Limitations and future studies

The current study has provided key insights into the acceptance of high seaweed content novel foods using *Ulva* spp. and *Undaria pinnatifida* and some differences in cross-cultural perception. However, a limitation is acknowledged in that other ingredients could have had a determining impact on product acceptability not just the main ingredient, seaweed.

Further studies where varying concentrations of edible seaweed are evaluated are needed to determine the optimal levels of seaweed addition that lead to an acceptable product across different cultures, whilst still providing increased nutritional benefits. Additionally, efforts have recently been directed towards fermenting edible seaweed to mitigate the unappealing traits (Hung et al., 2023). As a result, further studies are needed to evaluate the sensory acceptance of such processed seaweed ingredients.

5. Conclusions

The results of this study, especially the low liking and WTP ratings, indicated that sensory experiences pose a challenge in the acceptance of high seaweed content novel foods using *Ulva* spp. and *Undaria pinnatifida*. Compared with SG, participants in NZ showed higher acceptance as well as higher perceptions of healthiness and sustainability for both dumplings and pasta. Overall liking of both products was positively driven by umami taste in both countries, whereas slimy texture in NZ and fish-like flavour in SG had negative impacts on their overall liking. In terms of emotional response, more NZ participants indicated positive emotions, particularly when evaluating the pasta. The dumplings evoked more activated emotions, whilst the pasta evoked more deactivated ones. In summary, improvement of those high seaweed content novel foods is needed, with special consideration given to cross-cultural differences. For instance, reducing the slimy texture in NZ and minimising the fish-like flavour preserved in SG could be the strategies to enhance overall acceptance and consumer satisfaction.

Ethics statement

Ethics approvals were obtained from Massey Human Ethics Committee (reference OM1 23/26) on 11 September 2023, and A*STAR

Institutional Review Board (reference 2023–106) on 30 August 2023 for data collection in New Zealand (NZ) and Singapore (SG), respectively. All procedures were performed in compliance with relevant laws and institutional guidelines. The privacy rights of participants were observed and informed consent was obtained.

Funding

This work was funded by two NZ Ministry of Business and Education (MBIE) Future Food Catalyst Fund: the joint Massey (Grant number: MAUX2001) and A*STAR (Grant number: A20D3b0075) project ‘Te Rangahau Taha Wheako mō ngā Kai o Āpōpō: The Consumer Dimension of Future Foods’, and the AgResearch (Grant number: C10 × 2002) and A*STAR (Grant number: A20D3b0074) project ‘Cooking and processing of seaweed to improve consumer acceptance, protein digestion and nutrient bioavailability’.

CRediT authorship contribution statement

Ao Chen: Writing – review & editing, Writing – original draft, Formal analysis. **Amanda JiaYing Lim:** Writing – review & editing, Project administration, Methodology, Investigation. **Jia Wen Xanthe Lin:** Writing – review & editing, Project administration, Methodology, Investigation. **Geraldine Oh:** Writing – review & editing, Methodology. **Pey Sze Teo:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation. **Dale Bowie:** Resources. **Santanu Deb-Choudhury:** Supervision, Investigation, Formal analysis, Conceptualization. **Linda M. Samuelsson:** Funding acquisition, Conceptualization. **James Chum Yip Chan:** Funding acquisition. **Siew Bee Ng:** Supervision, Methodology. **Meika Foster:** Supervision, Funding acquisition. **Caroline Giezenaar:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Joanne Hort:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

None.

Acknowledgements

The authors wish to acknowledge the support of Rosie Linklater, Robyn Maggs and Rebekah Orr in organising and conducting the study sessions. We thank AgriSea New Zealand Ltd for in-kind provision of the NZ-harvested *Ulva* and *Undaria* seaweed. We thank A*Star SIFBI Bioactive and Human Health Platform for their in-kind provision of SG wild-harvest *Ulva* seaweed and the National University of Singapore Tropical Marine Science Institute in the Department of Biological Sciences for their technical expertise in identification of the seaweed genus.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.fufo.2024.100511](https://doi.org/10.1016/j.fufo.2024.100511).

Data availability

Data will be made available on request.

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