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Exploring the Nutritional and Sensory Impact of Red Seaweed Fortification in Dark Chocolate

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Abstract

The present study was aimed to develop seaweed-based chocolates and evaluate their nutritional, textural and sensory properties. Seaweed powder prepared from the red seaweeds *Gracilaria edulis* and *Kappaphycus alvarezii* was added separately to dark chocolate at different concentrations of 1%, 2.5%, 5%, and 7.5% (w/w) and stored under chilled condition (2-4°C) for further studies. Incorporation of seaweed in chocolate improved the protein and mineral content in the products. The addition of seaweed significantly ($p<0.05$) increased the breaking strength of the chocolate, with the force required to break the chocolate increasing proportionally with the seaweed concentration. Chocolate enriched with *K. alvarezii* exhibited significantly ($p<0.05$) lower breaking strength compared to chocolate enriched with *G. edulis*. Chocolate enriched with 1% and 2.5% *K. alvarezii* had similar hardness and chewiness of that of control chocolate. Sensory evaluation revealed that chocolate containing up to 7.5% red seaweed was deemed acceptable, with no detectable seaweed smell. The flavour of the dark chocolate effectively masked the seaweed flavour and odour. Moreover, organoleptic acceptance was significantly higher ($p<0.05$) for chocolate enriched with *K. alvarezii* as compared to chocolate enriched with *G. edulis*. Results shows that red seaweed such as *G. edulis* and *K. alvarezii* can be considered as a potential ingredient for formulating healthy confectionery products without affecting consumer acceptance.

Keywords: Seaweed, *Gracilaria edulis*, *Kappaphycus alvarezii*, chocolate

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Introduction

Chocolate is a globally popular confectionery enjoyed by people of all ages and genders. Renowned for its unique and distinctive taste, chocolate consumption and gifting became widespread following the industrial age (Clarence-Smith, 2016). Chocolate consumption in moderation is linked to healthy lifestyle, however high caloric intake from consuming commercial chocolate diminishes its health benefits (Latham, Hensen, & Minor, 2014). Growing trends and demands of consumers preferring to eat natural and healthy foods have resulted in decline of consumption of high sugar and high saturated fat based confectionary products (Thomas, 2017). Chocolate formulation is a key aspect for ascertaining nutritional content and perceived health benefits (Mellor et al., 2015; Del Prete & Samoggia, 2020). Enriching formulation that leads to chocolate-based functional foods is a welcoming and feasible option for nutritional and health benefits. An increasing trend is observed regarding studies for the enrichment or fortification of chocolate with other ingredients for nutrition and health benefits (Montagna et al., 2019; Samanta et al., 2022). Researchers and food industries have embarked on modification of chocolate formulations to improve the nutritional profile of chocolate confectionery by reducing sugar and saturated fat content or by addition of components with healthy alternatives without affecting sensory and textural properties (Di Monaco, Miele, Cabisidan, & Cavella, 2018).

Marine macroalgae, commonly known as seaweed are regarded to have a high nutritional value due to their high fibre, unsaturated fatty acids, vitamins, bioactive antioxidants and minerals such as magnesium, zinc, iron and iodine (MacArtain, Gill, Brooks, Campbell, & Rowland, 2007). Seaweeds are utilized as ingredients in functional foods, contributing to the development of innovative products with significant health benefits (Holdt & Kraan, 2011). Seaweeds have been consumed for centuries, primarily in Asian countries such as Japan, South Korea, the Philippines, Malaysia, and Indonesia (Phillips, 2023). Certain communities residing on the coastal European countries also have history of consuming seaweed as part of daily diet (Delaney, Frangoudes, & Ii 2016). Seaweed-derived components are highly versatile and possess high commercial value and are used to produce a wide range of products, ranging from pharmaceuticals to agricultural goods (Ito & Hori, 1989; Pati, Sharma, Nayak, & Panda, 2016). Seaweed as a natural food remains largely underutilized, with its direct consumption primarily seen in Asian countries like Japan and South Korea (Rioux, Beaulieu, & Turgeon, 2017; Mouritsen, Rhatigan, & Pérez-Lloréns, 2019). Increased awareness for better health and wellness, and demand for environmental-friendly products drives demand for greener and sustainable food products. The untapped potential of seaweeds creates new opportunities to develop seaweed fortified food products with high nutritional value and health benefits, and such products add towards sustainable ocean economy (Tiwary & Troy, 2015; Yong, Thien, Rupert, & Rodrigues, 2022) In recent years, there has been increasing interest in incorporating seaweed into confectionery products due to its potential health benefits and unique flavour profiles. Incorporating seaweed into chocolate can enhance its nutritional profile, thus providing additional health benefits. In India, seaweed chocolate was reported to be an ideal food supplements specially for iron deficiency to anaemic adolescent girls (Banu & Mageswari, 2015). It can also impart unique flavour and texture to the food products. Although seaweed chocolates are available in the international market, there has been limited research on the nutritional profiling, textural properties, and physico-chemical properties of seaweed-fortified chocolate (Salgado, Moreira-Leite, Afonso, Infante, & Mata, 2023 & 2024). Most of the researchers had attempted to understand consumers preferences, organoleptic perception and willingness to purchase the seaweed-based chocolate. Therefore, the present study was aimed to develop seaweed-based chocolates and evaluate their nutritional, textural and sensory properties.

Materials and Methods

Red seaweeds namely, *G. edulis* and *K. alvarezii* were collected from Mandapam coast of Tamil Nadu region. Seaweed were washed with clean water to remove dirt and sand particles and dried (moisture content <15%) under shade. Dried seaweed were powdered, packed in polyethylene pouch and stored at ambient temperature for further application.

Dark chocolate was purchased from local market in Visakhapatnam from the brand Morde (Morde foods Pvt. Ltd.). All the chemicals and reagents used for the analysis of the samples for this work were of analytical grade.

The preparation of seaweed enriched chocolate involves melting of chocolate in a clean dry bowl put over a container with hot water under medium flame. Once the chocolate was melted, red seaweeds powder prepared from *G. edulis* and *K. alvarezii* were added, separately, to dark chocolate at different concentration of 1%, 2.5%, 5% and 7.5% (w/w) and mixed thoroughly. The chocolate with seaweed mixture was poured into moulds and kept in freezer for 15 minutes. Then it was removed carefully and primarily packed in aluminum foil and then final packed was done using polythene bag and stored at 2-4°C for further analysis. Flow chart of the preparation of seaweed enriched chocolates are illustrated in Fig. 1. The Control sample was prepared without addition of seaweed and samples were coded as follows,

Choco	:	Control
GE1	:	Dark Chocolate & 1 % *G. edulis*
GE2	:	Dark Chocolate & 2.5 % *G. edulis*
GE3	:	Dark Chocolate & 5 % *G. edulis*
GE4	:	Dark Chocolate & 7.5 % *G. edulis*
KA1	:	Dark Chocolate & 1 % *K. alvarezii*
KA2	:	Dark Chocolate & 2.5 % *K. alvarezii*
KA3	:	Dark Chocolate & 5 % *K. alvarezii*
KA4	:	Dark Chocolate & 7.5 % *K. alvarezii*

Proximate composition of seaweed enriched chocolate was done in triplicates for moisture, protein, lipid and ash (AOAC, 2000). Carbohydrades was analysed as per method described by Hedge and Hofreiter (1962). The water activity (a_w) was measured using AquaLab Pre Water Activity Meter (Decagon Devices, Inc., Pullman, WA, USA) by loading 2 ± 0.5 g of chocolate sample in a sample holder at 25 ± 2°C. The energy value of the chocolate was calculated according to the Atwater coefficients (Merril & Watt, 1955).

Energy value (Kcal/100g DM) = (% proteins × 4 Kcal) + (% carbohydrates × 4 Kcal) + (% lipids × 9 Kcal)

Estimation of minerals such as sodium (Na) and potassium (K) were carried out using flame photometric method (Flame Photometer 128, Systronics, India) (AOAC, 1990). For the analysis of Na and K, ashed sample was dissolved in concentrated hydrochloric acid and made up to 100 ml in a standard flask. The working standards in the range of 10, 20 and 40 ppm were made from stock standard of 1000 ppm for each mineral (Na and K).The instrument was standardized with the above series of working standards. Samples were aspirated into the flame and the corresponding readings were recorded. From the standard curve, mineral concentration present in the sample was calculated.

The samples for instrumental texture profile analysis (TPA) were prepared by equilibrating the sample at room temperature for 15 minutes. The analysis of the prepared samples were carried out using a texture analyser (TA Plus, Lloyd Instruments-Ametek, Hampshire, UK) equipped load cell of 50 kg (Bourne, 1978). TPA was carried out by using a cylindrical plunger of 50 mm in diameter and the parameters were set for test speed 1mm.s^{-1}, trigger force 20gf and compression at 50%. The texture parameters such as hardness, cohesiveness, springiness, gumminess and chewiness of the samples were analysed.

Snap strength test was carried out to determine the breaking strength and deformation of chocolate using a three-point bend rig in texture analyser (TA Plus, Lloyd Instruments-Ametek, Hampshire, UK) (Bahari & Akoh, 2018). The samples were conditioned by holding the samples at ambient temperature for 1 hour prior to analysis. The parameters were set for test speed (1 mm.s^{-1}), distance (10 mm), load cell (50 kg) and trigger force (5 g). The breaking strength and deformation were calculated and express in gf and mm.

The colour values of L* (lightness), a* (redness), and b* (yellowness) of seaweed-enriched chocolate samples was analsyed using Hunter's colorimeter (ColorFlex EZ, Hunter Lab). The instrument was calibrated with both black and white standard ceramic plate prior to analysis.

Sensory analysis of chocolate samples were assessed by the panellists. The scoring was based on a 9-point hedonic scale as described by Amerine, Pongborn, and Roescler, (1965) sensory characteristics evaluated were colour and appearance, texture, odour and flavour. The overall acceptability score was determined by taking into account the total score obtained for samples.

All results in this study were expressed as mean ± standard deviation of three replicates. One-way analysis of variance (ANOVA) and Duncan's multiple range tests were used to determine the significant differences between the variables using SPSS 16.0 software package.

Results and Discussion

The Proximate composition of dried red seaweeds and seaweed enriched chocolate were analysed (Table 1 and 2). Energy value of dark chocolate was 571.75±0.34 Kcal/100g. The *G. edulis* fortified chocolates (516.11±0.69 to 549.79±1.65 Kcal/100g) and *K. alverazii* fortified chocolates (506.02±0.19 to 561.14±0.51 Kcal/100g) had significantly ($p<0.05$) lower energy value than the control sample (Table 2). Water activity and moisture content of the chocolate and seaweed enriched chocolate were between 0.42 to 0.44 and 0.60±0.03% to 1.80±0.00%, respectively. Chocolate products are known to be low microbiological risk food products due to its low a_w and low moisture content. Similar a_w was report in milk chocolate (0.44), chocolate (0.4386), white chocolate (0.44) and semisweet chocolate (0.42) (Hiramatsu, Matsumoto, Sakae, & Miyazaki, 2005; Marchioretto et al., 2024). Incorporation of red seaweed had a boosting effect on the protein content of seaweed enriched chocolate and the highest protein content was found in the chocolate enriched with 7.5% *K. alverazii* (9.03±0.04%) followed by chocolate with 7.5% *G. edulis* (8.60±0.06%). Dark chocolate had a protein content of 3.22±0.01%, which was significantly ($p<0.05$) lower than other chocolate fortified with seaweed. Sukotjo, Syarafina, and Irianto, (2020) reported that the protein content of seaweed (*Eucheuma cottonii*) chocolate pudding was 3.92%, which is much lower that the protein content in all the seaweed fortified chocolate reported in our study. The increased protein content in red seaweeds fortified chocolate may be attributed to the naturally high protein levels found in dried *G. edulis* (14.29±0.04%) and *K.* alveraziі1 (2.59±0.04%) (Table 1).

The crude fat content of the dried *G. edulis* and *K. alverazii* was 1.87±0.05% and 1.92±0.03%, respectively, while ash content was 18.21±0.05% and

Table 1. Proximate composition of dried red seaweeds

Proximate Composition (%)	*G. edulis*	*K. alverezii*
Moisture	12.88±0.07	14.79±0.07
Protein	14.29±0.03	12.59±0.03
Fat	1.87±0.05	1.92±0.03
Ash	18.21±0.05	20.23±0.13
Ch	50.51±0.06	48.36±0.22

20.23±0.13%, respectively (Table 1). The addition of red seaweed to dark chocolate led to a significant ($p<0.05$) decrease in crude fat content compared to that of control chocolate (36.23±0.05%, Table 2). The present study demonstrated that adding *G. edulis* and *K. alvarezii* to dark chocolate can reduce crude fat content by approximately 7.67% to 22.69% and 2.82% to 23.57%, respectively. However, it also revealed that fortifying dark chocolate with seaweed significantly ($p<0.05$) increases the ash content in all samples. Chocolate with *G. edulis* seaweed had an ash content ranging from 1.95±0.01 to 2.49±0.04%, while ash content in chocolate with *K. alverazii* seaweed was in the range of 2.62±0.11 to 4.39±0.03% (Table 2). There was a significant ($p<0.05$) increase in carbohydrate in the chocolate fortified with 2.5% and 5% *G. edulis*, whereas, a significant decrease in carbohydrate content was found in all the sample fortified with seaweed *K. alverazii* when compared with the control sample (Table 2). Nutritional seaweeds are identified by key characteristics viz. low in fat, rich in protein, fibre, vitamins and minerals and other bioactive compounds (Ortiz et al. 2009; Cian, Drago, De Medina, & Martínez-Augustin, 2015; Agregán et al., 2017; Pereira & Valado, 2021; Debbarma, Viji, Rao, & Ravishankar, 2022).

Sodium and potassium in seaweed enriched chocolate are shown in Table 2. The Na content in seaweed-enriched chocolate was significantly higher ($p<0.05$) in all samples, except for the chocolate containing 1% *K. alvarezii*, which showed an increase, though the Na content was not significant ($p>0.05$), compared to the control sample. Similarly, the addition of seaweed resulted in significant ($p<0.05$) increase in K content in all the sample compared to that of control sample. These findings are in agreement with the ash content in seaweed chocolate. As ash content increased significantly ($p<0.05$) with gradual addition of both type of seaweed, an increase in mineral content such as Na and K of the samples was also observed. Chocolate and seaweeds are known as rich sources of essential mineral that can contribute to healthy diet (Debbarma et al., 2016; Marchioretto et al., 2024). Debbarma et al. (2016) reported that Na and K value in *G. edulis* was 423.33 mg/100g and 282.5±0.5 mg/100g, respectively. However, mineral content in seaweeds vary

Table 2. Proximate composition, Minerals and Colour analysis of dark chocolate and seaweed enriched chocolate

Parameters	Choco	GE1	GE2	GE3	GE4	KA1	KA2	KA3	KA4
Proximate Composition									
Moisture (%)	0.76 ± 0.05^{b}	0.60 ± 0.03^{a}	0.87 ± 0.04^{c}	1.00 ± 0.03^{d}	2.23 ± 0.05^{g}	1.02 ± 0.04^{d}	1.39 ± 0.03^{e}	0.88 ± 0.01^{c}	1.80 ± 0.00^{f}
Protein (%)	3.22 ± 0.01^{a}	4.97 ± 0.04^{c}	5.24 ± 0.04^{d}	7.28 ± 0.05^{e}	8.60 ± 0.06^{g}	4.19 ± 0.03^{b}	5.21 ± 0.01^{d}	7.77 ± 0.04^{f}	9.03 ± 0.04^{h}
Fat (%)	36.23 ± 0.05^{i}	33.45 ± 0.16^{f}	31.88 ± 0.06^{d}	29.71 ± 0.04^{c}	28.01 ± 0.04^{b}	35.21 ± 0.07^{h}	34.42 ± 0.06^{g}	32.09 ± 0.04^{e}	27.69 ± 0.05^{a}
Ash (%)	1.28 ± 0.04^{a}	1.96 ± 0.02^{b}	1.95 ± 0.01^{b}	1.89 ± 0.04^{b}	2.49 ± 0.04^{c}	2.62 ± 0.11^{d}	3.71 ± 0.01^{e}	4.39 ± 0.03^{f}	4.37 ± 0.00^{f}
CH (%)	58.22 ± 0.02^{g}	57.22 ± 0.03^{e}	58.36 ± 0.15^{h}	58.52 ± 0.04^{i}	57.41 ± 0.02^{f}	56.87 ± 0.05^{d}	54.51 ± 0.00^{a}	54.75 ± 0.04^{b}	55.19 ± 0.02^{c}
Minerals									
Sodium (Na, mg/100gm)	25.34 ± 0.91^{a}	39.24 ± 0.13^{b}	52.17 ± 0.30^{d}	56.75 ± 0.21^{e}	62.27 ± 0.35^{g}	26.04 ± 0.31^{a}	50.24 ± 0.13^{c}	60.50 ± 0.20^{f}	75.05 ± 0.21^{h}
Potassium (K, mg/100gm)	435.38 ± 0.13^{a}	451.00 ± 0.10^{c}	476.08 ± 0.28^{d}	479.25 ± 0.30^{e}	485.73 ± 0.40^{f}	449.30 ± 0.18^{b}	521.31 ± 0.04^{g}	532.76 ± 0.18^{h}	549.26 ± 0.23^{i}
Colour									
L*	21.23 ± 1.05^{bcd}	23.08 ± 1.49^{cd}	23.35 ± 1.61^{d}	22.79 ± 2.25^{cd}	18.56 ± 1.63^{a}	21.07 ± 0.52^{bc}	21.48 ± 0.52^{bcd}	19.66 ± 0.85^{ab}	19.66 ± 0.85^{ab}
a*	2.04 ± 0.10^{ab}	1.77 ± 0.25^{ab}	1.72 ± 0.17^{a}	1.74 ± 0.22^{a}	2.56 ± 0.38^{c}	2.55 ± 0.17^{c}	1.81 ± 0.10^{ab}	2.05 ± 0.16^{ab}	2.11 ± 0.10^{b}
b*	1.48 ± 0.11^{cde}	0.97 ± 0.26^{ab}	0.75 ± 0.17^{ab}	0.90 ± 0.11^{ab}	1.95 ± 0.56^{e}	1.61 ± 0.35^{de}	0.66 ± 0.12^{a}	1.07 ± 0.28^{abc}	1.22 ± 0.18^{bcd}

Results are mean ± standard deviation, values within a row with different superscript letters are significantly different ($p<0.05$).

depending on various factors such as geographical location, growing environments, season, physiology of the seaweed etc. (Debbarma et al., 2022).

Macro minerals are required in relatively large quantities for several key physiological functions in the human body (Roohinejad et al., 2017). Na, abundant in seaweeds, plays a critical role in regulating blood pressure. Both low and excessive Na intake have been associated with increased mortality rates (Whelton, 2014a; Pereira, 2018). Besides being an essential element for human physiology, K is a healthy alternative to Na consumption. Maintaining a balanced Na to K ratio is crucial to mitigate adverse health effects, since high Na to low K ratios increase hypertension risk (Whelton, 2014b & Pereira, 2018). The Na and K values of control chocolate were 25.34±0.91 mg/100g and 435.38±0.13 mg/100g, respectively (Table 2). The Na content in *G. edulis* and *K. alverazii* enriched chocolate ranged from 39.24±0.13 to 62.27±0.35 mg/100g and 26.04±0.31 to 75.05±0.21 mg/100g, respectively, while, the K content ranged from 451.00±0.10 to 485.73±0.40 mg/100g and 449.30±0.18 to 549.26±0.23 mg/100g, respectively (Table 2). The World Health Organization (WHO) recommends consumption of less than 2000 mg of Na and more than 3510 mg of K per day and an optimal Na to K ratio of ≤1.0 to support cardiovascular health (WHO, 2012). In the present study, the Na to K ratio in the seaweed enriched chocolate was <1.0

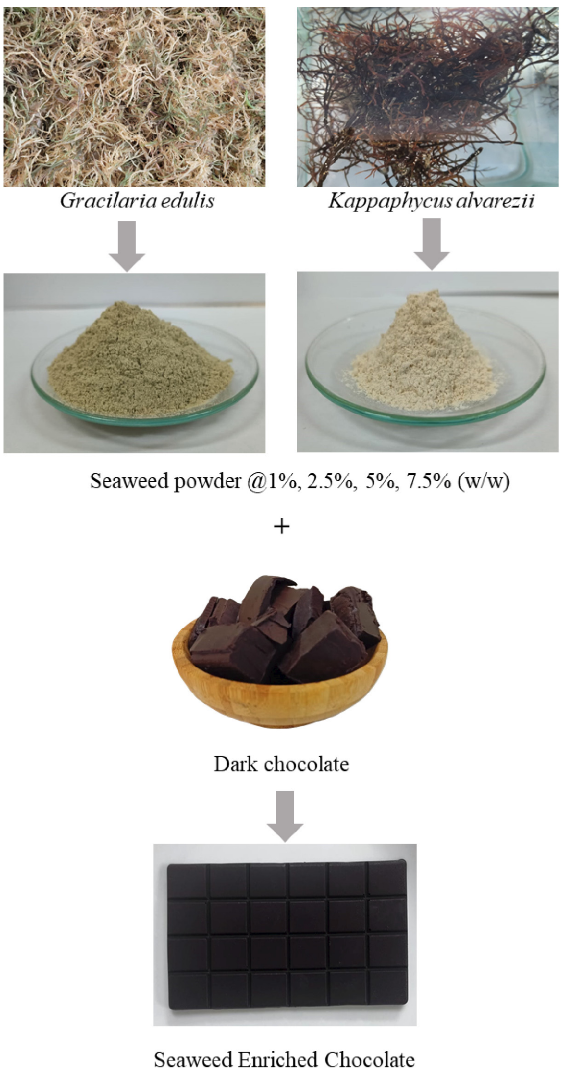

Fig. 1. Flow chart of preparation of seaweed enriched chocolate

Adding seaweed to dark chocolate increased its breaking strength. Except for the KA1 sample (chocolate with 1% *K. alvarezii*), all seaweed-enriched chocolate samples exhibited significantly ($p<0.05$) higher breaking strength. However, no significant ($p>0.05$) changes in deformation were observed in any of the samples (Fig. 2). As the

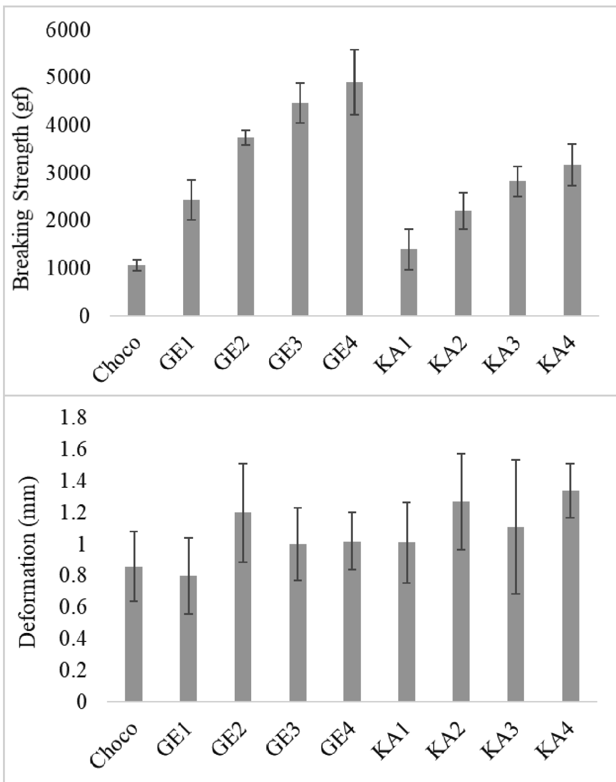

Fig. 2. Snap test of dark chocolate and seaweed enriched chocolate a) break strength (gf) and b) deformation (mm)

concentration of seaweed increased the force required to break the chocolate also increased. These findings suggest that higher levels of seaweed powder, particularly those with elevated protein content, increase the shear force required to cut the chocolate, thereby enhancing its resistance to break. Significantly lower breaking strength was found for *K. alvarezii* enriched chocolate than *G. edulis* enriched chocolate (Fig. 2 a). Similarly, textural profile analysis revealed that as concentration of seaweed increased, hardness also increased significantly ($p<0.05$) in the chocolate fortified with 1 to 7.5% *G. edulis* and 5 to 7.5% % *K. alvarezii* as compared with the control sample (Table 3). The chewiness values were significantly higher for all the chocolates with *G. edulis*, whereas chewiness was not significantly higher for the chocolate with *K. alvarezii* as compared with the control sample. Chocolate with 1% and 2.5% *K. alvarezii* had similar hardness and chewiness of that of control chocolate. The results are consistent with previous studies involving the addition of red seaweed *K. alvarezii* (9-10%) to muffins (Mamat, Akanda, Zainol, & Ling, 2018). and the incorporation of *Arthrospira platensis*, a microalgae, into white chocolate (Özbal, Çelekli, Gün, & Bozkurt, 2022). Hadnađev et al. (2023) reported significantly higher breaking force and hardness in dark chocolate fortified with fish oil microcapsulation. In the present study, texture profile analysis indicated that hardness 1 of the seaweed enriched chocolate increased with increasing concentration of both the seaweed species. The chocolate fortified with *G. edulis* exhibited a clear trend of increasing hardness 2 as the concentration of seaweed increased. In contrast, harness 2 of the chocolate enriched with *K. alvarezii* did not show a consistent trend with varying seaweed concentration. It was also observed that the concentration of seaweed did not result in proportional changes in the springiness, cohesiveness, and adhesiveness of the seaweed-enriched chocolate. The observed effects of seaweed addition on the textural properties of the chocolate samples may be attributed to the high protein and fiber content, which are the principal components of the seaweed. High protein content in *G. edulis* (14.29±0.04%) and *K. alvarezii* (12.59±0.04%) may interact with other ingredients, leading to formation of additional bonds or networks within the food metric, thereby increasing the hardness.

The colour value (L*, a* and b*) of chocolate and seaweed enrich chocolate are shown in Table 2. Generally, adding red seaweed to a food product significantly affects its colour value. However, all the seaweed chocolate samples showed a similar appearance, with no significant ($p>0.05$) changes in lightness value (L*), regardless of the level of incorporation, compared to the control sample. Control and seaweed enriched chocolates were characterized with positive a* and b* values. The colour changes in seaweed chocolates were acceptable to the sensory panellists, indicating that it is feasible to incorporate seaweed into dark chocolate while preserving both its colour and appearance.

The sensory properties of seaweed enriched chocolate and dark chocolate are illustrated in Fig. 3. The addition of seaweed can enhance nutritional content, physicochemical characteristics, functional, and texture properties of the food. However, unique flavour profile may adversely affect the organoleptic

Table 3. Texture profile analysis of dark chocolate and seaweed enriched chocolate

Sample	Hardness 1 (N)	Hardness 2 (N)	Cohesiveness	Springiness (mm)	Gumminess (N)	Chewiness (Nmm)	Adhesiveness (kgf.mm)
Choco	122.39±6.18^{b}	50.39±6.86^{b}	0.09±0.03^{ab}	1.30±0.24^{e}	10.48±3.13^{ab}	14.19±6.08^{bc}	0.63±0.10^{ab}
GE1	162.54±22.49^{c}	68.88±11.26^{bcd}	0.14±0.03^{c}	1.22±0.06^{de}	22.46±1.42^{d}	27.40±3.01^{d}	0.73±0.05^{ab}
GE2	182.72±23.06^{c}	80.66±16.92^{de}	0.13±0.04^{bc}	1.24±0.05^{e}	23.31±4.58^{d}	28.87±5.59^{d}	0.61±0.35^{ab}
GE3	198.62±7.60^{cde}	73.31±10.78^{cd}	0.11±0.02^{abc}	0.87±0.29^{bcd}	21.23±3.26^{d}	28.20±6.36^{bc}	0.10±0.04^{a}
GE4	209.52±6.05^{de}	91.50±2.90^{e}	0.09±0.02^{ab}	1.12±0.14^{de}	18.94±5.02^{cd}	31.31±7.22^{cd}	1.40±0.03^{b}
KA1	80.20±14.16^{a}	23.54±4.34^{a}	0.06±0.00^{a}	0.51±0.26^{a}	4.74±1.08^{a}	2.28±0.91^{a}	0.02±0.01^{a}
KA2	121.88±20.99^{b}	51.42±11.43^{b}	0.10±0.03^{abc}	1.00±0.19^{cde}	12.55±3.10^{bc}	5.64±0.74^{a}	0.22±0.00^{a}
KA3	168.71±17.29^{cd}	51.99±6.07^{b}	0.08±0.02^{ab}	0.59±0.15^{ab}	13.60±2.51^{bc}	9.84±1.49^{ab}	0.03±0.01^{a}
KA4	171.06±24.32^{cd}	61.76±14.86^{bc}	0.10±0.03^{abc}	0.68±0.22^{abc}	17.78±6.74^{cd}	17.23±5.51^{bc}	0.22±0.00 ^{a}

Results are mean ± standard deviation, values within a column with different superscript letters are significantly different ($p<0.05$).

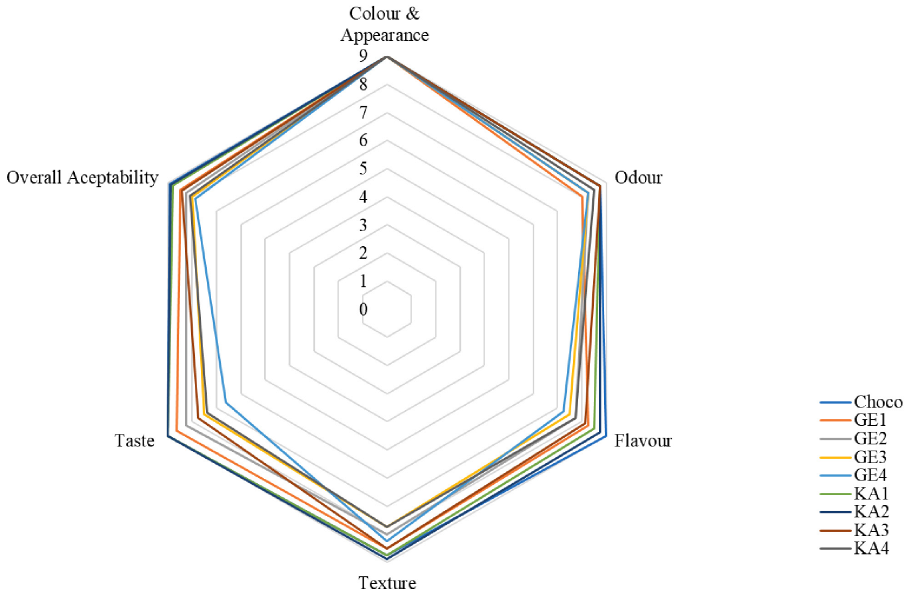

Fig. 3. Sensory Evaluation of dark chocolate and seaweed enriched chocolate

properties and potentially reduce consumer acceptability of the final product. Therefore, the evaluation of organoleptic characteristics of the seaweed enriched chocolate was very important. Sensory evaluation reveals that chocolate with the addition of *G. edulis* and *K. alvarezii* (up to 7.5%, w/w) was sensorily acceptable, with no detectable seaweed odor. The flavor of the dark chocolate effectively masked the seaweed flavor and odor. Additionally, organoleptic acceptance was significantly ($p<0.05$) higher for chocolate with *K. alvarezii* compared to chocolate with *G. edulis*. In the case of chocolate fortified with *G. edulis*, a noticeable granule-like mouthfeel was observed at higher seaweed concentrations (5% and 7.5%). This granule-like mouthfeel was not present in chocolate fortified with *K. alvarezii*. However, all the samples were organoleptically acceptable, as their mean scores for overall acceptability were above 6.0 on a 9-point hedonic scale, which is regarded as a threshold for good acceptability in dark chocolate (Botelho et al., 2014). Several studies demonstrate that seaweed can positively enhance flavour when added in appropriate concentrations. The results of the present study are supported by Stefani, Pratama, Rostini, and Afrianto, (2019) and Sukotjo et al. (2020), which found that milk chocolate and chocolate pudding containing seaweed had better sensory characteristics and overall acceptability compared to control samples. Salgado et al. (2023 & 2024) reported that incorporating seaweed into chocolates not only altered sensory perceptions but also evoked distinct emotional responses among consumers.

Consumers looking for organic, nutritious, and sustainable food products often face a shortage of affordable healthy options in the market. This study demonstrates that incorporating red seaweed, specifically *G. edulis* and *K. alvarezii*, into dark chocolate enhances its nutritional profile without compromising sensory quality. The addition of these seaweeds significantly increased the protein, mineral content, and ash content of the chocolate while reducing its crude fat content. Sensory evaluations confirmed that chocolates with up to 7.5% seaweed were acceptable, with *K. alvarezii*-enriched chocolates showing higher organoleptic acceptance compared to those with *G. edulis*. These findings suggest that red seaweeds can be successfully used to create healthier chocolate products with good consumer acceptance. Future research should focus on optimizing formulations and exploring the long-term health benefits and broader consumer acceptance of seaweed-enriched chocolate.

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