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Contents

List of Figures

List of Tables

1 Introduction

1.1 Energy Food Supplementation

The oxidation of fat and carbohydrates (CHO) provide the main sources of fuel during physical activity (Gollnick and Matoba 1984). CHO consumption during activity delays fatigue and improves performance through the maintenance of blood plasma glucose and CHO oxidation in the latter stages (Coggan and Swanson 1992). The International Society of Sports Nutrition (ISSN) advises that for extended periods of activity (>70 minutes), CHO should be consumed at a rate of 30-60g/h in a CHO-electrolyte solution (Kersick et al. 2017). Consuming CHO in the form of glucose and fructose simultaneously utilise different transporters, therefore, permit higher CHO absorption via sodium-glucose transporter 1 (SGLT1) and GLUT5 (Baur et al. 2014). CHO gels (energy gels) can provide a practical, concentrated source of energy, often taken before or throughout physical activity (Kreider et al. 2010).

Nutritionally, energy gels should contain at least 15g CHO, achieved from a combination of simple sugar molecules (Moreira et al. 2018). Many mainstream gels typically contain glucose through the addition of maltodextrin (Stevens et al. 2020). However, maltodextrin is a highly processed food additive derived from starch, linked to altering the gut microbiota and can lead to inflammation (Nickerson et al. 2014). The “clean label” trend has created a demand for the use of natural sugars and free from artificial ingredients (Asioli et al. 2017), giving rise to energy brands developing products with natural sugars and flavourings. Rice, date, maple or agave syrup, honey or cane sugar are often incorporated as thickeners, with fruit purees, fresh ginger, citrus fruits, and cacao powder as flavourings (33 Fuel 2021, Huma 2021, Honey Stinger 2021, Spring Energy 2021, Veloforte 2021).

Food gels are viscoelastic mixtures, usually composed of polysaccharides and proteins and held together by inter-molecular forces (Banerjee and Bhattacharya 2012). The consistency of energy gels on the market can vary and reflect consumer preference. Some are highly viscous, compared to the thickness of honey, yet many available gel brands have a higher water content to give a thinner density (Stevens et al. 2020). Gelling agents used within energy gels are generally pectin, gellan or xanthan gum (Moreira et al. 2018, Stevens et al.

2020, SIS 2021) with some natural gel brands using rice flour or chia seeds (Huma 2021, Spring Energy 2021). Rice flour can form particularly strong, rigid gels due to the high concentration of amylose; it is the interaction of amylose and amylopectin molecules producing a network that holds the starch molecules together (Ai and Jane 2018).

1.2 Seaweed Nutrition and Functionality

Seaweeds could be advantageous for the creation of functional foods to support athletic health and performance (Gleeson et al. 2004, Satalic 2016) and there is emerging research on the application of these within sports nutrition. Seaweed supplementation has been shown to reduce the effect of oxidative stress during high intensity resistance exercise in rats, therefore may boost performance and combat exercise induced muscle damage (Korivi et al. 2019). Fucoidan, a bioactive polysaccharide naturally found in a variety of brown seaweeds, may improve gut health, and support the immune function of high performing athletes (Cox et al. 2020).

Laminaria Digitata (Kombu), is an abundant brown seaweed which grows along the shores and coastline of Scotland (Purcell-Meyerink et al. 2021), rich in bioactive compounds such as alginic acid (32.2 g/100g), fucoidan (5.5g/100g), laminarian (14.4 g/100g) and mannitol (13.3 g/100g) (MacArtain et al. 2007). These polysaccharides have prebiotic potential, associated with supporting gut health, immune function with some possessing antioxidant and anti-inflammatory properties (Purcell-Meyerink et al. 2021). The minerals, sodium, magnesium, calcium, potassium, and iodine, contained within this species (MacArtain et al. 2007, Mussig 2009) are among those essential for a range of metabolic and physiochemical processes in the body (Soetan et al. 2010). Periods of intense exercise can result in considerable losses of these via sweat (Smyth and Duntas 2005, Montain 2017) Therefore, the addition of *Laminaria Digitata* within energy food would be advantageous in supporting the health and mineral intake for sporting practitioners.

Alginate, carrageenan, and agar, derived from seaweeds are widely used in the food industry as hydrocolloids as gelling, thickening and emulsifying agents (Qin 2018a). Alginate occurs in brown seaweeds and consist of linear co-polymers of guluronic acid (G) and mannuronic acid (M). Their sequential composition varies among algal species and is responsible for their gel strength (Qin 2018b). The M/G ratio of alginates extracted from

Laminaria Digitata support the formation of soft and elastic gels (Fertah et al. 2017), consequently may contribute positively to the rheology of an energy gel.

1.3 Seaweed Consumption and Acceptance

The addition of seaweed into food products either as an extract or in a powdered form has been shown to improve their nutritional content or positively contribute to their textural and sensory properties (Roohinejad et al. 2017). New food and drink product launches comprising of seaweed is a huge area of growth, increasing by 147% in Europe between 2011 and 2015 (Mintel 2018). This is reinforced by a growing interest in seaweed consumption and acceptance amongst European consumers who view algae as healthy, natural, and interesting (Birch et al. 2019, Lucas et al. 2019, Palmieri and Forleo 2020, Wendin and Undeland 2020). Focus is now shifting to sustainable food systems such as edible seaweeds, providing natural alternatives for protein and other important nutrients (Askew 2018). Recently the European Commission has recognized “aquaculture”, which includes the cultivation of seaweeds for food, as a key driver for sustainable growth and innovation (EC 2021). In terms of sport nutrition research is limited, only two studies for products enriched with *Spirulina* could be identified (Carvalho et al. 2016, Moreira et al. 2018), therefore, gaps exist within the literature. These studies demonstrated that *Spirulina* could be added within food to fuel physical activity and provide nutritional benefits without influencing athlete’s acceptance for the products or impacting sensory characteristics.

Seaweeds can add complex flavours to foods as they are especially rich in umami compounds such as glutamate, aspartate, and inosinate (Mouritsen et al. 2018), *Laminaria Digitata* is especially rich in free glutamate (Milinovic et al. 2021). Umami is widely accepted as the “fifth basic taste”, imparting a savoury characteristic, in addition the umami peptides and derivatives are also known to enhance other tastes and flavours (Zhang et al. 2019). For example, inclusion of 1% sea tangle powder within breakfast sausages received significantly higher sensory scores for flavour compared with a control (Hyun-Wook et al. 2010). However, seaweed addition needs to be managed in terms of appearance. Brown algae gets its main pigmentation from the carotenoid fucoxanthin (Sulistiyani et al. 2021) which is unstable and breaks down during heating, revealing the green pigmentation of chlorophyll (Blikra et al. 2018). Arufe et al. (2017) included brown seaweed powder within a wheat bread formulation, finding the addition significantly increased the green colouration of the bread crust leading to a negative effect on consumer acceptance. Moreira et al. (2018) developed energy gels with the addition of the microalgae *Spirulina* and appearance was deemed to be acceptable with no significant difference in colour reported. However, formulations also included colourants which could have masked any variations.

1.4 Mara Seaweed

Mara Seaweed, founded in 2011 are a company based in Edinburgh who harvest and process seaweed from the coasts of Scotland and Ireland. They produce a range of dried seaweed flakes and powders for seasoning which add depth of flavour to food (Mara Seaweed 2021). Currently they do not have any other food products which contain seaweed within their range therefore there is an opportunity for new food development avenues to expand their offering, including products targeted to sports nutrition. Mara Seaweed have supplied their kombu powder *(Laminaria Digitata)* for use within this study.

1.5 Aims and Objectives

The overall aim of this study is to develop an energy gel from natural ingredients, enriched with kombu powder. The energy gel should be formulated to support physical activity and will be assessed for nutritional relevance. Acceptance for the gel from target consumers will be evaluated via sensory analysis and a consumer survey will determine attitudes and perceptions.

2 Materials and Methodology

2.1 Energy Gel Formulations

The kombu powder (KP) was provided by Mara Seaweed, the remaining ingredients were sourced online with available nutritional information provided on the labelling. A range of energy gels marketed as only using “real food” and “all-natural” ingredients were evaluated for reported nutritional value and used as a guide for the energy gel formulation.

2.2 Prototype Ingredients and Preparation

Pilot work for recipe development was undertaken to test initial prototypes of the energy gel, trialling KP levels, sweetening agents, and flavourings. Formulations in table 1 for versions 1-9 (V1-9). Experiments were carried out to visually examine the solubility and viscosity of the kombu paste by adding cold water or by heating with water.

Table 1. Formulations for prototypes (versions 1-9)

Ingredients	V1	V2	V3	V4	V5	V6	V7	V8	V9
Kombu Powder	2g	2g	2g	2g	1g	1g	1g	1g	1g
Whole dates	10g	0	0	0	0	0	0	0	0
Date Puree	0	0	20g	20g	10g	10g	0	0	0
Date Syrup	0	10g	0	0	5g	5g	0	0	0
Rice Syrup	15g	15g	15g	15g	15g	15g	25g	25g	25g
Agave Nectar	4g	4g	4g	4g	4g	4g	4g	4g	4g
Sea Buckthorn Juice	8g	8g	6g	0	4g	0g	4g	4g	0
Water	5g	5g	5g	5g	5g	5g	10g	30g	30g
Fresh Lemon Juice	0	0	0	4g	0	4g	0	0	4g
Pressed Ginger Juice	0	0	0	0.5g	0	0.5g	0	0	0

New formulations were devised following the results of the prototypes to improve the sensory profile, incorporating rice flour as a thickening agent and alternative flavourings. Ingredients and method including in tables 2 and 3.

Table 2. Formulations for chocolate and sea-buckthorn energy gel (CS1-CS4)

Ingredients	CS1	CS2	CS3	CS4
Kombu Powder	1g	1g	1g	-
Rice Syrup	10g	15g	15g	15g
Rice Flour	6g	6g	6g	6g
Date Syrup	2g	5g	5g	5g
Agave Nectar	-	7g	7g	7g
Maple Syrup	5g	-	-	-
Sea Buckthorn Juice	1g	2g	2g	2g
Cacao Powder	2g	2g	2g	2g
Water	42g	42g	42g	42g
Method	*Flour and water heated (60-80ºC for 10 minutes) forming viscous paste and cooled to 5ºC; remaining ingredients then mixed in*	*All ingredients heated together (60-80ºC for 10 minutes) forming viscous paste - except from kombu and sea-buckthorn which was incorporated once cooled to 5ºC*	*All ingredients heated together (60-80ºC for 10 minutes) - except sea buckthorn which was incorporated once cooled to 5ºC*	*All ingredients heated together (60-80ºC for 10 minutes) - except sea buckthorn which was incorporated once cooled to 5ºC*

Table 3. Formulations for apple and cinnamon energy gel (CS1-CS4)

Ingredients	AC1	AC2	AC3
Kombu Powder	1g	1g	1g
Rice Syrup	10g	14g	14g
Rice Flour	6g	6g	6g
Maple Syrup	5g	-	-
Agave Nectar	5g	5g	7g
Water	42g	42g	42g
Fresh Lemon Juice	1g	1g	1g
Apple Puree	15g	15g	15g
Cinnamon	0.5g	0.5g	0.5g
Method	*Flour and water heated (60-80ºC for 10 minutes) forming viscous paste and cooled to 5ºC; remaining ingredients then mixed in*	*All ingredients heated together (60-80ºC for 10 minutes), forming viscous paste - except from kombu, apple puree, lemon, and cinnamon which was incorporated once cooled to 5ºC.*	*All ingredients heated together (60-80ºC for 10 minutes) forming viscous paste - except from apple puree, lemon, and cinnamon which was incorporated once cooled to 5ºC.*

2.3 Sensory Analysis

Two untrained panelists assessed the sensory aspects for the different versions of developed energy gels, taking place across 4 sittings. Each participant was presented with a plastic cup filled with 20g of the sample. Sensory attributes assessed included the use of a

9-point hedonic scale for overall acceptability, panelists were also asked to provide quantitative descriptive analysis (QDA) for 6 sensory profiles (table 4). The evaluation was undertaken in individual rooms within the researchers home ensuring no external distractions. Participants were provided with crackers and water to cleanse their palate between sensory questions and subsequent samples in line with sensory practices (Lawless and Heymann 2010).

Table 4. Details of questions and measurements undertaken for sensory analysis.

Question Number	**Category**	**Sensory Question**	**Measurement**
1	Hedonic	Overall liking of appearance	9-point hedonic scale (1=dislike extremely to 9 = like extremely)
2	Hedonic	Overall liking of flavour	9-point hedonic scale (1=dislike extremely to 9 = like extremely)
3	Hedonic	Overall liking of texture	9-point hedonic scale (1=dislike extremely to 9 = like extremely)
4	Hedonic	Overall liking of odour	9-point hedonic scale (1=dislike extremely to 9 = like extremely)
5	Hedonic	Overall liking of sample as a whole	9-point hedonic scale (1=dislike extremely to 9 = like extremely)
6	QDA	Intensity of sweetness	Likert Scale (1= very mild to 9 = very intense)
7	QDA	Intensity of saltiness	Likert Scale (1= very mild to 9 = very intense)
8	QDA	Intensity of seaweed flavour	Likert Scale (1= very mild to 9 = very intense)
9	QDA	Intensity of seaweed odour	Likert Scale (1= very mild to 9 = very intense)
10	QDA	Thickness	Likert Scale (1= very thin to 9 = very dense)
11	QDA	Smoothness	Likert Scale (1= very grainy to 9 = very smooth)

2.4 Nutritional Analysis

Samples were analysed for their nutritional values using the Scottish Centre for Food Development and Innovation (SCFDI) developed nutritional excel spreadsheet. This calculated calories per serving, macronutrients (CHO, protein, fats), salt and fibre content for the formulations by inputting the nutritional composition provided on the packaging for each ingredient. Vitamin and mineral content were only provided for the kombu powder; therefore, the missing values were estimated based on a combination of analysis from previous studies and similar product references using the US Department of Agriculture's (USDA) nutritional database. Estimated values were calculated for calcium, magnesium, potassium, Iron and Vitamin C.

2.5 Consumer Survey: data collection, the sample and questionnaire

A cross-sectional survey was developed to gather information about consumer attitudes and perceptions towards an energy gel enriched with seaweed. The survey was created and hosted online using Google Forms and made available during the period 9th – 15th March 2021. Eligibility criteria required recruitment of adults aged 18+ who undertake competitive physical activity by focusing on individuals who run. Participants were recruited with permission via the social platform WhatsApp from the Corstorphine Amateur Athletics Club (CAAC) group chat. The participation information form and survey link were sent directly to those wishing to take part in the study.

The decision to run an online survey was made to allow quick and cost-effective data collection whilst adhering to governmental Covid-19 restrictions. An online survey is also in line with current literature (Palmieri and Forleo 2019, Wendin and Undeland 2020). The survey consisted of 14 questions (table 5) and collected demographic information (age and gender), importance of attribute motivators when purchasing an energy gel, intension to purchase a seaweed enriched gel and attitudes towards a seaweed gel and preference for specific flavours.

Table 5. Consumer survey questions and answer options

Question number	Question	Answer Options
1	What is your age?	• Under 18 • 18-24 • 25-34 • 35-44 • 45-54 • 55-64 • 65+
2	Gender: how do you identify?	• Female • Male • Transgender • other
3	Have you previously consumed an energy gel to fuel physical activity?	• Yes • No
4 - 11	Please rank the importance between 1 and 5 for each of the following attributes which you consider when purchasing an energy gel. Price Flavour Contains natural ingredients Does not contain artificial ingredients Carbohydrate content Contains electrolytes Contains additional nutritional benefits Packaging can be recycled/sustainable packaging	(One choice for each attribute) • 1 (Not important at all) • 2 • 3 • 4 • 5 (Very important)
12	Have you previously consumed seaweed?	• Yes • No
13	Would you consider purchasing an energy gel that had been enriched with seaweed?	• Definitely • Probably • Undecided • Probably not • Definitely not
14	Please give a brief reason why you would/would not purchase an energy gel enriched with seaweed.	(open question)

2.6 Statistical Analysis

Each sample for sensory analysis was tested once by each participant, sensory analysis of sample formulation for CS3 and AC3 were repeated with means calculated using both sets of data. Means and standard deviation of each sensory measurement were calculated using Excel (Microsoft Office, version 2102).

Consumer survey results were collected and analysed for frequencies and percentages and Mann Whitney U tests were performed to compare groups of consumers using SPSS (IBM SPSS Statistics, version 23) for significant associations ($p<0.05$). Graphs were generated using Excel (Microsoft Office, version 2102).

3 Results

3.1 Nutritional Results

The results from the nutritional analysis of both flavours of the developed energy gel are displayed in table 6 alongside target ranges from market analysis. The key nutritional elements for the formulations to achieve were target ranges for kcals, CHO and mineral ranges for sodium, potassium, magnesium, and calcium. Both formulations achieved these levels with kcals, CHO, potassium, and calcium levels being particularly high.

Table 6. Nutritional composition of developed energy gel formulations CS3 (chocolate and sea-buckthorn) and AC3 (apple and cinnamon) in comparison to mean values for natural energy gels on the market, alongside target ranges.

Nutritional Information	Mean Energy Gel Values of natural gels on the market *	Target range per serving for gel development *	Values (chocolate and sea-buckthorn)	Values (apple and cinnamon)
Energy (KJ)	460.5 (±34.66)	383 – 476	415	415
Energy (KCalories)	98.33 (±3.73)	87 – 100	99	99
Total fat (g)	1.35 (±1.56)	0 – 4	0.4	0.2
of which saturates (g)	*0.58 (±1.09)*	0 – 0.4	*0.2*	*0*
Carbohydrate (g)	19.55 (±4.25)	11.3 – 24	22.5	23.8
other sugars (g)	*10.92 (±4.42)*	5 – 17.5	*13.4*	*13.6*
Fibre (g)	1.62 (±1.69)	0 – 5	1	0.5
Protein (g)	1.10 (±0.74)	0 – 0.23	1.2	0.6
Vitamins and Minerals				
Sodium (mg)	97.12 (±71.35)	17.7 – 240	28	28
Potassium (mg)	49.28 (±36.41)	0.39 – 104	83.45*	41.45*
Magnesium (mg)	11 (±4)	0.39 – 104	49.79*	9.40*
Calcium (mg)	1.56 (±1.96)	0 – 15	17.24*	10.08*
Vitamin C (mg)	39.47 (±38.27)	1.2 – 77.74	20.76*	-
Iron (mg)	0.56 (±0.19)	0 – 0.82	0.04*	0.04*
Iodine (mg)	-	N/A	3.4	3.4

(* Source, Source: (33 Fuel 2021, Huma 2021, Honey Stinger 2021, Spring Energy 2021, Veloforte 2021).

3.2 Testing and Prototype Results

Initial experiments carried out visually determined the viscosity of the seaweed powder when combined with water with results shown in fig 1 to 4.

Fig. 1 2g KP combined with 10g cold water (20% Solution) producing a thick gel.

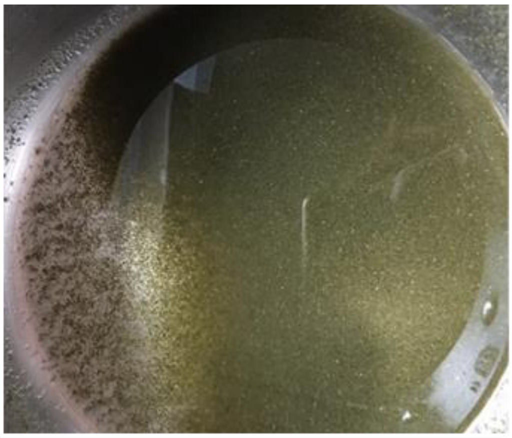

Fig. 2 8g KP combined with 100g cold water (8% solution).

Fig. 3 8g combined with 100g cold water then heated between 70-80ºC for 5 minutes (Increased viscosity and strong seaweed aroma)

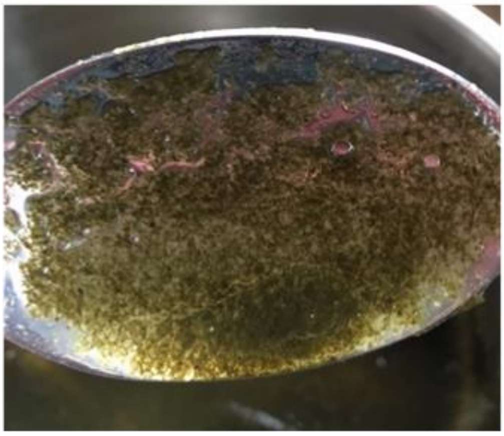

Fig. 4 Close up of consistency of resulting mixture shown in figure 3 (inhomogeneous solution with visible KP particles and intense green colouration.

Figure 1 - 4. Kombu powder and water gelation experiments.

Table 7 summarises the researchers qualitative notes on sensory aspects to determine which prototypes had potential to be developed further. Versions 2, 8 and 9 were used for initial sensory analysis and relabeled as follows; V2 (P1), V8 (P2) and V9 (P3).

Table 7. Formulations for prototypes (versions 1-9)

Prototype Samples	Researchers Evaluation
V1	Grainy, Sea Buckthorn too overpowering
V2	Smoother than version 1, Sea Buckthorn still overpowering
V3	Grainy, seaweed flavour overpowering
V4	Lemon flavour more appealing, a bit grainy, seaweed flavour intense
V5	Less grainy compared to previous versions, gloopy consistency, flavour ok but quite intense
V6	Less grainy than versions 1-4, flavour more pleasing, gloopy consistency
V7	Improvement on flavour, greenish/muddy appearance – not homogenous
V8	Flavour nicer– muddy/green appearance, more watery – not homogenous
V9	Lemon flavour more appealing, watery, muddy/green appearance not homogenous

3.3 Sensory Analysis

Figure 5 illustrates the mean ratings of hedonic sensory attributes for samples P1-3.

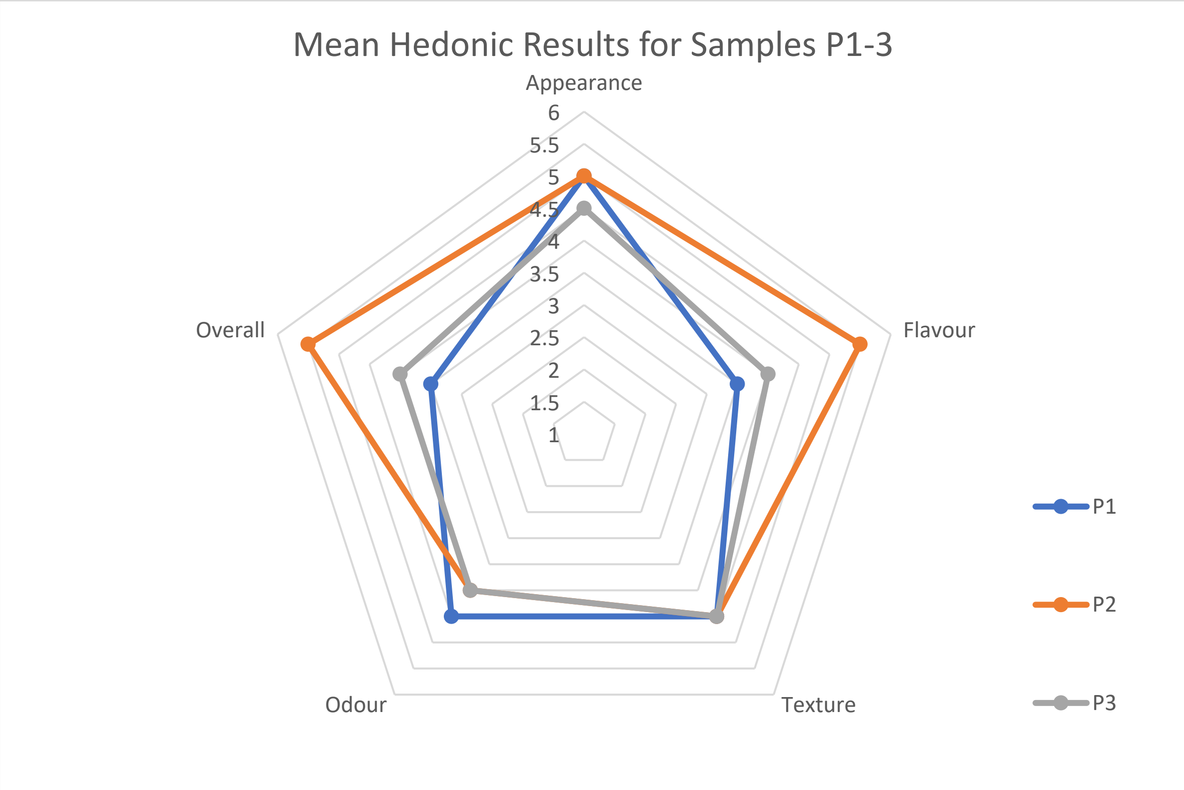

Figure 5. Mean hedonic ratings for appearance, flavour, texture, odour, and overall liking for samples P1-3 (P=4.5% KP, P2=1.6% KP & sea-buckthorn flavouring, P3=1.6% KP & lemon flavouring).

P1 and 33 reported similar values for each attribute whereas P2 was rated higher for flavour (mean = 5.5, ±1.5) vs sample 1 (mean = 3.5, ±0.5) and sample 3 (mean = 4, ±2) and overall liking achieving a mean of 5.5 (±0.5) vs means of 3.5 and 4 (±0.5, ±4) for P1 and P3 respectfully. For QDA results (fig. 6), main differences observed were the perceived saltiness and thickness of P1, scoring the highest for each attribute (mean = 3.5 ± 2.5 and mean = 5, ± 1 respectfully). P1 and P3 portrayed a similar pattern graphically for sensory attributes (fig 6) however, P3 scored higher for intensity of seaweed flavour and aroma, both rated a mean of 7 (±0).

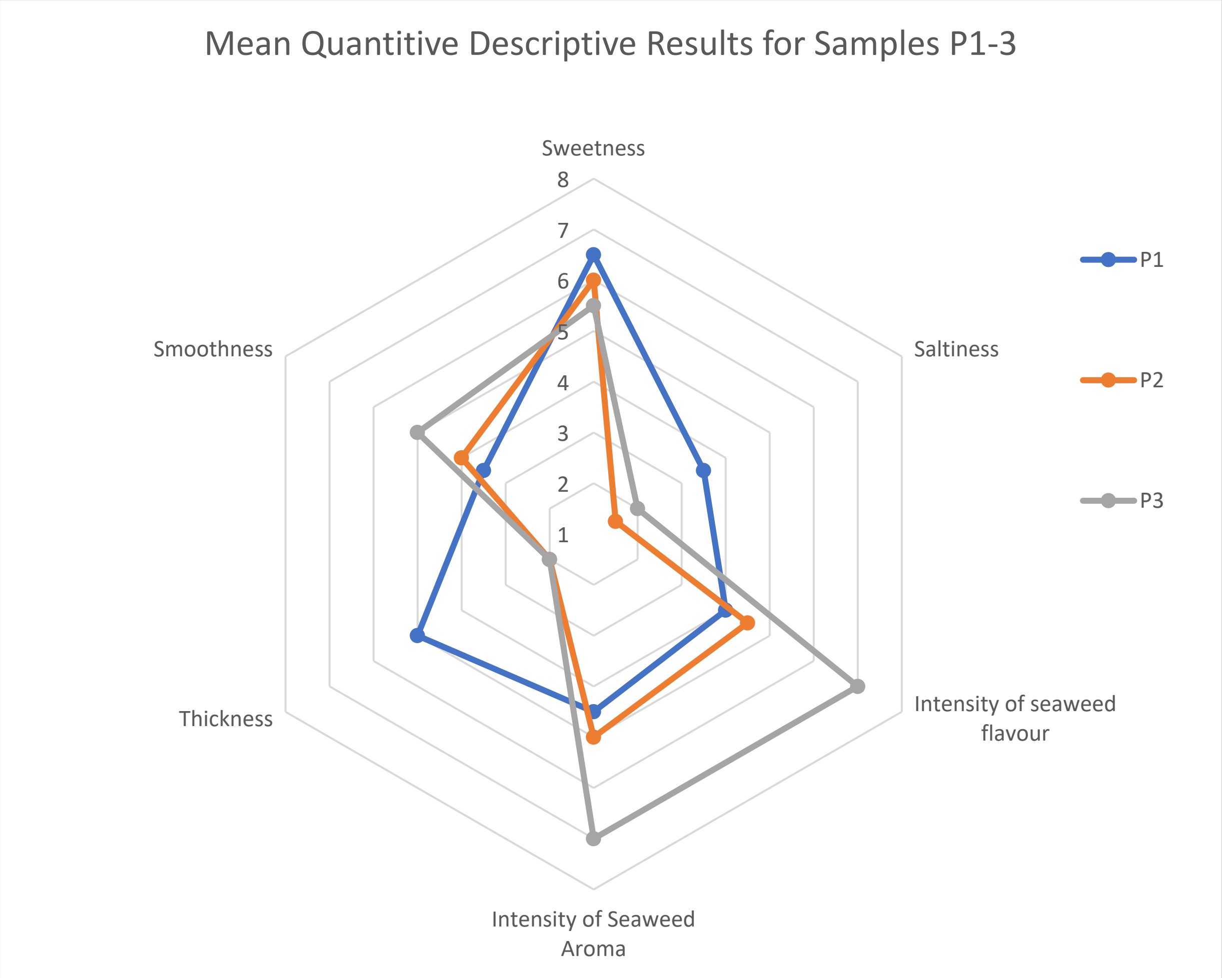

Figure 6. Mean quantitative descriptive ratings for sweetness saltiness, intensity of seaweed flavour and aroma, thickness, and smoothness for samples P1-3 (P1 = 4.5% KP, P2 = 1.6% KP, sea buckthorn flavouring, P3 = 1.6% KP, lemon flavouring).

Figure 7 demonstrates the mean hedonic ratings for formulations CS1-4 for chocolate and sea-Buckthorn flavour. The main differences highlighted a higher flavour rating for CS2 achieving a mean of 7.5 (±0.5). CS2 also had an increased rating for odour at 7.5 (±0.5) whereas CS3 had a higher mean rating for texture of 7.25 (±0.5). CS4 had mean ratings lower than CS1-3 for all hedonic attributes with biggest differences for flavour (mean = 5.5, ± 0.5), texture (mean = 6, ±) and overall liking (mean = 6, ± 0).

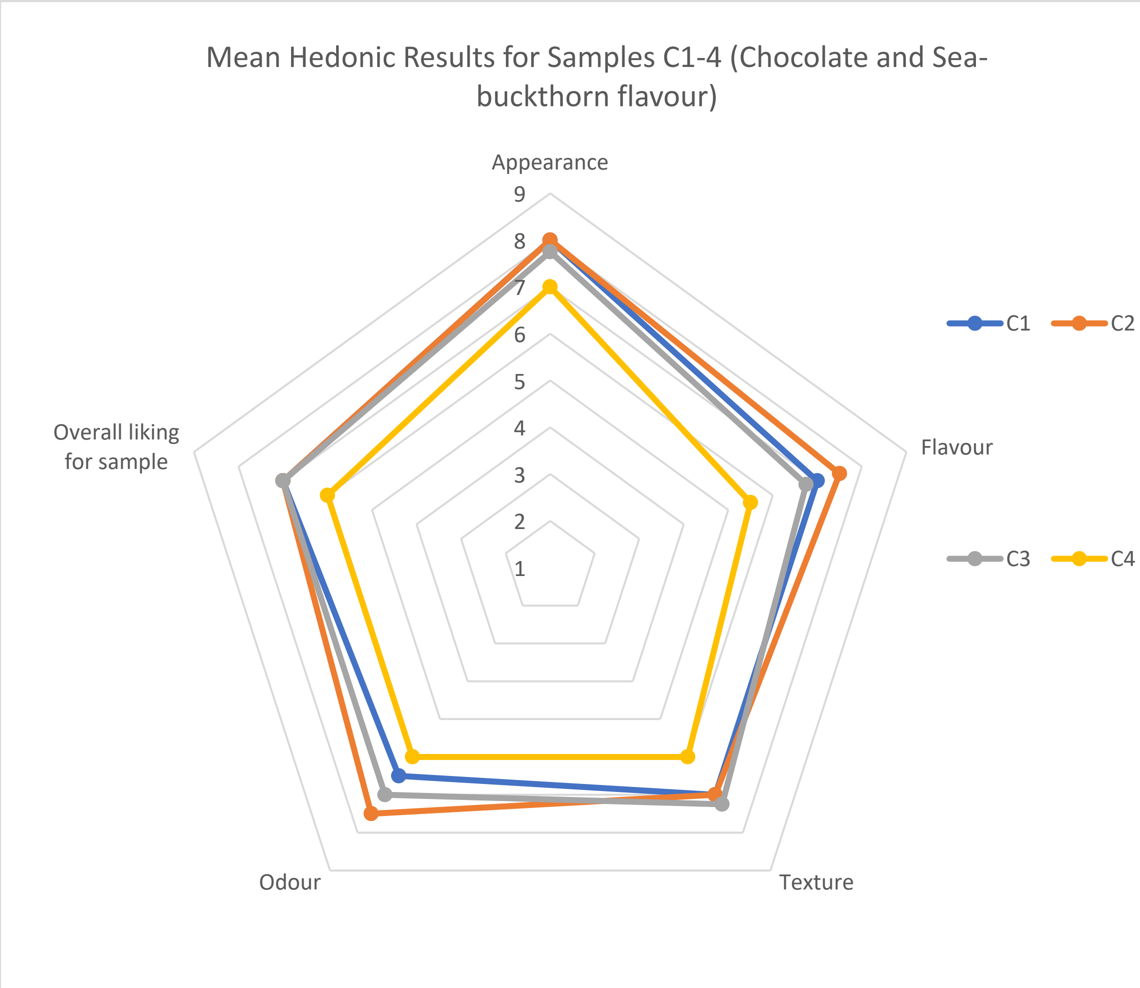

Figure 7. Mean hedonic ratings for appearance, flavour, texture, odour and overall liking for samples CS1-4 (1= very low to 9 = very high). CS1 = 1g KP, water heated then cooled before addition of remaining ingredients. CS2 = 1g KP, all ingredients heated together except from kombu and sea-buckthorn. CS3 = 1g KP, inclusion of heating KP with ingredients. CS4 = same as CS3 minus KP.

For mean QDA results (fig. 8), CS3 was perceived to have the thickest consistency with a mean of 7 (± 0) with lower sweetness ratings (5.25, ± 0) and lower intensity of seaweed aroma (2.75, ± 1). Sample CS2 was judged to be smoother (mean= 5.5, ± 0.5). Sample CS4 sweetness rating was much higher than the sample with KP, achieving a mean of 7.5 (± 1.5). Smoothness and thickness lower at 4 (± 0) and 5 (± 1) respectfully.

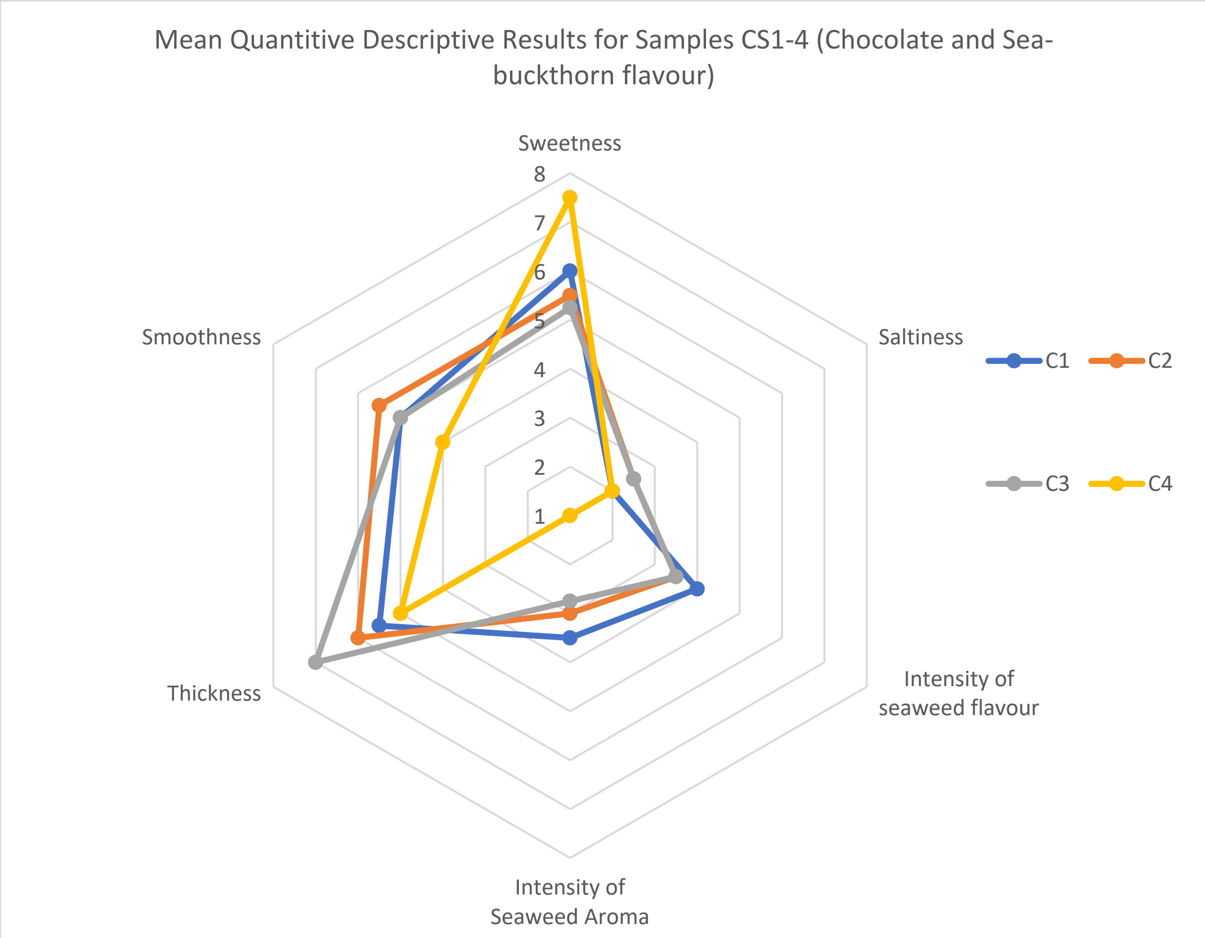

Figure 8. Mean quantitative descriptive ratings for sweetness, saltiness, intensity of seaweed flavour and aroma, thickness, and smoothness for samples CS1-4. CS1 = 1g KP, rice flour and water heated then cooled before addition of remaining ingredients. CS2 = 1g KP, all ingredients heated together except from kombu and sea-buckthorn. CS3 = 1g KP, inclusion of heating KP with ingredients. CS4 = same as CS3 minus KP.

Figure 9 summarises the mean hedonic ratings for samples AC1-3 for the apple and cinnamon flavour. All five attributes only differed a maximum of 0.5 mean points from each other therefore were broadly perceived to be similar. AC1 and AC3 received a higher rating for flavour (mean = 7.5, ± 0.5, ± 1 respectfully), AC2 had the highest overall rating for likability (7.5, ± 0.5) vs a rating of 7 for both AC1 (± 0) and AC3 (± 1).

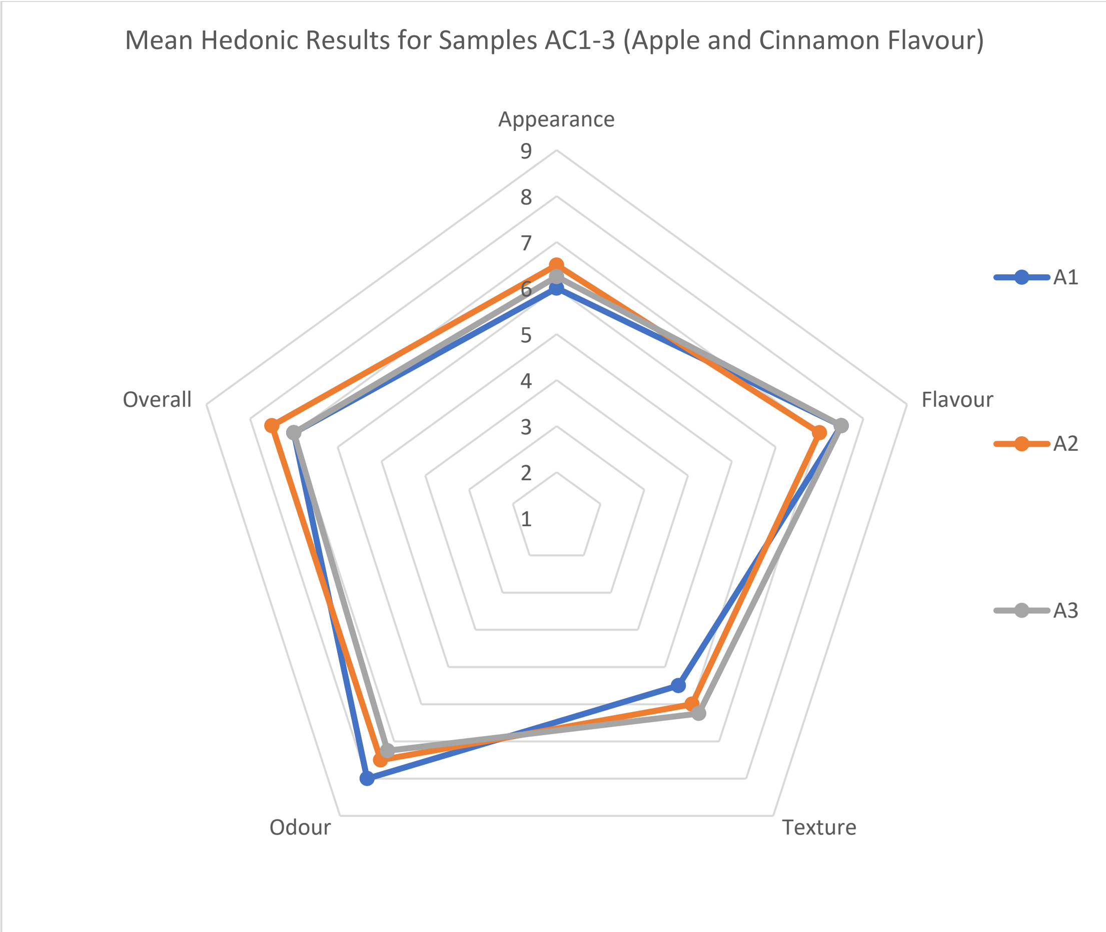

Figure 9. Mean hedonic ratings for appearance, flavour, texture, odour, and overall liking for samples AC1-3. AC1 = 1g KP, rice water and water heated then cooled before addition of remaining ingredients, AC2 = 1g KP, all ingredients heated together apart from kombu, apple and cinnamon, AC3 = All ingredients heated together apart from apple and cinnamon.

QDA means (fig 10) revealed that AC3 was perceived to be slightly saltier (mean = 2.25, ±1) with a more intense seaweed flavour (mean = 3.25, ± 1.5). AC1 was found to be less smooth (mean = 4, ± 1) and AC2 had the lowest perceived saltiness with a mean of 1.5 (± 0.5) with the least intense seaweed aroma (mean = 1.5, ± 0.5).

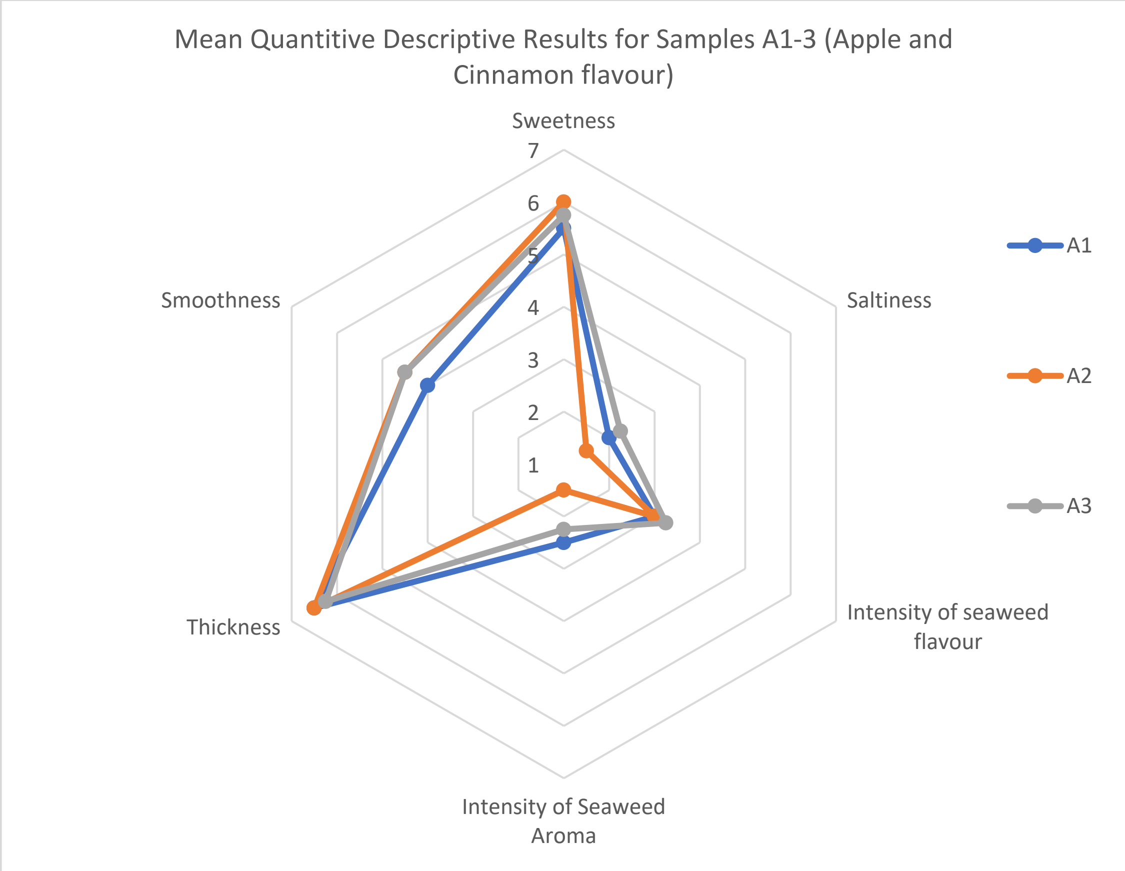

Figure 10. Mean quantitative descriptive ratings for sweetness, saltiness, intensity of seaweed flavour and aroma, thickness, and smoothness for samples AC1-3. AC1 = 1g KP, rice water and water heated then cooled before addition of remaining ingredients, AC2 = 1g KP, all ingredients heated together apart from kombu, apple, and cinnamon, AC3 = All ingredients heated together apart from apple and cinnamon.

The gel colours for final formulations CS3 (fig. 11) and AC3 (fig. 12) reveal that the KP has added a green/brown hue to AC3 with the KP particles visible. The chocolate and sea-buckthorns colour (rich brown) was not visibly altered with addition of KP powder.

Figure 11. Image for sample C3

Figure 12. Image for sample A3

3.4 Consumer Attitude and Perception Results

Consumer data from a total of 78 (n=78) Scottish respondents, aged 18 years or older was obtained during the period 9th – 15th March 2021. Most of the respondents were male (n=42, 53.8%) compared with 36 females taking part (46.2%) (table 8). Age ranges are detailed in table 9, just over half (n=41, 52.6%) were aged over 45 years with most respondents aged between 45-54 (n=30, 38.5%). Findings show that previous consumption of an energy gel to fuel physical activity was high (n=73, 93.6%) and nearly 70% (69.2%, n= 54) of respondents had eaten seaweed before.

Table 8. Demographic results from consumer survey – gender breakdown by frequency and percentage.

Gender	Frequency	Percent (%)
Male	42	53.8%
Female	36	46.2%
Total	**78**	**100**

Table 9. Demographic results from consumer survey – age group breakdown by frequency and percentage.

Age Group	Frequency	Percent (%)
18-24	1	1.3
25-34	16	20.5
35-44	20	25.6
45-54	30	38.5
55-64	10	12.8
65+	1	1.2
Total	**78**	**100**

Results for ranked attributes of importance when considering purchasing an energy gel from 1 (not important) to 5 (very important) are summarized in figure 11. The attributes ranked the highest for importance (4 or 5) were Flavour (n=64, 82%), recyclable/sustainable packaging (n=54, 69.2%), electrolyte content (n=54, 69.2%), CHO content (n=54, 69.2%) and containing natural ingredients (n=44, 59%).

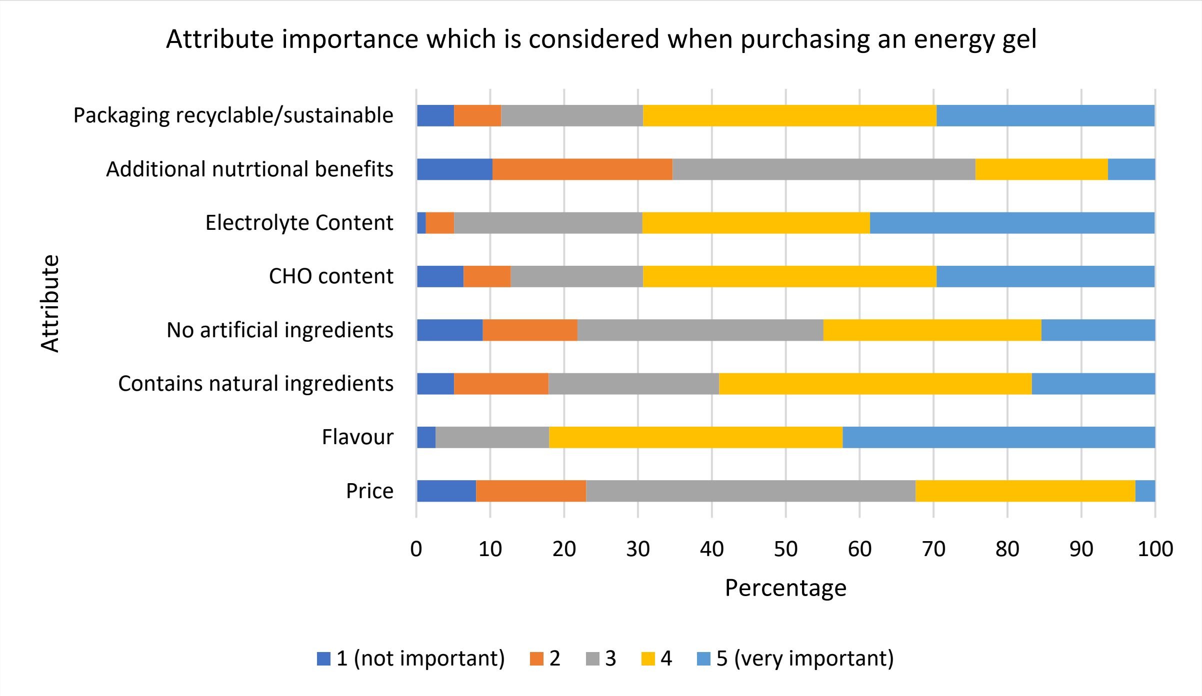

Figure 13. Consumer survey results for importance of attributes considered when purchasing an energy gel ranked from 1 (not important) to 5 (very important) (n=78).

Over 66% of respondents (n-52) had positive intentions (selecting probably or definitely) for purchasing an energy gel enriched with seaweed. A Mann-Whitney U test showed there was a significantly greater intent to purchase an energy gel enriched with seaweed if the respondent had consumed seaweed previously (mean rank = 44.73, n=54) compared to having not (mean rank = 27.73, n= 24, p=.001). Intent to purchase a gel enriched with seaweed was also ranked significantly higher in females (mean rank = 44.68, n=36) compared to male (mean rank = 35.06, n=42, p= .049).

Respondents were asked an open question to provide a reason for their answer on whether they would purchase an energy gel enriched with seaweed powder (summarised in tables 10 to 12) to capture and identify the main themes and establish motivators and barriers. The question was not mandatory, and 56 respondents chose to answer. The responses were organised within a matrix by those who with positive intensions (probably or definitely), neutral responses (undecided) and negative (probably not or definitely not) with key themes grouped together.

Many of those who were positive towards purchasing an energy gel enriched with seaweed were motivated by perceptions that seaweed is healthy or nutritious (50%, n=16), that seaweed is a natural ingredient (38%, n=12) or would be keen to try something new (19%, n=6). Of those who were undecided (n=18), the majority of respondents (66.7%, n=12) needed more information and confirmation of the potential benefits of seaweed for health or advantages gained for physical activity. Other reasons provided were brand loyalty (11%, n=2), unsure on flavour (11%, n=2) and does not like gels (5.5%, n=1). Finally, those who were unlikely to buy a seaweed enriched gel (n=6) the main barrier was perceptions of seaweed flavour (83%, n=5).

Table 10. Consumer survey results – qualitative data for reasons why respondents selected probably or definitely would buy an energy gel enriched with seaweed (n=32).

Summary of reasons for selecting probably or definitely, for purchasing an energy gel enriched with seaweed (n=32)		
Key Themes	Frequency	Percent (%)
Healthy/Nutritious	16	50
Natural Ingredient	12	38
Good for environment/sustainable	3	9
Would try something new/different	6	19
Interesting flavour	3	9

Table 11. Consumer survey results – qualitative data for reasons why respondents selected "undecided" for likelihood to purchase an energy gel enriched with seaweed (n=18).

Summary of reasons for selecting "undecided" for purchasing an energy gel enriched with seaweed (n=18)		
Key Themes	Frequency	Percent (%)
Need more information for nutritional/health benefits	12	66.7
Flavour off-putting	2	11
Brand loyal	2	11
Does not like gels	1	5.5

Table 12. Consumer survey results – qualitative data for reasons why respondents selected "probably not" or "definitely not" when asked would they purchase an energy gel enriched with seaweed (n=6).

Summary of reasons for selecting "undecided" for purchasing an energy gel enriched with seaweed (n=6)		
Key Themes	Frequency	Percent (%)
Unappealing flavour	5	83
Does not like gels	1	17

4 Discussion

4.1 Nutritional composition

The CHO content of the developed energy gels (table 6) reach target ranges based on a review of natural gels on the market and athletes consuming 2-3 servings per hour will achieve the ISSN recommended CHO intake. The final gel formulations incorporate CHOs consisting of glucose and fructose-based sugars. Ingesting a combination of carbohydrates, utilises different intestinal transporters for absorption and enhances performance in exercise (Jeukendrup 2010). The developed gels also reach the target ranges set for sodium, potassium, calcium, and magnesium. Sodium replacement is critical for rehydration by maintaining water balance and may prevent cramping and exercise-associated hyponatremia (Verle 2007). There is evidence of inadequate dietary intake of magnesium in athletes (Williams 2005), whereas young female athletes are prone to insufficient calcium intake (Volpe 2008).

The daily recommended dietary intake (RDI) for iodine is 140µg (PHE 2016). KP is a rich source of iodine and the final formulations AC3 and CS3 with the addition of 1g contains 2429% (3400µg) of the RDI. Brown seaweed typically has higher levels compared to red or green seaweeds with Laminaria Digitata containing one of the highest average concentrations (Mussig 2009). Iodine is essential for thyroid function, however too little or too much has a negative impact on health (Yeh et al. 2014). The safe tolerable upper limit for iodine is set by the Institute of Medicine at 1100µg/d (cited in Knust and Leung 2017, p139) however, the amount of bioavailable iodine from food is inconclusive, with research suggesting that it is much lower than the amount ingested (Dominguez-Gonzalez et al. 2017). Athletes are more susceptible to compromised thyroid status if stores become depleted due to sweat losses, which could negatively impact performance (Smyth and Duntas 2005). The developed gels would provide a good source of iodine to sports practitioners who struggle to ingest adequate amounts and would be a unique selling point compared to other options on the market.

Bioactive compounds such as carotenoids, fucoidans and phenols, found in *L. Digitata* (Rajauria 2019), have been proven to have antioxidant and anti-inflammatory capabilities (Jazwir and Monsur 2011). Based on research by Rajauria (2019) and McArtain et al. (2007) on antioxidant compounds present in *L. Digitata,* it is estimated that 1g of KP within the formulations has a carotenoid content of 2.19 µg, phenolic content of 52.7 mg and 55mg of fucoidans (McArtain et al. 2007). Exercise, especially of higher intensity and longer durations result in the production of reactive oxygen species (ROS), increasing oxidative damage to cells (Thirupathi and Pinho 2018). There is evidence that for trained athletes undertaking regular strenuous physical activity, antioxidant supplementation can reduce oxidative stress (De-Oliveira et al. 2019).

4.2 Sensory Evaluation

Mean ratings of above 5 on a 9-point hedonic scale is typically regarded as an acceptable sensory quality, above 7 is deemed to be highly acceptable (Everitt 2009). The prototype samples P1 & P3 scored 5 or less for all hedonic sensory qualities, thereby demonstrating the formulations unsuitability for consumer acceptance. P2 scored <5 for appearance, texture, and odour, and only just acceptable for flavour and overall liking (mean score 5.5), hence based on results, this sample was also disregarded. The formulations for “chocolate and sea-buckthorn” and “apple and cinnamon”, achieve mean ratings that determine a high sensory acceptance for overall liking, indicating that KP can be successfully incorporated into an energy gel formulation. Moreira et al. (2018) reported 74% acceptance for the inclusion of spirulina within an energy gel formulation from the target market. This also mirrors previous sensory research where breakfast sausages containing 1% brown seaweed powder (*Saccharina Japonica*) had high acceptability (Hyun-Wook et al. 2010). However, there were sensory qualities that could be improved further to achieve scores of >7.

4.2.1 Appearance and texture characteristics

The KP forms a green paste upon hydration with water (fig 1) which is also present after heating (fig 3). This is consistent with findings from Blikra et al. (2018) where contact with water and exposure to high temperatures resulted in the transformation of brown algae to a green colour. Colour is a significant sensory cue for consumer expectations and acceptance of a product, abnormal or off-colours encourages food rejection (Spence 2015). For this study, the addition of cacao powder imparted a rich brown colour for “Chocolate and sea-buckthorn” formulations (fig. 11) with the KP giving a green hue for “Apple and Cinnamon” formulations (fig. 12), high acceptance of appearance suggested their colour supported pre-conceived expectations for these (Spence 2015).

The prototype formulations received low mean ratings which could be the result of visible particles and the agglomeration present (fig. 4). Alginate contributes to 40% of dry matter (Draget et al. 2006) however, is most effective as a thickener or gelling agent when it is extracted in its sodium form to enable water solubility (Fertah et al. 2017). KP is rich in alginates however, its other constituents may inhibit gel formation. For example, calcium and potassium ions can affect the stability and mechanical properties of alginate gels if not controlled, resulting in the formation of aggregates (Nussinovitch et al. 1990, Wang and Spencer 1998). KP also possess insoluble dietary fibers primarily of cellulose (Strachan 1998), these may be contributing to the particle formation.

Rice flour, included within the CS and AC formulations, had a positive effect on the mean ratings for texture compared to those of the prototypes and could be a result of the reported increased thickness. Rice flour was heated with water and additional ingredients to form the gel formulations (CS1-4 and AC1-3) using slightly different methods. Starch gelation is known to occur at specific gelatinisation temperatures (between 58 - 80ºC for rice) (Ai and Jane 2018), which was observed during this study. Rice flour, when combined with water, forms an irreversible viscous gel upon heating (Kapri and Bhattacharya 2008), a result of the starch granules swelling, absorbing water, losing crystallinity, and releasing amylose (Mariotti et al. 2018). The differences in methods of incorporating the ingredients with the rice flour/water and heating at different stages had inconsistent results on perceived thickness and smoothness of the formulations, therefore no conclusions can be inferred from these.

The rice flour and KP appeared to work in synergy for the CS and AC gel formulations to produce an acceptable texture. The gelling characteristics of alginate may have contributed towards the formation of a smoother and thicker gel (Fertah et al. 2017). Consequently, when KP was removed from the CS formulations the mean ratings for thickness and smoothness were reduced.

4.2.2 Flavour and Odour Characteristics

The formulations (CS and AC) with the inclusion of KP are highly acceptable in terms of overall liking for flavour and odour, with low ratings for seaweed flavour intensity and aroma (mean <5). Untreated fresh seaweed can sometimes give undesired fishy odours (Keyimu and Abdullah 2014), and consumer expectations of seaweed aromas are likened to those most “seafood like” (Vilar et al. 2020). Peinado et al. (2014) reported that the *Laminaria* species had the strongest “seaweed like” aroma out of 5 species, which may be displeasing within the energy gel formulations. Vilar et al. (2020) found that brown seaweeds also have appealing odour characteristics, identified as “grassy/herbal/floral”, “fruity” and “fatty” aromas. The amount of KP within the formulations therefore could have contributed favourably to the aroma. When this was removed from the CS formulation, overall liking of odour received a lower score compared to the formulations which included KP.

It was observed that removing KP from the CS formulation impacted the flavour profile. Participants perceived higher levels of sweetness and slightly reduced mean ratings for saltiness (fig. 8). The umami flavours in some foods have been found to enhance or add complexity to other taste sensations such as sweetness and saltiness (Fuke and Yeda 1996). Therefore, the loss of KP and its umami flavours may have created an imbalance increasing the perceived level of sweetness and reducing the overall hedonic rating for flavour.

4.3 Consumer Survey

Overall, intensions for purchasing an energy gel enriched with seaweed were positive (66%) amongst surveyed sports practitioners. This parameter proved higher than that of Moreira et al. (2018), where 50.5% of the athletes included within their study would be willing to purchase an energy gel formulated with spirulina. Preference for flavour was ranked as an important determinant influencing purchasing decisions as well CHO content and containing electrolytes. The flavours “chocolate and Sea-buckthorn” and “apple and cinnamon” were well received, and the developed gels reached nutritional and mineral targets. This therefore indicates acceptance of the formulated gel products.

Consumer acceptance to food is multi-faceted, determined by responses to sensory and physiological characteristics as well as past experiences, attitudes, and beliefs (Costell et al. 2009). Consumer beliefs are reported to have the biggest influence on acceptance of new seaweed food products (Phang et al. 2010), with potential health benefits or heath consciousness being key determinants towards the likelihood of consuming foods containing seaweed (Birch et al. 2019, Mohammed at al. 2019). This reason is consistent with our findings. When respondents were asked why they would (answering probably or definitely) consider purchasing an energy gel formulation enriched with seaweed, they mostly perceived seaweed to be healthy or nutritious.

Consumption of seaweed is familiar to the respondents with the majority having previously eaten seaweed before (70%). Food familiarity and exposure are important in influencing consumer preferences for novel foods (Tuorila et al. 1994). A barrier highlighted by respondents in prohibiting purchase intent for an energy gel enriched with seaweed was a preconceived dislike in seaweed flavour, likely due to unfamiliarity and neophobia (Tuorila et al. 1994). A study by Birch et al. (2018) revealed that those who had eaten seaweed products in the past were more likely to consume them in the near future. This is reflected in this study, where previously eating seaweed had a significant association with the respondents being more willing to purchase an energy gel enriched with seaweed powder ($p=0.001$). A significant association was also found between women and purchase intent ($p=0.049$) compared to males, the differences in gender could be explained by research concluding that women are more willing to accept new foods (Beardsworth et al. 2002).

The highlighted barrier towards purchasing an energy gel enriched with seaweed, were an unawareness of direct health benefits or how seaweed could nutritionally benefit physical activity. Lack of knowledge is a commonly expressed attitude in the reluctance to try functional foods (Barrios et al. 2008) and seaweed products (Phang et al. 2010). Consequently, it is recommended that to promote consumption of new seaweed products and consumer acceptance, information of the nutritional benefits and sensory characteristics of seaweed should form the basis of any marketing strategies (Phang et al. 2010, Palmieri and Forleo 2020, Figueroa et al. 2021).

5 Limitations of the study

One of the limitations of the study was the sample size for sensory analysis (n-2), due to COVID governmental restrictions the project had to be carried out at home. It is consensus that sample size for sensory tests should be between 40-100 participants.to ensure significant differences can be detected, with a minimum of 5 panelists needed for sufficient statistical power (Gacula and Rutenbeck 2006) and 16 needed to use analysis of variance (ANOVA) tests (Sawyer 2009). Therefore, statistical tests for significance could not be performed. Another limitation was the use of an untrained panel, the lack of experience and possible bias could have affected the QDA ratings therefore it is difficult to imply results and only observations could be reported. Testing also could not be carried out in an appropriate sensory testing facility therefore any aspects which could not be controlled may have influenced scores.

Time constraints meant sample size for the consumer survey was slightly lower compared to other similar consumer studies, ranging from 110 – 495 (Moreira et al. 2018, Lucas et al. 2019, Palmieri and Forleo 2010, Wendin and Undeland 2020). Larger panel sizes allows for error and bias-free data as well as improving segmentation (Dolnicar et al. 2016). In this study e.g., the age groups were unevenly distributed with some groups 5, consequently groups had to be merged.

6 Future Research

This research contributes to the current literature validating the incorporation of seaweed into food targeted at sports nutrition. The results and recommendations can be used to optimise the development of energy gel formulations which include *Laminaria Digitata* or other seaweed species. Future research can build on the findings within the study for sensory analysis, consumer preferences and acceptance by involving larger panels.

The formulated gels are designed to fuel physical activity, therefore, to evaluate these gels further it would be important to determine athlete's sensory acceptance during training as carried out by Stevens et al. (2020) and to evaluate athlete performances whilst ingesting the gel to determine their effectiveness, demonstrated by Moreira et al (2018). Future research should build on the emerging literature of seaweeds and in particular *Laminaria Digitata's* bio-active compounds in relation to supporting performance. This would assist in building knowledge to provide information to consumers. Motivators and barriers uncovered for purchasing intent of an energy gel enriched can be utilised by marketers to influence consumer attitudes.

7 Conclusion

This study demonstrated the inclusion of 1g of KP (*Laminaria Digitata*) within an energy gel formulation resulted in a highly acceptable product based on sensory evaluation. The addition of KP within the energy gel formulations would provide athletes undertaking extended periods of exercise important minerals. Nutritional analysis proved the formulations provided the necessary nutrient profile to fuel physical activity and met target ranges based on similar products available on the market. Iodine levels exceed the RDI therefore could be therapeutic for athletes with inadequate dietary intake to combat losses, however, could pose a risk to those who suffer with thyroid issues. Consequently, guidance should be provided for product consumption and future studies may wish to investigate other seaweed species containing less iodine.

A consumer survey amongst sporting practitioners indicated positive attitudes towards purchasing a gel enriched with seaweed as well as liking for developed flavours of "Chocolate and Sea-Buckthorn" and "Apple and Cinnamon". Consuming seaweed previously had a significant association with positive purchase intensions towards purchasing a gel enriched with seaweed, females also were significantly more likely to want to purchase a seaweed enriched gel. Agreeing with existing literature, this study found the majority of consumers viewed seaweed as healthy or nutritious however providing information on the health benefits or how seaweed could support sport would assist in reducing barriers for purchase intention.

In conclusion, this study found that the formulation of a novel energy gel enriched with seaweed was observed to have highly acceptable sensory attributes, could provide important minerals and was appealing to the target consumer market.

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