

Chemical Composition and Functional Properties of Selected Seaweeds from the Kenya Coast

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Abstract

The aim of the study was to determine the chemical and functional properties of five Kenyan seaweed species namely; (*Hypnea musciformis*, *Euचेuma denticulatum*, *Laurencia intermedia*, *Sargassum oligocystum*, *Ulva fasciata*) as a potential fat replacer in chicken sausage processing. The proximate composition was investigated using the standard AOAC methods, while the nitrogen-free extract (NFE) was determined by weight difference of the proximate components. The seaweeds were analyzed for mineral composition using atomic absorption spectrophotometry while the fatty acid profile was determined by gas chromatography. The water holding capacity and the emulsion capacity of the seaweed were determined using AACC procedures. The highest proximate component was NFE (65.06 %) while the least was crude fat (0.87 %). Among the nine minerals analyzed, calcium was the highest (1185.29 mg/100g) while lead was not detected. Saturated fatty acids (SFA) were the highest with a range of 53.03-71.05 % followed by monounsaturated fatty acids (4.83-17.71%) and polyunsaturated fatty acids (PUFA) (2.75 - 10.13%). The highest emulsifying activity was obtained in *Ulva fasciata* (75.66 %) and *Euचेuma denticulatum* (75.69 %) while the lowest was obtained in *Sargassum oligocystum* (59.19 %). The highest water holding capacity was obtained in *Sargassum oligocystum* (13.75ml/g) while the lowest was recorded in *Euचेuma denticulatum* (8.42ml/g) and *Ulva fasciata* (9.16ml/g). The findings of this study demonstrated the potential of seaweeds in improving the chemical and functional characteristics of processed foods.

Keywords: chemical composition, fatty acid, functional properties, mineral composition seaweed

1. Introduction

Seaweed is a common term for marine macroalgae. They are classified based on their chemical and nutrition composition as phaeophyta (brown algae), rhodophyta (red algae) and chlorophyta (green algae) (Dawczynski et al., 2007). The seaweeds are used as sources of minerals, phycocolloids and food. Seaweeds are largely consumed as human food in Japan, Vietnam, Korea, China, Indonesia, Philippines and Taiwan (Dawes, 1998). The production of seaweeds is increasing (Azad & Xiang, 2012) due to interest in utilization in the food industry (Gupta & Abu-Ghannam, 2011) and the potential of therapeutic use against cancer, diabetes and other degenerative conditions (Mohamed et al., 2012). About 150 out of 250 species of commercially used seaweeds are consumed in fresh or dry form and the rest of the species are used as animal feeds, fertilizer, fungicide, herbicides and various industrial applications (Fleurence, 1999; Kumari et al., 2010).

Seaweeds are important sources of macronutrients such as carbohydrates, proteins, lipids, fiber and micronutrients such as vitamins and minerals as well as other bioactive compounds (Ortiz et al., 2006). It is therefore presumed that consumption of seaweed may help in reducing obesity, undesirable lipoproteins and minimize the risk of coronary heart disease (Benjama and Masniyom, 2011). Seaweeds vary greatly in nutrient and chemical composition due to environmental factors such as salinity, water temperature and nutrients (Dawes, 1998). These variations may promote or inhibit the biosynthesis of biological compounds, thus affecting nutritional composition (Lobban et al., 1985). The protein of the macroalgae has been reported to possess all the essential amino acids, which may vary depending on the season. In addition, the macroalgae contain an estimated 1 – 6 g of fat per 100 g. (Fleurence et al., 1994). According to van Ginneken et al., (2011), red and brown algae contains polyunsaturated fatty acids, mainly arachidonic and eicosapentanoic acid.

In recent years, there has been an increasing interest on the seaweed varieties along the Kenya coast, therefore their characterization by De Clerck et al., (2000). An estimated 386 species of seaweeds were identified including 214 rhodophytes, 116 chlorophytes and 56 phaeophytes (Bolton et al., 2007). While the consumption of seaweeds has seen an increasing trend in Asia and some Western countries, their utilization in Africa has not been fully established (Dawczynski et al., 2007). Notwithstanding, the growing knowledge on the nutritional benefits of seaweeds has led to a focus on the utilization of seaweeds as sources of proteins in the previously low consumption regions (Fleurence, 1999). Recently, Mwalugha et al., (2015) attempted to characterize the seaweed varieties available on the Kenya coast in terms of their proximate composition. However, far too little attention has been paid to the nutritional composition of this seafood. Currently, there are no reliable sources on the fatty acids, mineral composition and functional properties of the seaweeds found on the Kenyan Marine resources. Therefore, the aim of this study was to investigate the chemical composition and functional properties on five selected seaweeds from the Kenya coast.

2. Materials and Methods

2.1 Study Area

The seaweeds were collected near Mombasa along the Kenya coast (Latitude 4° 3'0''S and Longitude 39°40'0''E).

2.2 Seaweed Sample Collection and Preparation

Five seaweed species (*Hypnea musciformis*, *Eucheuma denticulatum*, *Laurencia intermedia*, *Sargassum oligocystum*, *Ulva fasciata*) were collected at the intertidal zone near Mombasa. The five seaweeds were the dominant species in terms of biomass in the study area. The seaweed samples were handpicked and immediately washed using seawater to remove any foreign particles. The clean samples were kept in buckets and transported to Kenya Marine and Fisheries Research Institute (KEMFRI) laboratories in Mombasa for identification and drying. Thereafter, a second washing was carried out on the samples using deionized water to remove surface adhering salts. The seaweeds were then sun dried, ground into a powder and refrigerated at 4°C until further analysis. The collected seaweed voucher species are preserved at the department of Food Science and Technology in JKUAT. Analytical grade chemicals were purchased for analysis.

2.3 Proximate Analysis

The moisture content, crude ash, crude fat, crude protein and crude fiber of the seaweed samples were determined according to the official method of analysis of AOAC international, (2000). The moisture content was determined by oven drying method at 105 °C where two grams of the sample were used. Crude ash content was analysed by incineration where five grams of the sample were ashed in an electric muffle furnace (Shimadzu KL- 420, Japan) at 550 °C for 16 h to a constant weight. The crude fat was extracted from five grams of the algal sample using the Soxhlet apparatus with petroleum ether as the solvent and determined gravimetrically after oven-drying at 70°C for 1 hour.

The crude protein content of seaweeds was determined according to the Kjeldahl method and conversion factor of 6.25 was used to calculate the crude protein content from the nitrogen content.

The crude fibre was determined by sequential digestion of seaweed samples with 1.25% H₂SO₄ and 1.25% NaOH using the fibreglass as a container. For drying and ashing, the crucible with the sample was dried in an oven for 5 hours at 105 °C and ashed in the muffle furnace at 550 °C for 16 hours. The weight of crucible with sample after drying and ashing was recorded and the crude fibre content was calculated.

The NFE were calculated based on weight difference using crude protein, crude fat, crude fibre, and crude ash and data as follows.

$$\text{NFE}\% = 100 - (\text{crude fibre} + \text{crude protein} + \text{crude ash} + \text{crude fat}) \quad (1)$$

2.4 Fatty Acid Analysis

The fatty acid profile of the seaweed samples was determined by gas chromatography after fat extraction using modified Bligh and Dyer method (1959). One gram of algal sample was put in a 50ml glass stoppered centrifuge tube. Methanol and chloroform were then added in a ratio of 2:1. The contents were centrifuged at 30,000 rpm for 10 minutes. The supernatant was transferred to a conical flask and 15mls of chloroform was added to the remnant. The contents were centrifuged at 30,000 rpm for 10 minutes and supernatant one and two were combined and then passed through a defatted cotton wool. The contents were then put in a rotary flask and evaporated to dryness. Five millilitres of 95% methanol and 5% hydrochloric acid were added followed by refluxing at 100 °C for 1 hour. The contents were then cooled in running water before transferring to a separating

funnel where 10ml of hexane was added followed by shaking vigorously. The contents were then left to settle where the upper layer of hexane was collected in a conical flask and the lower layer was further re extracted using hexane and the two hexane layers were mixed. The hexane layer were put in a separating flask and washed with water. The contents were then passed through a plugged funnel with cotton wool and anhydrous sodium sulphate. The contents were evaporated in a rotary evaporator to 0.5-1 μ l and put in vials. 1 μ l of the sample was drawn and injected into a gas chromatography (GC) (Shimadzu GC-9A, No. 41991A - Japan). Known concentrations of fatty acids standards were fed into the GC and identification done by comparing the retention time. The percentage fatty acid composition was determined using Eq. (2).

$$\text{Fatty acid \%} = \left(\frac{\text{Peak area of fatty acid}}{\text{Total peak area of fatty acids} - \text{Peak area of Hexane}} \right) * 100 \quad \text{Eq. (2)}$$

2.5 Mineral Analysis

The mineral content of seaweeds was determined by the dry ash method. Two grams of the algal samples were ashed at 550-600 °C for 2 hours then diluted using 1N HCl and filtered using Whatman filter paper no. 4. The absorbance of the standards followed by the samples was determined using an atomic absorbance spectrophotometer (Shimadzu, AA-6200-Japan).

2.6 Emulsifying Activity (EA) and Water Holding Capacity

The emulsion activity of seaweed samples was determined using a modification of the method described by Naczka *et al.*, (1986). Two gram of seaweed powder was dissolved in 20 mL of distilled water then the suspension was vortexed for 10 min using (Vortex mixer model TM- 151 –Japan). At the 5th minute, 20 mL of corn oil was added continuously with stirring. The emulsion was then centrifuged at 2100 rpm for 10 min at 25 °C (Beckman CS-6 centrifuge). The Volume of the emulsified layer was then recorded and the emulsion activity was calculated according to Eq (3)

$$\text{EA\%} = \left(\frac{\text{volume of emulsified layer}}{\text{volume of the suspension}} \right) * 100 \quad \text{Eq. (3)}$$

The water holding capacity (WHC) was determined according to AACC (1983) as the maximum amount of water retained by one gram of sample under low-speed centrifugation (2060 rpm for 10 min; Beckman CS-6 centrifuge) at 25 °C . Only enough water was added to saturate the sample and not to cause a liquid phase. All analyses were conducted in triplicates.

2.7 Data Analysis

All data were expressed as mean \pm standard error. Data concerning chemical and functional properties for seaweed species were analysed using one-way analysis of variance (ANOVA) and the means were separated using Duncans multiple range test (DMRT) using the statistical package for social scientists (SPSS®) Ver. 20.

3. Results and Discussion

3.1 Proximate Composition

The proximate composition revealed that NFE formed the highest mean component in seaweeds (Table 1). The results indicated that seaweed varieties of *Hypnea musciformis* and *Sargassum oligocystum* had the highest levels of NFE at 73.07 and 71.42 % respectively. The NFE values for *Hypnea musciformis* were considerably higher than those reported by Siddique, (2013) and Mwalugha *et al.*, (2015), who obtained 20.60% and 43.76% respectively. In addition, the NFE values for *Sargassum oligocystum* was higher than 53.21% reported by Azad and Xiang, (2012) and 30.30% reported by Kumar *et al.*, (2011). These variation could be attributed to differences in biological, physical, and environmental factors (i.e. harvest period), which are related to the difference in species, habitat and seasonality (Marinho-Soriano *et al.*, 2006). The least proximate component was crude fat (0.87%), where *Euचेuma denticulatum* had the highest value among the five seaweed species. The crude fat content of *Euचेuma denticulatum* was within the range of (1-6%) (Fleurence *et al.*, 1994) and close to (1.5%) reported by Kumar *et al.*, (2011) in *Kappaphycus alvarezii* (*Euचेuma cottonii*) from the Indian coast. Additionally, the value was close to (1.10%) reported by Matanjun *et al.*, (2009) in *Euचेuma cottonii* from Malaysia. The other species recorded the lowest amount of crude fat which was close to 0.48% obtained by Azad & Xiang, (2012).

Table 1. The proximate composition (% dry weight) of seaweed species from the Kenya coast (mean \pm SE, $n=3$)

Seaweed species	Ash	Crude fiber	Crude fat	Crude protein	Nitrogen Free Extract (NFE)
<i>Eucheuma denticulatum</i>	27.13 \pm 1.46 ^c	5.22 \pm 1.67 ^a	1.78 \pm 0.67 ^b	5.06 \pm 0.36 ^a	60.81 \pm 1.95 ^{ab}
<i>Hypnea musciformis</i>	12.79 \pm 2.58 ^a	6.49 \pm 1.21 ^{ab}	0.77 \pm 0.17 ^a	6.88 \pm 1.22 ^b	73.07 \pm 0.22 ^c
<i>Laurencia intermedia</i>	25.62 \pm 1.36 ^c	7.50 \pm 0.79 ^b	0.47 \pm 0.17 ^a	8.48 \pm 0.41 ^c	57.93 \pm 0.20 ^a
<i>Sargassum oligocystum</i>	13.08 \pm 2.74 ^a	9.40 \pm 1.39 ^c	0.46 \pm 0.07 ^a	5.64 \pm 0.19 ^{ab}	71.42 \pm 2.13 ^c
<i>Ulva fasciata</i>	19.92 \pm 3.42 ^b	7.10 \pm 0.32 ^b	0.86 \pm 0.11 ^a	10.06 \pm 0.90 ^d	62.06 \pm 3.10 ^b

Means with different superscript letters in each column are significantly different at $p < 0.05$.

Eucheuma denticulatum and *Laurencia intermedia* had the highest ash content which differed with (36.21%) and (30.32%) obtained by Mwalugha et al., (2015). Similarly, the ash content of *Hypnea musciformis* differed with (21.57%) reported by Siddique, (2013) and (20.77%) reported by Mwalugha et al., (2015). In this study the ash content of *Sargassum oligocystum* was considerably lower than 24.88% reported by Azad and Xiang, (2012) and (42.40%) in *Sargassum polycystum* obtained by Matanjun et al., (2009). The variation in ash content could be related to habitat, the habitats may have varying amounts of inorganic compounds and salts, additionally, temperature and pH could have an influence on mineralization (Mendis & Kim, 2011; Polat & Ozogul, 2009).

Crude fiber accounts for the indigestible components of the seaweed (Dawczynski et al., 2007). *Sargassum oligocystum* recorded the highest amount of crude fiber which varied slightly with (7.74%) obtained by Marinho-Soriano et al., (2006) and (7.58%) reported by Azad and Xiang, (2012). *Eucheuma denticulatum* and *Hypnea musciformis* recorded the lowest amount of crude fiber. The crude fiber of *Eucheuma denticulatum* was similar to (5.91%) in *Eucheuma cottonii* obtained by Matanjun et al., (2009). The variation in crude fiber content could be attributed to differences in photosynthetic activity, growth stage and seasonality which is as a result of changes in the environment that influences photosynthesis and nutrient absorption (Siddique, 2013; Wong & Cheung, 2000).

The crude protein of *Ulva fasciata* was in line with (7.31%) obtained by Frikha et al., (2011) and (10.69 %) reported by Tabarsa et al., (2012). The crude protein of *Eucheuma denticulatum* was slightly lower than (9.76%) obtained by Matanjun et al., (2009). The protein content of *Sargassum oligocystum* was in agreement with (5.63%) reported by Mwalugha et al., (2015). The variation in protein content in seaweeds could be attributed to differences in seasonality and growth conditions in the environment (Dawczynski et al., 2007).

3.2 Mineral Composition

Table 2. Mineral composition (mg/100g) of seaweed species from the Kenya coast (mean \pm SE, $n=3$)

Seaweed species	<i>Hypnea musciformis</i>	<i>Sargassum oligocystum</i>	<i>Ulva fasciata</i>	<i>Eucheuma denticulatum</i>	<i>Laurencia intermedia</i>
Minerals					
Sodium	20.50 \pm 5.61 ^b	18.79 \pm 1.82 ^b	17.42 \pm 2.43 ^b	9.88 \pm 1.25 ^a	21.88 \pm 0.71 ^b
Potassium	2.55 \pm 0.18 ^c	0.50 \pm 0.03 ^a	2.56 \pm 0.10 ^c	1.36 \pm 0.25 ^b	0.75 \pm 0.06 ^a
Phosphorus	2.21 \pm 0.53 ^a	3.35 \pm 0.24 ^a	2.36 \pm 0.49 ^a	2.43 \pm 1.35 ^a	2.96 \pm 1.03 ^a
Magnesium	411.56 \pm 7.66 ^b	397.12 \pm 2.19 ^a	429.88 \pm 2.47 ^c	436.97 \pm 1.06 ^c	445.09 \pm 2.68 ^d
Zinc	1.29 \pm 0.23 ^a	1.51 \pm 0.22 ^a	4.12 \pm 0.30 ^b	4.25 \pm 1.85 ^b	0.99 \pm 0.11 ^a
Iron	7.34 \pm 1.71 ^a	25.82 \pm 1.34 ^b	51.39 \pm 2.58 ^c	48.80 \pm 1.0 ^d	30.71 \pm 1.27 ^c
Cadmium	0.17 \pm 0.01 ^a	0.18 \pm 0.05 ^{ab}	0.24 \pm 0.05 ^{ab}	0.30 \pm 0.10 ^b	0.21 \pm 0.05 ^{ab}
Lead	nd	nd	nd	nd	nd

nd = not detected (LOD for lead =0.0692ppm)

Means with different superscript letters in each row are significantly different at $p < 0.05$.

Among the nine minerals analysed calcium was the dominant mineral followed by magnesium (Table 2), similarly Calcium and Magnesium were found to be the major minerals in brown and red seaweeds (Rupérez, 2002). *Eucheuma denticulatum* recorded the highest amount of calcium while *Hypnea musciformis* had the lowest amount ($p < 0.001$). The calcium content of *Eucheuma denticulatum* was considerably higher than (442 mg/100g) in *Eucheuma spp* obtained by Krishnaiah et al., (2008). The calcium content in all the seaweed species was substantially higher compared to lettuce (35mg/100g), cabbage (40mg/100g) and spinach (99mg/100g) (USDA, 2016). From these findings, seaweeds showed a potential of being utilized as a supplement of vegetables in the human diet. Calcium plays a key role in construction and maintenance of bones and ensuring normal functioning of muscles and nerves (Soetan et al., 2010). Seaweeds have been found to possess diverse

mineral content due to their habitat in the marine environment. As a result of this, minerals such as calcium are able to accumulate in much higher content compared to terrestrial plants (MacArtain et al., 2007). This could potentially explain why calcium was among the dominant minerals in the seaweed species.

The highest levels of magnesium was recorded in *Laurencia intermedia* (445.09 mg/100g), while *Sargassum oligocystum* had the lowest at 397.12 mg/100g. The content of magnesium in *Laurencia intermedia* obtained in the current study was lower than (640 mg/100g) reported by Kumar et al., (2011) in *Laurencia cruciata*. In addition, the level of magnesium in *Sargassum oligocystum* was lower than 487.81 mg/100g reported by Matanjun et al., (2009) in *Sargassum polycystum*. 700 mg/100g) obtained in *Sargassum swartzii* (Kumar et al., 2011) and (1160 mg/100g) reported in *Sargassum echinocarpum* by McDermid et al., (2007). Magnesium is a cofactor for enzymes involved in important biochemical pathways in the human body (Soetan et al., 2010).

Ulva fasciata and *Hypnea musciformis* had the highest levels of potassium while *Laurencia intermedia* and *Sargassum oligocystum* had the lowest. The potassium content of *Ulva fasciata* was lower than 520mg/100g reported by Rohani-Ghadikolaei et al., (2012) in *Ulva Lactuca*, 2450mg/100g reported by MacArtain et al., (2007) and 4340mg/100g obtained by Kumar et al., (2011) in *Ulva* species. The potassium content of *Laurencia intermedia* was considerably lower than (6040mg/100g) reported by Kumar et al., (2011) in *Laurencia cruciate*.

High Zinc content was reported in *Eucheuma denticulatum* and *Ulva fasciata* while the rest of the species had the lowest amount. The Zinc content of the seaweed species (0.4-1.7mg/100g) was within the range reported for seaweeds. The Zinc content of *Eucheuma denticulatum* was slightly higher than (0.545%) in *Eucheuma isiforme* obtained by Robledo & Freile Pelegrin, (1997) and lower than (6.63%) in *Eucheuma spp* reported by Krishnaiah et al., (2008). The variation in mineral composition could be attributed to the difference in geographical location (Rao et al., 2007), and also difference in species. For instance, seaweeds bioaccumulate a lot of minerals and are a good source of Magnesium, Iron, Iodine and other trace elements (MacArtain et al., 2007).

There was no significant difference in the Cadmium content among the seaweed species ($p = 0.163$). The Cadmium content in *Ulva fasciata* was higher than (0.05 mg/100g) reported by Topçuoğlu et al., (2001) in *Ulva lactuca* and a range of 0.0031-0.0033mg/100g reported by Besada et al., (2009). The Cadmium content of *Sargassum oligocystum* was lower than (0.70mg/100g) in *Sargassum wightii* stem and higher than (0.14mg/100g) in *Sargassum polycystum* stem (Jothinayagi & Anbazhagan 2009). The presence of Cadmium could be attributed to water contamination by sewage, effluent from metal product manufacturers, fertilizers and by-products from oil refining (Wong et al., 1982).

3.3 Fatty Acids Composition

Table 3. Fatty acid profile of seaweed species from the Kenya coast (mean \pm SE, $n=3$)

Fatty acids (%)	<i>Eucheuma denticulatum</i>	<i>Hypnea musciformis</i>	<i>Laurencia intermedia</i>	<i>Sargassum oligocystum</i>	<i>Ulva fasciata</i>
Caprylic (C8:0)	0.31 \pm 0.54 ^a	0.07 \pm 0.13 ^a	nd	0.33 \pm 0.50 ^a	0.26 \pm 0.45 ^a
Capric (C10:0)	2.62 \pm 4.54 ^a	36.09 \pm 24.14 ^b	13.37 \pm 1.05 ^a	11.40 \pm 10.06 ^a	23.40 \pm 1.75 ^{ab}
Lauric (C12:0)	0.34 \pm 0.31 ^{ab}	0.22 \pm 0.37 ^{ab}	1.81 \pm 0.21 ^{bc}	0.02 \pm 0.04 ^a	2.09 \pm 1.81 ^c
Myristic (C14:0)	4.24 \pm 0.39 ^c	2.08 \pm 0.87 ^b	6.09 \pm 0.06 ^d	4.50 \pm 0.23 ^c	0.72 \pm 0.63 ^a
Palmitic (C16:0)	43.22 \pm 17.76 ^b	21.06 \pm 3.88 ^a	46.88 \pm 0.37 ^b	41.56 \pm 3.27 ^b	34.74 \pm 3.85 ^{ab}
Stearic (C18:0)	2.30 \pm 1.06 ^a	4.60 \pm 0.58 ^a	2.90 \pm 0.07 ^a	2.86 \pm 0.32 ^a	4.28 \pm 1.85 ^a
Arachidic (C20:0)	nd	nd	nd	0.95 \pm 0.58 ^b	3.24 \pm 0.45 ^c
SFA ¹	53.72 \pm 11.55 ^a	64.12 \pm 20.82 ^a	71.04 \pm 0.49 ^a	61.63 \pm 6.17 ^a	68.73 \pm 0.41 ^a
Oleic (C18:1)	4.83 \pm 3.43 ^a	8.41 \pm 1.64 ^b	11.22 \pm 0.13 ^b	17.71 \pm 1.12 ^c	11.77 \pm 1.55 ^b
MUFA ²	4.83 \pm 3.43 ^a	8.41 \pm 1.64 ^b	11.22 \pm 0.13 ^b	17.71 \pm 1.12 ^c	11.77 \pm 1.55 ^b
Linoleic (C18:2)	2.27 \pm 1.50 ^a	3.27 \pm 2.43 ^a	2.70 \pm 0.19 ^a	6.33 \pm 0.23 ^b	3.81 \pm 0.94 ^a
Linolenic (C18:3)	0.49 \pm 0.18 ^a	1.48 \pm 1.41 ^a	0.37 \pm 0.15 ^a	3.80 \pm 0.56 ^b	5.64 \pm 0.77 ^c
PUFA ³	2.75 \pm 2.10 ^a	4.75 \pm 3.84 ^a	3.07 \pm 0.06 ^a	10.13 \pm 0.79 ^b	9.45 \pm 1.69 ^b

nd = not detected

¹Total saturated fatty acids (SFA) = the sum of C8 to C20.

²Total mono unsaturated fatty acids (MUFA) = the amount of C18:1

³Total poly unsaturated fatty acids (PUFA) = the sum of C18:2 and C18:3

Means with different superscript letters within the rows are significantly different at $p < 0.05$.

The fatty acid composition of the seaweed species varied from 0.07% to 46.88% in SFA. The total saturated fatty acids ranged from 53.72 to 71.04% however there was no significance difference among the species. In this study, the total saturated fatty acids in *Sargassum oligocystum* (61.63%) was higher than the value reported by

Kumari et al., (2013) (49.6%). Total saturated fatty acids of *Ulva fasciata* (68.73%) was close to (68.97%) reported for *Ulva lactuca* by Yaich et al., (2011) however the value was higher than (38.50%) reported in *Ulva* species (Durmaz et al., 2008). Palmitic acid was the most dominant saturated fatty acid, *Hypnea musciformis* (21.06%) and *Ulva fasciata* (34.74%) recorded the lowest amount of palmitic acid while the rest of the species had the highest ($P < 0.027$). The results of this study were in agreement with that of Gressler et al., (2010) who reported palmitic acid as the dominant saturated fatty acid in seaweeds.

Sargassum oligocystum had the highest amount of total Mono Unsaturated Fatty acids (MUFA) (17.71%) and *Eucheuma denticulatum* had the lowest amount of total MUFA (4.83%) ($P < 0.001$). The total MUFA in *Sargassum oligocystum* was within the range reported in seaweeds by Van Ginneken et al., (2011) (3-56%). The total MUFA in *Eucheuma denticulatum* was within the range of 1.8-12.5% (Khotimchenko et al., 2002), however the total MUFA of *Eucheuma denticulatum* was lower than the range reported in seaweeds by Gressler et al., (2010) (6.6-10.5%). The variation in MUFA content could be as a result of exclusion of palmitoleic and eicosenoic fatty acids.

The total polyunsaturated fatty acids (PUFA) included Linoleic acid and Linolenic acid. *Sargassum oligocystum* and *Ulva fasciata* recorded the highest amount of PUFA (10.13%) and (9.45%) respectively which are lower than the range reported by Dawczynski et al., (2007) (34 -74%). The PUFAs in *Ulva fasciata* (9.45%) was considerably lower than (33.76%) reported by Durmaz et al., (2008) similarly the value in this study was lower than (56.9%) obtained in *Ulva lactuca* (Khotimchenko et al., 2002). *Eucheuma denticulatum*, *Hypnea musciformis* and *Laurencia intermedia* recorded the lowest amount of PUFAs (Table 3) ($P < 0.003$), the total PUFA in *Laurencia intermedia* was lower than (70.5%) reported in *Laurencia okamuria* (Li et al., 2002) and (16.7%) obtained in *Laurencia filiformis* (Gressler et al., 2010). The total PUFA in *Eucheuma denticulatum* was lower than (26.97%) reported in *Kappaphycus alvarezii* (*Eucheuma cottonii*) (Kumar et al., 2011). Arachidic acid was only found in *Sargassum oligocystum* and *Ulva fasciata*. The difference in the fatty acid among the seaweed is related to difference in species and habitat (Khotimchenko et al., 2002). Additionally, the difference in PUFAs could be attributed to environmental temperature since algae normally accumulates PUFAs when there is a decrease in environmental temperature (Kayama et al., 1985). The incorporation of seaweed in low salt meat emulsion models was shown to increase the PUFA content (López-López et al., 2009), this shows the potential of seaweed as a substrate in food processing.

3.4 Emulsion Activity

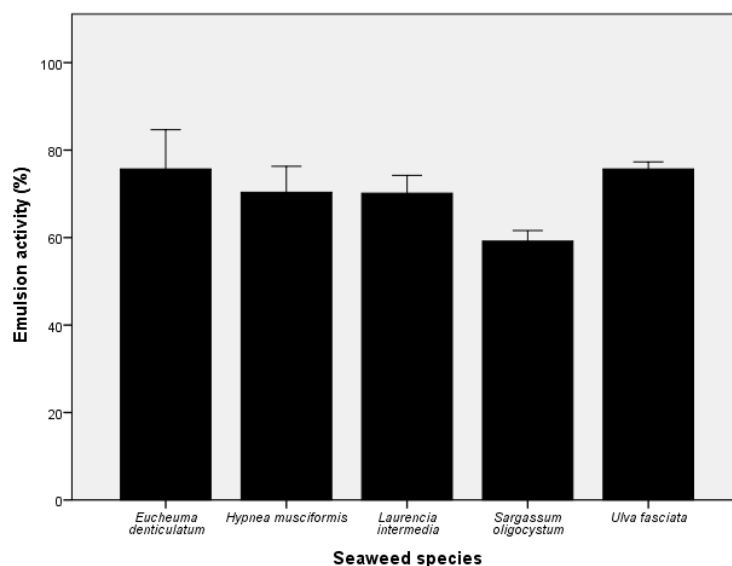


Figure 1. Emulsion activity (%) of seaweed species from the Kenya coast (mean \pm SE, $n=3$)

The emulsion activity of the seaweed species ranged from 59.19% to 75.69% (Figure 1) with *Eucheuma denticulatum* (75.68%) and *Ulva fasciata* (75.66%) recording the highest values and *Sargassum oligocystum* (59.19%) recording the lowest value ($P < 0.001$). The emulsion activity of *Eucheuma denticulatum* was similar to (75.68%) in *Kappaphycus alvarezii* (*Eucheuma cottonii*) obtained by Kumar et al., (2014) where cotton seed oil was used. In this study the emulsion capacities of the seaweed species compares well with lupin seed (60%) and soya bean (70%) whose extract are used as emulsifiers in the food industry (Tömösközi et al., 2001). The good

emulsifying ability of seaweeds is attributed to phycocolloids which is widely used in meat processing as a result of their good thickening, emulsifying, thickening and stabilizing properties (Cofrades et al., 2011).

3.5 Water Holding Capacity

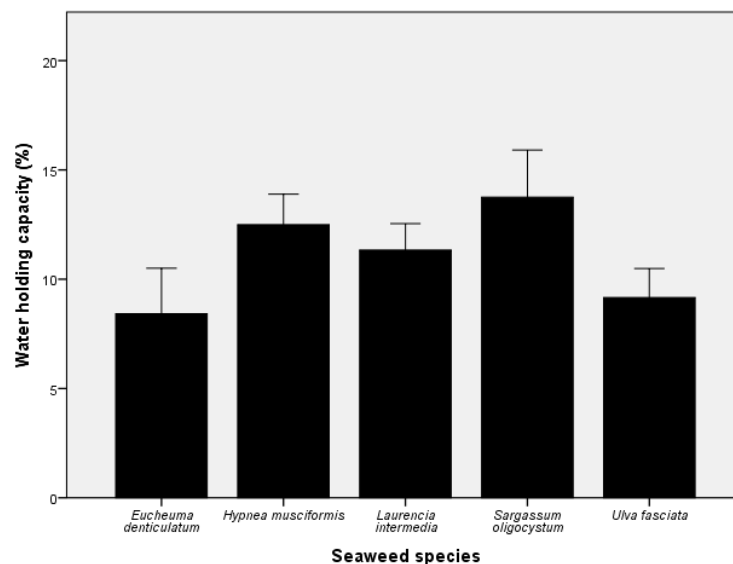


Figure 2. Water holding capacity (ml/g) of of seaweed species from the Kenya coast (mean \pm SE, $n=3$)

Sargassum oligocystum (13.75 ml/g) recorded the highest water holding capacity while the lowest was recorded in *Eucheuma denticulatum* (8.42 ml/g) and *Ulva fasciata* (9.16 ml/g) (Figure 2; $P<0.001$). The water holding capacity of *Ulva fasciata* reported in this study was higher than (6.66-7.00ml/g) reported in *Ulva lactuca* (Yaich et al., 2011). The water holding capacity of *Eucheuma denticulatum* was lower than (17.7 ml/g) in *Eucheuma* powder (Senthil et al., 2005). The water holding capacity of the seaweed species was slightly higher than the range reported for commercial dietary fibre supplements (6.60-9.00ml/g) (Goñi & Martín-Carrón, 1998). The variation in water holding capacity could be as a result of varying fibre and protein content of the seaweeds that have an influence on the functional properties (Fleurence, 1999; Yaich et al., 2011). In this study *Sargassum oligocystum* had the highest crude fiber and considerably high amount of crude protein while *Eucheuma denticulatum* had the lowest crude fiber and crude protein (Table 1). Seaweeds have been shown to improve the water holding capacity of emulsions, this consequently has had an influence on hardness and chewiness of cooked products (Cofrades et al., 2008).

4. Conclusions

This study has revealed that Kenya seaweeds could be a good source of dietary fibre, proteins and nitrogen free extract (NFE). The seaweeds have potentially good mineral content especially calcium and magnesium compared to lettuce, cabbage and spinach. For this reason, seaweeds could be consumed as food supplement to aid in achieving the recommended daily intake of macro and trace minerals. Lead was not detected in the seaweed species however cadmium was detected. In the seaweed species the SFA were the highest followed by MUFA and finally PUFA. Emulsion activity and water holding capacity are among the key functional properties of food ingredients. Seaweed have been utilized as gelling agent and stabilizers in the pharmaceutical and food industry. The emulsion activity of the seaweeds were similar to that of soybean and even higher than that of lupin seeds. The water holding capacities of the seaweeds were relatively higher than that of commercial fibre products. These characteristics show that seaweeds can be incorporated in food products to provide nutrients as well as improve the physiochemical properties, specifically *Eucheuma denticulatum* due to its high total mineral composition, high emulsion activity and availability. Further research should be conducted to investigate functional properties and other parameters such as phytochemical and antioxidant properties of other seaweeds along the Kenyan coast.

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