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Research Article

Macroalgae as Alkalizing Marine Drugs with a Low Potential Renal Acid Load

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A growing interest in more sustainable and alternative food sources has brought seaweed and macroalgae to the spotlight for the general worldwide cuisine. Algae are often praised for their high nutritional value and are rich in potassium, calcium, and magnesium. Abundant in base precursors, algae are particularly interesting from an acid-base perspective. Their unique biochemical composition suggests a low potential renal acid load (PRAL), which is a commonly used estimate for the amount of acid or base a certain food produces in humans. Here, we analyzed the PRAL value of $n = 106$ macroalgae. Results suggested a strong alkalizing potential, with a mean PRAL value of −86.76 mEq/100 g. The lowest PRAL values were found for *Laminaria ochroleuca* (−286.78 mEq/100 g), *Gelidium micropterum* (−268.46 mEq/100 g), and *Palmaria palmata* (−259.16 mEq/100 g). We observed a strong inverse relationship of PRAL with algae's potassium content (Spearman's rho = −0.79, $p < 0.001$) and a moderate relationship with algae's calcium content (Spearmen's rho: −0.34, $p < 0.001$). Our data point at a potential role for several macroalgae as potent alkalizing marine drugs and suggest that a 10 g edible portion of some algae alone could contribute to a substantial PRAL reduction of up to −28.68 mEq. This might be of particular importance for individuals who benefit from a more alkaline diet and warrants further investigation in future studies.

1. Introduction

A growing interest and awareness for more sustainable and alternative food sources and gradual changes toward more plant-based dietary patterns have brought seaweed and macroalgae to the spotlight for the general worldwide cuisine [1]. Traditionally popular in Asia [2], macroalgae are often praised for their high nutritional value [3–5]. Macroalgae are considered good sources of fiber, omega-3 and omega-6 fatty acids, selenium, iodine, and vitamin B_{12} [1, 6–9]. They are also abundant in calcium, magnesium, and potassium [10–13].

The combination of these nutritional features and the biochemical composition of algae is particularly interesting from an acid-base perspective on foods. Foods rich in alkali precursors (particularly potassium salts and magnesium salts) and low in phosphorus and phosphate additives are usually characterized by a low PRAL (potential renal acid load) value [14–16].

The PRAL value is the most commonly used estimate for the amount of acid or base a certain food produces in the human body [17, 18]. Low PRAL values indicate that a specific food is abundant in base precursors, whereas high values indicate that a food is rich in acid precursors [19, 20]. Typical examples of acidifying high-PRAL foods include fish, cheese, and meats [21, 22]. Alkalizing low-PRAL foods, on the other hand, are largely of plant-based origin, including tomatoes, kale, spinach, raisins, carrots, and celery [23, 24].

The PRAL value of different algae has rarely been subject to a dedicated and systematic PRAL quantification in the scientific literature. We deemed this to be important, however, because the popularity of seaweeds and macroalgae is rapidly increasing in Western societies [25–27].

Macroalgae also have a varying nutritional profile, depending on their origin and the surrounding environmental conditions in which they grow [28, 29]. Further to that, harvesting and processing techniques are also supposed to affect algae's nutrient content. As such, a "one-size-fits-all" PRAL estimation for algae in general might be too imprecise, and family or genus-specific approaches are warranted.

Here, we argue that macroalgae could be used as potent marine drugs with strong alkalizing properties due to their very specific nutritional profiles, which could help in offsetting the health repercussions from a high dietary acid load. We hypothesized that algae would be largely characterized by alkalizing properties due to their high calcium and potassium content. We also hypothesized that significant differences in PRAL between the different algae phyla/classes (*Chlorophyta*, *Rhodophyta*, and *Phaeophyceae*) exist. Finally, we sought to identify those macroalgae candidates with the strongest alkalizing properties, examining their potential use to reduce the overall acid load burden from diet.

2. Materials and Methods

2.1. Data Extraction. We extracted the nutrient content of the examined macroalgae from previous publications in the field of phycology. For this, we identified original articles and scientific reviews using three different search engines: PubMed, Web of Science, and Google Scholar. The following search terms were used in various combinations during the search process: macroalgae, seaweed, nutrients, calcium, magnesium, potassium, phosphorus, composition, and minerals. The search was restricted to publications from the last 15 years. Only articles in English language were considered. Reference lists and cross-references as well as Google Scholar's "cited by" function were used to capture additional articles of interest. Only macroalgae with a complete nutrient composition profile (including protein and the following minerals: calcium, magnesium, potassium, and phosphorus) in g or mg/100 g were considered. No data were imputed and incomplete profiles for PRAL-relevant nutrients were not considered. The literature research was performed in July 2023.

2.2. Potential Renal Acid Load Estimation. PRAL (in mEq/100 g) was estimated using the commonly used and validated formula by Remer and Manz [16]:

PRAL (mEq/100 g) = (0.49 * total protein intake (in g/100 g)) + (0.037 * phosphorus intake (in mg/100 g))−(0.021 * potassium intake (in mg/100 g))−(0.026 * magnesium intake in (in mg/100 g))−(0.013 * calcium intake (in mg/100 g)).

This formula considers the average intestinal absorption rates of anions and cations present in foods and has been tested against urinary pH in the past [30]. PRAL values were estimated for 100 g portion sizes (which reflects the standard procedure [31]) and 10 g portion sizes, which might be practically relevant for a potential future application of macroalgae as alkalizing marine drugs.

2.3. Statistical Analysis. Data were analyzed with STATA 14 statistical software (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). Histograms and Stata's Shapiro–Wilk test were used to check whether the examined data were normally distributed or not. Normally distributed data were described with the mean and standard deviation, whereas non-normally distributed data were described with the median and interquartile range in parenthesis. We also used the rank-based nonparametric Kruskal–Wallis H test to check for statistically significant differences in selected nutrients between the examined algae phyla. A p value <0.05 was considered statistically significant. Further to that, we ran Spearman's rank-order correlations to assess the relationship between the content of selected nutrients and PRAL for the examined algae items. Scatterplots and separated scatter plots were created to visualize the results.

3. Results

3.1. Sample Description. We identified $n = 106$ macroalgae items with a complete nutrient profile to estimate the PRAL [32–47]. Of these, $n = 28$ belonged to the Chlorophyta phylum, $n = 52$ belonged to the Rhodophyta phylum, and $n = 26$ belonged to the Phaeophyceae class. The majority of the analyzed macroalgae originated from India ($n = 35$), followed by Sweden ($n = 22$) and Russia ($n = 14$).

Table 1 shows the macro- and micronutrient content, as well as the PRAL value of these items in great detail. The mean PRAL value of the entire sample ($n = 106$ items) was −86.76 ± 87.47 mEq/100 g. Based on dry weight data only, the mean PRAL value of the sample ($n = 101$ items) was −90.69 ± 87.75 mEq/100 g. The lowest PRAL value was found for *Laminaria ochroleuca* (Phaeophyceae) with −286.78 mEq/100 g, followed by *Gelidium micropterum* (Rhodophyta) and *Palmaria palmata* (Rhodophyta) with PRAL values of −268.46 and −259.16 mEq/100 g, respectively. Approximately 11% of the sample ($n = 11$ algae items) were characterized by acidifying properties (as suggested by a PRAL value >0 mEq), whereas the remaining items had alkalizing properties (PRAL values < 0 mEq).

We generally observed a large heterogeneity with regard to the calcium, potassium, magnesium, and phosphorus content of the examined $n = 106$ algae items. The median potassium content was 2900 (3521.7) mg/100 g and ranged from 22.32 mg/100 g in *Ulva flexuosa* (formerly *Enteromorpha flexuosa*) (Chlorophyta) to 12480 mg/100 g in *Palmaria palmata*. The median calcium content was 1035 (1351) mg/100 g and also varied considerably, ranging from 151.4 mg/100 g in *Pyropia tenera* (formerly *Porphyra tenera*) (Rhodophyta) to 8220 mg/100 g in *Delesseria sanguinea* (Rhodophyta). Median magnesium and phosphorus content (in mg/100 g) were as follows: 765 (1018.48) and 214 (253). The median protein content was 15.4 (9.76) g/100 g and also varied widely across the examined food items. *Gracilaria corticata* (Rhodophyta) had the lowest protein content with 3.3 g/100 g, whereas *Porphyra* sp. had the highest with 53.9 g/100 g.

Table 1: Macro- and micronutrient content as well as PRAL values of $n = 106$ macroalgae.

Name	Protein (g/100 g)	Ca (mg/100 g)	K (mg/100 g)	Mg (mg/100 g)	P (mg/100 g)	PRAL (mEq/100 g)	Origin	Type*
Acanthophora spicifera [40]	20.2	430	52.08	480	210	−1.50	India	Rho
Ahnfeltia plicata [44]	5.57	654	347	205	141	−13.17	Russia, White Sea	Rho
Ahnfeltia plicata [42]	20.1	4000	2300	680	182	−101.40	Sweden, West Coast	Rho
Amphiroa anceps [45]	6.9	1630	10900	420	470	−240.24	India, Saurashtra coast	Rho
Amphiroa fragilissima [33]	29	1596	5139	1478	1757	−87.88	Egypt, Alexandria	Rho
Ascophyllum nodosum [42]	5.9	1240	2600	870	67	−87.97	Sweden, West Coast	Pha
Bifurcaria bifurcata [46]	8.92	996.42	9316.28	528.04	169.54	−211.68	Spain, Galician coast	Pha
Vertebrata byssoides (formerly Brongniartella byssoides) [42]	15.8	4940	6300	770	202	−201.32	Sweden, West Coast	Rho
Caulerpa racemosa [32]	24.57	2660	2070	1260	140	−93.59	India, North-West Coast	Chl
Caulerpa racemosa [45]	8.68	5970	3920	1130	190	−178.03	India, Saurashtra coast	Chl
Caulerpa scalpelliformis [45]	12.24	3820	4300	1390	280	−159.74	India, Saurashtra coast	Chl
Caulerpa veravalensis [45]	9.19	2320	3220	860	250	−106.39	India, Saurashtra coast	Chl
Ceramium sp. [42]	15.8	550	6700	1510	242	−170.41	Sweden, West Coast	Rho
Ceramium virgatum [44]	32.25	578	1018	647	252	−20.59	Russia, White Sea	Rho
Chondrus crispus [42]	10.3	1250	3000	800	103	−91.19	Sweden, West Coast	Rho
Chondrus crispus [35]	12.4	2230	3410	750	160	−107.36	Spain, Galicia	Rho
Chondrus crispus [41]	15.7	420	4100	650	110	−96.70	Portugal	Rho
Chorda filum [42]	6.3	1490	8400	780	105	−209.08	Sweden, West Coast	Pha
Cladophora glomerata [33]	27.5	931	505	1693	5757	159.76	Egypt, Alexandria	Chl
Lychaete pellucida (formerly Cladophora pellucida) [33]	25	746	445	1256	3700	97.45	Egypt, Alexandria	Chl
Cladophora rupestris [42]	18.4	760	4200	440	142	−95.25	Sweden, West Coast	Chl
Cladophora sp. [42]	13.9	540	8500	760	171	−192.14	Sweden, West Coast	Chl
Coccotylus brodiei [44]	15.87	450	705	313	138	−15.91	Russia, White Sea	Rho
Corallina officinalis [33]	19	1304	101	1530	1834	18.32	Egypt, Alexandria	Rho
Cystoclonium purpureum [44]	27.1	395	1499	461	228	−26.89	Russia, White Sea	Rho
Cystoclonium purpureum [42]	17.2	580	6500	910	226	−150.91	Sweden, West Coast	Rho
Polycladia indica (formerly Cystoseira indica) [45]	12.95	1810	9070	700	500	−207.35	India, Saurashtra coast	Pha
Delesseria sanguinea [42]	18.3	8220	2200	950	227	−160.39	Sweden, West Coast	Rho
Desmarestia aculeata [42]	11.5	4790	2500	880	216	−124.02	Sweden, West Coast	Pha
Dilsea carnosa [42]	15.2	320	3500	510	230	−74.96	Sweden, West Coast	Rho
Ulva compressa (formerly Enteromorpha compressa) [32]	29.54	770	3420	2230	350	−112.39	India, North-West Coast	Chl
Ulva compressa (formerly Enteromorpha compressa) [38]	17.48	4760	1380	890	1640	−44.75	India, North-West Coast	Chl
Ulva flexuosa (Enteromorpha flexuosa) [40]	17.29	712	22.32	436	270	−2.60	India	Chl
Ulva linza (formerly Enteromorpha linza) [38]	12.5	5120	230	1180	410	−80.78	India, North-West Coast	Chl
Enteromorpha prolifera [33]	22	1323	2737	1799	3813	30.41	Egypt, Alexandria	Chl
Ulva flexuosa (as Enteromorpha tubulosa) [38]	19.09	5070	270	1560	390	−88.36	India, North-West Coast	Chl
Euthora cristata [44]	13.06	673	185	483	237	−10.02	Russia, White Sea	Rho
Fucus serratus [42]	7.1	1040	2900	730	123	−85.37	Sweden, West Coast	Pha
Fucus vesiculosus [36]	12.4	779	3696	813	117	−98.48	Portugal, West Coast	Pha
Fucus vesiculosus [46]	12.99	1160.27	3745.05	732.37	193.57	−99.24	Spain, Galician coast	Pha
Fucus vesiculosus [42]	7.1	1140	3800	890	102	−110.51	Sweden, West Coast	Pha
Furcellaria lumbricalis [44]	15.98	218	609	555	129	−17.45	Russia, White Sea	Rho
Furcellaria lumbricalis [42]	17.1	2560	4600	1100	131	−145.25	Sweden, West Coast	Rho

Table 1: Continued.

Name	Protein (g/100 g)	Ca (mg/100 g)	K (mg/100 g)	Mg (mg/100 g)	P (mg/100 g)	PRAL (mEq/100 g)	Origin	Type*
Gelidium micropterum [45]	12.66	6140	8740	890	320	−268.46	India, Saurashtra coast	Rho
Chondracanthus teedei (formerly Gigartina teedei) [33]	21	1072	4359	1551	5212	57.33	Egypt, Alexandria	Rho
Gracilaria corticata [45]	17.14	1300	10860	630	240	−244.06	India, Saurashtra coast	Rho
Gracilaria dura [32]	14.29	210	5560	290	190	−113.00	India, North-West Coast	Rho
Gracilaria edulis [40]	18.04	410	52.12	580	124	−8.08	India	Rho
Gracilaria gracilis [36]	28.8	624	8920	402	415	−176.42	Portugal, West Coast	Rho
Gracilaria salicornia [45]	10.34	1340	9680	510	340	−216.31	India, Saurashtra coast	Rho
Gracilaria corticata [39]	3.3	4337	2819	3568	5500	−3.23	India, Central West Coast	Rho
Halidrys siliquosa [42]	7.9	990	3600	660	71	−99.13	Sweden, West Coast	Pha
Himanthalia elongata [35]	6.4	1030	7110	750	120	−174.62	Spain, Galicia	Pha
Jania rubens [33]	26	1656	105	1638	2076	23.23	Egypt, Alexandria	Rho
Kappaphycus alvarezii [32]	7.94	450	5590	340	270	−118.20	India, North-West Coast	Rho
Kappaphycus alvarezii Doty [43]	19.25	840	4100	740	120	−102.39	India, North-West Coast	Rho
Laminaria digitata [42]	6.6	1240	2900	650	179	−84.06	Sweden, West Coast	Pha
Laminaria ochroleuca [35]	8.1	1060	8430	4100	180	−286.78	Spain, Galicia	Pha
Palisada cruciata (formerly Laurencia cruciate) [45]	16.11	1200	6040	640	290	−140.46	India, Saurashtra coast	Rho
Lobophora variegata [47]	34.2	1020.6	1078.3	1712.6	1477.3	−9.02	India, South-East Coast	Pha
Odonthalia dentata [44]	14.78	407	1070	286	125	−23.33	Russia, White Sea	Rho
Padina gymnospora [40]	12.07	820	30.02	780	164	−19.59	India	Pha
Padina pavonica [33]	11	708	257	1765	1787	11.02	Egypt, Alexandria	Rho
Padina tetrastromatica [45]	22.11	6650	2490	1140	190	−150.52	India, Saurashtra coast	Pha
Palmaria palmata [35]	10.7	430	7620	230	180	−159.69	France, Bretagne	Rho
Palmaria palmata [36]	41.8	1591	3452	222	110	−74.40	Portugal, West Coast	Rho
Palmaria palmata [41]	14.4	160	12480	250	120	−259.16	Portugal	Rho
Palmaria palmata [44]	19.94	161	1999	92	212	−28.85	Russia, White Sea	Rho
Petalonia fascia [33]	10	1307	4165	1533	5104	49.43	Egypt, Alexandria	Pha
Phycodrys rubens [44]	13.21	666	142	855	268	−17.48	Russia, White Sea	Rho
Polyides rotunda [44]	9.23	369	486	315	99	−15.01	Russia, White Sea	Rho
Polysiphonia stricta [44]	18.58	449	1033	350	122	−23.01	Russia, White Sea	Rho
Pyropia columbina (formerly Porphyra columbina) [34]	24.61	443.7	1444.17	491.52	379.9	−22.76	Argentina, San Jorge Gulf	Rho
Porphyra dioica [36]	35.7	225	2863	617	393	−47.06	Portugal, West Coast	Rho
Pyropia haitanensis (formerly Porphyra haitanensis) [37]	32.16	460.6	2734	612	885.4	−30.80	Japan/Korea	Rho
Porphyra sp. [41]	23.7	160	1920	370	210	−32.64	Portugal	Pha
Porphyra sp. [32]	36.19	420	4400	650	330	−84.82	South Korea, Wando Island	Rho
Porphyra sp. [35]	53.9	640	3190	440	320	−48.50	Spain, Galicia	Rho
Pyropia tenera (formerly Prophyra tenera) [37]	36.88	151.4	2802	420.3	820.1	−23.32	Japan/Korea	Rho
Ptilota gunneri [44]	8.92	663	872	334	242	−22.29	Russia, White Sea	Rho
Rhodomela confervoides [44]	24.26	544	1432	503	245	−29.27	Russia, White Sea	Rho
Rhodomela confervoides [42]	14.8	2480	5800	560	158	−155.50	Sweden, West Coast	Rho
Saccharina latissima [42]	6.9	950	1500	460	144	−47.10	Sweden, West Coast	Pha
Sarconema filiforme [45]	10.57	1580	9080	480	480	−200.76	India, Saurashtra coast	Rho
Sargassum ilicifolium [39]	3.86	4320	4640	3348	3500	−109.26	India, Central West Coast	Pha
Sargassum swartzii [45]	11.21	1860	7710	700	430	−182.89	India, Saurashtra coast	Pha

Table 1: Continued.

Name	Protein (g/100 g)	Ca (mg/100 g)	K (mg/100 g)	Mg (mg/100 g)	P (mg/100 g)	PRAL (mEq/100 g)	Origin	Type*
Sargassum tenerrimum [45]	10.75	2510	8360	820	380	−210.18	India, Saurashtra coast	Pha
Sargassum vulgare [33]	16	708	198	898	5260	174.57	Egypt, Alexandria	Pha
Savoiea arctica [44]	24.95	419	856	257	112	−13.74	Russia, White Sea	Rho
Spatoglossum asperum [45]	9.89	2740	2940	1200	140	−118.53	India, Saurashtra coast	Pha
Sphacelaria cirrosa [42]	12	2560	3300	860	212	−111.22	Sweden, West Coast	Pha
Ulva lactuca (as Ulva fasciata) [40]	22.7	740	27.2	420	142	−4.73	India	Chl
Ulva lactuca (as Ulva fasciata) [39]	3.45	3940	3125	3478	3125	−89.96	India, Central West Coast	Chl
Ulva lactuca (as Ulva fasciata) [33]	27	1091	2320	1781	4183	58.79	Egypt, Alexandria	Chl
Ulva lactuca (as Ulva fasciata) [45]	14.3	3300	4340	2180	130	−178.90	India, Saurashtra coast	Chl
Ulva intestinalis [42]	9	840	1700	2620	100	−106.63	Sweden, West Coast	Chl
Ulva lactuca [32]	14.48	2040	2590	2680	150	−137.94	India, North-West Coast	Chl
Ulva lactuca [33]	16	1253	2444	1874	3637	26.07	Egypt, Alexandria	Chl
Ulva lactuca [42]	9.3	1040	3000	2660	97	−137.53	Sweden, West Coast	Chl
Ulva linza [33]	13	1901	422	1855	200	−68.04	Egypt, Alexandria	Chl
Ulva reticulata [45]	16.72	4700	3690	2330	220	−182.84	India, Saurashtra coast	Chl
Ulva rigida [45]	18.57	2640	4710	1770	160	−164.23	India, Saurashtra coast	Chl
Ulva rigida [36]	19.5	354	1364	1860	127	−23.83	Portugal, West Coast	Chl
Ulva sp. [41]	15.6	550	2180	5580	180	−183.71	Portugal	Chl
Ulva sp. [35]	7	910	1950	3300	110	−131.08	Spain, Galicia	Chl
Undaria pinnatifida [35]	18.6	1120	370	760	540	−13.00	Spain, Galicia	Pha

Table 1 is based on data from References [32–47]. Ca = Calcium. Mg = Magnesium. K = Potassium. P = Phosphorus. *Chl. = Chlorophyta; Rho. = Rhodophyta; Pha. = Phaeophyceae. The nutrient content is based on 100 g dry weight, except for the following five items: *Acanthophora spicifera, Ulva flexuosa* (formerly *Enteromorpha flexuosa*), *Gracilaria edulis, Padina gymnospora,* and *Ulva fasciata,* which were obtained from Reference [40].

3.2. Analyses by Phylum. We additionally compared the PRAL-relevant nutrient content of the examined algae items by phylum (Chlorophyta vs. Rhodophyta vs. Phaeophyceae). For this analysis, only algae with nutrient content data based on dry weight were considered ($n = 101$). Significant differences between the three examined phyla were detected for protein, calcium, and magnesium. The highest median calcium and magnesium content were observed for the Chlorophyta phylum (Table 2). The PRAL values for the different phyla were as follows: −100.82 (−159.74 - (−67.35)), −74.68 (−150.91–(−20.59)), and −105.90 ± 94.66 mEq/100 g. The PRAL differences were not statistically different ($p = 0.367$).

3.3. Correlation Analyses. We ran multiple Spearman's correlations to assess the relationship between PRAL and the micronutrient content of the examined algae items. To visualize the interrelationship, we used portion sizes of 10 g of edible algae. As expected, a moderate and significant positive correlation was found for PRAL and protein (Figure 1), with a Spearman's rho of 0.35 ($p < 0.001$). In a similar style, Figure 2 shows the relationship between PRAL and the potassium content of the examined algae. Hereby, a strong and significant inverse relationship (Spearman's rho = −0.79, $p < 0.001$) was observed.

Figures 3 and 4 display the calcium and phosphorus content of the examined macroalgae and their relationship with PRAL. Calcium content was inversely associated with PRAL (Spearmen's rho: −0.34, $p < 0.001$), whereas phosphorus was positively associated with PRAL (Spearmen's rho: 0.31, $p = 0.001$). No significant relationship was observed between PRAL and magnesium content (not shown).

Figures 5–8 display phylum-separated scatterplots visualizing the PRAL value and the content of potassium, calcium, magnesium, and protein of each group. Apart from magnesium, no clear clustering was observed for the examined nutrients and PRAL values, indicating that not the phylum but the family and genus are important when it comes to the identification of alkalizing macroalgae.

4. Discussion

The present analysis explored the PRAL of $n = 106$ macroalgae. Results largely confirmed our hypothesis that algae have a strong alkalizing potential, with a mean PRAL value of −86.76 ± 87.47 mEq/100 g in the entire sample. We also found a strong inverse relationship of PRAL with algae's potassium content (Spearman's rho = −0.79, $p < 0.001$) and a moderate relationship with algae's calcium content (Spearmen's rho: −0.34, $p < 0.001$). Both are important base precursors and can be readily found in algae. The median potassium content of the examined algae (2900 (3521.7) mg/100 g) is particularly noteworthy and substantially contributed to their low PRAL values in the examined sample. A reservation must be made, though, that our results could not confirm our second hypothesis: we found no significant PRAL differences between the examined algae phyla/classes. In fact, the obtained separated scatterplots suggested that the family and genus are potentially more important when it comes to the PRAL value of algae.

Macroalgae and seaweed nowadays enjoy growing popularity in Western societies [1]. Their potential benefits in terms of dietary acid load and their alkalizing properties, however, have been rarely discussed. We raised the hypothesis that algae could be used as alkalizing agents due to their high content of base precursors. The very low (and to our best knowledge unmatched) PRAL value of many algae supports this idea. A typical contemporary Western diet produces between 60 and 100 mEq of acid per day [48, 49]. The human kidneys, in contrast, can only excrete 40–70 mEq of acid within 24 h [50]. Once that limit is reached, acid is retained in the human body, with potentially harmful effects for human health [51–56]. As summarized in a previous review, dietary acid load has been linked to several cardiovascular disease risk factors, unfavorable metabolic alterations, diabetes, and chronic kidney disease [20]. Algae could play an important role here, as our results suggest that the daily intake of only 10 g of algae may decrease the total PRAL score by up to −28.68 mEq, depending on the consumed algae type. This might be of particular importance in patients with kidney disease, who benefit from the key features of an alkaline diet [57, 58]. A reservation must be made, however, that the alkalizing effect of algae is likely variable and depended on various other factors, including harvesting and processing.

Macroalgae are also considered good sources of other important and frequently under-consumed nutrients in the human diet, including fiber, omega-3 and omega-6 fatty acids, selenium, iodine, and vitamin B_{12} [1, 6–9]. Including them in menus on a more frequent basis could thus serve many concomitant purposes beyond a simple PRAL reduction. Algae supplements of particularly alkalizing species (*Laminaria ochroleuca*, *Gelidium micropterum*, and *Palmaria palmata*) are also a possible idea but have not yet been tested to the best of our knowledge.

While seaweeds have been suggested as important functional ingredients for a healthy diet [2], their high biosorption and accumulation capacities must also be kept in mind [1]. Some macroalgae have been reported to include high amounts of potentially harmful elements, including (but not limited to) lead, cadmium, mercury, and inorganic arsenic [59–61]. While a detailed discussion of this topic is beyond the scope of this PRAL analysis, one must keep in mind that an excessive algae consumption could be harmful, as well. Finally, algae also stand out for their high iodine content [62, 63]. While not contributing to the PRAL of algae, a regular and excessive intake of iodine could be problematic in certain individuals and patient groups, potentially inducing autoimmune thyroiditis and other adverse medical conditions [64]. Whether suitable under such circumstances remains an individual decision and warrants thorough context-specific considerations.

While our analysis fills a gap in the field of PRAL and dietetics, it has several limitations that must be considered.

Table 2: Macro- and micronutrient content of $n = 101$ macroalgae based on 100 g dry weight.

Nutrient	Chlorophyta ($n = 26$)	Rhodophyta ($n = 50$)	Phaeophyceae ($n = 25$)	p value
Protein (g/100 g)	16.31 ± 6.75	16.05 (11.95)	10 (5.85)	0.001
Ca (mg/100 g)	1612 (2980)	647 (1160)	1160.27 (839.4)	<0.001
K (mg/100 g)	2517 (2310)	3095 (4767)	3600 (4610)	0.170
Mg (mg/100 g)	1790 (1074)	557.5 (450)	813 (198)	<0.001
P (mg/100 g)	210 (1498)	238.5 (239)	190 (307)	0.581

Ca = Calcium. Mg = Magnesium. K = Potassium. P = Phosphorus.

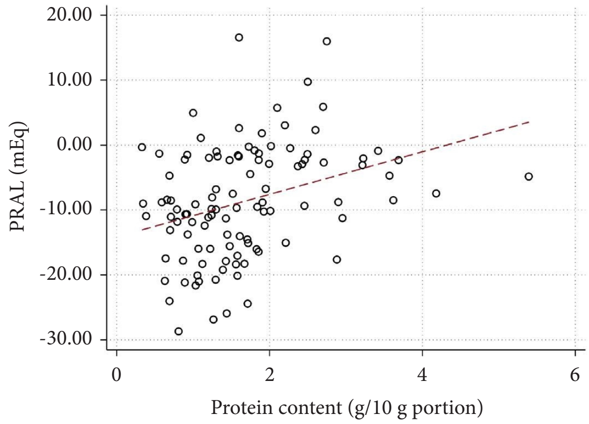

Figure 1: Scatterplot visualizing the relationship between PRAL (in mEq) and the protein content (in g in a 10 g edible macroalgae portion). $n = 101$ algae were considered for this analysis.

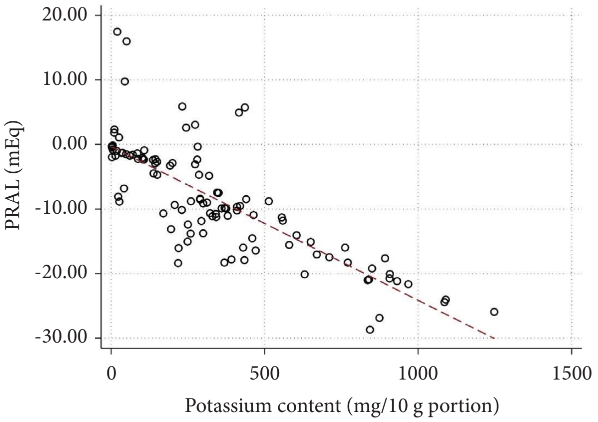

Figure 2: Scatterplot visualizing the relationship between PRAL (in mEq) and the potassium content (in mg) in a 10 g edible macroalgae portion. $n = 101$ algae were considered for this analysis.

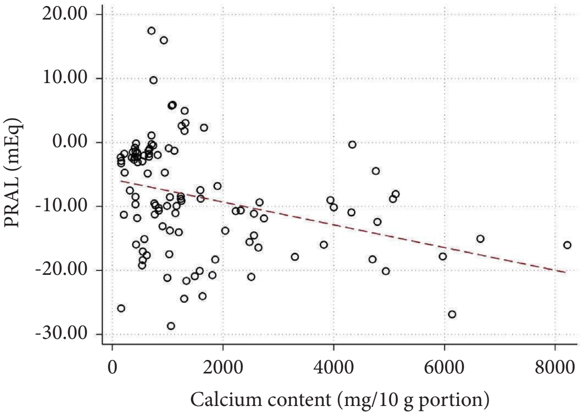

Figure 3: Scatterplot visualizing the relationship between PRAL (in mEq) and the calcium content (in mg) in a 10 g edible macroalgae portion. $n = 101$ algae were considered for this analysis.

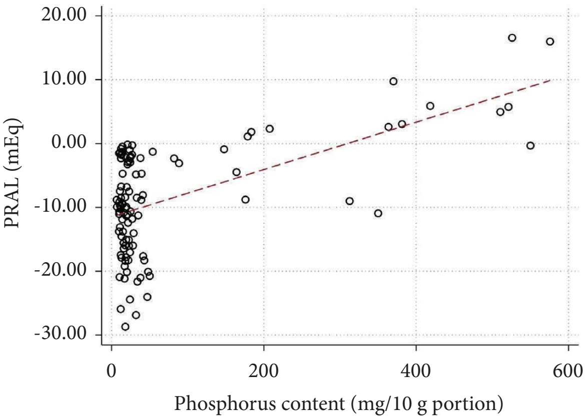

Figure 4: Scatterplot visualizing the relationship between PRAL (in mEq) and the phosphorus content (in mg) in a 10 g edible macroalgae portion. $n = 101$ algae were considered for this analysis.

The cross-sectional analysis does only allow for preliminary statements, and randomized-controlled trials will be necessary to test the alkalizing potential of algae in a clinical setting. We also observed a large heterogeneity in the PRAL value of the examined macroalgae. While origin was registered, other factors were not considered in the present analysis. These include harvesting techniques, harvesting season, and processing methods to name a few. As for the origin, we mainly investigated mainly algae found in India ($n = 35$), Sweden ($n = 22$), and Russia ($n = 14$). Additional items came from Argentina ($n = 1$), Egypt ($n = 13$), France ($n = 1$), Japan and Korea ($n = 3$), Portugal ($n = 9$), and Spain ($n = 8$). It is known that macroalgae have a varying nutritional profile, depending on their origin and the surrounding environmental conditions in which they grow [28, 29]. The diverse origin of the examined algae items must thus be kept in mind when discussing our results.

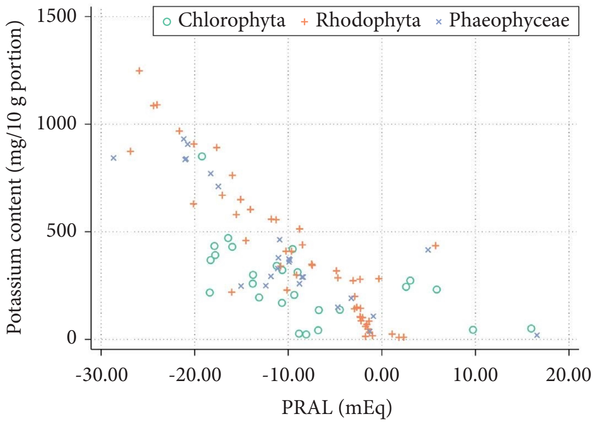

Figure 5: Scatterplot visualizing the PRAL value (in mEq) and the potassium content (in mg) in a 10 g edible macroalgae portion by phylum/class. $n = 101$ algae were considered for this analysis.

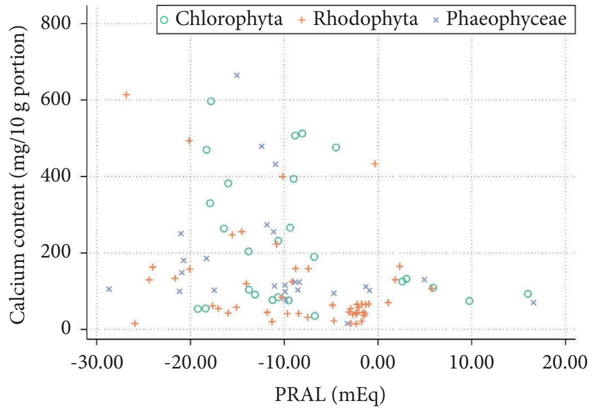

Figure 6: Scatterplot visualizing the PRAL value (in mEq) and the calcium content (in mg) in a 10 g edible macroalgae portion by phylum/class. $n = 101$ algae were considered for this analysis.

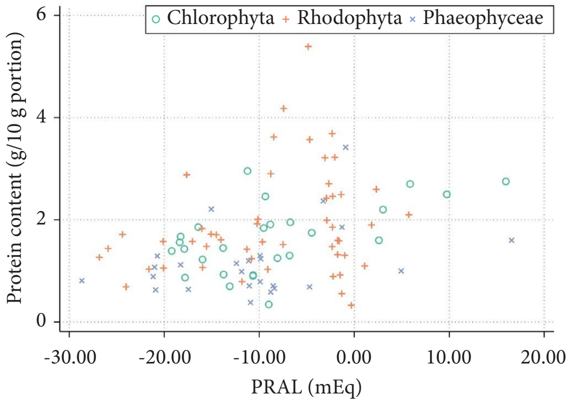

Figure 7: Scatterplot visualizing the PRAL value (in mEq) and the protein content (in g in a 10 g edible macroalgae portion by phylum/class. $n = 101$ algae were considered for this analysis).

Further to that, it must be emphasized that the laboratory methods to determine the nutrient content of the examined algae items varied from study to study. Supplementary Table 1 gives a brief overview about the employed analytical methods (Supplementary Table 1). The varying analytical techniques must also be kept in mind when glancing at our results and could pose a potential confounder.

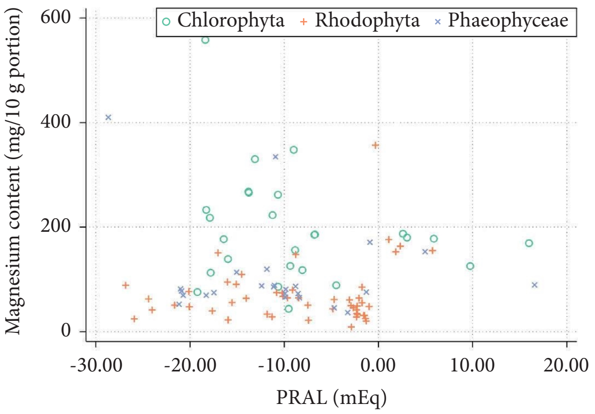

Figure 8: Scatterplot visualizing the PRAL value (in mEq) and the magnesium content (in mg) in a 10 g edible macroalgae portion by phylum/class. $n = 101$ algae were considered for this analysis.

Future studies will be necessary to explore these factors in greater detail. Despite these limitations, this analysis also builds upon a number of strengths, including its innovative character, the rigorous search strategy, and the modest sample size. Nevertheless, additional studies will be necessary to understand the role of macroalgae in PRAL management.

5. Conclusion

Many macroalgae apparently exert a strong alkalizing potential. This suggests a potential role for algae as alkalizing marine drugs for individuals who benefit from a more alkaline diet.

Data Availability

The datasets used and analyzed to support the findings of this study are available from the corresponding author upon reasonable request.

Additional Points

Institutional Review Board Statement. This study is a secondary data analysis that does not involve human participants or animals.

Disclosure

This study is a secondary data analysis that does not involve human participants or animals.

Conflicts of Interest

The author declares that they have no conflicts of interest.

Authors' Contributions

Maximilian Andreas Storz is the sole author of this article.

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Supplementary Materials

Supplementary Table 1 gives a brief overview about the employed analytical methods that were used in the original studies to determine algae's nutrient content (Supplementary Table 1). (*Supplementary Materials*)

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