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Chemical Composition of Common Seaweeds from the Kenya Coast

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Abstract

The gross nutritional profile of 34 seaweed species from three sites (Mkomani, Kibuyuni and Mtwapa) in coastal Kenya were studied. The crude fat, crude protein, crude fibre and crude ash were determined by the standard AOAC methods while the nitrogen-free extract (NFE) was calculated by weight difference of the chemical components. The chemical constituents of the seaweeds varied significantly among the algal divisions, species, months and sites (p<0.05). The major chemical components was the NFE with a mean value of 42.09 ± 0.83% dry weight (DW) followed by crude ash (31.94 ± 0.78% DW), crude fibre (14.08 ± 0.26% DW), crude protein (10.09 ± 0.26% DW), whereas the least component was crude fat with a mean value of 1.81 ± 0.04% DW (p<0.05). The crude protein levels were positively correlated with nitrogen content and in crude fibre and negatively with NFE, crude fat and crude ash (p<0.05). The findings on the gross nutritional profile of the seaweeds in this study could be used as a basis for more advanced research on nutritional information guideline and as potential resources for seaweed-based products for improved human and animal nutrition.

Keywords: gross nutritional profile, nutrition, seaweeds, variation

1. Introduction

Seaweed also referred to as marine macroalgae are classified based on anatomy, pigmentation, morphology, chemical composition among other characteristics as green algae (Chlorophyta), brown algae (Phaeophyta) and red algae (Rhodophyta) (Dawczynski et al., 2007) . Seaweeds are valuable sources of macronutrients such as protein, fibre, carbohydrates and lipids, and micronutrients such as minerals and vitamins, as well as important bioactive compounds (Ortiz et al., 2006; Yaich et al., 2013). Thus, they have been recognized as being beneficial for human and animal health (Fleurence, 1999). Seaweed is commonly consumed in Asian countries as human food, mainly Japan, China, Korea, Vietnam, Indonesia and Taiwan (Dawes, 1998). Approximately 25% of all food consumed in Japan consists of seaweed prepared and served as sushi wrappings, seasonings, condiments and vegetables and thus has become a main income source for the fishermen (Anantharaman et al., 2010; Ortiz et al., 2006). Seaweeds are also known as sources of thickening and gelling agents (phycocolloids) for various applications in food and pharmaceutical industries. Furthermore, they are also used for improving nutrients in animal feed, cosmetics, medicine and fertilizers (Balboa et al., 2013; Fleurence, 1999; Lordan et al., 2013; Marinho-Soriano et al., 2006).

Nutrient content variation of seaweeds are related to several environmental parameters such as water temperature, salinity, light and nutrients (Dawes, 1998). These environmental parameters vary according to season and the changes in ecological conditions can stimulate or inhibit the biosynthesis of several nutrients (Lobban et al., 1985). About 400 Kenyan seaweeds species have been documented (Bolton et al., 2007). However, no published report on the chemical composition of the seaweeds in Kenya has been made. It is imperative to investigate on nutrient composition of seaweeds in Kenya in the search for highly nutritious food sources for use in human and animal nutrition. The aim of this study was to determine the chemical composition of seaweeds from three coastal locations in Kenya in March, July and October, 2013, in order to obtain information about their nutritional value. This is part of a larger project entitled "Nutritional evaluation of selected seaweeds potential for sustainable nile tilapia (*Oreochromis niloticus* L.) production in Kenya."

2. Materials and Methods

2.1 Sampling Sites

The seaweed species were collected from three different habitats: Mkomani (4º3'25.26"S, 39º41'3.50"E), Kibuyuni (4º38'53.11"S, 39º19'40.21"E) and Mtwapa (3º56'40.51"S, 39º46"22.19"E) at the Kenya coast (Figure 1) with a wide diversity of algal species. The Kenyan coast experiences two distinct monsoon seasons, the northeast monsoon (NEM) locally referred to as '*kaskazi'* and the southeast monsoon (SEM) locally referred to as '*kusi'*. The SEM runs from May to October and NEM from December to March (Church & Obura, 2004).

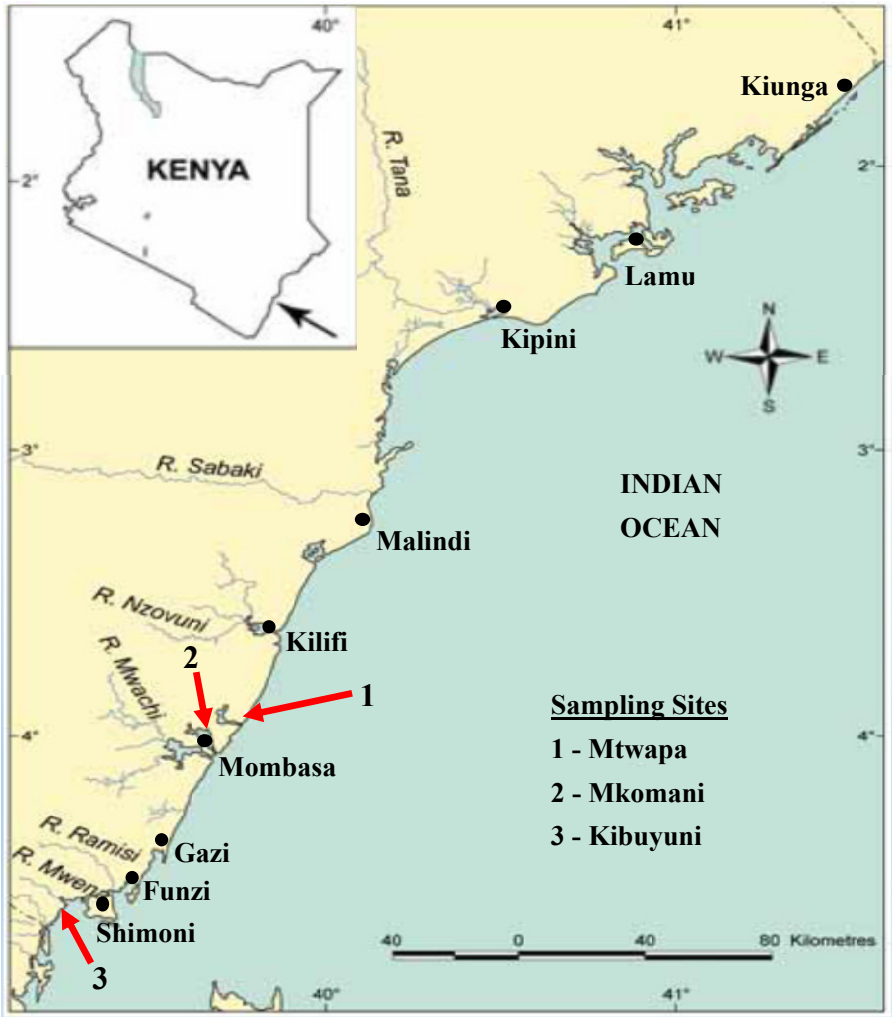

Figure 1. Map of Kenya showing the sampling sites (numbered)

2.2 Sample Collection and Preparation

The seaweeds species were collected in Mkomani and Kibuyuni during the months of March, July and October of 2013 and in Mtwapa in July and October of 2013 as listed in Table 1. Sampling was not done in March at Mtwapa due to logistical issues. Collection of seaweeds was done during the low tide at the intertidal zones and samples were picked by hand and immediately washed with seawater to remove foreign particles, sand and epiphytes. The seaweed samples were kept in clean buckets and immediately transported to the laboratory at Kenya Marine and Fisheries Research Institute (KMFRI) in Mombasa for identification. The samples were washed thoroughly using tap water to remove the salt on the surface of the seaweeds. Seaweeds were spread on blotting paper to remove excess water before they were sundried to constant weight, and ground into powder. The powdered samples were then refrigerated prior to chemical analysis.Voucher specimens of seaweed species collected are deposited in KMFRI.

2.3 Chemical Analysis

The following analyses were carried out in triplicates to determine chemical composition of the seaweeds.

2.3.1 Moisture

The moisture content of seaweeds was determined according to the oven drying method described by AOAC (2000). Two (2) gram of algal samples were put in a crucible and dried in a hot air oven at 105°C to constant weights.

2.3.2Crude Ash

The ash content of seaweeds was determined according to the incineration method described by AOAC (2000). Five (5) gram of algal samples were burnt and ashed in a muffle furnace at 550°C overnight until constant weight was obtained.

2.3.3 Crude Fat

The crude fat was determined according to the Soxhlet method described by AOAC (2000). The crude fat was extracted from five (5) gram of algal samples using the Soxhlet apparatus with petroleum ether as the solvent. The crude fat content was determined gravimetrically after oven-drying (80ºC) the extract overnight.

2.3.4 Nitrogen Content and Crude Protein

The crude protein content of seaweeds was determined according to the Kjedahl method. Approximately two (2) g of algal sample was weighed into a digestion flask together with a combined catalyst of 5 g potassium sulphate (K_2SO_4) and 0.5 g of copper (II) suphate ($CuSO_4$), and 15ml of concentrated sulphuric acid (H_2SO_4) and then shaken gently. Digestion was performed until clear blue/green solution was obtained. Digested samples were cooled for 10-20 minutes. Distillation was then performed before titration using 0.02 N hydrochloric acid (HCl) solution to determine the nitrogen content of the samples in percentage. A conversion factor of 6.25 was used to calculate the crude protein content from the nitrogen content (AOAC, 2000).

2.3.5 Crude Fibre

The crude fibre was determined by sequential digestion of seaweed samples with 1.25% H_2SO_4 and 1.25% NaOH using the fibre glass as a container. For drying and ashing, the crucible with sample was dried in an oven for 5 hours at 105°C and ashed in the muffle furnace at 550°C overnight. The weight of crucible with sample after drying and ashing was recorded and the crude fibre content was calculated according to AOAC (2000).

2.3.6 Nitrogen-free extract (NFE)

The NFE were calculated based on weight difference using crude protein, crude fat, crude fibre, and crude ash data as follows, according to James (1996):

NFE% = 100 - (crude fibre + crude protein + crude ash + crude fat)

2.4 Statistical Analysis

All results are expressed on % dry weight (DW) basis as means ± standard error (SE). The analysis of variance (ANOVA) was used to compare differences in the means of the crude ash, crude protein, NFE, crude fibre and crude fat among species, algal divisions, sites and months. This was followed by Duncan's multiple range test (DMRT) to determine the differences between species, algal divisions, sites and months. A Pearson correlation coefficient (r) was computed for the chemical components. A significant difference was considered at the level of $p<0.05$. The data collected in this study were analyzed using the Statistical Package for the Social Sciences (SPSS) version 20.0.

3. Results and Discussion

3.1 Chemical Composition

3.1.1 Variation among Seaweed Species

Table 1 shows the nutritive contents of the seaweeds on dry weight basis. The major chemical component was the nitrogen-free extract (NFE) (42.09 ± 0.83%) followed by crude ash (31.94 ± 0.78%), crude fibre (14.08 ± 0.26%), crude protein content (10.09 ± 0.26%) and the lowest component was crude fat (1.81 ± 0.04%; $p<0.05$). The crude fat contents of *Dictyota* sp. 1 (4.04 ± 0.00%) and sp. 2 (4.21 ± 0.00%) were the highest whereas that of *Gracilaria arcuata* was the lowest (1.07 ± 0.16%; $p<0.05$). *Laurencia intermedia* had the highest crude fibre (21.73 ± 3.47%) whereas *Halimeda macroloba* had the lowest crude fibre (9.88 ± 1.45%; $p<0.05$). Nitrogen contents of *Hypnea* sp. (3.42 ± 0.01%) and *Hypnea musciformis* (3.17 ± 0.23%) were the highest while *Dictyota* sp. 2 had the lowest (0.27 ± 0.00%) ($p<0.05$). *Hypnea* sp. and *Hypnea musciformis* had the highest crude protein

content of 21.39 ± 0.06% and 19.79 ± 1.44%, respectively while *Dictyota* sp. 2 had the lowest crude protein content of (1.71 ± 0.02%; $p<0.05$). The crude ash contents of *Codium dwarkense* (69.94 ± 0.11%) and *Halimeda macroloba* (66.08 ± 1.05%) were the highest while that of *Gracilaria arcuata* was the lowest (16.51±0.85%; $p<0.05$). *Dictyota* sp. 2 had the highest NFE (61.42±0.04%) ($p<0.05$) while the *Codium dwarkense* had the lowest NFE (4.61 ± 0.50%; $p<0.05$).

Table 1. Chemical composition (% dry weight) of collected Kenyan seaweeds; values given as means ± SE (n = 3)

Species	Crude fat	Crude fibre	Crude protein	Crude ash	Nitrogen-free extract
Chlorophyta					
Caulerpa racemosa	1.91 ± 0.06^{efghi}	12.38 ± 0.10^{cdefgh}	5.17 ± 0.06^{m}	53.50 ± 0.12^{b}	27.04 ± 0.05^{hi}
Caulerpa scapelliformis	2.49 ± 0.03^{cdef}	12.61 ± 0.14^{cdefgh}	18.05 ± 0.08^{abc}	19.41 ± 0.26^{jkl}	47.54 ± 0.09^{abcdef}
Chaetomopha crassa	2.20 ± 0.08^{defg}	10.77 ± 0.08^{efgh}	10.92 ± 0.62^{fghi}	20.18 ± 0.11^{ijkl}	55.93 ± 0.52^{ab}
Codium dwarkense	1.54 ± 0.04^{ghij}	16.59 ± 0.54^{abcde}	7.32 ± 0.05^{ijklm}	69.94 ± 0.11^{a}	4.61 ± 0.50^{j}
Codium geopiorum	1.91 ± 0.06^{cdef}	16.34 ± 0.31^{bcdef}	14.86 ± 0.13^{cde}	37.96 ± 0.05^{cde}	28.92 ± 0.34^{ghi}
Enteromopha kylinii	1.42 ± 0.18^{hij}	14.20 ± 0.61^{cdefgh}	8.40 ± 0.95^{ijklm}	42.73 ± 2.40^{c}	33.24 ± 2.12^{efgh}
Enteromopha muscoides	1.83 ± 0.24^{fghi}	17.75 ± 2.80^{abc}	10.67 ± 0.72^{fghijk}	30.02 ± 1.48^{defghij}	39.73 ± 4.77^{bcdefgh}
Halimeda macroloba	1.95 ± 0.11^{efghi}	9.88 ± 1.45^{h}	5.28 ± 0.50^{m}	66.07 ± 0.60^{a}	16.82 ± 2.04^{ij}
Ulva fasciata	1.63 ± 0.18^{ghij}	10.74 ± 1.36^{fgh}	10.23 ± 0.62^{ghijk}	29.28 ± 5.07^{efghijk}	48.12 ± 6.48^{abcdef}
Ulva lactuca	1.65 ± 0.17^{ghij}	13.57 ± 0.14^{cdefgh}	14.99 ± 0.54^{cde}	23.67 ± 0.36^{hijkl}	46.11 ± 0.51^{abcdef}
Ulva pulchra	1.31 ± 0.04^{ij}	13.60 ± 0.40^{cdefgh}	10.67 ± 0.51^{fghijk}	22.04 ± 1.38^{hijkl}	52.38 ± 2.32^{abc}
Ulva reticulata	1.34 ± 0.09^{ij}	11.86 ± 0.92^{defgh}	12.80 ± 0.84^{efgh}	18.60 ± 2.38^{jkl}	55.40 ± 2.42^{ab}
Phaeophyta					
Cystoseira myrica	1.58 ± 0.11^{ghij}	17.15 ± 1.33^{abcd}	8.16 ± 0.55^{ijklm}	41.38 ± 2.99^{cd}	31.75 ± 3.60^{fgh}
Cystoseira trinodis	2.08 ± 0.29^{efgh}	15.38 ± 0.95^{bcdefgh}	6.94 ± 1.14^{jklm}	33.64 ± 3.04^{cdefgh}	41.97 ± 4.57^{bcdefgh}
Dictyota bartaynesiana	3.10 ± 0.03^{bc}	12.95 ± 0.30^{cdefgh}	14.21 ± 0.06^{cde}	30.09 ± 0.02^{defghij}	39.65 ± 0.26^{bcdefgh}
Dictyota cervicormis	3.65 ± 0.09^{ab}	13.36 ± 0.96^{defg}	10.83 ± 0.06^{fghij}	36.54 ± 0.43^{cdef}	35.62 ± 0.36^{defgh}
Dictyota sp. 1	4.04 ± 0.00^{a}	14.11 ± 0.01^{cdefgh}	6.74 ± 0.00^{klm}	22.70 ± 0.11^{hijkl}	52.42 ± 0.11^{abc}
Dictyota sp. 2	4.21 ± 0.00^{a}	13.18 ± 0.02^{cdefgh}	1.71 ± 0.02^{n}	19.49 ± 0.00^{jkl}	61.42 ± 0.04^{a}
Harmophysa cuneiformis	1.82 ± 0.15^{fghi}	14.92 ± 1.51^{bcdefgh}	6.94 ± 0.61^{jklm}	33.19 ± 0.47^{cdefgh}	43.13 ± 1.52^{bcdefgh}
Hydroclathrus clathrus	1.62 ± 0.07^{ghij}	13.17 ± 0.29^{cdefg}	7.73 ± 0.54^{ijklm}	33.58 ± 8.01^{cdefgh}	43.90 ± 7.57^{bcdefg}
Padina tetrastromatica	1.91 ± 0.13^{efghi}	12.17 ± 0.39^{cdefgh}	7.62 ± 0.38^{ijklm}	41.24 ± 3.46^{cd}	37.07 ± 3.55^{cdefgh}
Sargassum cristaefolium	2.76 ± 0.11^{cd}	16.74 ± 0.12^{abcd}	9.41 ± 0.47^{hijkl}	24.64 ± 0.41^{ghijkl}	46.46 ± 0.10^{abcdef}
Sargassum oligocystum	2.56 ± 0.17^{cde}	15.12 ± 0.53^{bcdefgh}	7.56 ± 0.57^{ijklm}	26.38 ± 1.70^{efghijkl}	48.37 ± 1.79^{abcde}
Sargassum sp.	2.19 ± 0.19^{defg}	13.34 ± 1.04^{cdefgh}	5.63 ± 0.55^{lm}	25.64 ± 0.39^{fghijkl}	53.20 ± 1.40^{abc}
Spatoglossum asperum	1.76 ± 0.12^{ghij}	16.35 ± 0.27^{bcdef}	17.17 ± 0.64^{bcd}	18.01 ± 1.56^{kl}	46.70 ± 1.03^{abcdef}
Rhodophyta					
Acanthophora spicifera	1.39 ± 0.06^{hij}	13.15 ± 0.35^{cdefgh}	13.73 ± 0.96^{defg}	36.01 ± 2.05^{cdefg}	35.71 ± 2.59^{cdefgh}
Chondrophycus papillosus	1.52 ± 0.12^{ghij}	16.04 ± 0.68^{bcdefg}	9.61 ± 0.95^{hijk}	31.52 ± 1.23^{cdefghi}	41.30 ± 2.77^{bcdefgh}
Eucheuma denticulatum	1.82 ± 0.25^{fghi}	10.34 ± 1.98^{gh}	5.07 ± 0.46^{m}	36.21 ± 3.59^{cdefg}	46.56 ± 5.70^{abcdef}
Gracilaria arcuata	1.07 ± 0.16^{j}	19.89 ± 0.07^{ab}	13.79 ± 0.31^{defg}	16.51 ± 0.85^{l}	48.75 ± 0.45^{ij}
Gracilaria salicornia	1.47 ± 0.04^{hij}	12.52 ± 0.61^{cdefgh}	9.55 ± 0.71^{hijk}	29.10 ± 1.90^{efghijk}	47.37 ± 1.97^{bcdefgh}
Hypnea musciformis	1.38 ± 0.11^{hij}	14.30 ± 2.22^{cdefgh}	19.79 ± 1.44^{ab}	20.77 ± 1.36^{ijkl}	43.76 ± 5.00^{bcdefg}
Hypnea sp.	1.44 ± 0.05^{hij}	15.24 ± 0.13^{bcdefgh}	21.39 ± 0.06^{a}	26.85 ± 0.10^{efghijkl}	35.07 ± 0.07^{efgh}
Laurencia intermedia	1.51 ± 0.15^{ghij}	21.73 ± 3.47^{a}	12.40 ± 1.16^{efgh}	30.32 ± 1.65^{defghij}	34.04 ± 6.13^{efgh}
Soliera robusta	1.57 ± 0.25^{ghij}	11.57 ± 0.04^{defgh}	10.84 ± 0.85^{fghij}	24.51 ± 1.56^{hijkl}	51.86 ± 2.67^{abcd}

Values followed by different letters in superscript within columns are significantly different at $p<0.05$ Duncan's multiple range test (DMRT).

The phaeophytes had the highest crude fat of 2.32 ± 0.09% while rhodophytes and chlorophytes had the lowest crude fat of 1.50 ± 0.04% and 1.65 ± 0.06%, respectively (p<0.05) (Table 2). There was no significant differences in crude fibre and NFE among the algal divisions (p>0.05). The rhodophytes and chlorophytes had the highest nitrogen contents of 1.85 ± 0.79% and 1.68 ± 0.67% respectively while phaeophytes had the lowest nitrogen contents of 1.31 ± 0.55% (p<0.05). The crude protein contents of rhodophytes (11.56 ± 0.50%) and chlorophytes (10.52 ± 0.42%) were the highest whereas that of phaeophytes was the lowest (8.20 ± 0.33%; p<0.05). The chlorophytes had the highest crude ash (35.08 ± 1.89%) whereas the lowest values were obtained in rhodophytes (29.29 ± 0.89%) and phaeophytes (31.96 ± 1.22%; p<0.05).

Table 2. Variation of chemical composition (% dry weight) of seaweeds collected by algal divisions; values given as means ± SE (n = 3)

Algal divisions	Crude fat	Crude fibre	Nitrogen content	Crude protein	Crude ash	Nitrogen-free extract
Rhodophyta	1.50 ± 0.04[b]	14.28 ± 0.53[a]	1.85 ± 0.79[a]	11.56 ± 0.50[a]	29.29 ± 0.89[b]	43.37 ± 1.31[a]
Chlorophyta	1.65 ± 0.06[b]	13.30 ± 0.52[a]	1.68 ± 0.67[a]	10.52 ± 0.42[a]	35.08 ± 1.89[a]	39.44 ± 1.80[a]
Phaeophyta	2.26 ± 0.08[a]	14.08 ± 0.26[a]	1.31 ± 0.55[b]	8.20 ± 0.33[b]	31.96 ± 1.22[b]	43.05 ± 1.24[a]

Values followed by different letters in superscript within columns are significantly different at p<0.05 Duncan's multiple range test (DMRT).

The NFE consist of carbohydrates (CHO) except some polysaccharides such as cellulose, hemicellulose and lignin The *Dictyota* sp. 2 had the highest NFE but lowest crude protein content. In this study, crude protein content was negatively correlated to NFE. This suggests that seaweed species with high concentrations of NFE had low concentrations of crude protein content. This trend may be related to the nitrogen deficiency in macroalgae (Lobban & Harrison, 1994). Under long-term short supply of nitrogen, it is observed that an increase in total carbohydrate and a progressive decrease of the concentration of nitrogenous substances (protein, pigments, intracellular inorganic nitrogen, nucleic acids, etc.) over time occur, which is in accordance to literature (Lobban & Harrison, 1994; Lourenço et al., 2004). In this study, *Codium dwarkense* had the least NFE.In this study, there was no significant difference in carbohydrates (NFE) among the algal divisions. Previous studies showed that the maximum carbohydrate content was recorded in the chlorophyte as opposed to phaeophytes and rhodophytes (Anantharaman et al., 2013; Chakraborthy & Santra, 2008). Dhargalkar et al. (1980) from the Maharashtra coast in India noted maximum value of carbohydrate content in rhodophytes than in phaeophytes and chlorophytes. The high content of carbohydrate in phaeophytes might be due to higher phycocolloid content in their cellwalls (Dhargalkar et al*.,* 1980). Variation in NFE among seaweeds is related to species, habitat and monthal changes (Dhargalkar et al*.,* 1980; Marinho-Soriano et al., 2006).

The least chemical component among the seaweeds collected in this study was crude fat. The crude fat of seaweed was less than 5% reported on crude fat of seaweeds in other works (Chan, Cheung & Ang Jr, 1997) hence seaweeds are not considered to be good sources of crude fats. In this study, the crude fat contents of *Dictyota*sp. 1 and sp. 2 were the highest whereas that of *Gracilaria arcuata* was the lowest. However, a previous study showed higher crude fat content in Hawaiian *Dictyota acutiloba* and *Dictyota sandvicenis* (McDermid & Stuercke, 2003) as opposed to the one of *Dictyota* species species in this study. The crude fat content of *Gracilaria arcuata* was lower than that of *Gracilaria fisheri* containing 2.2% dry weight (DW) and *Gracilaria tenuistipitata* of 2.8% DW from Thailand (Benjama & Masniyom, 2012) and Hawaiian *Gracilaria coronopifolia* (2.1% DW),*Gracilaria salicornia*(2.4% DW) and *Gracilaria parvispora* (2.8% DW) (McDermid and Stuercke, 2003) but was higher than that of *Gracilaria cervicornis* (0.43% DW) and *Sargassum vulgare* (0.45% DW) of Brazil (Marinho-Soriano et al., 2006). The crude fat contents of *Hypnea* sp. and *Hypnea musciformis* in this study were higher than those of *Hypnea charoides* and *Hypnea japonica* (<1.00% DW) (Wong and Cheung, 2000), but similar to *Hypnea pannosa* (1.56% DW) and *Hypnea musciformis* (1.27% DW) from Bangladesh (Siddique et al., 2013). Among the algal divisions, the phaeophytes had the highest crude fat while rhodophytes and chlorophytes had the lowest crude fat. The variations in crude fat contents among different species can occur due to differences in growth stages among seaweed species (Norziah & Ching, 2000) and climate and geography of development of the seaweed (Marinho-Soriano et al., 2006).

The crude fibre fraction represents the indigestible portion of seaweeds. In this study, *Laurencia intermedia* had

the highest crude fibre while *Halimeda macroloba* had the lowest crude fibre. *Hypnea musciformis* from this study had crude fibre content lower than that found in *Hypnea pannosa* (40.59% DW) and *Hypnea musciformis* (37.92% DW) from Bangladesh (Siddique et al., 2013). The crude fibre levels showed positive correlations with nitrogen and crude protein content levels but showed a negative correlation with NFE impying the lower amount of crude fibre were probably due to the suitable environmental conditions such as temperature, salinity, water transparency for synthesis of NFE and increased nutrient uptake (Wong & Cheung, 2000). The variations in crude fibre of seaweeds can occur due to differences in growth stages and photosynthetic activity among seaweed species, and season brought about by changing environmental parameters that influence photosynthesis and uptake of nutrients (Wong & Cheung, 2000; Siddique et al., 2013).

The crude protein contents of seaweed species in this study were highest in *Hypnea* sp. and *Hypnea musciformis* and were within the range for red seaweeds of 10-47% DW (Fleurence, 1999). The crude protein content of *Hypnea* sp. and *Hypnea musciformis* are comparable to 20% DW of *Hypnea* species in Brazil but lower than 47%DW from Korean *Ulva*. Variations in the crude protein content of seaweeeds can occur due to differences among species and season (Fleurence, 1999). The crude protein content of *Hypnea* sp. and *Hypnea musciformis* were higher than that of *Sargassum polycystum*(5.4% DW) (Matanjun et al., 2009), Brazilian *Gracilaria domingensis*(6.2% DW)and *Gracilaria birdiae*(7.1% DW) (Gressler et al., 2010), and it was closely related to *Hypnea pannosa* (16.31% DW) from Bangladesh (Siddique et al., 2013). In this study, the *Dictyota* sp. 2 had the lowest crude protein content. In this study, *Gracilaria* species had mean crude protein content within the crude protein content range (7-13% DW) for most *Gracilaria* species (Briggs & Smith, 1993). *Ulva lactuca* had crude protein content higher than that of Iranian *Ulva lactuca* (10.69% DW) (Tabarsa et al., 2012) and Tunisian *Ulva rigida* (7.31% DW) (Frikha et al., 2011), but similar to that of *Ulva pertusa* (15.4% DW) and *Ulva intestinalis* (17.9% DW) from Bangladesh (Benjama & Masniyom, 2011) but lower than that of *Ulva lactuca* (4.2% DW) found in the Philipines (Portugal et al., 1983).In this study, all the seaweed species were lower in crude protein content than those of other seaweed species such as *Porphyra tenera* (47% DW) and *Palmaria palmata* (35% DW) (Fleurence, 1999). The nitrogen levels varied probably due to algal species, season, site and environment (Ito and Hori, 1989). Protein content varied among different genera and also in different species of the same genus (Dhargalkar et al., 1980). There was positive correlation between nitrogen content and crude protein content implying that crude protein content of seaweeds is largely attributed to the surrounding concentration of nutrients (nitrogen) in water (Dave & Parekh, 1975).

The crude ash content obtained in this study is in accordance with within the wide range of 8-40% in seaweeds (Mabeau & Fleurence, 1993). Generally, seaweeds have high crude ash because of their cell wall polysaccharides and proteins contain anionic carboxyl, sulfate, and phosphate groups that are excellent binding sites for metal retention (Davis et al., 2003) which invariably indicates the presence of appreciable amounts of diverse mineral components (Matanjunet al., 2008). In this study, *Codium dwarkense* had the highest crude ash as compared to its closely related *Codium geppiorum* in the same study implying differences among species in the same genera. *Gracilaria arcuata* had the least crude ash which was lower than that of *Gracilaria fisheri* (21.2%DW) and *Gracilaria tenuistipitata* (17.0% DW) from Thailand (Benjama & Masniyom, 2011) and Brazilian *Gracilaria domingensis* (23.8% DW) and *Gracilaria birdiae* (22.5% DW) (Gressler et al., 2010). *Ulva fasciata* had a crude ash content similar to that of *Ulva pertusa* (27.2% DW) and *Ulva intestinalis* (27.6% DW) from Thailand (Benjama & Masniyom, 2012). Differences in ash content within species could be due to differing habitats where they grow which may have varying concentration of inorganic compounds and salts in water environment and differing methods of mineralization in the species influenced by temperatures and pH (Mendis & Kim, 2011; Polat & Ozogul, 2009).

3.1.2 Variation with Month

The chemical composition of seaweed species varied with month as shown in Table 3. The month of March had the highest crude fat of 2.26 ± 0.13% while the months of July and October had the lowest crude fat of 1.73 ± 0.05% and 1.66 ± 0.05%, respectively (p<0.05). The crude fibre contents of the months of October and July were the highest, 15.51 ± 0.35% and 15.06 ± 0.34%, respectively, while that of the month of March was the lowest (9.18 ± 0.53%; p<0.05). The months of July and October had the highest nitrogen content of 1.86 ± 0.06% and 1.70 ± 0.06%, respectively) while the month of March had the lowest (0.93 ± 0.07%; p<0.05). The highest crude protein content was obtained in the months of July (11.62 ± 0.38%) and October (10.64 ± 0.36%) while that of the month of March was the lowest (5.84 ± 0.43%; p<0.05). The month of October had the highest crude ash of 37.51 ± 1.24% while the months of July and March had the lowest crude ash of 28.86 ± 0.96% and 27.09 ± 1.95%, respectively (p<0.05). The month of March had the highest NFE of 55.63 ± 1.83% while the month of October had the lowest NFE of 34.68 ± 1.17% (p<0.05).

Table 3. Variation of chemical composition (% dry weight) of seaweeds collected by month in 2013; values given as means ± SE (n = 3)

Month	Crude fat	Crude fibre	Nitrogen content	Crude protein	Crude ash	Nitrogen-free extract
March	2.26 ± 0.13[a]	9.18 ± 0.53[b]	0.93 ± 0.07[b]	5.84 ± 0.43[b]	27.09 ± 1.95[b]	55.63 ± 1.83[a]
July	1.73 ± 0.05[b]	15.06 ± 0.34[a]	1.86 ± 0.06[a]	11.62 ± 0.38[a]	28.86 ± 0.96[b]	42.72 ± 0.98[b]
October	1.66 ± 0.05[b]	15.51 ± 0.35[a]	1.70 ± 0.06[a]	10.64 ± 0.36[a]	37.51 ± 1.24[a]	34.68 ± 1.17[c]

Values followed by different letters in superscript within columns are significantly different at p<0.05 Duncan's multiple range test (DMRT).

The month of March had highest nitrogen-free extract (NFE) values while the lowest values were obtained in July and October. The month of March is within northeast monsoon (NEM) and is characterized by high sea water surface temperatures, averaging 28.4°C (maximum 29°C) due to long duration of sunlight while July and October fall under the southeast monsoon (SEM) (Camberlin & Philippon, 2002; Mutai & Ward, 2000).Synthesis of carbohydrates (NFE) has been reported to be favoured by intensity of light, temperature and decrease of nitrogen (Bird et al., 1990; Dawes et al., 1974) while for crude protein content these parameters acted inversely (Rosenmberg & Ramus, 1982). It appears that the high NFE in the month of March was probably due to high light intensity, increased temperatures and decrease in nitrogen.In this study, NFE and crude fat were both highest in March implying the environmental conditions that favor photosynthesis favoured crude fat synthesis (Bird et al., 1990). Notably, crude fat was positively correlated to NFE. This is in contrast with findings reported by Sanchez-Machado et al. (2004) and Khairy & El-Shafay (2013) that as the temperature increased, the crude fat content decreased and remained almost stable until the end of the growing season while carbohydrates increased.

The month of March had the lowest crude protein content and the crude protein content levels were negatively correlated to NFE. This study is consistent with previous studies suggesting that plants exhibiting faster growth rates showed a higher ratio of crude protein content to carbohydrate and vice-versa (Bird et al., 1990; Dawes et al., 1974; Marinho-Soriano et al., 2006). Synthesis of carbohydrates seemed to be favoured by both intensity of light and temperature while decreasing the proteins. Higher protein levels were observed during the end of the winter period and spring whereas lower amounts were recorded during the summer months (Galland-Irmouli et al., 1999). In this study, the cooler months, July and October had high crude protein content and fibre whereas the month of March had the lowest crude protein content and fibre.October had the highest crude fibre and protein probably due to favourable environmental conditions (high salinity and low water surface temperatures which in turn suppressed photosynthesis thus low NFE. October had the least crude fat content due to unfavorable environmental conditions. (Camberlin & Philippon, 2002; Mutai & Ward, 2000). Rosemberg and Ramus (1982) related the carbohydrate synthesis to periods of maximum growth, increased photosynthetic activity and a reduction in nitrogen and protein contents

3.1.3 Variation with Site

The chemical composition of the seaweeds collected varied among the three sites (Table 4). The Kibuyuni site had the highest crude fat content of 2.01 ± 0.08% while Mtwapa had the lowest crude fat of 1.58 ± 0.05% (p<0.05). Mtwapa had the highest crude fibre of 15.45 ± 0.34% while Mkomani and Kibuyuni had the least crude fibre of 13.58 ± 0.50% and 13.77 ± 0.40%, respectively (p<0.05). The nitrogen content was highest in Mtwapa (1.95 ± 0.07%) while Kibuyuni had the lowest nitrogen content of 1.32 ± 0.05% (p<0.05). Mtwapa site had the highest crude protein content of 12.16 ± 0.43% while Kibuyuni had the lowest and crude protein content of 8.25 ± 0.33% (p<0.05). There was no significant differences in crude ash among the sites (p>0.05). Kibuyuni had the highest NFE of 44.04 ± 1.47% while Mtwapa had the lowest NFE of 39.08 ± 1.09% (p<0.05).

Table 4. Variation of chemical composition (% dry weight) of seaweeds collected by site; values given as means ± SE (n = 3)

Site	Crude fat	Crude fibre	Nitrogen content	Crude protein	Crude ash	Nitrogen-free extract
Mkomani	1.74 ± 0.07^{b}	13.58 ± 0.50^{b}	1.71 ± 0.08^{b}	10.71 ± 0.47^{b}	32.06 ± 1.34^{a}	41.92 ± 1.42^{ab}
Kibuyuni	2.01 ± 0.08^{a}	13.77 ± 0.40^{b}	1.32 ± 0.05^{c}	8.25 ± 0.33^{c}	31.93 ± 1.30^{a}	44.04 ± 1.47^{a}
Mtwapa	1.58 ± 0.05^{b}	15.45 ± 0.34^{a}	1.95 ± 0.07^{a}	12.16 ± 0.43^{a}	31.73 ± 1.33^{a}	39.08 ± 1.09^{b}

Values followed by different letters in superscript within columns are significantly different at $p<0.05$ Duncan's multiple range test (DMRT).

The Kenyan coast is characterized by uncovered or almost uncovered reef platform. The surface of the reef platform is very uneven with parts completely uncovered in Kibuyuni, parts with shallow water in Mkomani and parts with larger and smaller pools in Mtwapa during the low tide spring tide. The uneven character of the reef surface together with the existence of many pools could possibly explain the differences in chemical composition.

The tissue nitrogen content is a measure of the nutrients (nitrogen) in sea water. Seaweeds exposed to sunlight had lower nitrogen contents as opposed to those semi-exposed or partially or completely covered by a film of seawater implying that nitrogen content varied with sunlight exposure. Crude protein content is an expression of nitrogen content thus its composition varies as well. This study supports findings of Dawes et al. (1974) and Hurtado-Ponce (1995) exhibiting that intense sunlight exposure causes degradation of protein and subsequent bleaching. The crude protein content levels were positively correlated to nitrogen content implying that there was higher nitrogen content in waters from Mtwapa and Mkomani sites than Kibuyuni.The fluctuation in the protein values in all the three sites could probably be explained by variation in environmental conditions such as nutrients (Burtin, 2003; Dawes, 1998).

3.1.4 Correlation between Chemical Components

The crude fat contents were positively correlated to NFE (r = 0.215) while negatively correlated to crude fibre (r = -0.160), nitrogen contents (r = -0.226), crude protein content (r = -0.226) and crude ash (r = -0.155). The crude fibre contents were positively correlated to nitrogen contents (r = 0.333), crude protein content (r = 0.333) and crude ash (r = 0.087) while negatively correlated to NFE (r = -0.493). The nitrogen contents were positively correlated to crude protein content (r = 0.961) while negatively correlated to crude ash (r = -0.285) and NFE (r = -0.138). The crude protein contents were negatively correlated to crude ash (r = -0.285) and NFE (r = -0.138). The crude ash contents were negatively correlated to NFE (r = -0.867).

Table 5. Pearson correlation (r) between chemical components of collected seaweeds

Chemical component	Crude fat %	Crude fibre %	Nitrogen content %	Crude protein %	Crude ash %
Crude fibre %	-0.160*				
Nitrogen content %	-0.226**	0.333**			
Crude protein %	-0.226**	0.333**	0.961**		
Crude ash %	-0.155**	0.087	-0.285**	-0.285**	
Nitrogen-free extract %	0.215**	-0.493**	-0.138*	-0.138*	-0.867**

* correlation significant at 0.05 level
** correlation significant at 0.01 level

4. Conclusion

This study revealed that rhodophytes and chlorophytes were the most nutritionally rich species, with respect to crude protein content, crude fibre and nitrogen-free extract (NFE). The *Hypnea* species (*Hypnea* sp. and *Hypnea musciformis*) had the highest crude protein content and could be used in feed formulation as well as food supplements. However, the nutritional values here are based exclusively on chemical analysis. In order to establish the nutritional value of these seaweeds for human and animal nutrition, biological analysis using animal feeding trials would be required.

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