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Seasonal variations in the proximate composition of *Pyropia yezoensis* harvested along the western and southern coast of Korea

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Authors Info

S.M. Jung, S.G. Kang, J.H. Jeon, J.S. Son, H.J. Lee, T.H. Park, S.H. Han, W.B. Jeon and H.W. Shin*

Department of Life Science and Biotechnology, Soonchunhyang University, Asan City, Choongnam Do, 336-745, South Korea

*Corresponding Author Email : hwshin@sch.ac.kr

Edited by
Professor Chae Woo Ma

Reviewed by
Dr. Chiyoung Lim
Professor Dong Soo Hwang

Abstract

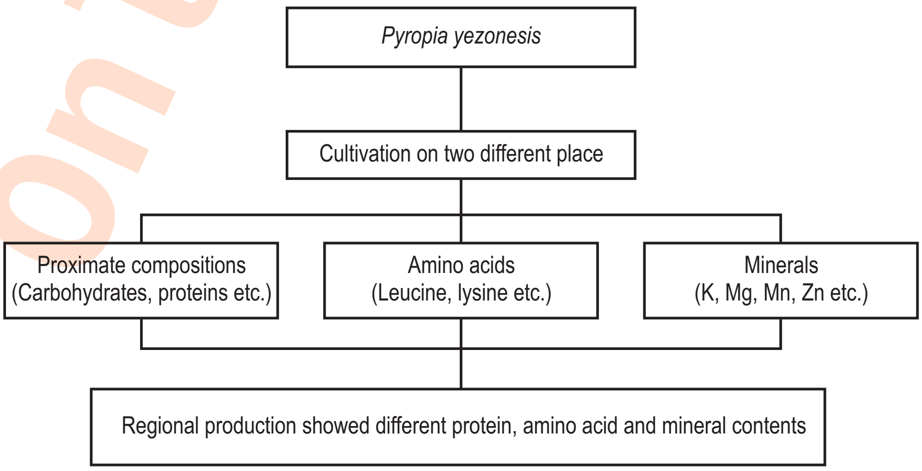
Aim: *Pyropia yezoensis* is a widely consumed edible seaweed that contains substantial carbohydrates, proteins, lipids, amino acids and minerals. In this study, the proximate composition, amino acid content and mineral content of *P. yezoensis* were compared at two culture sites in South Korea (Goheung and Gunsan) during same time period.

Methodology: This study followed AOAC methods for proximate composition. Amino acid and mineral were analyzed by amino acid analyzer and inductively coupled plasma.

Results: The highest measured protein contents were 39.66±0.49% in December at Goheung and 38.77±0.59% in January at Gunsan. Proximate compositions did not differ significantly between Gunsan and Goheung. Among amino acids, isoleucine, leucine, threonine, lysine, histidine and valine were present at higher concentrations during November and December harvesting periods. The levels of Ca and P were higher in *Pyropia* at Gunsan from November to February compared with *Pyropia* at Goheung.

Interpretation: Clear temporal and spatial variations were observed in amino acid and mineral contents, but not in proximate composition. Our study provides important information about the nutritive properties of *P. yezoensis*.

Key words: Amino acids, Carbohydrate, *Pyropia yezoensis*, Seasonal variations



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Introduction

In many countries, marine algae have significant nutritional and environmental resources. Edible algae are widely consumed in Asian countries in fresh and dried forms and are often used as ingredients in certain dishes. In particularly, the red alga genus *Pyropia*is commonly used for food and is the basis of large industries in Korea, Japan and China (Nisizawa *et al*., 1987). Although algae are not widely consumed in Europe compared with Asia, they have gained popularity as a natural source of bioactive compounds. Owing to its nutritive value and health benefits, *Pyropia* consumption has increased in Western countries in recent years (Dawczynski *et al*., 2007). Because of its low fat content and proteins and carbohydrates that cannot be entirely digested by human intestinal enzymes, it contributes relatively few calories to the diet (Jurkovic *et al*., 1995; Kishi *et al*., 1982; Lahaye and Kaeffer, 1997).

Dried algae contain large quantities of carbohydrates, proteins, ash, lipids, minerals and other constituents. For example, the carbohydrate and protein levels of *Pyropia* are 34.3–50.2% and 25–50% (Noda, 1993; Jung *et al*., 2016a). Shin *et al*. (2013) reported carbohydrate, protein and lipid contents of 39.47–47.2%, 29.8–40.8% and 0.7–1.1%, in algae harvested from the Seochun coast of Korea. On the Wando coast of Korea, the protein contents of *P. tenera* and *P. haitanesis* ranged from 32.16% to 36.88%, respectively (Hwang *et al*., 2013).

Pyropia contain high levels of essential amino acids such as leucine, lysine, threonine, valine, phenyl alanine, tyrosine, methionine and cysteine. Cian *et al*. (2013) analyzed the amino acid composition of *Pyropia* and reported high levels of leucine (7.38 g100 ml^{-1}), lysine (6.01 g100 ml^{-1}), threonine (5.91 g100 ml^{-1}) and valine (5.85 g100 ml^{-1}). Hwang *et al*. (2013) found that *Pyropia* sp. contained 141.98–171.37 mg $(100\ g)^{-1}$ aspartic acid. Amino acids such as alanine, aspartic acid and glycine are responsible for peculiar flavors of *Pyropia* sp. (Shin, 1997; Mabeau *et al*., 1992).

Pyropia may be an important source of certain minerals that are not abundant in terrestrial plants (Ortega-Calvo, 1993). Ruperez (2002) identified various minerals by atomic absorption spectrophotometry, which revealed high levels of macrominerals (8,083-17,875 mg 100 g^{-1}) and microminerals (5.1-15.2 mg 100 g^{-1}). Similarly, *P. purpurea* was found to contain high levels of potassium and phosphorus: 1.602 mg 100 g^{-1} and 720.2 mg 100 g^{-1} (Toboada *et al*., 2013). Other recent studies have reported iron levels of 21.3 mg $(100\ g)^{-1}$ and 10.3 mg $(100\ g)^{-1}$ in *P. columbina* and *P. tenera*, respectively (Ruperez, 2002; Perez *et al*., 2007). However, the nutritional value of algae may be affected by environmental factors such as salinity, water and air temperatures, and pH, as well as by seasonal and spatial variations (Shin *et al*., 2013; Phillips, 1990). Most environmental parameters vary according to season, and changes in ecological conditions can stimulate or inhibit biosynthesis of several nutrients (Lobban *et al*., 1985). However, the associations between spatial and temporal variables and the chemical composition and properties of *Pyropia* have not yet been investigated; most studies to date have focused on other seaweed species.

In the present study, *Pyropia yezoensis* was cultivated at Gunsan on the western coast of South Korea simultaneously with *P. yezoensis* cultivated at Goheung on the southern coast. Proximate compositions, amino acid and mineral contents, and environmental conditions between these two sampling sites were compared.

Materials and Methods

Samples : *P. yezoensis* samples were collected from cultivation sites at Gunsan on the western coast of South Korea, and Goheung, on the southern coast of South Korea. Sampling was carried out every month from November 2015 to March 2016. *P. yezoensis* samples were transported in plastic bags in an ice box at low temperature. The weight of the transported wet samples was measured, and samples were then dried in an oven at 60 ºC for 24 hr. To complete the drying process, the samples were placed in an oven three times for 1 hr at 105 ºC. All samples were ground and passed through a 0.5 mm mesh sieve prior to further analysis. The proximate composition, amino acid and mineral content of these samples were compared.

Analysis of proximate composition : The total proximate composition, including carbohydrate, protein, lipid and ash was determined following the Association of Official Analytical Chemists (AOAC, 1995) method.

For protein analysis, 1 g of sample was placed in a Kjeldahal flask with $CuSO_47H_2O$:K_2SO_4 in 1:4 ratio and then heated. Total protein content was determined by the Kjeldahal method using fixed nitrogen:protein conversion factor of 6.25 (AOAC, 1995).

For analysis of lipid, samples were dried in an oven for 24 hr. and then 2 g of sample was filtered using a micro filter tube (pore size = 8 μm, ID = 25 mm, OD = 28 mm, L = 100 mm). The micro filter tube was blocked using cotton and then placed into a Soxhlet extractor. Diethyl ether (300 ml) within a round flask was affixed to the Soxhlet siphon, which was then installed in a water bath at temperature increasing from 40 to 55 ºC for over 10 hr. The extracted sample was evaporated, after which it was dried in an oven for 30 min and placed in a desiccator for 1 hr at room temperature; this process was repeated three times. Sample weight was measured at 20–25 ºC. Lipid concentrations were calculated by the formula: lipids (%) = [X/sample weight]×100; where, X = initial weight of the round flask – final weight of the round flask (AOAC, 1995).

For ash analysis, the ground dried samples were turned into ash by heating for 5 hr in an electric oven at 500 ºC (AOAC, 1995).Carbohydrates were quantified as the difference of sum of protein, lipid and ash contents, subtracted from 100% (AOAC, 1995).

Amino acids were analyzed using an amino acid analyzer (L8900, Hitachi High-Technologies, Tokyo, Japan). The sample (1 g) was hydrolyzed with 6 N HCl (20 ml) and then incubated for over 20 hr at 120 ºC. The hydrolyzed sample was filtered (pore size 2.5 µm) and then evaporated using a pressure evaporator to remove acids. The sample was mixed with 10 ml of 0.2 M sodium citrate buffer (pH 2.2), filtered using a syringe filter (pore size 0.2 µm) and diluted 40-fold with distilled water. Standard amino acid mixture solution was purchased from Wako Co. (Japan) as a reference material. The conditions and solvent system used for the amino acid analyzer are provided in Table 1.

Pulverized *Pyropia* (0.5 g) was placed in a beaker and carefully mixed with 1 ml HNO_3. The mixture was placed on a hot plate at 50℃ to digest the sample under a fume hood. After acid digestion, the contents were left to cool, and the acid was evaporated, for 30 min. After evaporation of acid, the digested samples were transferred into a 50 ml volumetric flask with deionized water. Ca, K, Mg, Na, P, Mn, Fe, Cu and Zn were analyzed using an inductively coupled plasma optical emission spectrometer (Vista-PRO, Agilent Technologies, Waldbronn, Germany). Triplicate measurements were performed for each element. The concentration of each element was determined based on its standard calibration curve.

Statistical analyses : All data are presented as mean ± SD. Student's t-tests were used to assess difference between paired means derived from the samples collected from Gunsan and Goheung. The statistical significance of differences between means (threshold: $P<0.05$) was estimated based on one-way ANOVA and Tukey's HSD *post hoc* test using SPSS ver. 17.

Results and Discussion

South Korea is surrounded by the East, West and South Seas, with a coastline of approximately 2,413 km. Approximately, 90% of cultivated seaweed was farmed on the West and South coasts. Cultivated species include *Cauleerpa* sp., *Laminaria* sp., *Hizikia fusiformis*, *Monostroma* sp., *Codium* sp. and *Pyropia* sp. The red alga *Pyropia* sp. accounts for approximately 90% of all cultivated seaweed on both coasts, including the sites of Gunsan on the west coast and Goheung on the south coast (Kim *et al.*, 2014).

Air, water temperature and salinity were measured at the cultivation sites at Gunsan and Goheung from November 2015 to March 2016. The water temperature at Gunsan decreased from 16.38 ºC in November to 1.8 ºC in mid-January, before increasing again to 8.7ºC in March. The water temperature at Goheung followed a similar pattern; however, it was 1–3 ºC higher than that at Gunsan on average, with greater daily fluctuations. The salinity ranged from 29.8 psu to 32.7 psu at Goheung and from 27.1 psu to 30.4 psu at Goheung (Fig. 1). Another red algae, *Gracilaria* can tolerate a wide range of salinities, from about 10–40 psu, though they grow best between 25–33 psu (Gorman *et al*., 2017).

The proximate composition, including protein, lipid, carbohydrate and ash contents, of *P. yezoensis* were compared between Gunsan and Goheung (Table 2). Crude protein and ash contents showed statistically significant variations over time ($P<0.05$), while crude lipid and carbohydrate contents did not vary significantly. Red seaweed contain high protein levels (Galland-Irmouli *et al*., 1999). *Pyropia* spp. contained protein levels comparable to those of terrestrial plant foods, such as white soybeans (33.8%) (Norziah and Ching, 2000).

The highest protein content was 39.66% in the samples collected at Goheung (December) and 38.77% in the Goheung samples (January). From November to February, the ash content of the Goheung samples remained fairly consistent, ranging from 5.29% to 5.55%. The lowest ash content, 4.48%, was observed in March. The proximate composition did not differ significantly between the Gunsan and Goheung samples. Proximate compositions may vary depending on climate, temperature, pH, geographical differences, species and season (Fleurence 1999; Ortriz *et al*. 2006). Noda *et al*. (1971) reported that proximate composition in red algae followed temporal and spatial patterns. Conversely, the carbohydrate content was higher during the later cultivation period (Park *et al*. 2001). Marinho-Soriano *et al*. (2006) reported that nitrogen content in red algae was positively correlated with protein content but negatively with carbohydrate content, salinity and water temperature.

P. yezoensis harvested from Gunsan and Goheung was analyzed for essential amino acids, such as isoleucine, leucine, threonine, methionine, phenylalanine, lysine, histidine, valine and arginine. Among these amino acids, isoleucine, leucine, threonine, lysine, histidine and valine were present at higher concentrations in samples harvested in November and December. The most abundant amino acid was leucine, ranging from 9.34 g 100 g^{-1} to 18.89 g 100 g^{-1}. The most abundant amino acids were threonine, phenylalanine, lysine, valine and arginine, ranging 6.51 g 100 g^{-1} to 14.17 g 100 g^{-1}. *Pyropia* harvested from Goheung contained significantly higher concentrations of isoleucine, leucine, threonine, lysine, histidine, valine and arginine compared with *Pyropia* harvested from Gunsan ($P<0.05$). Conversely, from November to January,*Pyropia* from Gunsan contained higher concentrations of methionine and phenylalanine compared with *Pyropia* from Goheung ($P<0.05$) (Table 3). Aspartic and glutamic acids constitute a large proportion of amino acid fraction, representing 22–44% of total amino acids (Munda, 1977). Alanine, glutamic acid and aspartic acids were the most abundant amino acids (Lee *et al*., 2012; Jung *et al*., 2016b)

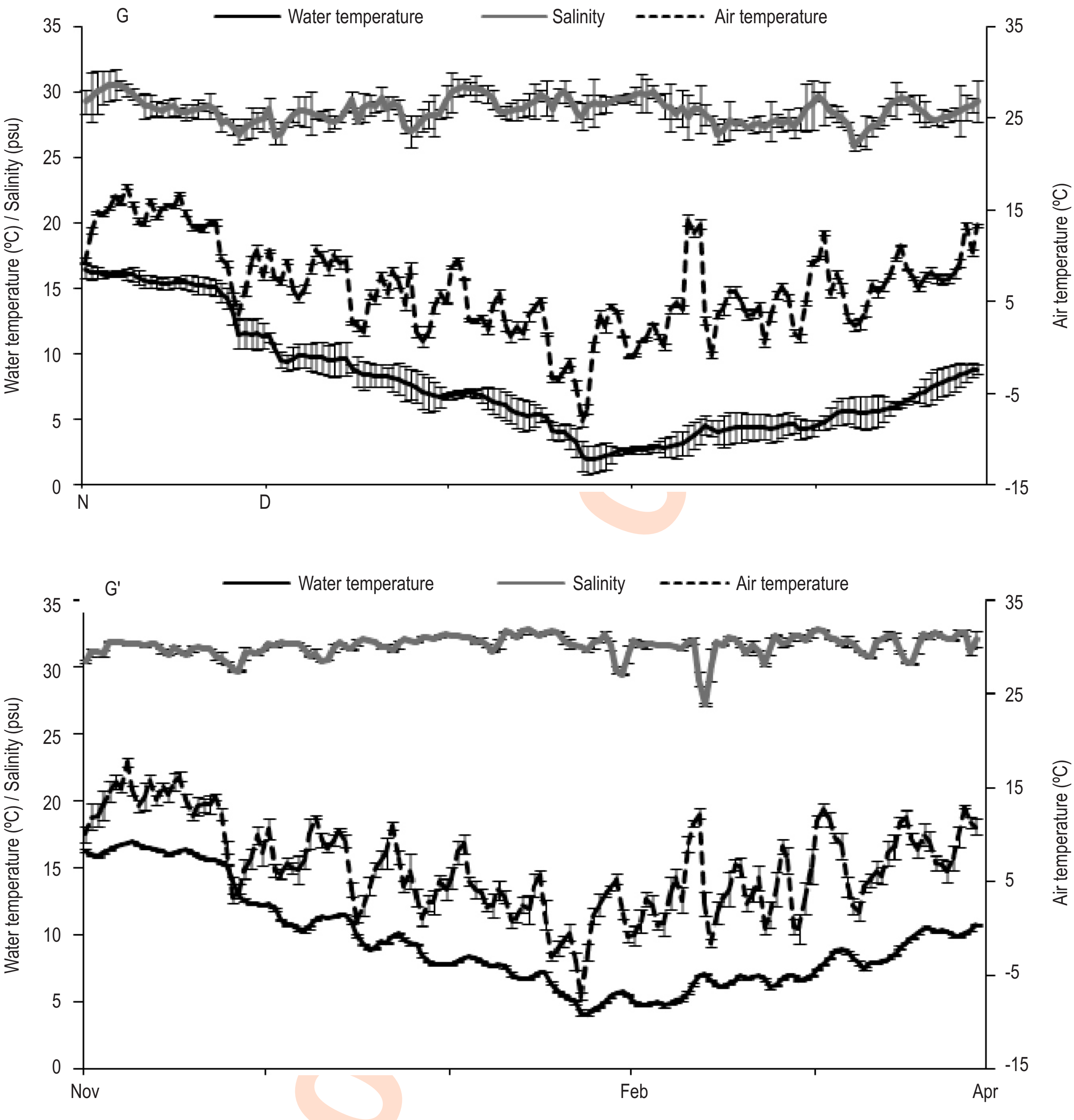

Fig. 1 : Physiological parameter of water, air temperature and salinity at Gunsan (G) and Goheung (G').

Pyropia samples contained not only essential amino acids but also non-essential amino acids, such as aspartic acid, glycine, tyrosine, serine, glutamic acid, alanine and proline. Among these amino acids, glutamic acid, aspartic acid, glycine and alanine were present high concentrations. The highest concentrations of glutamic acid and aspartic acid was 41.48 g 100 g^{-1} and 37.10 g 100 g^{-1}, respectively (P<0.05), in *Pyropia* harvested from Gunsan in November and December. Glycine and serine were present at higher concentrations in samples collected from Goheung (P<0.05). From November to January, *Pyropia* samples from Gunsan contained higher concentrations of tyrosine and alanine compared with the Goheung samples (P<0.05) (Table 4).

Table 1 : Conditions and solvent system of the amino acid analyzer

Comparts	Conditions
Column	4.6 mm ID X 60 mm L (packed with Hitachi custom ion exchange resin)
Injection volume	20 µl
Temperature	Oven 57 ºC; Reactor 135 ºC
Wavelength	570 nm, 440 nm
Flow rate	Pump 1 : buffer : 0.4 ml min^{-1} Pump 2 : buffer : 0.35 ml min^{-1}
Mobile phase	Pump 1 : Wako L-9800 : buffer solution : PH-1, PH-2, PH-3, PH-4, H_2O, PH-RG Pump 2 :Ninhydrin solution, Ninhydrin buffer, 5% ethanol (Wako Co.)

Table 2 : Monthly crude protein, lipid, carbohydrate and ash contents of laver from *Pyropia yezoensis* (% d. wt.)

	Area	Nov	Dec	Jan	Feb	Mar
Protein	Goheung	38.89±0.38^{c}	39.66±0.49^{bc}	39.10±0.32^{c}	37.82±0.20^{ab}	37.03±0.48^{a}
	Gunsan	38.58±0.51^{b}	38.33±0.20^{b}	38.77±0.59^{b}	38.13±0.20^{b}	37.16±0.45^{a}
Lipid	Goheung	4.44±2.89^{NS}	3.45±0.15	2.94±0.08	3.07±0.12	3.03±0.12
	Gunsan	3.45±1.06^{NS}	3.13±0.92	3.02±0.14	2.99±0.04	3.08±0.13
Carbohydrate	Goheung	51.22±3.29^{NS}	52.60±0.34	52.45±0.33	53.56±0.45	55.10±0.37
	Gunsan	53.56±1.53^{NS}	53.42±0.99	52.58±0.36	53.10±0.24	54.32±0.44
Ash	Goheung	5.45±0.22b^{b*}	5.29±0.22^{b}	5.51±0.04^{b}	5.55±0.20^{b}	4.48±0.13^{a}
	Gunsan	4.42±0.15^{a}	5.12±0.09^{b}	5.63±0.10^{cd}	5.78±0.08^{d}	5.45±0.05^{a*}

Values are mean of three replication ± SD; $^{a-c}$ Values with the same superscripts in each row are not significantly different at p<0.05; ^{NS} it is not statistically significant; *p<0.05, indicating significant difference between Gohueng and Gunsan group

Table 3 : Comparison of essential amino acid content of *Pyropia yezoensis* (g 100g^{-1}d. wt.)

		Nov	Dec	Jan	Feb	Mar
Isoleucine	Goheung	4.25±0.19^{c**}	2.73±0.03^{a***}	4.64±0.11^{c***}	4.38±0.20^{c**}	3.83±0.21^{b***}
	Gunsan	3.59±0.10^{cd}	2.19±0.06^{a}	3.80±0.07^{d}	3.40±0.18^{c}	2.47±0.01^{b}
Leucine	Goheung	18.89±0.81^{c}	14.24±0.10^{a***}	17.03±0.49^{c**}	16.42±0.79^{bc*}	14.99±0.79^{ab***}
	Gunsan	17.89±0.50^{d}	12.11±0.36^{b}	15.54±0.24^{c}	14.84±0.84^{c}	9.34±0.02^{a}
Threonine	Goheung	11.31±0.51^{b*}	8.22±0.08^{a**}	12.39±0.33^{b}**	11.56±0.52^{b*}	11.27±0.57^{b***}
	Gunsan	10.19±0.30^{c}	7.04±0.21^{a}	11.23±0.17^{d}	10.09±0.52^{c}	8.16±0.02^{b}
Methionine	Goheung	1.15±0.05^{b}	1.40±0.01^{c}	0.31±0.01^{a}	4.00±0.17^{e*}	3.67±0.18^{d***}
	Gunsan	2.23±0.05^{b***}	2.26±0.11^{b***}	1.40±0.02^{a***}	3.69±0.18^{d}	2.81±0.08^{c}
Phenylalanine	Goheung	10.33±0.43^{bc}	8.77±0.07^{a***}	10.81±0.30^{c}	10.13±0.46^{bc}	9.73±0.50^{b***}
	Gunsan	12.65±0.35^{c***}	7.70±0.25^{b}	10.56±0.16^{c}	11.08±0.60^{c*}	6.51±0.02^{a}
Lysine	Goheung	11.60±0.51^{b}	8.39±0.09^{a***}	13.17±0.33^{c***}	11.42±0.57b*	10.54±0.51^{b***}
	Gunsan	11.01±0.31^{c}	7.32±0.23^{a}	10.66±0.11^{c}	9.91±0.58^{b}	6.91±0.03^{a}
Histidine	Goheung	3.32±0.14^{c}	2.42±0.03^{a***}	3.28±0.10^{c*}	3.20±0.14^{bc*}	2.93±0.16^{b***}
	Gunsan	3.22±0.09^{d}	2.06±0.05^{b}	3.11±0.01^{cd}	2.93±0.16^{c}	1.78±0.12^{a}
Valine	Goheung	12.17±0.53^{c*}	8.46±0.04^{b***}	7.90±0.21^{ab**}	7.62±0.33^{a*}	7.20±0.34^{a***}
	Gunsan	11.33±0.29^{d}	7.37±0.25^{c}	7.34±0.11^{c}	6.68±0.31^{b}	5.02±0.01^{a}
Arginine	Goheung	13.39±0.58^{a}	10.17±0.09^{a**}	12.20±0.34^{c*}	11.79±0.70^{bc***}	10.85±0.37^{ab***}
	Gunsan	14.17±0.41^{c}	9.05±0.26^{b}	11.51±0.17^{c}	6.89±0.01^{a}	6.90±0.04^{a}

Values are mean of three replication± SD; $^{a-d}$ Values with the same superscripts in each row are not significantly different at p<0.05; ^{NS} it is not statistically significant; *p<0.05, **p<0.01 and ***p<0.001, indicating significant difference between Gohueng and Gunsan group

Table 4 : Comparison of non-essential amino acid content of *Pyropia yezoensis* (g 100g^{-1}d.wt.)

		Nov	Dec	Jan	Feb	Mar
Aspartic acid	Goheung	34.62±1.54^{a}	26.84±0.27^{b*}	22.13±0.57^{a**}	22.01±1.01^{a}	20.56±1.01^{a***}
	Gunsan	37.10±1.05^{d*}	25.27±0.75^{c}	20.62±0.31^{b}	20.72±1.12^{b}	13.71±0.04^{a}
Glycine	Goheung	26.19±1.18^{d}	21.69±0.16^{c**}	17.11±0.41^{b**}	15.54±0.73^{ab}	15.18±0.79^{a***}
	Gunsan	25.47±0.73^{d}	19.26±0.58^{c}	15.85±0.28^{b}	15.20±0.81^{b}	11.18±0.04^{a}
Tyrosine	Goheung	3.21±0.16^{c}	2.81±0.00^{b}	1.57±0.05^{a}	5.25±0.22^{e}	4.88±0.26^{d***}
	Gunsan	4.81±0.13^{b***}	3.16±0.11^{a**}	4.64±0.08^{b***}	5.67±0.32^{a}	3.26±0.01^{a}
Serine	Goheung	12.21±0.56^{b}	9.61±0.10^{a**}	12.15±0.34^{b*}	11.71±0.52^{b}	11.35±0.56^{b***}
	Gunsan	12.80±0.38^{c}	8.63±0.23^{a}	11.54±0.17^{b}	11.43±0.58^{b}	7.92±0.01^{a}
Glutamic acid	Goheung	37.81±1.68^{c}	27.39±0.27^{b}	23.61±0.64^{a}	26.42±1.21^{b**}	22.78±1.13^{a**}
	Gunsan	41.48±1.19^{e*}	27.27±0.76^{d}	23.49±0.34^{c}	21.59±1.19^{b}	15.92±0.04^{a}
Alanine	Goheung	23.36±1.05^{b}	17.65±0.15^{a}	31.25±0.90^{c}	35.54±1.61^{d}	30.56±1.56^{c***}
	Gunsan	24.66±0.72^{b}	23.25±0.64^{b***}	34.72±0.50^{c**}	35.52±1.90^{c}	20.11±0.03^{a}
Proline	Goheung	14.03±0.57^{b}	10.60±0.02^{a}	11.32±0.32^{a*}	10.64±0.48^{a}	10.40±0.52^{a***}
	Gunsan	15.45±0.07^{d**}	10.57±0.23^{bc}	10.88±0.11^{c}	10.17±0.55^{b}	8.02±0.06^{a}

Values are mean of three replication ± SD; $^{a-d}$ Values with the same superscripts in each row are not significantly different at p<0.05; ^{NS} it is not statistically significant; *p<0.05, **p<0.01 and ***p<0.001, indicating significant difference between Gohueng and Gunsan group

Table 5 : Macro mineral contents of *Pyropia yezoensis* laver (mg 100g^{-1}d. wt.)

Macro-M		Nov.	Dec.	Jan.	Feb.	Mar.
Ca	Goheung	136.11±1.30a	183.85±1.37b	151.54±12.34ab	263.34±10.61c**	178.56±30.84b
	Gunsan	196.54±1.41c***	185.15±2.63bc	153.53±8.33a	226.72±13.12d	164.74±15.27ab
K	Goheung	2496.81±17.58b**	2498.44±24.43b***	2493.53±278.34b*	1647.87±33.83a	2078.61±362.37ab
	Gunsan	1521.63±9.21a	1768.41±10.50ab	1899.31±88.49b	1879.99±149.60b*	1929.23±220.36b
Mg	Goheung	183.33±0.86b***	135.53±1.28a	199.32±15.76bc	146.92±5.75a	227.39±25.95c
	Gunsan	103.24±0.31a	162.36 ±1.41b***	183.25±12.23bc	203.84±16.67cd**	232.77±22.49d
Na	Goheung	644.84±1.39d***	308.72±2.77b***	401.76±32.01c*	142.91±7.62a	454.02±66.60c
	Gunsan	79.89±0.05a	291.21±1.45b	343.79±19.11bc	397.17±37.67c***	568.16±63.43d
P	Goheung	485.06±2.47ab	433.24±3.60a	524.66±28.13b	481.57±27.07ab	527.62±28.77b***
	Gunsan	586.50±3.16c***	452.47±3.99b**	547.14±41.04c	588.03±43.30c*	242.12±19.64a

Values are mean of three replication± SD; $^{a-d}$ Values with the same superscripts in each row are not significantly different at p<0.05; ^{NS} it is not statistically significant; *p<0.05, **p<0.01 and ***p<0.001, indicating significant difference between Gohueng and Gunsan group

Five macrominerals (Ca, K, Mg, Na and P) and four microminerals (Mn, Fe, Cu and Zn) were measured in *Pyropia* samples collected at the Gunsan and Goheung cultivation sites. Mineral content in algae may also be affected by factors such as algal species, oceanic residence time, geographical location of harvest, wave exposure, season and processing method (Yoshie *et al*., 1994). K was present in highest concentrations, followed by P, Na, Ca and Mg. The concentration of K in *Pyropia* cultivated at Goheung ranged from 2493.53 mg 100 g^{-1} to 2498.44 mg 100 g^{-1} from November to January, which was higher than the concentration in *Pyropia* cultivated at Gunsan (P<0.05). Similarly, Ruperez (2002) found that K was the most abundant mineral in *Chodrus* and *Pyropia*, occurring at concentrations from 3,184 to 3,500 mg 100 g^{-1}. Macro- and micromineral contents vary by season and region. Conversely, the levels of Ca and P were higher in *Pyropia* samples from Gunsan than in *Pyropia* samples from Goheung from November to February (P<0.05). Mg and Na concentrations exhibited irregular patterns over the harvesting period. Among the microminerals, Fe was present at highest concentrations, ranging from 7.54 mg 100 g^{-1} to 62.64 mg 100 g^{-1} (Table 5). Fe concentration was higher in *Pyropia* from Gunsan in November, February and March but in *Pyropia*from Goheung in January and February. Mn and Cu followed similar pattern as Fe. The Zn level was higher in *Pyropia* from Gunsan than in *Pyropia* from Goheung from November to February (Table 6).

The present study, confirmed that environmental conditions have an impact on biosynthetic pathways. The physical parameters of seawater have a major influence on *Pyropia*'s growth and development, including its carbohydrate, protein, lipid, ash, amino acid and mineral contents. While proximate composition varied temporally and spatially; these effects were not statistically significant. Conversely, amino acid and mineral contents differed significantly depending on both

Table 6 : Micro mineral contents of *Pyropia yezoensis* (mg $100g^{-1}$ d. wt.)

Micro-M		Nov.	Dec.	Jan.	Feb.	Mar.
Mn	Goheung	2.42±0.01c	2.22±0.03c***	2.19±0.09c**	1.32±0.09a	1.71±0.18b
	Gunsan	3.29±0.02c***	1.62±0.02a	1.63±0.14a	1.97±0.16b**	1.94±0.14b
Fe	Goheung	12.09±0.05b	12.67±0.09b***	24.68±1.21d***	7.96±0.43a	14.50±0.62c
	Gunsan	14.64±0.01ab***	9.15±0.1a	7.54±1.16a	26.05±6.62b**	62.64±11.05c**
Cu	Goheung	0.56±0.01b	0.96±0.02c***	0.35±0.09a	0.51±0.06b	0.27±0.06a
	Gunsan	0.75±0.01c***	0.47±0.01b	0.24±0.01a	0.76±0.04c**	0.28±0.06a
Zn	Goheung	3.54±0.03NS	3.09±0.01	3.29±0.23	3.13±0.19	3.46±0.27
	Gunsan	8.81±0.03c***	3.20±0.02ab**	3.76±0.42b	3.45±0.31ab	3.08±0.22a

Values are mean of three replication± SD; a-d Values with the same superscripts in each row are not significantly different at $p<0.05$; NS it is not statistically significant; ** $p<0.01$ and *** $p<0.001$, indicating significant difference between Gohueng and Gunsan group

season and region.

Edible marine seaweeds may be an important source of nutrition, because some of their constituents are nearly or entirely absent from terrestrial vegetation. Based on the results of this study, temporal and spatial variations may influence the proximate composition, amino acid and mineral content of red algae, and knowledge of these patterns may be useful for both producers and consumers.

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