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Nutritional and Toxicological Importance of Selected Seaweeds from Visakhapatnam Coast

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ABSTRACT

The objective of the present study is to determine the contents of macro, trace and ultra-trace elements (essential, probably essential and toxic) by the energy-dispersive X-ray fluorescence spectrometry (EDXRF) in 15 edible dried seaweeds of red and green algae those collected along the Visakhapatnam coast. The seaweeds are procured from different estuarine stations to analyse them by using SPECTRO XEPOS, EDXRF spectrometer and Si-Li detector. Results are obtained, by which the concentrations of Na, Ca, P, K, Mg, I, Zn, Se, Cu, Mo, Cr, Mn, Fe, Co Pb, Cd, Hg and As have been determined. This study suggests that these seaweeds could be potential sources of several essential nutrients and will contribute positively to the diet. As the concentration of some toxic elements exceeds the maximum permissible limits in the present seaweeds due to the collecting site, after processing to eliminate toxic elements accumulated due to contamination; consumption of these seaweeds is encouraged to meet the recommended daily intake of the essential minerals, trace elements and also because of their medicinal properties.
Keywords : Seaweeds, Nutrition, EDXRF, Trace elements, Elemental analysis.

I. INTRODUCTION

Seaweed is the common name for endless types of marine plants and algae that grow in the seas, rivers, lakes and other water bodies. In coastal waters, they grow almost like grass in large areas extending over hundreds of kilometres. Biologically, seaweeds are classified as macroalgae, with subclassification as red algae (Rhodophyceae), brown algae (Phaeophyceae), green algae (Chlorophyceae) and blue-green algae (Cyanophyceae) (Apaydın et. al). For a common man, these plants are of little use and only a few people know about these seaweeds. These were found to use as food, fertilisers and medicines since ancient times (Sahoo et. al). India has a long coastal line of about 7000 km and nearly 770 species of seaweeds have been reported from the Indian marine environments (Sahoo et al). The importance of seaweed wealth on the Indian coast has been greatly realised.

Seaweeds draw from the sea as an extraordinary wealth of mineral elements, most prominently calcium, copper, iodine, iron and micronutrients such as vitamin B12, vitamin C and vitamin E. Seaweeds have large proportion of iodine when compared to dietary minimum requirements, which is primarily known as a source of iodine nutrient (Burtin et. al). They are rich in polysaccharides, dietary fibres and show an interesting polyunsaturated fatty acid composition that called as omega-3; which plays a role in the prevention of cardiovascular diseases and diabetes. The protein content of brown seaweeds is generally low whereas red and green seaweeds show higher protein contents. Brown seaweeds are particularly rich in carotenoids especially in fucoxanthin, β-carotene, violaxanthin. The main carotenoids in the red algae are the β-carotene, α-carotene and their dihydroxylated derivatives (Burtin et. al).

Based on the medicinal properties of some seaweeds; extracts of them have been applying to the preparation of medicine for the last so many years. Brown algae are effective in curing goitre because of their iodine content. Other seaweeds have been used as vermifuges; to make cough medicines, smoothing lotions and cosmetics (Lobban et. al). Recent studies have revealed about antiviral drug activity of some extracts related to Hongkong and Brazilian seaweeds (Wang et. al), (Soares et. al). More recently, the action of brown seaweeds on breast cancer prevention mechanisms have been more intensely documented (Jane et. al). Many studies have explored the use of seaweeds to fight against several diseases, including colorectal cancer (Ghislain et. al). It was mentioned that the bioactive compounds in Sargassum, brown algae appear to play a role as immune modulators and could be useful in the treatment of thyroid related diseases such as Hashimoto's thyroiditis (Liu L et. al). Though these seaweeds have application to prepared medicines, their direct usage in the preparation of medicines is not yet developed properly.

The human consumption of seaweeds is common in some of the Asian countries, mainly in China, Japan and Republic of Korea. In India, although seaweeds are used for industrial purposes but yet to be utilised on a larger scale as dietary food; which is not being done due to lack of awareness among the Indian populace (Dhargalkar et. al). Therefore, in India, it was proposed to determine the composition of essential elements those lie largely in these seaweeds (red and green) by using energy dispersive X-ray fluorescence (suitable nuclear analytical technique) method.

II. SAMPLE COLLECTION AND THEIR PREPARATION

The study area of the sample collection was Visakhapatnam; which has no river openings into the sea along its coastline (9.6 km). The sampling site contains a vast resource of marine algal species. The seaweed samples (10 red algae, 5 green algae) were collected from different locations of the coast. Algal samples were handpicked, washed thoroughly with seawater to remove all the impurities, sand particles and epiphytes. They were transported to the laboratory and washed thoroughly by using tap water and then sterilized with distilled water to remove the salt on the surface of the algae. The samples were spread on a blotting paper to remove excess water and shade dried at room temperature for about 4 hours avoiding the possibility of contamination from the surroundings. Dried samples were cut into small pieces and oven dried at 60^0 C for 20 hours. The concentration of Potassium (K) can be changed if the drying temperature is higher than 70^0 C (Bino devi et. al). Therefore, the oven temperature was preset to 60^0C to avoid this effect. These samples were grounded to get homogeneity by using a clean agate mortar and pestle. 150 mg of the sample powder was pelletized into a thin pellet of uniform thickness having 13 mm in diameter under a pressure of 100 -110 kg/cm^2 for five minutes using a die and pelletizer.

The die surface was cleaned with acetone every time before pelletization to avoid the possibility of contamination that occurs due to previously pelletized samples. X-ray intensity increases with pelletization pressures that apply to raise sample density, above a certain pressure, the X-ray intensity saturates (Gakuto et. al). This effect can be minimised by keeping the pelletization pressure at constant for each sample. If the target pressure is reached too quickly, the sample may crack due to the expansion of the air trapped in the sample when pressure is released. Therefore, sample pressure was released several times before target pressure is reached to let air escape from the sample to avoid sample breakage. Without a binder, fine powder particles may fall off or scatter from the pellet surface and cause contamination of the spectrometer’s sample chamber in vacuum mode (Gakuto et. al) and a special care was taken to avoid this.

III. EXPERIMENTAL METHOD AND ANALYSIS

Energy-dispersive X-ray fluorescence (XRF) spectrometry is an elemental analysis technique that exhibits several advantages over other methods and capable of detecting a wide range of elements simultaneously. It is a non-destructive, fast, highly accurate and environment-friendly (Min Yao et. al). EDXRF spectrometry can be used on different forms of the sample such as bulk, liquid, powder and gas. It can also detect particles in the air. EDXRF works based on the principle that when individual atoms of a target excited by an external energy source, emit X-ray photons of a characteristic energy or wavelength. By counting the number of photons emitted from a sample, the corresponding elements present may be identified and quantified (Min Yao et. al) for each energy. The identification of elements is possible due to their characteristic radiation emitted from the inner electronic shells of the atoms under certain conditions. The emitted quanta of radiation are X-ray photons whose specific energies permit the identification of their source atoms.

The present experiment was performed at NCCCM, here the experimental set-up consists of a SPECTRO XEPOS, EDXRF spectrometer. This consists of an X-ray tube with a binary cobalt/palladium alloy as an anode, which provides extra sensitivity and lower LODs for specific element groups. This binary alloy anode emits radiation due to palladium excitation that gives best results for sodium to chlorine, iron to molybdenum and hafnium to uranium while cobalt emits radiation by its excitation for potassium to manganese. It's like having two tubes in one instrument. The SPECTRO XEPOS debuts a new design of silicon drift detector. This resolution of detector was high with low spectral interference, possessing an enlarged surface ($30\ mm^2$) besides maximised active area ($20\ mm^2$). Its high- speed read-out system provides an ultrahigh-count rate up to 1 million counts per second. It contributes to the system's improved peak to background ratios having extremely low LODs and ultra-high sensitivity. The system uses the SPECTRO XRF Analyzer Pro operating software.

The qualitative analysis depends on the assurance of the right top position of each peak (centroid) in the spectrum of a sample. Change of the peak centroid channels to energies is made on utilising energy calibration curve. Therefore, distinctive standard references elements with known energies for K_α or K_β were secured to cover the interesting energy region 1–25 KeV for the present energy calibration. The spectrum obtained from each standard was analysed by spectrum analysis software to attain the energy–channel relationship on utilizing least square fitting method. Quantitative analysis of the desired samples relies on the standard curve established by standard specimens. The measured intensity value of the unknown element fed into the standard curve to obtain the elemental contents.

The validity of the EDXRF set up was performed by analysing standard reference materials (SRM) those obtained from National Institute of Standards and Technology (NIST). Apple leaf (SRM1515) and Oriental Tobacco leaves (CTA-OTL-1) were used for quantification of the elements as shown in Table 1, and verifying the reliability of the data obtained by the present system.

Table-1: Concentrations of elements obtained from NIST (SRM 1515) Apple leaves and Tobacco leaves (CTA-OTL-1) with our experimental set-up

Elements	NIST (SRM 1515)		(CTA-OTL-1)	
	Certified value	Present work	Certified value	Present work
Ca	15260.00	15581.52	_3.17±0.12_*	_3.038_*
K	16100.00	15878.04	_1.56±0.05_*	1.36*
S	18000.00	18780.64	_0.732±0.12_*	_0.684_*
P	15900.00	15278.01	2892±134	4723.83
Zn	12.5	14.5	49.9±2.4	46.69
Cu	5.64	7.08	14.1±0.5	12.57
Ni	0.91	0.73	6.32±0.65	6.68
Fe	83.00	71.70	989	1000.34
Mn	54.00	47.98	412±14	421.12
Cr	0.30	1.15	2.59±0.32	2.13
Ba	49.00	67.97	84.2±11.5	82.26
Sr	25.00	29.29	201±20	205.27
Rb	10.20	9.85	9.79±1.27	10.61
Br	1.80	4.26	9.28±1.06	11.78
Se	0.05	0.11	0.153±0.018	0.11

Italic in (%), Normal text (ppm)

IV. RESULTS AND DISCUSSION

In the present study, 15 edible dried seaweeds were analyzed as mentioned above; in which concentration of 18 elements was determined in all the samples. The elements those obtained in the seaweeds are divided as major and trace elements (essential and toxic). The variation of the major and trace elemental concentrations in the analyzed samples is shown in the tables 2, 3 and 4.

Phosphorus works in association with calcium to develop and maintain strong bones and teeth for human beings. It enhances the use of other nutrients and also essential for energy processing. Among the present selected seaweeds, the highest concentration of Phosphorus (P) (350.6ppm) is detected in Gelidiella Acerosa followed by Gelidiopsis Variabilis (348.3ppm) and Grateloupia Lithophila (311.6ppm) while it has the lowest concentration (152.6ppm) in Jania Rubens. The recommended quantity of Phosphorus (P) is 700 mg per day, and the tolerable upper intake level (UL) is 4,000 mg per day for adults and if the age is above 70 years, 3,000 mg per day is sufficient. In the present study, the phosphorus content of the samples is found to be higher when compared to the earlier reported results [Christine et. al]. These seaweeds can be used as a staple food source for phosphorous. These are also useful for the primary prevention of osteoporosis.

Potassium deals with muscle and nerve function besides functioning as a major component of the intracellular fluid. It regulates heartbeat, maintains fluid balance and helps muscles contract. The highest content of Potassium is found in Spongomorpha Indica (802.5ppm) showing a disagreement with the earlier reported value [Apaydin et. al] while indicating the lowest (42.8ppm) in Jania Rubens.

The recommended average intake of Potassium is 2300 mg/day for adult women and 3100 mg/day for adult men. The upper intake level (UL) for this mineral is unknown, but taking a lot of potassium supplements can cause hyperkalemia due to a higher quantity of potassium presence in the blood leading to a health hazard. The result of the present study indicates that the selected seaweeds are found to be rich in potassium and thus consumption of them reduces high blood pressure.

Calcium is essential to develop and maintain healthy bones and teeth, assists in blood clotting, muscle contraction and nerve transmission; helps to reduce the risk of osteoporosis. The Ca is found to be very rich especially in Amphiroa Fragilissima and Jania Rubens relative to all other samples of the present study. The obtained value of calcium concentration in Amphiroa Fragilissima is 11720.4ppm and in Jania Rubens is 11410.0ppm. As the present samples have higher Calcium, these may be more useful for elderly people particularly women who reached to menopause stage to take these as a part of their daily diet based on their requirement. This indicates that Amphiroa Fragilissima and Jania Rubens can be used widely to develop Calcium rich food items and medicines. On the other hand, very low concentration of Ca is observed in Ulva fasciata and Gelidium Pusillum. This observed discrepancy in the value of Ca concentration may be due to change in the surrounding water where they grew naturally and climatic condition too.

Although iodine requirement is very small amount to the proper functioning of human body, still it plays an important role. It is needed for the thyroid hormones that are involved in cellular oxidation, growth, reproduction and the activity of the central and autonomic nervous systems. Iodine required not only for the biosynthesis of thyroxine but also for other important organs such as breast, stomach, salivary glands, thymus, etc. Therefore, iodine is needed in larger quantities relative to trace minerals. The concentration of iodine in the present samples is very high ranging from 4.3 ppm to 303.1 ppm. The recommended daily intake of iodine is 150μg/day. Gelidium Pusillum, Gelidiella Acerosa, Spongomorpha Indica and Grateloupia Lithophila contained abundant amounts of iodine. Hence, these four seaweeds can be used to develop iodine rich food items and medicine. The observed large variation in the iodine content of the present specimens can be attributed to the difference in oceanic origin and also elemental uptake by the algae; which might depend on climatic condition and surrounding environment of the sample collected site.

Zinc is essential for proper digestion, metabolism, reproduction and wound healing; which involve more than 200 enzymes. Its deficiency is characterized by recurrent infections. Zn content in present samples is found to be in the range of 64.2ppm – 944.2ppm as shown in Table 3. The obtained result has a consistent and close agreement with the earlier reported data [Marcelo et. al]. The observed variation of Zn content among different seaweeds might be due to change in the variety besides elements absorbing nature; growing area etc. Zinc accumulation of the present studies is in the order of Caulerpa Racemosa > Gelidiella Acerosa > Grateloupia Lithophila > Bryocladia Strunoids > Hypnea Valentiae and so on. The RDA value of Zn is 4 mg for children ranging the ages 4–8 years, 8 mg for 9–13 years, 11 mg for a male from 14 years onwards while 9 mg for female children of about 14–18years, and 8 mg for female adults from 19 years onwards. It is observed that there is a direct association between Zinc deficiency and cancer [Emily et. al]. Zinc plays a protective role against carcinogenesis and the presence of considerable amounts of Zinc in all these samples may be used for the treatment of cancer.

A small quantity of selenium is highly required for all the living organisms; at a higher concentration of this element was reported as toxic one [Jennifer et. al]. It is readily absorbed, transported through the plasma and deposited in all tissues. Selenium has antioxidant nature rising immune system facilitating to maintain good health. It is very important for the function of several proteins and constituent of several enzymes. In the present studies, selenium is determined only in three seaweeds with very low concentration and not detected in the remaining samples having contradictory to the earlier findings [Binodevi et. al].

Copper acts as a catalyst to store and release iron for the formation of haemoglobin and contributes to central nervous system function. It participates in normal red blood cell and connective tissue formations. As shown in Table 3, the level of copper (Cu) ranges from 4.9ppm to 56.4ppm in the present samples. This result has good agreement with the results reported earlier [Areej et. al]. In the present studies, maximum concentration (56.4ppm) of copper is obtained in Bryocladia Strunoids while its lowest (4.9ppm) concentration found in

Amphiroa Fragilissima. Copper concentration of the present samples is lower than the required maximum limit that set by FAO/WHO. Adequate intake (AI) levels of copper for infants i.e. 0 to 6 months of age and in between 7 to 12 months of age have been recognized as 200 and 220 g/day respectively. The RDAs for 1–3 years, 4–8 years, 9–13 years, 14–18 years and 19–50+ years of age are 340, 440, 700, 890, 900 and 900 mg/day, respectively. The RDAs during pregnancy (14 through 18 years and 19 through 50 years) and lactation (14 through 18 years and 19 through 50 years) are 1000 and 1300 g/day respectively. Although copper is indispensable one to the good health, excessive consumption may result in serious health problems like kidney and liver damage. Consequently, 10 mg/day has been established as upper intake level (UL) for adults who are older than 19 years of age [19]. The obtained levels of copper in the present study are lower than the UL that set by FAO/WHO; therefore these seaweeds are very important for proper growth of human beings.

Manganese is essential for proper bone structure, reproduction, and for the good functioning of the central nervous system. The functional values of Manganese are as a Lewis acid and catalyst for oxidation. Manganese exists in a number of oxidation states, of which Mn (II) is the predominant form in biological systems. The concentration of Mn in foodstuffs varies considerably but mostly lies below 5 mg/kg. This trace element is connected with the synthesis of proteins and nucleic acids also. A certain interrelation is assumed between manganese deficiency and development of lupus erythematosus. Manganese rich food is useful to prevent diseases like diabetes mellitus. According to the scientific findings, the rate of growth in children largely depends on the manganese consumption. It is established in the present samples as Spongomorpha Indica (246.5ppm), Bryocladia Strunoids (117.5ppm) and Caulerpa Racemosa (108.5ppm); these have a rich concentration of Mn when compared to other seaweeds. The lowest content of Mn (14.3ppm) is detected in Ulva fasciata. In the present work; concentration of Mn in some of the samples present is found to be higher than the permissible limit that set by FAO/WHO (2001). Daily required minimum concentration of manganese for adults is approximately 2 to3 mg, but intake of 2 to 9 mg per day results in optimum performance.

Iron is required for the composition of haemoglobin, myoglobin and certain enzymes. It is necessary for red blood cell formation; brain function for children and women of the reproductive age who most often suffer from iron deficiency. In children, iron deficiency can be caused by improper nutrition and fast growth of the organism. In women, iron deficiency arises from the constant loss of blood in the course of menstruation. Iron deficiency is dangerous, particularly during pregnancy period. Anaemia arising from iron deficiency can cause the death of the fetus due to a shortage of oxygen. The necessary intake of iron is 10 to 30 mg per day. However; a dose of 200 mg per day produces a toxic effect. The permissible limit of Fe as set by FAO/WHO (2001) is 425.5 ppm. Iron concentration as shown in Table 3, the highest content (6941.0ppm) is observed in Caulerpa Sertularioides, while the lowest content of Fe is found in Ulva fasciata (286.4ppm). RDAs for iron are 10 mg/day for children of 4–8 years, 11mg/day for males of 14–18 years, 15 mg/day for females of 14–18 years, 8 mg/day for 19–50 years of male adults,18 mg/day for 19–50 years of female adults, and 8mg/day for >50 years of male/female adults. In the present study, the concentration of Fe is found to be very high in all the samples which signifies that these seaweeds can be used for the preparation of iron rich foodstuff items for those persons having iron deficiency syndrome.

Cobalt is an essential component of vitamin B12, which is necessary for normal red blood cell formation. An excess intake of cobalt may cause the overproduction of red blood cells. Cobalt concentration presented in table 3 is found to be low in the presently selected seaweeds. It ranges from 0.1ppm to 3.5ppm in a very narrow range and not detected in Gelidiopsis Variabilis, Bryocladia Strunoids and Gracilaria Corticata. The RDA of Co is 1-2 mg for a normal male adult of 22 years of age. Deficiency of Vitamin B-12 can cause to form red blood cells improperly. Consequently, this prevents red blood cells to carry out enough oxygen from lungs to the different parts of a body causing a condition called anaemia.

Vegetables and seafood may contain significant amounts of lead. At higher levels, inorganic lead acts as a metabolic poison showing the effect on the neurological and reproductive systems. Lead breaks the blood-brain barrier and interferes with the normal development of the brain in infants. Lead is responsible for lower IQ levels in children. Lead is transferred to postnatal from the mother breast milk. At elevated levels, lead poisoning would eventually result in death. The Joint FAO/WHO

Expert Committee on Food Additives provisionally recommends that the weekly intake of lead should not exceed 25μg/kg of bodyweight per week for adults, children and infants. The maximum permitted concentration of Pb in all food in solid form is 6ppm and in liquid form is 1ppm. However, in the present samples, the concentration of Pb is found to be very high ranging from 9.3 ppm to 135.8ppm. Therefore, these seaweeds need to processed for elimination of toxic elements before utilization for the benefit of their nutritional contents.

Cadmium is a metal most often encountered in earth's crust combined with chlorine (cadmium chloride), oxygen (cadmium oxide) or sulphur (cadmium sulphide). It exists as small particles in the air as a result of smelting, soldering or other high temperature industrial processes. Human uptake of cadmium takes place mainly through foodstuffs like shellfish, mussels and dried seaweeds that are rich in cadmium by accumulation. The concentration of Cd is very low in all the present samples ranging from 0.3ppm to 1.9ppm. The Joint FAO/WHO Expert Committee on Food Additives recommends that 7μg of cadmium/Kg of body weight should be regarded as the maximum tolerable weekly intake of cadmium.

The seaweeds absorb great amounts of methyl mercury from sea waters every day as it accumulates in marine organisms and in the food chains. The effects that mercury has on humans are kidneys damage, stomach disruption, damage to intestines, reproductive failure and DNA alteration. The concentration of Hg in the present samples ranges from 1.4 ppm to 49.1 ppm; which is not in safe limit according to WHO regulations. The Joint FAO/WHO Expert Committee on Food Additives provisionally recommends that total mercury intake should not exceed 5 μg/kg of body weight per week with not more than 3.3 μg/kg per week as methyl mercury.

Arsenic compounds are known to be toxic since ancient times. The biological effects of arsenic depend on the chemical form in which the element is presented, inorganic compounds being more toxic than most organic ones. The organic compounds containing arsenobetaine, dimethylarsenoribosides or arsenolipids are metabolites of aquatic organisms. These compounds contribute substantial amounts of arsenic to human diets containing seafood. The major cause of concern in connection with arsenic is the potential toxicity of its compounds to humans. Acute poisoning, characterized by nausea, vomiting, diarrhoea and severe abdominal pain, is relatively rare. Chronic toxicity, on the other hand, is known to occur as a result of exposure to natural sources in some countries or from accidental contamination of foodstuff. Food items related terrestrial origin contain less than $1\mu g$ of arsenic/g dry weight; the levels present in those of marine origin are substantially higher, ranging up to $80\ \mu g/g$. Dietary intake is therefore greatly influenced by the amount of seafood in the diet. Based on recent surveys [ ] in several countries, the daily arsenic intake of adults is estimated to be less than $200\mu g$, and often below $100\ \mu g/day$. Extrapolation from animal experiments suggests that human adult intakes in the range 12-25 $\mu g/day$ are probably adequate to meet any possible requirement. However, the metabolism and effects of arsenic can differ depending on the chemical nature of the arsenic source; these differences partly account for the nature of the recommended safe exposure limit for adults of $15\mu g/kg$ of body weight per week. The concentration of As in all the samples is beyond this limit except in Jania Rubens, Gelidium Pusillum, Amphiroa Fragilissima and Bryocladia Strunoids. As the concentration of arsenic in the present samples exceeds the maximum permissible limit, it may be a cause for short term (nausea, vomiting, diarrhoea, weakness, loss of appetite, cough and a headache) and long term (cardiovascular disease, diabetes and vascular diseases) health effects.

Table-2: Major elements and their concentrations (ppm) in 15 different edible seaweeds

Sample name	Variety	Na	P	K	Ca	Mg
Ulva fasciata	Green	3.0	229.5	337.2	681.4	4.5
Enteromorpha Compressa	Green	3.6	269.4	140.8	972.7	1.0
Spongomorpha Indica	Green	5.7	203.0	802.5	4112.1	1.3
Caulerpa Sertularioides	Green	5.0	160.4	67.7	1017.3	0.8
Caulerpa Racemosa	Green	5.4	202.3	111.0	1680.1	0.9
Jania Rubens	Red	4.9	152.6	42.8	11410.0	11.0
Gelidium Pusillum	Red	5.4	226.2	571.5	823.2	0.0
Amphiroa Fragilissima	Red	5.4	204.9	160.3	11720.4	11.2
Hypnea Valentiae	Red	4.1	268.8	139.9	1191.1	0.0
Bryocladia Strunoids	Red	4.6	200.8	253.2	1207.5	0.8
Pterocladia Heterosporous	Red	2.8	231.2	88.9	1662.3	0.1
Grateloupia Lithophila	Red	3.7	311.6	512.8	1143.3	0.0
Gelidiopsis Variabilis	Red	3.7	348.3	260.8	1768.3	0.0
Gelidiella Acerosa	Red	3.9	350.6	459.2	1030.8	0.0

Table-3: Essential and probably essential trace elements and their concentrations (ppm) in 15 different edible seaweeds

Sample name	Variety	I	Zn	Se	Cu	Mo	Cr	Mn	Fe	Co
Ulva fasciata	Green	4.3	274.2	ND	18.0	1.4	2.8	14.3	286.4	0.9
Enteromorpha Compressa	Green	25.8	280.5	ND	33.7	ND	10.0	60.2	5015.0	2.2
Spongomorpha Indica	Green	215.5	145.3	2.4	33.5	ND	11.1	246.5	5950.7	2.9
Caulerpa Sertularioides	Green	9.5	173.8	3.9	41.9	ND	13.3	76.3	6941.0	3.5
Caulerpa Racemosa	Green	9.1	944.2	1.8	39.7	ND	16.2	108.5	5640.3	2.8
Gracilaria Corticata	Red	8.3	125.4	ND	7.4	1.4	3.3	75.2	329.9	0.0
Jania Rubens	Red	30.6	67.4	ND	5.9	ND	3.8	44.8	1286.9	0.4
Gelidium Pusillum	Red	303.1	230.0	ND	51.5	1.6	2.9	22.2	1292.3	1.1
Amphiroa Fragilissima	Red	43.4	64.2	ND	4.9	0.5	2.2	49.3	720.8	0.3
Hypnea Valentiae	Red	5.5	291.6	ND	11.3	1.1	5.8	39.2	1274.5	1.4
Bryocladia Strunoids	Red	36.7	519.2	ND	56.4	ND	6.9	117.5	6238.8	ND
Pterocladia Heterosporous	Red	16.7	225.1	ND	23.4	0.5	6.3	57.7	3294.3	1.0
Grateloupia Lithophila	Red	170.5	532.7	ND	21.2	1.7	2.5	30.3	680.9	1.1
Gelidiopsis Variabilis	Red	96.3	186.9	ND	15.5	0.0	6.8	35.9	1735.4	ND
Gelidiella Acerosa	Red	248.8	590.4	ND	28.1	1.1	1.8	38.0	739.6	0.1

Table-4: Potentially toxic elements and their concentrations (ppm) in 15 different edible seaweeds

Scientific name	Variety	Pb	Cd	Hg	As
Ulva fasciata	Green	17.2	1.9	ND	30.6
Enteromorpha Compressa	Green	30.6	1.6	ND	43.4
Spongomorpha Indica	Green	28.0	0.3	2.4	16.6
Caulerpa Sertularioides	Green	27.5	0.7	2.8	32.9
Caulerpa Racemosa	Green	21.7	1.6	2.5	24.0
Gracilaria Corticata	Red	10.4	0.5	1.4	28.0
Jania Rubens	Red	9.3	0.3	ND	ND
Gelidium Pusillum	Red	45.8	1.1	10.1	ND
Amphiroa Fragilissima	Red	10.2	1.2	ND	ND
Hypnea Valentiae	Red	11.8	1.3	2.6	22.5
Bryocladia Strunoids	Red	135.8	0.9	49.1	ND
Pterocladia Heterosporous	Red	22.3	0.6	3.5	25.3
Grateloupia Lithophila	Red	40.1	1.2	7.0	33.4
Gelidiopsis Variabilis	Red	18.2	0.6	ND	22.8
Gelidiella Acerosa	Red	37.9	1.1	5.2	33.4

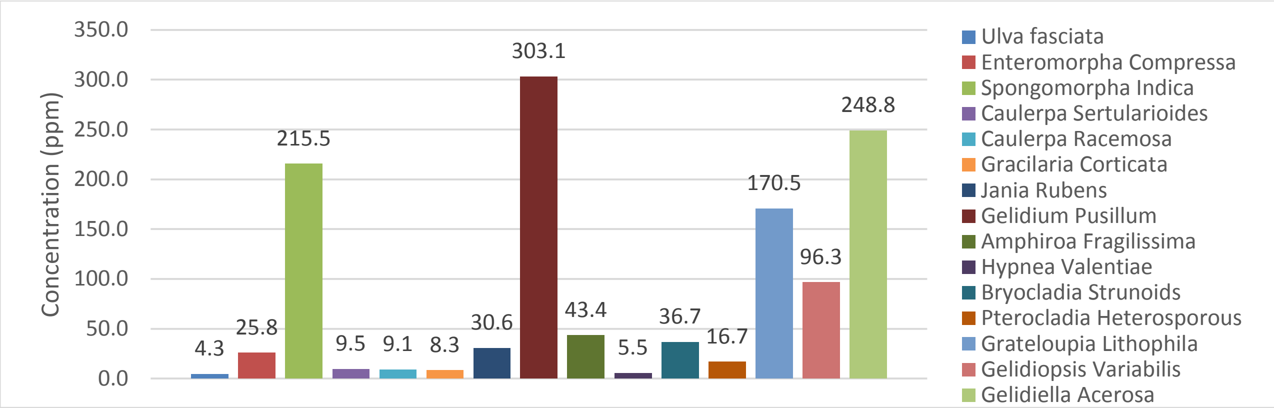

Fig-1: Variation of I concentration in 15 different algae samples

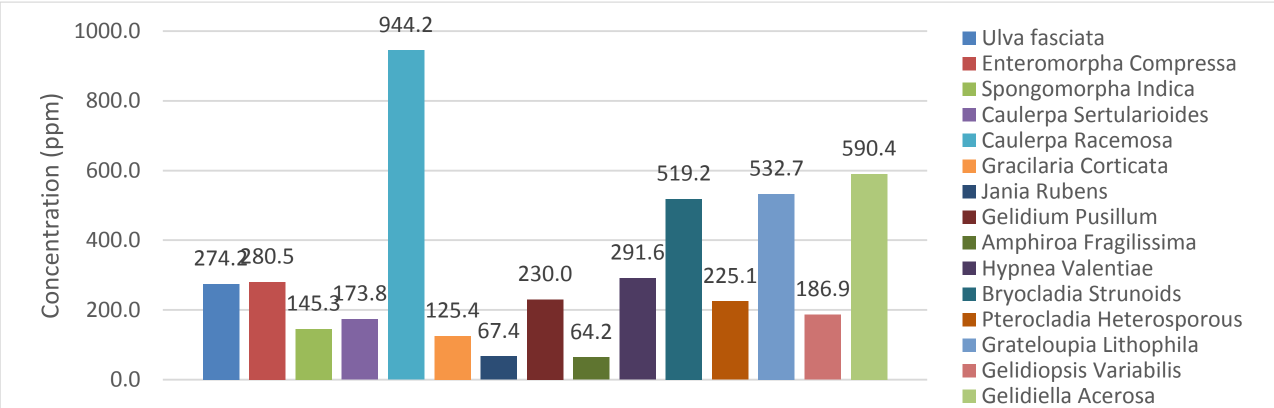

Fig-2: Variation of Zn concentration in 15 different algae samples

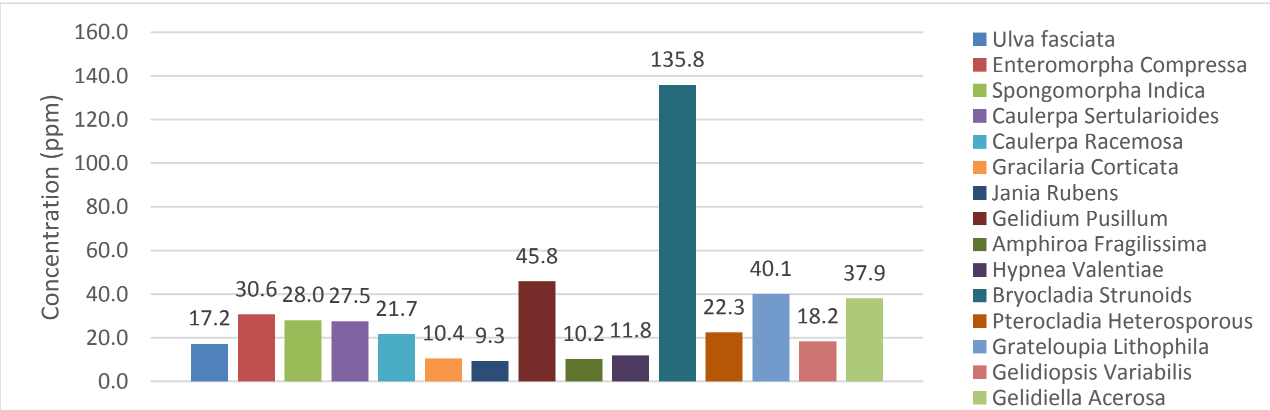

Fig-3: Variation of Pb concentration in 15 different algae samples

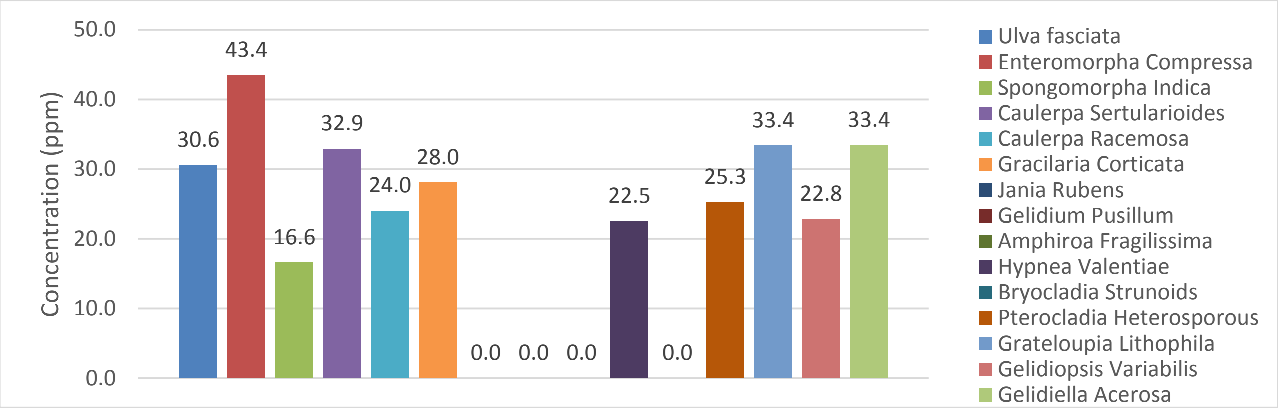

Fig-4: Variation of As concentration in 15 different algae samples

Table-5: Linear correlation of major elements in 15 different edible seaweeds

	Na	*P*	*K*	*Ca*	*Mg*
Na	1.0000				
P	0.3167	1.0000			
K	0.3660	0.4182	1.0000		
Ca	0.4196	-0.1533	-0.1455	1.0000	
Mg	0.2925	-0.2270	-0.2411	0.9289	1.0000

Table-6: Linear correlation of essential trace elements in 15 different edible seaweeds

	I	*Zn*	*Se*	*Cu*	*Mo*	*Cr*	*Mn*	*Fe*	*Co*
I	1.0000								
Zn	0.0768	1.0000							
Se	-0.0498	0.0549	1.0000						
Cu	0.3265	0.4456	0.3794	1.0000					
Mo	0.3439	0.0302	-0.4430	-0.2156	1.0000				
Cr	-0.2924	0.3334	0.7577	0.4677	-0.6905	1.0000			
Mn	0.0979	0.0457	0.5667	0.3316	-0.5038	0.5747	1.0000		
Fe	-0.1786	0.2391	0.7082	0.6887	-0.7377	0.8712	0.6729	1.0000	
Co	-0.0613	0.1707	0.8254	0.4090	-0.3374	0.8092	0.4693	0.6898	1.0000

Table-7: Linear correlation of potentially toxic elements in 15 different edible seaweeds

	Pb	*Cd*	*Hg*	*As*
Pb	1.0000			
Cd	0.0341	1.0000		
Hg	0.9739	-0.0240	1.0000	
As	-0.2947	0.3324	-0.4103	1.0000

V. CONCLUSION

The concentrations of major and trace elements those present in 15 different seaweeds that collected from Visakhapatnam sea coast have been determined by using EDXRF technique. The concentrations of some of the essential elements are relatively higher when compared with the earlier investigations. Therefore, after processing to eliminate toxic elements accumulated due to contamination; consumption of these seaweeds is encouraged to meet the recommended daily intake of the essential minerals; trace elements and also because of their medicinal properties. Some potential toxic elements like lead, mercury and arsenic are determined in these seaweeds. As algae; being one of the best bio-accumulator of various elements, it can be used to study the environment where it grows.

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