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Physicochemical and sensory quality of high antioxidant fruit leather of red dragon fruit and watermelon rind enriched with seaweed

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Abstract
Fruit, as a source of antioxidants and phenolic compounds, is perishable. It also has an underutilized component. Fruit leather has a long shelf life in the form of thin sheets with a distinctive texture. This study aimed to investigate the effect of seaweed (*Eucheuma cottonii*) addition on the physicochemical and sensory quality of fruit leather made from the combination of red dragon fruit and watermelon rind. The physicochemical quality was characterized by measuring the critical quality parameters of fruit leathers, including proximate analysis, water activity, total phenol, antioxidant activity, texture, and organoleptic analysis. The statistical analysis of phenolic compound activity, antioxidant activity, vitamin C, moisture content, carbohydrates, and water activity (a_w) was conducted using a one-way ANOVA test, while the analysis of ash content, protein, fat, tensile strength, elongation, and organoleptic properties was performed using the Kruskal–Wallis test. Increasing seaweed concentration significantly increased moisture, ash, protein, vitamin C, total phenol, water activity, and elongation but decreased fat content. Furthermore, the increase in seaweed concentration reduced liking toward taste and color significantly but increased texture liking. The best product was the F2 product with 10% seaweed. F2 has the following attributes: 11.07% of moisture content, 2.34% of ash, 1.53% of protein, 0.19% of fat, 84.86% of carbohydrate, 8.17 mg/100 g of vitamin C, 0.41 of water activity, 0.54 N/m2 of tensile strength, 22.22% of elongation, 107.39 ppm of IC50, 1.66 mg/GAE g of total phenolics.

Keywords Fruit leather · Seaweed · Red dragon fruit · Watermelon rind

1 Introduction

Fruit leather is a form of fruits in thin sheets with a distinctive texture, a long shelf life and 10–20% moisture content at a thickness of 2–3 mm [1]. Fruit leather is created by dehydrating a thin layer of fruit puree to produce a product with a chewy texture. It serves as an economical and convenient alternative to natural fruits, offering high nutritional value, particularly in terms of energy, minerals, antioxidants, and fiber, as all the nutrients are concentrated [2]. Multiple combinations of fruits and vegetables have been used to produce fruit leather, including lapsi [3], apple, plum, banana, and guava [4]. However, combining high-antioxidant fruit with underutilized food parts, which are still discarded and end up as food waste, has yet

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to be explored. This approach has the potential to preserve high-antioxidant fruits while also contributing to the reduction of food waste by utilizing these neglected parts.

Red dragon fruit (*Hylocereus sp.*) contains nutrients, bioactive compounds, vitamins, and minerals with potent antiradical properties. Red dragon fruit flesh contains a total phenolic content of 0.24 ± 0.95 mg GAE/g [5]. The red dragon fruit's flesh and peel boast elevated phenolic content and antioxidant properties in contrast to its white counterpart. Although white dragon fruit pulp yields more and contains higher sugar content, red dragon fruit pulp excels in phenolic compounds, offering significant antioxidant potential. Additionally, red dragon fruit contains essential vitamins (B5, C, and E) and minerals (K, Mg, Ca, P, Fe, and Zn) [6]. The inhibitory value of the IC50 radical of DPPH in dragon fruit flesh extract was observed to fall within the IC50 value range of 3.77 to 11.83 mg/g extract, which is classified as very strong [7]. The fruit's flesh also has a refreshing, sweet, and sour taste and is known for its attractive red color. Unfortunately, dragon fruit is highly perishable with 84% water content [6]. Therefore, employing advanced processing techniques, such as transforming red dragon fruit into fruit leather, can serve as a potential alternative for preserving red dragon fruit. Additionally, Red dragon fruit contains pectin with a low degree of methoxylation (DM) [8]. This low DM produces a less flexible gel compared to pectin with high DM [9]. The addition of seaweed that contains carrageenan improves the gel characteristics.

Watermelon (*Citrullus vulgaris* Schard) fruit is easily accessible throughout the year. Watermelon rind, which makes up 30% of the fruit, needs to be utilized [10]. Based on national production data from the Indonesian Central Statistics Agency in 2022, watermelon production reached 367,816 tons per year, of which approximately 110,344 tons per year consist of unused watermelon rind. Therefore, the utilization of watermelon rind for food processing contributes to sustainability by reducing waste while simultaneously increasing the added value of food products. Additionaly, watermelon rind contains bioactive compounds like L-citrulline, phenolic compounds such as 4-hydroxybenzoic acid and vanillin, saponins, terpenoids, phenols, and alkaloids, making it a high-potential antioxidant source. The phenolic content in the watermelon rind was approximately 0.021 ± 0.003 mg GAE/g. Additionally, watermelon rind's free radical scavenging activity is significantly higher than that of melon skin [11]. On the other hand, watermelon rind contains vitamins (A, B1, B2, B3, B6, C) and minerals (Fe, Mn, P, Ca, Na, Zn, Mg, K), offering significant potential to enhance the nutritional value of fruit leather [12]. Additionally, carbohydrates, specifically polysaccharides, are the primary compounds found in watermelon rind, and it has been suggested that it could serve as a raw material for pectin extraction, serving as gelling, thickening, and stabilizing agents in fruit leather. It is known that the pectin content in watermelon rind is 19.3% with a degree of methyl esterification (DM) greater than 50%, classifying it as high methoxyl pectin. This type of pectin can only form a gel at low pH (< 3.5), requiring the addition of acid [13].

Furthermore, watermelon rind is mixed with other ingredients such as red dragon fruit that has high water content. Then, it needs additional binders to optimize the gel structure's firmness, making it more durable especially in high moisture materials. These agents, known as hydrocolloids, are widely utilized in many fruit leather formulations to maintain the desired texture, extend shelf life, and preserve various other physicochemical properties [2]. Seaweed (*Eucheuma cottonii*) has been utilized as a hydrocolloid due to its carrageenan content. Carrageenan, contained in seaweed, generally forms strong and rigid gels [14]. Additionaly, its also possesses antioxidant properties. Seaweed had a total phenolic content of 3.96 mg GAE/g in methanol extract and antioxidant activity with methanol of 72.49 ppm, which was considered strong [15]. Therefore, seaweed has the potential to increase the antioxidant capacity and contribute to forming double helix structure by interacting with bivalents ions. This structure increase viscosity and protecting phenolic compounds from the heating process, resulting in less damage to antioxidant component in fruit leather processing [16, 17].

The objective of this study was to investigate the effect of seaweed addition on the physicochemical and sensory quality of red dragon fruit and watermelon rind leather (RDWS). The physicochemical quality was characterized by measuring the critical quality parameters of fruit leathers, including proximate composition, water activity, total phenolic, antioxidant activity, texture, and organoleptic properties. We hypothesized that adding seaweed in RDWS can improve the critical quality parameters, thus enhancing its potential to become functional food products.

2 Materials and methods

2.1 Raw materials

Ripe red dragon fruit (*Hylocereus polyrhizus*) and ripe red watermelon (*Citrulus lanatus*) were supplied by a local market in Semarang, Indonesia, while dried red seaweed (*Euchuema cottonii*) was purchased from Moluccas, Indonesia and stored at 10 ℃ and used within 5 days after arrival. Dragon fruit should have a red–violet color and smooth peel to

indicate the ripeness [18] with no browning or blackening [19] and no visible injury. Mature ripe red watermelon with red flesh, brown tendril and yellow ground spot and no visible injury was used for the material [20]. The collection of red dragon fruit and red watermelon used in this study complied with local and national guidelines.

2.2 Fruit leather processing

The preparation of fruit leather follows the method outlined by Kc et al. [3] with modification [3]. The base fruit leather composition was pectin source, sugar, and gelling agent. Watermelon rind was a pectin source, as high as 21%, seaweed was used as the carrageenan source for the gelling agent [21]. Furthermore, the composition variation composition was obtained with optimization and adjusted for preferred texture and taste as directed by Khusnul Khotimah [21]. The watermelon rind was peeled and cleaned from the flesh and then the seaweed was rehydrated by soaking in water for 12 h and rinsing it in flowing water. Afterwards, the red dragon fruit was peeled before being used for formulation. Watermelon rind, red dragon fruit, and seaweed were milled using a Waring blender. The composition of ingredients used is shown in Table 1. The quantities of watermelon rind and red dragon fruit are measured at 50 g each, whereas the seaweed is weighed in varying percentages (0%, 10%, 20%, and 30%) relative to the total weight of watermelon rind and red dragon fruit. Then, the mixtures were added with 0.2% citric acid and 15% sugar of the total weight of red dragon fruit, watermelon rind, and seaweed. Due to the high-water content in red dragon fruit and watermelon rind, no additional water was added. Mixture was heated for 1 min at a temperature of 40–50 ℃, homogenized by stirring with a spatula, and then molding into 2–3 mm thick products. The mold used in this process is a flat tray made of stainless steel. The mixtures were then dried using a convection oven at 50 ℃ for 6 h to obtain moisture contain of up to 20%. Then the fruit leather was cooled, cut into 3 × 0.5 cm, packed in sealed plastic bags, and stored at − 20 ℃ until further use. The experiments were performed in triplicate. The thickness of the final fruit leather was 1–2 mm.

2.3 Proximate analysis

The water content of the samples was determined in triplicate by the gravimetric method using oven ESCO Isotherm IFA-54–8 [22]. The fat content was determined in duplicate by the Soxhlet method [23]. The protein content was determined by the Kjeldahl method [23] in duplicate using DK 6 (Velp Scientifica, Milan, Italy) as digester and UDK 129 (Velp Scientifica, Milan, Italy) as distiller. The ash content was determined in triplicate using the dry ashing method using *Thermo Scientific Thermolyne FB1410M* [23]. The carbohydrate content was calculated by difference.

2.4 Water activity test

Based on the manufacturer's specifications, water activity was determined in triplicate using an Aw meter (LabSwift-aw, Novasina, Lachen, Switzerland). The sample was fitted into the sample container at a 5 cm diameter [24].

Table 1 Fruit leather ingredients (g)

Ingredients	F1	F2	F3	F4
Main component (100 g)				
Red dragon fruit	50	50	50	50
Watermelon rind	50	50	50	50
Additional component (add % seaweed from main component)				
Seaweed	0%	10%	20%	30%
Total component (g)	100	110	120	130
Minor component (% from total component)				
Sugar (15%)	15	16.5	18	19.5
Citric acid (0.2%)	0.2	0.22	0.24	0.26

2.5 Tensile strength and elongation

The tensile strength of the fruit leather was measured in triplicate with a texture analyzer (Brookfield CT3, Middleborough, United States) using a clamp probe with a sample size of 30 × 5 mm. Settings used were as follows: *Trigger* was set at 4.5 g. *deformation* at 50 mm, with 1.0 mm/s of test speed, and 4.5 kg of load cell [25]. Results were expressed as tensile strength in N/m^2 and elongation in %.

2.6 Vitamin C content

Vitamin C content was measured using a spectrophotometer (Supelco Spectroquant Prove 300, Darmstadt, Germany) according to Sari, Martha [26]. One gram of the sample was homogenized with 20 ml aquadest and was centrifuged for 10 min at 3000 rpm. An amount of 0.1 ml supernatant was diluted by aquadest to 10 ml. Spectrophotometric analysis was done at 288 nm. A calibration curve was prepared using ascorbic acid (Merck) at 2, 4, 6, 8, and 10 ppm.

2.7 Total phenol

Total phenol was measured in triplicate using the Folin-Ciocalteu method, according to Wardhani et al. [27]. The fruit leathers were homogenized with a waring blender and macerated with water and ethanol (1:1) for 2 h to produce 10.000 ppm extract. An amount of 0.25 ml extracts was added by 1.25 ml aquadest, 1.25 ml Folin-Ciocalteu (Merck Supelco, 109,001), and 0.25 ml ethanol, incubated for 5 min and was added by 0.5 ml Na_2CO_3 (Merck, 106,392) 5% in aquadest; and were incubated in dark for 1 h and ready to be measured. Spectrophotometric analysis was done using a spectrophotometer UV–Vis (Supelco Spectroquant Prove 300, Darmstadt, Germany) at 725 nm. A calibration curve was prepared using gallic acid (Merck, 842,649) at 5, 10, 15, 20, 25, 50, and 100 ppm. Total phenol expressed as milligrams of gallic acid equivalent per gram (mg GAE/g).

2.8 IC_{50} of antioxidant activity

Half-maximal inhibitory concentration (IC_{50}) of antioxidant activity was measured in triplicate using DPPH (2,2-dhipenyl-1-picryhydrazyl) method. The IC_{50} assay was performed by adding a constant aliquot of 1.5 ml sample at 2, 4, 6, 8, and 10 ppm in 96% ethanol to 1,5 ml DPPH 0,1 mM. The same procedure was done for vitamin C as the working reference at 2, 4, 6, 8, and 10 ppm in ethanol 96%. All the reactions were incubated in the dark for 30 min until measurements. Each absorption response of each mixture was measured immediately at 515 nm using an UV–Vis Spectrophotometer (Supelco Spectroquant Prove 300, Darmstadt, Germany) [28].

2.9 Organoleptic analysis

The organoleptic analysis was done using 30 consumer panelists. Two organoleptic analyses were taken simultaneously by the panelists: hedonic test analysis and descriptive analysis. The studies involving human participants were reviewed and approved by the Ethics Committee of the Dr. Moewardi General Hospital with ethical clearance No. 750/III/HREC/2024. The participants provided their written informed consent to participate in this study. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

2.9.1 Hedonic analysis

The fruit leathers were served to panelists one at a time, and the panelists were asked to indicate their hedonic response to the taste, color, aroma, and texture of the fruit leathers on the scale. There was 5-point scale used to determine the degree of liking for the fruit leather, including 1: dislike very much, 2: slightly dislike, 3: slightly like, 4: like, 5: like very much [29].

2.9.2 Descriptive analysis

After the panelists had done the hedonic analysis, they continued to fill in the descriptive analysis. There was 5 point scale [30] used to determine the degree of specific sensory attributes related to the fruit leathers, including taste intensity, red color, fishy aroma, and elasticity, as listed in Table 2.

2.10 Best formulation analysis

The best formulation was chosen based on a Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) [31], with physicochemical properties as the priority among other quality attributes. The best formulation was chosen based on the best value from the calculation of the rating of each variable and the score.

The calculation was done in Microsoft Excel as follows: First, the importance of the variables was sorted and ranked by their significance to the fruit leather quality from the lowest to the highest as follows: fat, carbohydrate, protein, ash, moisture, water activity, vitamin c, phenol, ic50, tensile strength, elongation, texture, aroma, color, taste. Second, normalized weight (A) was calculated by dividing the value of each rank by the total rank value. Third, define the dimensionless value (B) by calculating the difference between the worst value among formulas and the formulation value divided by the difference between the worst value among formulas and the best value among formulas. Fourth, multiply the normalized weight (A) with dimensionless value (B) to get the weight value. Finally the total weight value of each attribute was summed by each formulation. The formula with the highest total weight value was the best formula.

2.11 Statistical analysis

The statistical analysis of phenolic compound activity, antioxidant activity, vitamin C, moisture content, carbohydrates, and water activity (a_w) was conducted using a one-way ANOVA test, while the analysis of ash content, protein, fat, tensile strength, elongation, and organoleptic properties was performed using the Kruskal–Wallis test. Both analyses were carried out using SPSS version 25.

3 Results and discussion

3.1 Proximate

3.1.1 Water content

Table 3 shows the fruit leather's water content, which has a significant increase between groups ($p < 0.01$). The result is aligned with the addition of seaweed to the fruit leather of jujube fruit (*Ziziphus mauritiana*) and the skin of red dragon fruit, which provides a significant increase in the water content [32]. The water content in fruit leather products comes from the water-soaked seaweed, dragon fruit, and watermelon rind. Those three ingredients have a high water content, but all groups of the variations of seaweed addition have relatively low water content, under 25%. The low water content of fruit leather is required to inhibit bacterial growth and reduce other unwanted reactions such as sugar crystallization, non-enzyme browning, and lipid oxidation [33]. The samples during production can be observed in Fig. 1.

The water content of fruit leather ranged between 7.95 ± 0.64% and 13.99 ± 0.85%, with F1 having the lowest water content, whereas F3 has the highest water content. The elevation of water content aligned with the addition of seaweed. The increase of water content occurs due to the content of seaweed carrageenan, as a hydrocolloid, which has the ability to absorb water and form a gel [34]. Carrageenan in seaweed is able to hold the water molecule because it has a structure with a large number of hydroxyl groups [35]. The exact number of the hydroxyl groups was difficult to predict because of the variety of molecule weight of the carrageenan. Carrageenans consist mainly of potassium, sodium, calcium, magnesium and ammonium sulfate esters of galactose and 3,6-anhydrogalactose which are alternately linked α -1,3 and β

Table 2 Description analysis parameters

Scale	Taste intensity	Red color	Fishy aroma	Elasticity
1	Very not tasteless	Brown	Very not fishy	Very not elastic
2	Not tasteless	Brownies red	Not fishy	Not elastic
3	Slightly tasteless	Slightly red	Slightly fishy	Slightly elastic
4	Tasteless	Red	Fishy	Elastic
5	Very tasteless	Very red	Very fishy	Very elastic

Table 3 Fruit leathers physicochemical attributes

Parameters	Treatment			
	F1	F2	F3	F4
Moisture (%)*	7.95 ± 0.64^{a}	11.07 ± 1.95^{b}	13.99 ± 0.85^{c}	13.25 ± 0.85^{c}
Ash (%)**	1.71 ± 0.69^{a}	2.34 ± 0.42^{b}	3.14 ± 0.06^{c}	3.67 ± 0.20^{d}
Protein (%)**	1.27 ± 0.03^{a}	1.53 ± 0.02^{b}	1.64 ± 0.02^{c}	1.66 ± 0.07^{c}
Fat (%)**	0.22 ± 0.29	0.19 ± 0.13	0.10 ± 0.10	0.05 ± 0.00
Carbohydrate (%)*	88.85 ± 0.41^{a}	84.86 ± 0.85^{b}	81.13 ± 0.74^{c}	81.38 ± 0.74^{c}
Vitamin C (mg/100 g)*	6.53 ± 1.22^{a}	8.17 ± 1.07^{b}	8.05 ± 0.89^{b}	10.88 ± 1.37^{c}
Water activity *	0.38 ± 0.01^{a}	0.41 ± 0.01^{b}	0.42 ± 0.01^{b}	0.43 ± 0.01^{c}
Tensile strength (N/m^2)**	0.08 ± 0.03^{a}	0.54 ± 0.10^{b}	1.03 ± 0.26^{c}	1.47 ± 0.32^{d}
Elongation (%)**	17.17 ± 3.73^{a}	22.22 ± 2.12^{b}	29.94 ± 4.89^{c}	31.67 ± 5.47^{d}

0% seaweed (F1), 10% seaweed (F2), 20% seaweed (F3), 30% seaweed (F4). Significance < 0.05. *One way ANOVA, **Kruskal Wallis test. Different superscript letters indicate a significant difference between treatments. n (total sample) = 9 (water, ash, vitamin C content, and a_w. 3 experiment repetitions, three analysis repetition), n = 6 (protein content and tensile strength. 3 experiment repetitions, two analysis repetitions), n = 6 (fat and carbohydrate content. 3 experiment repetitions, two analysis repetition)

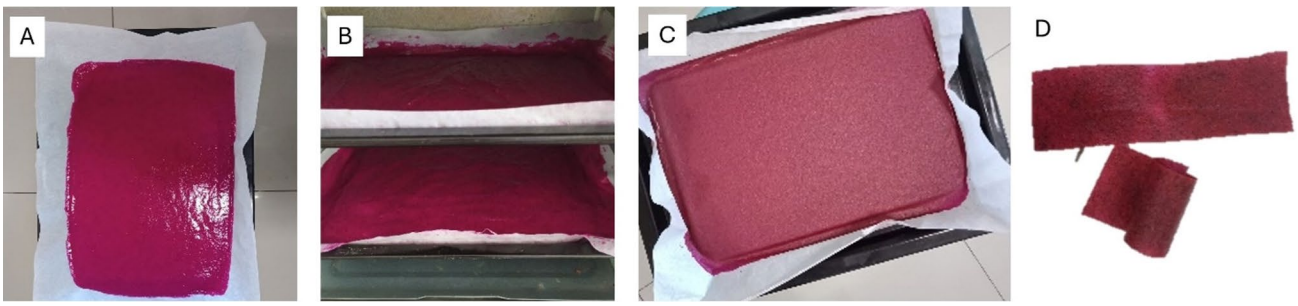


Fig. 1 Fruit leather during processing. **A** Sheeting the mixture; **B** Drying the mixture; **C** Dried fruit leather; **D** Sliced fruit leather

-1,4 in the polymer, with repeating galactose unit to the molecule weight more than 100 kDa [36]. Each unit consist of three hydroxyl groups and accumulate until the molecule weight is fulfilled.

3.1.2 Ash content

The ingredients of the product affect the ash content of a product. Seaweed contains quite high ash content, whereas the ash content of red dragon fruit is 0.54% and watermelon rind is 0.23% [37, 38]. The seaweed addition to the RDWS depicted a difference in ash content between treatments ($p < 0.01$) (Table 3). F1 has the lowest ash content, while F4 has the highest ash content. The addition of seaweed causes the increase of the ash content because the ash content of seaweed reaches 46.19% [39].

The ash content in food products serves as an indicator of the total mineral content present within the product. Seaweed, being a rich source of minerals, contributes significantly to the overall mineral profile of food items. Minerals found in seaweed include iron, magnesium, potassium, sodium, zinc, iodine, and calcium [39]. With the adding of seaweed into fruit leather, there is an observed increase in the ash content. This increasing suggests that the addition of seaweed can effectively enrich the mineral composition of fruit leather. As a result, fruit leather enriched with seaweed may offer enhanced nutritional benefits especially in mineral contain.

3.1.3 Protein content

The protein content between groups of fruit leather with the addition of seaweed indicates differences ($p < 0.01$). The results of protein content are not aligned with the research on the addition of seaweed to artificial rice, which shows no difference between treatments [40]. Based on the test results, the protein content in RDWS ranges from 1.27%

to 1.66%. The lowest protein content amounted to 1.27 ± 0.03% in F1, and the highest protein content amounted to 1.66 ± 0.07% in F4.

Its indicate that the protein content in RDWS increased along with the addition of seaweed. The higher the concentration of seaweed added, the higher the protein content. This could be attributed to the higher protein content of seaweed compared to other ingredients, where seaweed, red dragon fruit, and watermelon rind contain 9.76%, 1.45%, and 0.53% protein, respectively [37–39]. The low protein content of the main ingredients caused the protein content of fruit leather to be no more than 2%. Consequently, seaweed can enhance quality of fruit leather especially in protein content.

3.1.4 Fat content

The addition of seaweed shows no differences in the fat content between the fruit leather groups ($p = 0.177$). The result is different from the fat content of artificial rice with the addition of seaweed, which shows a difference between treatments [40]. Based on the test results, the protein content in RDWS ranges from 0.05% to 0.22%. The addition of seaweed decreased the fat content as shown in Table 3 with no significant difference. The lowest fat content amounted to 0.05 ± 0.00% in F4, and the highest fat content amounted to 0.22 ± 0.29% in F1. Its indicate that the fat content in RDWS decreased along with the addition of seaweed.

Seaweed, red dragon fruit, and watermelon rind have very low-fat content. Fat content in seaweed, red dragon fruit, and watermelon rind respectively were 1.10%; not detected; and 0.13% [37–39]. Therefore, the fat content of fruit leather becomes very low. Despite the low-fat content, the type of fat contained in the seaweed is mostly Polyunsaturated Fatty Acid (PUFA), which is 51.55% of the total fat content. In addition, seaweed contains omega-3 at 45.72% of the total fatty acids [39].

3.1.5 Carbohydrate content

The addition of seaweed indicates a difference in the carbohydrate content between fruit leather treatments ($p < 0.01$). The result is different from the carbohydrate content of artificial rice with the addition of seaweed which shows no differences between treatments [40]. The highest carbohydrate content is the result of F1 treatment, while the lowest carbohydrate content is the result of F3 treatment. The elevation in carbohydrate content is inversely proportional to the addition of seaweed. The addition of seaweed, decreased the carbohydrate content where F1 has a carbohydrate content of 88.66 ± 0.63%, F2 of 85.81 ± 0.27%, F3 of 80.84 ± 1.01%, and F4 of 80.99 ± 0.99%.

The carbohydrate content contained in the fruit leather is quite high, more than 80%. The carbohydrate content is derived from the composing ingredients of fruit leather, namely red dragon fruit, watermelon rind, seaweed, and added sugar. Red dragon fruit contains 12.97% carbohydrate and 2.64% dietary fiber, whereas watermelon rind contains 5.22% carbohydrate [38]. The carbohydrate content in seaweed amounted to 26.49% and dietary fiber amounted to 25.05% where the soluble fiber content amounted to 18.25% and insoluble fiber amounted to 6.80% [39]. The added sugar to each fruit leather formulation was 13.2% of the total weight of the fruit leather The carbohydrate content in fruit leather decreases with the increase in seaweed concentration. This is due to the increase in water content in RDWS. The addition of seaweed can strengthen the gel structure, thereby binding water and retaining the amount of water during the drying process [34].

3.2 Water activity

The addition of seaweed has an aw value below 0.7, although the material used has quite high water content. This happened due to the heating for 6 h at 50 ℃. The addition of seaweed affected the aw fruit leather ($p < 0.01$). F1 and F4 are significantly different from all groups, whereas there is no difference between F2 and F3.

F1 has the lowest a_w, which is 0.38 ± 0.01, while the largest a_w is F4, which is 0.44 ± 0.01. The a_w value of fruit leather increases along with the elevation of seaweed addition where the a_w value of F1 is 0.38 ± 0.01, F2 is 0.41 ± 0.01, F3 is 0.42 ± 0.01, and F4 is 0.43 ± 0.01. Higher a_w value decreases the fruit leather shelf life [33]. The a_w value below 0.7 is expected to extend the storage life of the fruit leather because it inhibits the growth of bacteria, molds, and yeasts [33].

3.3 Tensile strength and elongation

The amount of force needed to obtain maximum pull on each area unit of the product is indicated by the tensile strength value [41]. The tensile strength of all treatments with the addition of seaweed shows a significant difference between treatments ($p < 0.01$). The tensile strength result is aligned with the tensile strength of bidara fruit and the skin of the red dragon fruit plus different seaweed between treatments [32]. F4 has the highest tensile strength value, whereas F1 has the lowest tensile strength value. The elevation in tensile strength is aligned with the elevation of seaweed addition where the tensile strength in F1 is 0.08 ± 0.03 N/m^2, F2 is 0.54 ± 0.10 N/m^2, F3 is 1.03 ± 0.26 N/m^2, and F4 is 1.47 ± 0.32 N/m^2.

Fruit leather with a high tensile strength value has a plastic texture and is not easily broken and pulled apart [41]. This is the result of the gel formation and water binding by kappa carrageenan from seaweed where the polymer chains are joined and cross-linked to form a three-dimensional network. The formation of gel is reversible, so it will melt when heated. The heating process causes the carrageenan polymer to become a random coil and will create a double helix structure when the temperature is lowered. The polymers will be cross-linked and become stronger in the gel formation if the reduction in temperature continues [41].

Elongation is the ability of fruit leather to extend until it breaks from the initial length after the fruit leather is pulled [42] and indicates product elasticity. Table 3 indicates that seaweed increased the fruit leather elongation significantly ($p < 0.01$), where F1 has the lowest elongation at $17.17 \pm 3.73\%$, and the highest is in F4 at $31.67 \pm 5.47\%$. Kappa-carrageenan addition was mentioned to produce a tough and compact matrix so that the fruit leather becomes fragile [43].

The addition of sugar and citric acid in the making of fruit leather also plays a role in the texture formation. Sugar can form a solid gel because it can attract water molecules that bind to the carrageenan molecule [44]. The formation of texture is also influenced by the addition of citric acid because it affects the pH. H^+ from citric acid will cause negatively charged pectin to become uncharged, so that the pectin will clump and form a fine fiber which is chewy during the heating process. The addition of citric acid causes the gel formed to be stronger and the ability to bind water is higher, so that when drying the water released is lower [45].

3.4 Bioactive compounds and antioxidants activity

3.4.1 Vitamin C

Vitamin C content from the RDWS with the addition of seaweed shows a significant increase ($p < 0.01$). The result shown in Table 4 is different from the addition of seaweed to the fruit leather of bidara fruit and the skin of red dragon fruit which shows no significant differences in the vitamin C content [32]. The addition of seaweed increases the vitamin C content of fruit leather because vitamin C in seaweed amounted to 35.3 mg/100 g wet weight, higher than the other material (red dragon fruit and watermelon rind) [37–39]. The RDWS with the addition of different amounts of seaweed has a vitamin C content between 6.53 and 10.88 mg/100 g. F1 has the lowest vitamin C content, whereas F4 has the highest vitamin C content. This is aligned with the vitamin C content of carika fruit leather and fruit leather of bidara fruit and the skin of red dragon fruit which increase more along with the addition of seaweed [32, 46].

Vitamin C in the RDWS with the addition of seaweed shows that its content is lower compared to the vitamin C in its fresh fruit. Although vitamin C in red fruit amounted to 24.66 mg/100 g, watermelon rind amounted to 5.39 mg/100 g,

Table 4 Vitamin C, Antioxidant activity (IC_{50}), Total Phenol Fruit Leather

Treatments*	Vitamin C ±SD **(mg/100 g wb)	$IC_{50} \pm SD$** (ppm)	Total Phenol ± SD*** (mg GAE/g)
F1	6.53 ± 1.22^a	109.85 ± 8.14^a (medium)	1.58 ± 0.07^a
F2	8.17 ± 1.07^b	107.39 ± 6.43^a (medium)	1.66 ± 0.08^{ab}
F3	8.05 ± 0.89^b	96.81 ± 6.10^{ab} (strong)	1.75 ± 0.09^{ab}
F4	10.88 ± 1.37^c	80.42 ± 6.14^c (strong)	1.78 ± 0.07^b

* 0% seaweed (F1), 10% seaweed (F2), 20% seaweed (F3), 30% seaweed (F4). One-way Anova test followed by ** Duncan post-hoc test, *** Tukey post-hoc test. Numbers followed by different superscript letters indicate a significant difference ($p<0.05$), ** IC50 <50 ppm = very strong, IC50 50-100 ppm = strong, IC50 100-150 ppm = medium, IC50 150-200 ppm = weak, IC50>200 ppm = very weak

and seaweed amounted to 35.3 mg/100 g wet weight [37–39], the highest vitamin C content of the fruit leather is only at 10.81 mg/100 g. This occurs due to the heating and drying, which cause a considerable loss of vitamin C.

3.4.2 Total phenol and antioxidant activity

Antioxidant activity and total phenol compounds in the RDWS products with the addition of seaweed show a significant increase between groups ($p = 0.003$) and ($p = 0.022$) respectively (Table 4). Formula without seaweed (F1) produces the lowest values of antioxidant activity and total phenol compounds, respectively IC_{50} 109.85 ppm and 1,58 mg GAE/gram. The increase in antioxidant activity and total phenol compounds is aligned with the addition of *Eucheuma cottonii* seaweed in the RDWS products. *Eucheuma cottonii* seaweed, red dragon fruit, and watermelon rind are rich in antioxidant compounds. *Eucheuma cottonii* has several pigments (astaxanthin, fucoxanthin, carotenoids), phenol compounds (tannins, flavonoids, phenolic acids), vitamins, minerals, and polysaccharides (carrageenan) that contribute to the antioxidant activity [47].

The high antioxidant properties of red dragon fruit was contributed by its phenolic and betasianin content [48]. The antioxidant activity value of red dragon fruit was 67.45 ppm, which is classified as strong [49]. IC_{50} value of the watermelon rind was 14.729 ppm, which is classified as very strong [50]. Furthermore, watermelon rind is known to have bioactive compounds that have antioxidant properties, such as anthocyanins, phenols, flavonoids, and saponins [51].

These results also indicate that the higher the concentration of seaweed added, the greater the antioxidant activity. In addition to being an antioxidant compound, seaweed can play a role in protecting antioxidant compounds. The more double helices formed from seaweed, the stronger the ability to protect phenolic compounds from the heating process, resulting in less damage to phenolic compounds. Therefore, the higher the concentration of seaweed added, the more antioxidant compounds are protected, enhancing the antioxidant activity [16].

3.5 Organoleptic analysis

Organoleptic analysis was performed using the hedonic test and descriptive test. The Hedonic test measures the degree of liking or preference for a product, providing subjective data based on panelists' personal preferences, how much they like or dislike a product. In contrast, the Descriptive test provides objective data about the sensory characteristics of a product, such as taste, aroma, texture, and appearance. It describes these attributes in detail. Therefore, the Hedonic test is the best indicator of panelist preference as it directly measures their level of liking for the product [52].

Organoleptic test results with hedonic test and descriptive test on a fruit leather product can be seen in Table 5. The hedonic test on the RDWS with the addition of *Eucheuma cottonii* seaweed shows a significant difference in the level of flavor acceptance ($p < 0.001$), color ($p = 0.03$), texture ($p = 0.001$), but it is not significant for aroma ($p = 0.452$). In the descriptive test, there is also a significant difference in the level of flavor indicators ($p < 0.001$), color ($p < 0.001$), and texture ($p < 0.001$), but it is not significant for aroma ($p = 0.745$).

3.5.1 Taste

The taste liking of the fruit leather decreased significantly as the seaweed content increased. The maximum taste liking was the formula with 10% seaweed (F2) with the descriptive test result having not tasteless (bland). The bland taste of fruit leather increases with the seaweed addition. The result is similar to the research on noodles, that seaweed addition produces a blander taste [53].

The higher the concentration of seaweed in RDWS, the more it will replace the concentration of other ingredients, including red dragon fruit. As a result, the sugar content from red dragon fruit, which ranges from 5.13% to 7.06%, will decrease, leading to a blander taste in F4 with a high seaweed concentration [6].

3.5.2 Color

The color liking of the fruit leather decreased as the seaweed content increased. The maximum color liking was formula with 10% seaweed (F2) with the descriptive test result having a red color. The least favored color by panelists is fruit leather with the addition of seaweed 30% (F4) with a value of 3.2 which is classified as slightly liked with the descriptive results of slightly red. The color of fruit leather is determined by the natural color of red dragon fruit and the addition of

Table 5 Organoleptic test

Organoleptic test	Treatments *			
	F1	F2	F3	F4
Hedonic test				
Taste	4.1 ± 0.8^{a} (liked)	4.2 ± 0.79^{a} (liked)	3.3 ± 0.7^{b} (slightly liked)	3.0 ± 0.8^{b} (slightly liked)
Color	3.8 ± 0.9^{a} (liked)	4.0 ± 0.8^{a} (liked)	3.8 ± 1.0^{a} (liked)	3.2 ± 1.2^{b} (slightly liked)
Aroma	3.8 ± 0.8 (liked)	3.6 ± 0.8 (liked)	3.5 ± 0.7 (liked)	3.5 ± 0.8 (liked)
Texture	3.0 ± 0.1^{a} (slightly liked)	3.4 ± 0.9^{a} (slightly liked)	3.9 ± 0.9^{b} (liked)	3.9 ± 0.8^{b} (liked)
Descriptive test				
Taste	1.3 ± 0.5^{a} (very not tasteless)	2.0 ± 0.7^{b} (not tasteless)	2.6 ± 0.8^{c} (slightly tasteless)	2.9 ± 0.9^{c} (slightly tasteless)
Color	1.6 ± 1.0^{a} (red)	2.0 ± 0.9^{b} (red)	2.6 ± 0.8^{c} (slightly red)	3.1 ± 0.8^{d} (slightly red)
Aroma	2.0 ± 1.0 (not fishy)	2.1 ± 0.8 (not fishy)	2.0 ± 0.6 (not fishy)	2.0 ± 0.6 (not fishy)
Texture	2.6 ± 1.2^{a} (slightly elastic)	3.4 ± 0.9^{b} (slightly elastic)	4.0 ± 0.5^{c} (elastic)	4.0 ± 0.8^{c} (elastic)

*0% seaweed (F1), 10% seaweed (F2), 20% seaweed (F3), 30% seaweed (F4). Statistical analysis was done with Kruskall wallis followed by Mann-whitney test *Numbers which followed by different superscript letters indicate a significant difference ($p<0.05$)

seaweed, which means that as the seaweed content increased, the color intensity decreased. This is aligned with research on tamarillo fruit leather with the addition of seaweed reducing the color intensity from brown to slightly orange [54].

3.5.3 Aroma

The statistical analysis of aroma indicators for the liking test and descriptive analysis indicates that the treatment of adding *Eucheuma cottonii* seaweed to the RDWS has no significant difference ($p > 0.05$) on the aroma. According to panelists, the fruit leather products of red dragon fruit and watermelon rind with the addition of seaweed have no fishy aroma. It proves that the addition of *Eucheuma cottonii* seaweed, which has a distinctive fishy aroma, does not affect the aroma of the product. So, it can be said that the aroma of fruit leather products can be well received. The loss of fishy aroma in *Eucheuma cottonii* seaweed due to the washing, soaking, and boiling process reduced the volatile fishy odor [55].

3.5.4 Texture

The texture liking of the fruit leather increased as the seaweed content increased. The maximum texture liking was formula with 30% seaweed (F4) with the descriptive test result having an elastic texture. The texture of fruit leather products is highly influenced by *Eucheuma cottonii* seaweed because it contains carrageenan as the forming gel that can hold water by the double helix structure of the carrageenan polymer. Sugar combined with citric acid helps the gel formation and forms the desired texture [56, 57]. In addition, pectin in watermelon rind also improves the texture. Pectin is useful in thickening, modifying the flexible texture, and ensuring shape retention of dry products [58, 59].

3.6 Best formula

Multi-attribute quality combined with multiple product varieties made product development a complex process and could produce a bias. Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) [31] was used to pick the best product based on the selected attributes. Selected attributes included moisture, ash, protein, fat, carbohydrate, vitamin C, water activity, tensile strength, elongation, taste, color, aroma, and texture, with the weights as listed as described in Table 6. The best product was the F2 product with 10% seaweed. F2 has the following attributes: 11.07% of moisture content, 2.34% of ash, 1.53% of protein, 0.19% of fat, 84.86% of

Table 6 Score of Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) of the RDWS

Parameter (dimensionless)	rel.rank	F1	F2	F3	F4
Fat	1	1	0.82	0.29	0
Carbohydrate	2	1	0.48	0	0.03
Protein	3	0	0.67	0.95	1
Ash	4	0	0.32	0.73	1
Moisture	5	1	0.48	0	0.12
Water activity	6	1	0.4	0.2	0
Vitamin C	7	0	0.38	0.35	1
Phenol	8	0	0.4	0.85	1
Ic50	9	1	0.92	0.56	0
Tensile strength	10	0	0.33	0.68	1
Elongation	11	0	0.35	0.88	1
Texture	12	0	0.44	1	1
Aroma	13	1	0.33	0	0
Color	14	0.75	1	0.75	0
Taste	15	0.85	1	0.23	0
Total	120	7.60	8.33	7.48	7.15

carbohydrate, 8.17 mg/100 g of vitamin C, 0.41 of water activity, 0.54 N/m^2 of tensile strength, 22.22% of elongation, 107.39 ppm of IC50, 1.66 mg/GAE g of total phenol, and liked in the hedonic test for taste, color, and aroma, eventhough slightly liked for texture.

4 Conclusion

Increasing seaweed concentration increased moisture, ash, protein, vitamin C, total phenol, water activity, and elongation significantly, but decreased fat content. Furthermore, the increase in seaweed concentration was decreased liking toward taste, and color significantly, but increased texture liking. The best product was the F2 product with 10% seaweed. F2 has the following attributes: 11.07% of moisture content, 2.34% of ash, 1.53% of protein, 0,19% of fat, 84.86% of carbohydrate, 8.17 mg/100 g of vitamin C, 0.41 of water activity, 0.54 N/m^2 of tensile strength, 22.22% of elongation, 107.39 ppm of IC50, 1.66 mg/GAE g of total phenolics.

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Author contributions FA did study conception and design, acquisition of data, analysis and interpretation of data, and drafting of manuscript. AMA did drafting of manuscript and critical revision. DNA did drafting of manuscript and critical revision. GA did study, acquisition of data, analysis and interpretation of data, and drafting of manuscript. NN did study, acquisition of data, analysis and interpretation of data, and drafting of manuscript. HSW did analysis and interpretation of data, study conception and design, drafting of manuscript, and critical revision. DYF did drafting of manuscript and critical revision. LRT did study conception and design, drafting of manuscript, and critical revision. SA did study, acquisition of data, analysis and interpretation of data, and drafting of manuscript. AR did study, acquisition of data, analysis and interpretation of data, and drafting of manuscript. FZ did drafting of manuscript and critical revision. All authors contributed to manuscript revision, read and approved the submitted version.

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Data availability The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Code availability Not applicable.

Declarations

Research involving human participants and informed consent The organoleptic studies involving human participants were reviewed and approved by the Ethics Committee of the Dr. Moewardi General Hospital with ethical clearance No. 750/III/HREC/2024. The participants provided their written informed consent to participate in this study. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Competing interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential competing interests.

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