International Journal of Agricultural Technology 2026 Vol. 22(1):329-344
DOI: https://doi.org/10.63369/ijat.2026.22.1.329-344
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Characteristics of seaweed healthy salt from Indonesian Red Seaweed *Grateloupia angusta*

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Nurjanah, Nurilmala, M., Seulalae, A. V., Putri, R. M. S., Meiyasa, F. and Amalia, Y. D. N. (2026). Characteristics of seaweed healthy salt from Indonesian red seaweed *Grateloupia angusta*. International Journal of Agricultural Technology 22(1):329-344.

Abstract The results showed that differences in the ratio of flour to distilled water had a significant effect ($p<0.05$) on the yield, mineral content, Na/K ratio, %NaCl, total phenolic content, and antioxidant activity. *G. angusta* salt had the best treatment, namely a solvent ratio of 1:15 with the highest yield value of 20.9±2.30%, Na/K ratio 0.90, %NaCl 60.36±0.15%, total phenolic content 1,543.37±2.35 mg GAE/g sample, IC_{50} value of 150.6±8.81 µg/mL (moderate activity), and antioxidant capacity 37.30±1.43 µmol ascorbic acid/g sample. *G. Angusta* can serve as a raw material for producing healthy salt.

Keywords: Hypertension, Kalium, Na/K ratio, Phenolic, Sodium

Introduction

Hypertension, or high blood pressure, is a silent killer that contributes to various cardiovascular disorders, such as heart attacks, stroke, and kidney disease. Individuals with hypertension typically have a systolic blood pressure of ≥140 mmHg or a diastolic blood pressure of ≥90 mmHg. Hypertension sufferers in the world reach around 1.28 billion with an age range of 30-75 years and almost 67% of sufferers live in low to medium income countries (WHO, 2023a). Hypertension is also a non-communicable disease, the number of which continues to increase in Indonesia. In 2018, the prevalence of hypertension in Indonesia was 34.1% among individuals over 18 years of age, which was much higher than in 2013 (25.8%) (Riskedas, 2018). Data from the Ministry of Health Republic Indonesia for 2022 show that of the 3,000 outpatient cases of

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Indonesian Hajj pilgrims, 1,384 are due to hypertension (Kementerian Kesehatan, 2023).

Diseases related to hypertension are among the catastrophic diseases that cost the most from the Indonesian National Health Insurance (JKN) covered by Social Security Agency on Health (*BPJS*), including heart disease with the largest proportion of funding at 49%, stroke at 13%, and kidney failure at 11% (BPJS Kesehatan, 2023). The elevated risk of this disease is linked to unhealthy lifestyle habits, including consuming salt or sodium in amounts that exceed the recommended limit of less than 2 g per day (WHO, 2023b). High sodium consumption is correlated with increased fluid in the body, which increases the blood volume and pressure (Vaudin *et al*., 2022). One alternative way to prevent hypertension is to consume low sodium salt or salt that is high in potassium with a Na/K ratio close to one (WHO, 2023c). The Na/K ratio is used to regulate the balance of Na and K minerals (Farrand *et al*., 2019). Indonesia also regulates healthy salt, with a maximum NaCl percentage of 60% (BSN, 2016).

Seaweed is a fishery resource that is abundant in Indonesian waters. Seaweed has the potential to serve as a raw material for producing low-sodium salt (Magnusson *et al*., 2016). Seaweeds contain of minerals, amino acids (Iskandar *et al*., 2024; Ilhamdy *et al*., 2025), pigments, fiber (Nurjanah *et al*., 2022c), polysaccharides (Jacoeb *et al*., 2024), and other active components that act as antioxidants (Diachanty *et al*., 2017). The existence of secondary and primary metabolite components in seaweed has also been widely applied in the food (Nurjanah *et al*., 2022c) and non-food (cosmetics) (Nurjanah *et al*., 2021; Nurjanah *et al*., 2022a).

Studies on low-sodium salt derived from seaweed in Indonesia have been conducted using brown seaweed as the raw material (Nurjanah *et al*., 2020; Manteu *et al*., 2021; Nurjanah *et al*., 2021a; Nurjanah *et al*., 2021b; Nurjanah *et al*., 2022b; Seulalae *et al*., 2023), green (Nurjanah *et al*., 2024), and red (Nurjanah *et al*., 2023b) which are not the main export commodities. Previous research results show that green, brown and red seaweed salts have dominant potassium minerals, polyphenolic compound components, moderate to weak antioxidant activity, Na/K ratios ranging from 1.49-3.88 (salt from green seaweed), 0.69-0.72 (salt from brown seaweed), and 3.32-4.25 (salt from red seaweed) and NaCl levels <60%. A limitation of previous research is that the yield of seaweed salt produced is still low, including salt from brown seaweed (20-26%), green (10-27%), and red (1.76-7.47%). Optimization of seaweed salt production needs to be carried out to obtain seaweed salt with sustainable quality and quantity in the future. Moreover, the 911 Indonesian seaweed species that have been identified should be further explored for their potential as additional raw materials for low-sodium salt, particularly those that are not major export commodities, so that Indonesian seaweed can gain higher value and stronger competitiveness.

Grateloupia angusta seaweed is one of the red seaweeds or Rhodophyta that can be found in Indonesia. *Grateloupia* is distributed from waters with cold to tropical temperatures (Kim *et al*. 2014). The genus *Grateloupia* is the largest group within the Halymeniaceae family, comprising 50 species, several of which are challenging to identify because of their morphological variations and the absence of distinct morphological traits (Garcia-Jimenez *et al*. 2008). *Grateloupia* has high carbohydrate content (sulfated polysaccharides, antioxidants, and antimicrobials), protein (chromoprotein), secondary metabolites, and low lipid content (Felix *et al*. 2021). This type of seaweed has not yet been widely reported for its use in both food and non-food sectors. Thus, *G. angusta* seaweed holds potential as a raw material for producing low-sodium salt, as it contains primary and secondary metabolites that may offer health benefits. The aims were to determine the optimum ratio of seaweed flour and distilled water to produce seaweed salt with a high yield, %NaCl, optimum Na/K ratio, and antioxidant activity.

Materials and methods

G. angusta seaweed was obtained from Pameungpek Waters, Garut, West Java, Indonesia. Dried *G. angusta* seaweed was cleaned from foreign matters and sand. The seaweed was blended and then sieved through a 60-mesh filter to achieve a uniform particle size. The resulting seaweed flour was analyzed for heavy metal content (AOAC, 2005), proximate composition (AOAC, 2005), and mineral content (AOAC, 2005).

Maceration extraction was conducted following a modified method from Diachanty *et al*. (2017). A total of 50 g of *G. angusta* flour was extracted using 300 mL of ethanol p.a (v/v) for 72 hours. The mixture was first filtered using 500-micron filter paper and then refiltered with Whatman No. 42 paper. The resulting filtrate was evaporated with a rotary vacuum evaporator at 50°C for 12 hours to obtain the extract. The extract was subsequently analyzed for phytochemical composition (Harborne, 1987), total phenolic content (Apostolidis and Lee, 2010), antioxidant activity using the Cupric Reducing Antioxidant Capacity (CUPRAC) method (Apak *et al*., 2007), and the ABTS method (Re *et al*., 1999).

Seaweed salt was produced using the method described by Magnusson *et al*. (2016), with modifications applied to the stirring time during heating in a water bath shaker. A total of 50 g of seaweed flour was soaked in distilled water at different ratios (1:3), (1:5), and (1:10 w/v), heated at 40°C for 10 minutes in a water bath shaker, and then filtered using 85-mesh calico fabric. The filtrate was further filtered with Whatman No. 40 paper. The resulting filtrate was placed in a baking dish and dried in a dehydrator at 60°C for 48 hours to produce crystallized salt. The crystallized seaweed salt was then ground using a powder grinder for approximately 30 seconds. The *G. angusta* seaweed salt was analyzed for yield percentage, heavy metal content (AOAC, 2005), mineral content (AOAC, 2005), Na/K ratio, %NaCl (Day and Underwood, 1989), total phenolic content (Apostolidis and Lee, 2010), and antioxidant activity using the Cupric Reducing Antioxidant Capacity (CUPRAC) method (Apak *et al*., 2007) and the ABTS method (Re *et al*., 1999).

The experiment employed a completely randomized design (CRD) with one factor, specifically the different soaking concentrations in distilled water. Data were analyzed using analysis of variance (ANOVA) at a 95% confidence level and conducted in triplicate. Significant results ($p < 0.05$) were further evaluated using Duncan's Multiple Range Test (DMRT). Data processing was carried out using Statistical Product and Service Solutions (SPSS) version 25.

Results

Chemical composition of raw material

The chemical composition of *G. angusta* seaweed flour is presented in Table 1. The chemical composition of *G. angusta* seaweed was the highest in ash content and lowest in lipid content. *G. angusta* has a higher protein content than the red seaweed *Actinotrichia fragilis*, brown seaweed *Sargassum* sp., and the green seaweed *Ulva lactuca*.

Table 1. Chemical composition of *G. angusta* flour

Parameter (%)	*G. angusta*	*Actinotrichia fragilis*[1]	*Sargassum* sp.[2]	*Ulva lactuca*[3]
Moisture	13.52±0.40	9.23±0.01	6.71±0.58	28.41±0.11
Ash	36.57±0.08	61.96±0.27	36.81±0.48	24.97±1.19
Protein	15.57±0.30	4.23±0.07	6.82±0.13	5.14±0.35
Lipid	0.59±0.01	0.46±0.06	0.64±0.03	1.43±0.17
Carbohydrate (by difference)	33.75±0.62	24.17±0.41	49.02±0.54	40.05±1.13

Note: [1]Nurjanah *et al*. (2023b); [2]Nurjanah *et al*. (2022b); [3]Nufus *et al*. (2017).

Characteristics of seaweed salt

Yield, mineral, Na/K ratio, and NaCl percentage

The color of *G. angusta* seaweed salt tended to be dark brown in each treatment, but salt treatment at a ratio of 1:15 produced a brighter color than 1:5

and 1:10 (Figure 1). The treated 1:15 salt had a finer texture than the 1:5 and 1:10 salts, which had coarser grains.

Figure 1. Appearance of *G. angusta* seaweed salt

The results indicated that variations in the flour-to-water ratio significantly influenced yield, as well as the levels of Na, K, Ca, Fe, Mg minerals, the Na/K ratio, and %NaCl (Table 2). The yields obtained from the 1:5 and 1:10 ratio treatments did not differ significantly ($p>0.05$), whereas the 1:15 ratio treatment showed a significant difference ($p<0.05$). The highest yield was observed in the 1:15 ratio treatment at 20.9±2.30%. The Na and K minerals in the 1:5 and 1:15 ratio treatments were not significantly different ($p>0.05$), but the 1:10 ratio treatment showed a significant difference ($p<0.05$). The Na and K mineral contents of *G. angusta* seaweed salt were higher than those in the *G. angusta* flour. The highest Na mineral content occurred in the 1:10 ratio treatment, while the highest K mineral content was found in the 1:15 ratio treatment. Meanwhile, the Ca, Fe, and Mg contents in the 1:5 and 1:15 ratio treatments were not significantly different ($p>0.05$), but the 1:10 ratio treatment showed significant differences ($p<0.05$).

The Ca and Fe contents in *G. angusta* flour were higher than those in the seaweed salt, whereas the Mg content in the flour was lower compared to the seaweed salt produced using the 1:10 ratio. The highest Ca level in *G. angusta* seaweed salt was found in the 1:10 ratio treatment. The Fe content was highest in the seaweed salt from the 1:5 and 1:15 ratio treatments. The highest Mg content in the seaweed salt occurred in the 1:10 ratio treatment. The Na/K ratios for the 1:5 and 1:15 treatments showed no significant differences ($p>0.05$), while the 1:10 treatment exhibited a significant difference ($p<0.05$). The Na/K ratio of *G. angusta* flour was lower than that of the seaweed salt produced with the 1:10 ratio, but higher than those obtained from the 1:5 and 1:15 ratios. The %NaCl values for the 1:5 and 1:10 treatments were not significantly different ($p>0.05$), whereas the 1:15 treatment differed significantly ($p<0.05$). The 1:15 ratio treatment yielded the lowest %NaCl value, at 60.36±0.15%.

Table 2. Yield, mineral, Na/K ratio, NaCl percentage of *G. angusta* salt in different ratios

Parameter	*G. angusta* flour	*G. angusta* seaweed salt		
		1:5	1:10	1:15
Yield (%)	-	12.0±1.34[a]	15.3±2.87[a]	20.9±2.30[b]
Na (mg/g)	73.92± 0.15	219.69±0.72[a]	260.16±10.06[b]	206.90±0.14[a]
K (mg/g)	27.04±0.08	208.91±0.04[a]	60.79±0.49[b]	229.52±0.06[a]
Ca (mg/g)	8.87±0.18	4.66±0.004[a]	6.54±0.03[b]	4.88±0.003[a]
Fe (mg/g)	0.20±0.01	0.05±0.001[a]	0.02±0.001[b]	0.05±0.001[a]
Mg (mg/g)	5.82±0.08	3.36±0.001[a]	11.71±0.01[b]	3.50±0.001[a]
Na/K ratio	2.73±0.01	1.05±0.003[a]	4.28±0.20[b]	0.90±0.001[a]
NaCl (%)	-	63.62±0.29[a]	62.60±0.84[a]	60.36±0.15[b]

Note: Different letters in the same row indicate statistically significant differences ($p<0.05$, DMRT).

Heavy metal

The results showed that the seaweed *G. angusta* flour detected heavy metals Hg of 0.04±0.01 mg/kg and Pb of 0.11±0.00 mg/kg. The difference in the ratio of flour to distilled water solvent did not have a significant effect on the heavy metals in *G. angusta* seaweed salt (Table 3). The heavy metals Hg and As were not detected in *G. angusta* seaweed salt. *G. angusta* flour and *G. angusta* seaweed salt still meet the maximum threshold for dry seaweed and processed seaweed food so they are safe to use.

Table 3. Heavy metal (mg/kg) of *G. angusta* salt in different ratios

Parameter	*G. angusta* flour	*G. angusta* seaweed salt			Dry seaweed[1]	Food[2]
		1:5	1:10	1:15		
Hg	0.04±0.01	not detected	not detected	not detected	Max. 0.50	Max. 0.03
Cd	-	0.07±0.003[a]	0.06±0.002[ab]	0.05±0.007[b]	Max. 0.10	Max. 0.50
As	-	not detected	not detected	not detected	Max. 1.00	Max. 1.00
Pb	0.11±0.00	-	-	-	Max. 0.30	Max. 0.20

Note: Different letters in the same row indicate statistically significant differences ($p<0.05$, DMRT). [1](BSN Indonesia, 2015), [2](BPOM, 2022).

Total phenolic content and antioxidant activity

The results showed that variations in the flour-to-water ratio significantly affected the total phenolic content, IC_{50} values, and antioxidant capacity of *G. angusta* seaweed salt (Table 4). The total phenolic contents of the 1:5, 1:10, and

1:15 treatments did not differ significantly (p>0.05). The total phenolic content of *G. angusta* seaweed salt was lower than that of the *G. angusta* extract. The IC_{50} values for the 1:5 and 1:10 ratio treatments showed no significant differences (p>0.05), whereas the 1:15 treatment demonstrated a significant difference (p<0.05). The IC_{50} value of the *G. angusta* extract was lower than that of the seaweed salt. Among the seaweed salt treatments, the 1:15 ratio produced the lowest IC_{50} value. The antioxidant capacity measured using the CUPRAC method differed significantly across the 1:5, 1:10, and 1:15 ratios (p<0.05). The antioxidant capacity of the *G. angusta* extract was higher than that of the seaweed salt, while the 1:15 ratio treatment yielded the highest antioxidant capacity among the seaweed salt samples.

Table 4. Total phenolic content and antioxidant activity *G. angusta* salt in different ratios

Parameter	*G. angusta* extract	*G. angusta* seaweed salt		
		1:5	1:10	1:15
Total phenolic content (mg GAE/g sample)	4.260.22±22.8	1.527.24±5.07[a]	1.532.62±2.53[ab]	1.543.37±2.53[b]
IC_{50} ABTS method (µg/mL)	128.9±7.42	195.5±5.96[a]	178.4±0.48[a]	150.6±8.81[b]
CUPRAC (µmol ascorbic acid/g sample)	184.95±6.37	23.25±1.53[a]	31.83±0.27[b]	37.30±1.43[c]

Note: Different letters in the same row indicate statistically significant differences (p<0.05, DMRT).

Discussion

The moisture level of *G. angusta* seaweed flour was higher than that of red seaweed *A. fragilis* flour (9.23±0.01%) (Nurjanah *et al.*, 2023b), brown seaweed flour *Sargassum* sp. (6.71±0.58%) (Nurjanah *et al.*, 2022b), but lower than that of *U. lactuca* green seaweed flour (28.41±0.11%) (Nufus *et al.*, 2017). The moisture level of seaweed flour is affected by the type, location, and geographical condition of the seaweed habitat. Moisture level is closely related to shelf life because a high moisture content in a product causes very rapid increase of organisms (Rohani-Ghadikolalel *et al.*, 2012). The lower the moisture level in seaweed flour, the better the quality of seaweed flour. Seaweeds experience a decrease in moisture level during the drying process. The moisture level of dried seaweeds does not exceed 30% (BSN Indonesia, 2015). The ash level of *G. angusta* seaweed flour was lower than that of the red seaweed *A.*

fragilis (61.96±0.27%) (Nurjanah *et al*., 2023b), brown seaweed flour *Sargassum* sp. (36.81±0.48%) (Nurjanah *et al*., 2022b), but higher than that of *U. lactuca* green seaweed flour (24.97±1.19%) (Nufus *et al*., 2017). Ash level in seaweeds is affected by species, geographic origin, and demineralization methods (Sanchez-Machado, 2004). The elevated ash level may also result from the high mineral levels present in the seaweed. The holdfasts of seaweed are capable of absorbing both macrominerals and trace minerals (Diachanty *et al*., 2017).

The protein level in *G. angusta* seaweed flour exceeded that of the red seaweed *A. fragilis* (4.23±0.07%) (Nurjanah *et al*., 2023b), the brown seaweed *Sargassum* sp. flour (6.82±0.13%) (Nurjanah *et al*., 2022b), and the green seaweed *U. lactuca* flour (5.14±0.35%) (Nufus *et al*., 2017). Seaweed protein levels are generally higher than those of land plants (Nurjanah *et al*., 2024). Protein levels in seaweeds depend on the type and season (Fleurence *et al*., 2017). The lipid level of *G. angusta* seaweed flour is greater than that found in red seaweed *A. fragilis* (0.46±0.06%) (Nurjanah *et al*., 2023b), but is still below the lipid content of brown seaweed *Sargassum* sp. (0.64±0.03%) (Nurjanah *et al*., 2022b), and green seaweed flour *U. lactuca* (1.43±0.17%) (Nufus *et al*., 2017). Lipid content can be influenced by harvest age and weather conditions during rearing, and the type of seaweed (Ilhamdy *et al*., 2025). The carbohydrate level of *G. angusta* seaweed flour is greater than that of the red seaweed *A. fragilis* (24.17±0.41%) (Nurjanah *et al*., 2023b), but is still below the carbohydrate of brown seaweed *Sargassum* sp. (49.02±0.54%) (Nurjanah *et al*., 2022b), and green seaweed *U. lactuca* (40.05±1.13%) (Nufus *et al*., 2017). The carbohydrates present in seaweeds consist of fibrous components that are not broken down by digestive enzymes. This causes the calorie intake to be low, and seaweed is used in diet programs. The formation of carbohydrates in seaweeds is influenced by temperature, salinity, and light intensity (Safia *et al*., 2020).

The salt with the highest yield was the 1:15 ratio treatment (20.9±2.30%), while the lowest yield value was the 1:5 ratio treatment (12.0±1.34%). The resulting salt yield value was higher than in that reported by Nurjanah *et al*. (2023b) using *A. fragilis* seaweed at a temperature of 60°C and a drying time of 30 h in a 1:5 ratio treatment was (9.36±0.12%) and a 1:10 ratio (12.76±0.13 %). Distilled water used in high quantities can cause salt particles to dissolve easily in distilled water. The addition of a solvent can increase the yield of salt produced. The yield of seaweed-derived salt may be affected by various factors, such as the type of seaweed, its chemical constituents, and the amount of material lost during filtration (Manteu *et al*., 2021).

Seaweed flour and *G. angusta* seaweed salt treated at ratios of 1:5 and 1:10 were highest for Na minerals and lowest for Fe minerals, while the 1:15 ratio treatment was highest for K minerals and lowest for Fe minerals. Nurjanah *et al*. (2023b) showed that the *A. fragilis* salt had the highest Na, and the lowest Fe. The Na of seaweed salt was highest in the 1:10 ratio treatment (260.16±10.06) mg/g and the lowest in the 1:15 ratio treatment (206.90±0.14 mg/g). The Na mineral content obtained was higher than that of *G. angusta* flour and red seaweed salt *A. fragilis* in the 1:10 ratio treatment was 12.03±0.40 mg/g (Nurjanah *et al*., 2023b). The highest K mineral content was in the 1:15 ratio 229.52±0.06 mg/g and the lowest in the 1:10 ratio 60.79±0.49 mg/g. The potassium content obtained was higher than that of *G. angusta* flour and red seaweed salt *A. fragilis* in the 1:10 ratio treatment of was 4.48±0.49 mg/g (Nurjanah *et al*., 2023b). The difference in the Na and K mineral results obtained is partly due to differences in the seaweed species used. The mineral K is an important parameter in low-sodium salts. Potassium (K) provides important benefits to the body, as it helps lower both systolic and diastolic blood pressure by raising its concentration in intracellular fluids and pulling extracellular fluids inward, thereby contributing to a reduction in blood pressure (Listyaingsih *et al*., 2014).

The Ca and Mg contents of *G. angusta* salt are higher than those of *A. fragilis* salt (Nurjanah *et al*., 2023b). The Ca and Mg contents of *A. fragilis* salt in the 1:10 ratio treatment, namely 2.60±0.29 mg/g and 2.34±0.11 mg/g. Calcium functions in the body by supporting the development and preservation of bones and teeth; in addition, it contributes to the structural strength of the skeletal system (Almatsier, 2002). Magnesium in the body is useful for preventing tooth decay, nerve transmission, and enzyme activity and has an effect on the digestive system and kidneys (Srimariana *et al*., 2015). The Fe content of *G. angusta* salt is lower than that of *G. angusta* flour and *A. fragilis* salt (Nurjanah *et al*., 2023b). Iron plays an essential role in the biochemical processes involved in producing red blood cells. A lack of iron may lead to anemia, particularly in women during menstruation and pregnancy. Variations in the Ca, Mg, and Fe mineral values obtained were partly attributed to differences in the seaweed species utilized. The mineral profile of the resulting salt is also affected by the solvent ratio and the heating treatment applied during the salt production process. The heating process causes the concentration of minerals to increase so that seaweed salt has a higher concentration level than fresh seaweed (Magnusson *et al*., 2016).

The Na/K ratio decreased with increasing solvent content. The Na/K ratio of *G. angusta* salt treated with a ratio of 1:15 was the lowest compared to other ratio treatments and *G. angusta* flour. The Na/K ratio plays a crucial role in regulating blood pressure (Peng *et al*., 2013). The Na/K ratio of *G. angusta* salt treated with a ratio of 1:15 has a value that is closer to the Na/K balance, namely close to 1 (WHO, 2012) compared to *A. fragilis* salt treated with 1:10 which is 3.32±0.18 (Nurjanah *et al*., 2023b), green seaweed salt *U. lactuca* 1.74 and

Chaetomorpha sp. 1.63 (Nurjanah *et al*., 2024), and brown seaweed salt *Sargassum polycstum* 0.50 (Nurjanah *et al*., 2022b). The Na/K ratio required by the body must be balanced, and the maximum ratio is 1:1. Variations in the Na/K ratio may result from differences in seaweed species and habitat, as well as from the distinct soaking treatments using distilled water during the production of seaweed salt (Peng *et al*., 2013; Nurjanah *et al*., 2023b).

The highest percentage of NaCl in the 1:5 treatment was 63.62±0.29%, and the lowest in the 1:15 treatment was 60.36±0.15%. The 1:5 and 1:10 treatments had values above the maximum dietary salt limit, whereas the 1:15 treatment was included in the dietary salt limit, that is, a maximum of 60% (BSN, 2016). The salt produced from all treatments was still within the consumable salt limit, namely the minimum NaCl limit for consumable salt, namely 94% (BSN, 2016). The NaCl content decreased as the amount of solvent used in the salt-making process increased. The solvent concentration affected the amount of NaCl produced. The higher the distilled water ratio, the lower the NaCl levels (Alfiana *et al*., 2014). The NaCl content of *G. angusta* salt was still higher than that of *A. fragilis* salt at 47.22-51.16%, green seaweed *U. lactuca* salt at 57.36% (Nurjanah *et al*., 2024), and brown seaweed *S. polycystum* salt at 35.27% (Nurjanah *et al*., 2024; Nurjanah *et al*., 2022b).

Heavy metal testing was conducted to assess the levels of heavy metal contamination present in both the raw materials and the produced seaweed salt. The results showed that the seaweed *G. angusta* detected heavy metals Hg of 0.04±0.01 mg/kg and Pb of 0.11±0.00 mg/kg. The seaweed salt *G. angusta* detected heavy metals Cd. This value is still below the threshold for heavy metals Hg, Pb, and Cd for dried seaweed (BSN Indonesia, 2015) and food (BPOM, 2022). Heavy metals in seaweeds are thought to originate from water conditions and growing habitats. Heavy metals enter the seaweed through the entire surface of the thallus in the form of cations, anions, or organic compounds (Laily *et al*., 2019).

Phenolic compounds possess antioxidant potential, and their total concentrations are expressed in gallic acid equivalents (GAE). The GAE unit serves as a standard for quantifying the phenolic content present in the materials. Quantitative analysis of total phenolics in the salt showed a reduction in phenolic levels from the raw material in extract form to the final salt product. The highest total phenolic content was observed in the 1:15 ratio treatment, whereas the lowest value occurred in the 1:5 ratio treatment. The total phenolic content of *G. angusta* salt exceeded that of *A. fragilis* salt, ranging from 11.01–33.87 mg GAE/g seaweed salt. Phenolic levels in seaweed are influenced by factors such as species, seasonal variation, and habitat conditions. Measurement of total phenolics served as the basis for evaluating antioxidant activity, since phenolic compounds function to prevent oxidative reactions. Higher phenolic content corresponds to stronger antioxidant activity (Djapiala *et al*., 2013). Phenolic compounds counteract free radicals by donating electrons or hydrogen atoms. In algae, these compounds neutralize reactive oxygen species (ROS), stabilize free radicals, and act as enzyme modulators to inhibit lipid oxidation (Abdullah *et al*., 2021).

Antioxidants function by donating hydrogen atoms or by preventing free radicals from binding to cells in the body, thereby minimizing cellular damage (Abdullah *et al*., 2020). The findings indicated that an increase in the ratio of distilled water used as the solvent corresponded to a rise in the IC_{50} value of *G. angusta* salt. IC_{50} values are classified as very strong (<50 µg/mL), strong (50–100 µg/mL), moderate (100–150 µg/mL), and weak (150–200 µg/mL) (Molyneux, 2004). *G. angusta* salt treated with a 1:15 ratio and the *G. angusta* extract were categorized as moderate antioxidants, whereas the samples treated with 1:5 and 1:10 ratios fell into the weak antioxidant category. The IC_{50} value of *G. angusta* salt treated with a 1:15 ratio remained higher than that of *A. fragilis* salt treated with a 1:10 ratio, which showed an IC_{50} of 87.27±0.56 µg/mL and was classified as a strong antioxidant. Antioxidant activity measured using the ABTS method is expressed as IC_{50}, referring to the concentration of sample required to neutralize 50% of free radicals. Variations in IC_{50} values may be influenced by seaweed species, habitat, and the solvent concentration used.

The antioxidant capacity measured using the CUPRAC method is based on electron transfer. CUPRAC antioxidant activity is linked to the reduction of the turquoise-blue Cu^{2+} chelate to yellow Cu^{+} through electron donation from antioxidant compounds (Apak *et al*., 2008). The results demonstrated that the antioxidant capacity of *G. angusta* salt increased with higher distilled water ratios. The 1:15 treatment yielded the greatest antioxidant capacity among the salt samples, although it was still lower than that of the *G. angusta* extract. The CUPRAC antioxidant capacity of *G. angusta* salt at the 1:15 ratio was slightly lower than that of *A. fragilis* salt treated with a 1:10 ratio, which reached 38.21±0.29 µmol ascorbic acid/g seaweed salt. A higher CUPRAC value reflects stronger antioxidant potential. Differences in antioxidant capacity may be affected by several variables, including seaweed species, habitat, seasonal factors, harvest period (Nurjanah *et al*., 2024), as well as exposure to light and heat (Trissanthi & Susanto, 2016).

The best treatment for *G. angusta* seaweed salt was a ratio of 1:15 with the highest yield value (20.9±2.30%), %NaCl, which was in accordance with dietary salt standards, a Na/K ratio close to 1, and moderate antioxidant activity. The higher the distilled water solvent ratio, the higher the yield and antioxidant activity, and the lower the %NaCl.

Conflicts of interest

The authors declare no conflict of interest.

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(Received: 3 December 2024, Revised: 26 August 2025, Accepted: 30 August 2025)