POTENTIAL OF EDIBLE SEAWEED OF THE KENYAN COAST AS A MICRONUTRIENT SOURCE

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This dissertation is my original work and has not been submitted for award ofdegreeinanyotheruniversity.

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DEDICATION

This dissertation is dedicated to my beloved family, special gratitude to my lovely parents Mr. and Mrs Wekesa for being the best parents a child would ever wish for, you have been a fortress throughout this journey of life, scarifying and investing your resources to ensure my siblings and I get the best out of life. To my siblings and lovely daughter, your relentless love and support are my constant muse, because of all of you this life is worth a great living. I also dedicate this work to everyone out there making efforts and contributing to a better life for Kenyans and the world at large through Nutrition.

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ABREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
ANOVA	Analysis of Variance
COHA	Cost of Hunger in Africa
FAO	Food and Agriculture Organization
FFQ	Food Frequency Questionnaire
FNSP	Food and Nutrition Security Policy
HHH	House Hold Head
HH	House Hold
HIV	Human Immunodeficiency Virus
HPLC	High Performance LiquidChromatography
KMFRI	Kenya Marine and Fisheriesresearch institute
KES	Kenya Shillings
KNMS	Kenya National MicronutrientSurvey
MHLW	Ministry of Health, Labor and Welfare
MND	Micronutrient Deficiencies
NNAP	National Nutrition Action Plan
ODK	Open Data Kit
RDA	Recommended Dietary Allowance
SBEC	Sustainable Blue Economy Conference
Spp	Species
SPSS	Statistical Package for Social Sciences
TUL	Tolerable Upper Limit
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund.
UNDESA	United Nations Department of Economic and Social Affairs
UNGA	United Nation General Assembly
USD	United States Dollar
UV/ViS	UltraViolet-Visible Spectroscopy
VAD	Vitamin A Deficiency
WHO	World Health Organization

OPERATIONAL DEFINITIONS

Edible seaweed-An algae ‘sea vegetable’ found growing wildly along the Kenyan coastline orcultivated in Kwale County and can be consumed in many forms as a food source or additive in food preparation

Kenyan coastline- A 640 km stretch from Vanga to Kiunga of area where land meets the Indian **Ocean** which includes study areas of Kwale, Mombasa and Kilifi coastline.

Micronutrients- Vitamins and minerals of study concern required in very small quantities in ourbodies which are essential for a number of different functions, including growth and development, these include, Vitamins A, D, Folate, B_{12}, Iron, Zinc and Iodine.

Micronutrients deficiencies- Insufficiency of essential vitamins and minerals of concern inKenya, these are Vitamins A, D, Folate, B_{12}, Iron, Zinc and Iodine

ABSTRACT

For centuries, Algae case in point seaweed has been harvested and used for its nutrition benefits in East Asia and western countries but irregularly in Kenya. When compared to plants growing on land or animal food sources, consumption of seaweed as micronutrient source may contribute towards dietary diversification and alleviation of micronutrient deficiencies due to its high micronutrients content. Despite seaweed availability in Kenya farming has just recently been encouraged and supported by the Kenya Blue Economy citing its huge potential. Main objective of the study was to determine the potential of edible seaweeds found at the Kenyan coast as a micronutrient source. Comparative experimental design where 175 seaweed farmers from 5 villages of Kwale County were interviewed and 58 seaweed samples were randomly collected from 5 beaches in Mombasa, Kilifi and Kwale counties. Socio-demographic and seaweed consumption data was collected, presence of micronutrients (Vitamin A, D, B_9, B_{12}, Iron, Zinc, Iodine) and heavy metals (Mercury, Lead, Arsenic, Cadmium) was also determined. Seaweed farmers were majorly women (68%) between the ages of 30-40 years (p-value 0.014) with majority (90.8%) having attained upper primary and below. Average income levels per harvest of farmed seaweed ranged from $83-166, price per kg was approximately $0.25. Seaweed farming was practices majorly for purposes of income generation (74.7%) rather than consumption purposes (2.9%) (p-value= 0.043). Consumption was less than once per week (52.1%) with an average serving of 50-100 grams per day (74.4%) (p-value=0.034) preferring the cooked form to the dried or fresh seaweed. Slightly less than two thirds (59.9%) attributed lack of nutritive knowledge as main reason for low consumption, followed by fear of contamination (21.7%) (p-value=0.033).Edible seaweed species included 11 Phaeophyceae (S*argassum, Turninaria, Dictyota, Padina and Eucheuma),* 9 Chlorophyta (*Ulva* and C*aulerpa* and *Eucheuma)* 8 Rhodophyta (*Gracilaria Hypnea, Soliera* and *Eucheuma*). Seaweeds found in Kilifi had

highest mean levels of all tested vitamin, Vitamin B_{12} (464.9±203.6)μg/100g (p-value=0.031),Vitamin A (146.0±49.7)μg/100g (p-value=0.047) and Vitamin D (33.4±30.2)μg/100g (p-value=0.006) while seaweeds found in Kwale county recorded highest mean levels of Iron (269.9±154.6)mg/kg (p-value=0.047). Mean levels of Vitamin B_{12} (306.5±287.9)μg/100g, D (18.8±24.3)μg/100g, Zinc (53.3±60.8)μg/100g and Iodine (41.0±34.1)μg/100g highest in the Green seaweed Vitamin B_9 (73.0±122.3) and A (102.4±104.8) and Iron (274.0±158.6) highest in the Red seaweed, however no significance in difference in vitamin and mineral levels in relation to seaweed phyla was noted. Farmed *Eucheuma cotonii (Kappaphychus alvarezii)* recorded highest levels of Vitamin B_{12} (696.6μg/100g) and Vitamin A (298.6μg/100g), whereas *Hypnea cornuta* recorded highest levels of Vitamin B_9 (153.1μg /100g).*Caulerpa fastigiata* recorded highest level of Vitamin D (77.63μg /100g). *Ulva intestinalis* recorded highest levels of Iron(637.85mg/kg). *Caulerpa taxifolia* had highest level of Zinc (277.74mg/kg) and Iodine (142.8mg/kg). Mean Lead levels (0.774mg/kg) were highest in species found in Kilifi county whereas mean Cadmium levels (0.021mg/kg/) highest in Mombasa county. Mean Lead levels (0.56mg/kg) were highest in Brown seaweed whereas mean Cadmium levels (0.025mg/kg/) highest in Green seaweed. *Caulerpa taxifolia* recorded highest levels of Lead (2.0575mg/kg) and Cadmium (0.123mg/kg). Mercury was detected in only 4 species whereas Arsenic metal wasnot detected in all species.

Middle-aged women were majorly involved in seaweed farming practicing it for income generation rather than home consumption. Despite mild awareness of seaweed being edible, consumption was low and only seen in the middle-aged population. This was majorly attributed to low education levels, limited knowledge of its nutritive value and lack of knowhow in seaweed incorporation in diet much more than fear of contamination or its smell and taste properties. The study also established an association between increased likelihood of consumption with increased nutritive knowledge of seaweed as a micronutrient food source. Seaweed species found at the coastline were found to contain all micronutrient of studied and in high levels in majority of the seaweed species. The micronutrient contents of these seaweed species vary from one region to another with some species exhibiting high micronutrient levels than others. However, Vitamin D_3 levels were substantially high in only of few edible seaweed species collected. Traces of Lead and Cadmium were found in most of the edible seaweed species but were below the maximum permissible limit in most of the edible species.

The study recommends increased knowledge and education to the local community in Kenya on exploration of seaweed as an alternative macro and micronutrient sources and on ways of incorporation in diet.Exploring more research on increased nutritive value of various edible seaweeds found in the country. Increasing research on processing, value addition and incorporation in existing local market and local therapeutic and complementary diets for both children and adult consumption thus improving its acceptability by the Kenyan population.

Regulatory bodies need to set recommended guidelines for edible seaweeds by doing so, the nutritional and medicinal values of these seaweeds will be exploited. To avoid negative connotation that comes with the word ‘weed’, regulatory bodies could consider reviewing the name to of categorizing edible seaweeds under “sea plants” or “sea vegetable” to increase acceptability. Removing heavy metals through such processes as bio-adsorbent techniques could also be explored

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Malnutrition which is imbalances that occurs in the intake and utilization of energy and nutrients is manifested in three forms known as the triple burden of malnutrition, under nutrition, over nutrition and micronutrient deficiencies (WHO, 2016). Micronutrients Deficiencies (MND) is regarded as a significant contributor to the global burden of disease.Over two million of the world's population suffer from MNDs (WHO,2018). Prevalence of food insecurity, poor nutrition due to micronutrient deficiencies, inadequacy of food quality and diversity in regular Kenyan diet is still high, affecting more than 10 million people (FNSP, 2011). Micronutrients are significant in optimal physiological functions and in sustenance of life, being required in the body in minuscule amounts (West *et al.*, 2012). Consequences of their deficiencies on the other hand negatively impacts on heath through increased risk of morbidity, poor growth, intellectual impairments, perinatal complications, and ultimately death. Deficiencies occur either as a result of inadequate nutrient intake from the diet or malabsorption of sufficient intake due to disease, infections or inflammation (UNICEF,2020). Food-based interventions such as dietary diversification as well as supplementation and fortification are some of the recommendation of the KNMS 2011 to combat MNDs. Improved nutritional status has been noted due to dietary diversification in developing countries (Rah *et al.*, 2010). Hence, consumption of seaweed algae as sources of micronutrient would contribute towards dietary diversification.

For centuries, Algae has been harvested and used for its nutraceutical, health, and nutritional benefits in disease prevention especially in East Asia and Africa (Wells *et al.*,2017). The largest photosynthetic marine algae that forms the biomass in the inter-tidal zone is Seaweed, '*sea vegetables*' (Wells et al.,2017). In Asia, seaweed cultivation is a major industry; different nations consume different variety and amounts, for instance in Japan, daily consumption in a single day as part of diet ranged from 9.6 to11.0 grams of macroalgae between the years 2010 and 2014 (MHLW, 2014).

In comparison to terrestrial plants or foods from animal sources, seaweed contains approximately more micronutrients per unit dry mass (Peñalver et al., 2020). Water soluble B vitamins (Folate,B_{12},B_2,B_1) as well as Vitamin C and all fat-soluble Vitamins (K,D,E,K) are found in seaweed. In addition, over 10 essential minerals are in seaweed (Iodine, Zinc, Iron, Fluoride, Selenium, Magnesium, Phosphorus, Copper, Manganese, Calcium and Potassium (Qin, 2018; Mišurcová, 2011). Food sources, fertilizers and dyes were some of the traditional uses of seaweed. Development of mass food manufacturing in the 20^{th} century resulted into seaweed components being exploited for industrial purposes (Rhein-Knudsen *et al*., 2015; Zollman, 2019). Seaweed consumed by humans in known forms (example, *kelp, nori*) was estimated to be 38 % of the 23.8 million tons of aquatic plants (FAO, 2014).

In Kenya seaweed farming has recently been encouraged and supported by the Kenya Blue Economy citing its huge potential (Blue Economy Committee Report, 2016-unpubl). Kenya Marine and Fisheries Research Institute (KMFRI) under Kibuyuni Beach Management Unit supports a blue economy initiative of seaweed farming in Kibuyuni Kwale. Rather than consumption by local community as micronutrient source, seaweed farming is done majorly export purposes to countries in Asia and Europe (KMFR1, 2018). These countries utilize seaweed for cosmetics purposes, extraction of industrial gums and chemicals, as fertilizers as well as a food source. (KMFR1, 2018). If well tapped, seaweeds are likely to be a more sustainable micronutrients source, readily available both naturally and through farming (Mirera *et al.,* 2020; Odhiambo *et al*., 2020). Studies should focus on understanding the micronutrients that can be obtained from edible seaweed, use of these seaweeds as vegetables and supplementary diets, increase its production and explore ways to fortify food with seaweed for maximum micronutrient availability. The research thus aims to determine dietary intake, micronutrient content and any heavy metal contamination of edible seaweed of the Kenyan coastline and those being farmed.

1.2 Statement of the problem

Micronutrient deficient malnutrition is a major health concerns publicly and globally and poses a serious threat to the vulnerable members of the society. Yet seaweeds are available in plenty at the Kenyan Coastline which could be rich dietary sources of micronutrients. However, there is limited data on seaweed use, availability and nutrient content of the edible varieties in Kenya. The utilization of seaweed in Kenya is limited to the Kenyan Coastline with no information on its acceptability, why such rich micronutrient food source is not popular or spread to other parts of Kenya.

There are limited studies on the seaweed food chain, preparation or preservation processes as used currently. Does consumption of seaweed have a cultural dimension so that it should be socially marketed with caution? There should be possibilities of improving the seaweed market to various parts of Kenya as a food, incorporated into other foods or an edible wrap around other processed foods, making it visible.

1.3 Justification

Seaweed industry is estimated to be valued at US$ 6 billion, its consumption and use as 'food of the future' is growing steadily across the globe (FAO, 2012). Currently, the Pilot project for seaweed cultivation at the Kenyan south coast has presented economic potential and the opportunity for Kenya to become one of the leading seaweed producers (Wakibia, 2011).

In Kenya, Supplements have been a means of dealing with MNDs but due to its repetitive use and limited health resources, its compliance is poor especially when intake is frequent and over long periods. Fortified foods are not consumed in adequate amounts and may not fully meet the needs of certain nutritionally vulnerable subgroups due to poor bio-availability of some fortificants,challenges in fortifying staples such as rice and fortified foods not being frequently purchased (NNAP, 2011). Improving of dietary quality by exploring non-conventional nutrient sources has the benefit of increasing intake of many micronutrients simultaneously. In Kenya, seaweed grows wildly along the coastlines and production through cultivation is on the rise. Despite its availability, seaweed has greatly been consumed in other regions of the world as diet and micronutrient sources but not to any great extent in Kenya. This may be due to lack of extensive research, knowledge gaps of its nutrition properties and ways of its incorporation in diet.

Seaweed being a potential single source of numerous micronutrients, information on its utilization in Kenya could be used by the Ministry of Agriculture, Health, food producers and industries to strengthen the seaweed food market chain in Kenya. This will also contribute towards alleviation of MNDs especially among vulnerable groups and paving way for exploration of more non-conventional nutrient sources.

1.4 Goal of Study

To contribute towards alleviation of MNDs in Kenya through use of non- conventional micronutrient sources; case in point is seaweed.

1.5 Purpose of Study

To generate data on micronutrients present in selected edible seaweeds found at the Kenyan coast, determine its safety in terms of consumption and factors affecting its consumption.

1.6 Objectives

General objective

To determine the potential of edible seaweeds found at the Kenyan coast as a micronutrient source

Specific objectives

1. To determine socio-demographic characteristics of the Kenyan Coast study population
2. To determine seaweed consumption patterns at the Kenyan Coast study population
3. To determine micronutrients content present in edible seaweed types of the Kenyan coast
4. To determine level of heavy metal content present in edible seaweed types of the Kenyan coast

1.7 Hypotheses

1. No effect of socio-demographic characteristics on seaweed consumption patterns of the Kenyan Coast study population
2. Seaweed consumption is not affected by seaweed nutritive knowledge of study population
3. No difference in micronutrient content of various edible seaweed types in relation toseaweed phyla and location found
4. No heavy metal contamination in relation to seaweed types and location found

1.8 Assumptions

1. Monsoonal weather conditions of strong winds and tidal waves from the sea did not affected study seaweed for such conditions affect the quality of the algae

2. The environmental conditions that the seaweeds are growing are with sufficient nutrients, light, right salinity and temperatures which has not been affected by effluents, heavy metal disposal from factories and pollution of the sea

CHAPTER TWO

2.0 LITRETURE REVIEW

2.1 Malnutrition

Malnutrition is a health issue of global concern; it is manifested as under nutrition (underweight, stunting and wasting), over nutrition (obesity, overweight and morbidity) and micronutrient deficiencies. (WHO,2016). Maternal and child under nutrition contributes to about 10% of total global burden of disease and 45 % of child mortality (WHO, 2018). In Kenya, 2.4 million episodes of illnesses among children and 19.4% of all child mortality are associated with under nutrition (COHA, 2019). MNDs of concern globally and in Kenya are Vitamin A, Vitamin B_{12}, Iron, Iodine, Folate, and Zinc (KMNS, 2011). Despite the fact that there a various source of micronutrients and various interventions explored, prevalence of malnutrition resulting from micronutrient deficiency remains high, is a reoccurring issue and affects a large population of the country. Globally, at least 50% of children under five years suffer one or more micronutrient deficiency and more than two billion of the population is affected by the same (Ritchie & Roser, 2020).

In Kenya, prevalence of Iron deficiency stands at approximately 70%, highest percentages noted in pregnant women at 36% (KMNS, 2011). Compared to the global prevalence of 46%,the national levels are alarming (WHO, 2011). In Kenya, 5.4% of pregnant women are Vitamin A deficient (VAD) and highest levels observed in pre-school age children at 9.2%. Zinc deficiencies of more than 80% were observed in children and 68% in pregnant women. Folate and Vitamin B_{12} deficiencies of 32.1% and 7.7% respectively were highest in pregnant women (KNMS, 2011). Child mortality associated with malnutrition has also contributed to a 3.8% reduction of the Kenyan work force (COHA, 2019). The most vulnerable groups include children less than 5 years, school-age children, the pregnant and lactating women, refugee and displaced persons. This is due to their increased demand for micronutrients, losses and higher susceptibility to the harmful consequences of deficiencies (Ritchie and Roser, 2020; KNBS *et al*., 2015). These vulnerable groups need cheap and readily available sources of nutrients, especially micronutrients. Finding ways of alleviation of malnutrition will help the world and Kenya in particular to concentrate on other developmental issues.

Studies have found seaweed to be a single source of numerous micronutrients (Mathew & Ravishankar, 2018). In Kenya, seaweeds grow wildly along the coastlines and production through cultivation is on the rise. Despite its availability and affordable cost of 30 Kenyan shillings per kilogram, seaweed has not been consumed to any great extent in Kenya as compared to other eastern and western countries (Msuya *et al*.,2022). This may be due to lack of adequate knowledge on its nutritional properties and ways of incorporation to diet at household levels. Inaccessibility to local market could as well be a contributing factor as bulk of the seaweed produced in Kenya is for export purposes. Being a potential single source of numerous micronutrients, improving knowledge on its nutritional composition, demystifying its safety in terms of consumption and educating the local community on ways of its incorporation in or as diet can increase its utilization. This will contribute towards alleviation of MNDs especially among vulnerable groups; paving way for exploration of more non-conventional nutrient sources.

2.1.1 Conceptual framework

A schematic overview (Figure 2.1) shows where the study is anchored on to, UNICEF Conceptual framework to improving nutrition status of the vulnerable, depicting various determinants to improved nutrition. Governance, resources and norms being the enabling determinants (UNICEF,2020) and compares readily to the study areas situation**.** Globally immunodeficiency is majorly caused by under nutrition, highest burden of MNDs majorly being felt by low- and middle-income countries due to poverty (Krawinkel,2012). High poverty and low education levels in study area may consequently contributes to poor nutrition (Oketch,2019). This affects food security, practices and norms as well as contributing to unfavorable health environments hence leading to inadequate dietary intake and diseases.

The study aims to establish whether there exists a relationship between socio-demographic characteristics and seaweed consumption patterns of the study population. To establish whether improved nutritional education and knowledge on utilization of non-conventional and readily available micronutrient sources such as seaweed, may contribute towards alleviation of MNDs and malnutrition as a whole. Increase education to demystify norms and misconception surrounding seaweed consumption and increased seaweed production as food source for sale would contribute towards increased consumption, acceptability and income generation alleviating poverty and MNDs; hence contribute towards improved dietary practices consequently improving mother and child nutrition.

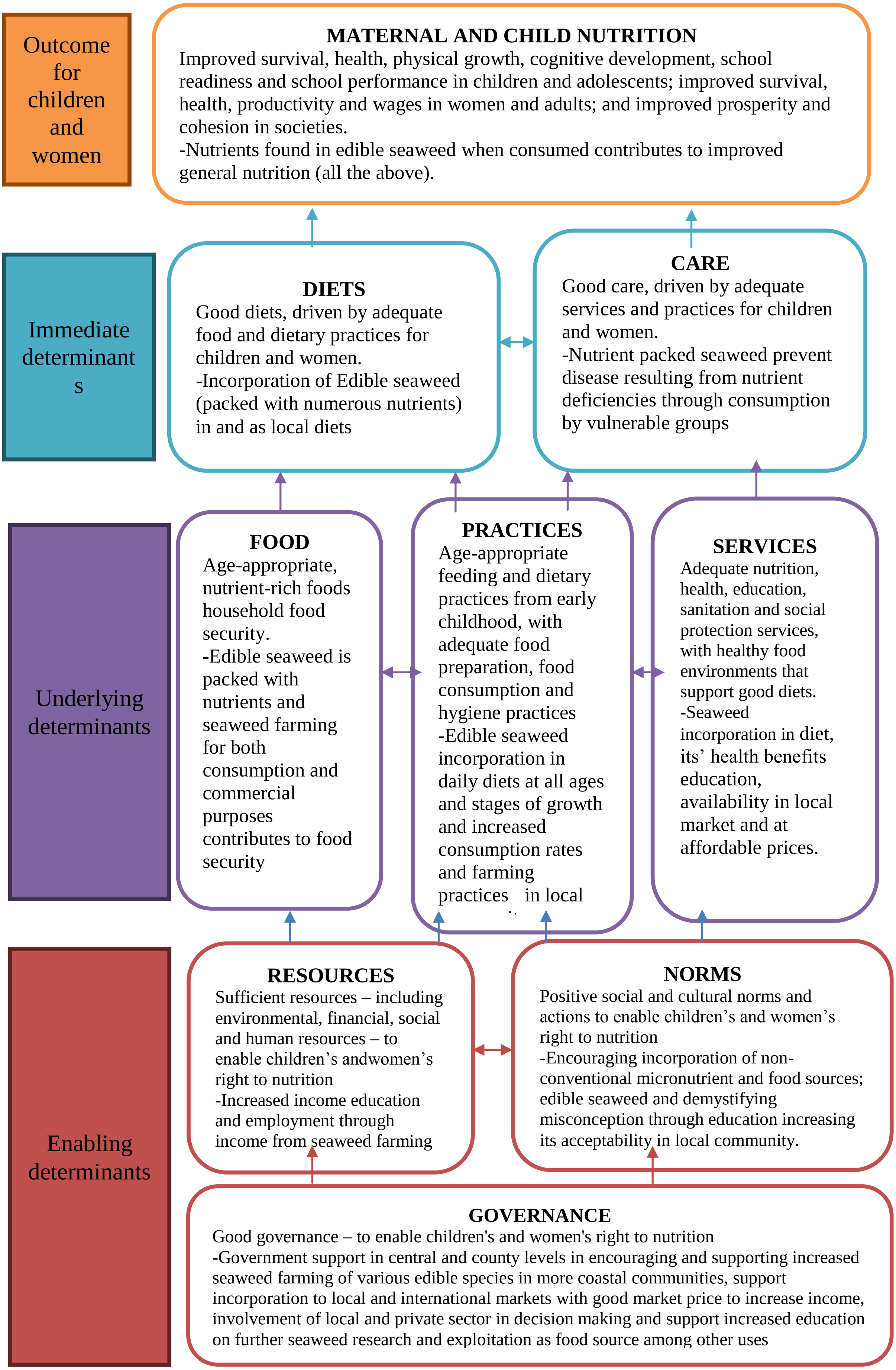

Outcome for children and women
MATERNAL AND CHILD NUTRITION
Improved survival, health, physical growth, cognitive development, school readiness and school performance in children and adolescents; improved survival, health, productivity and wages in women and adults; and improved prosperity and cohesion in societies.
-Nutrients found in edible seaweed when consumed contributes to improved general nutrition (all the above).
Immediate determinants
DIETS
Good diets, driven by adequate food and dietary practices for children and women.
-Incorporation of Edible seaweed (packed with numerous nutrients) in and as local diets
CARE
Good care, driven by adequate services and practices for children and women.
-Nutrient packed seaweed prevent disease resulting from nutrient deficiencies through consumption by vulnerable groups
Underlying determinants
FOOD
Age-appropriate, nutrient-rich foods household food security.
-Edible seaweed is packed with nutrients and seaweed farming for both consumption and commercial purposes contributes to food security
PRACTICES
Age-appropriate feeding and dietary practices from early childhood, with adequate food preparation, food consumption and hygiene practices
-Edible seaweed incorporation in daily diets at all ages and stages of growth and increased consumption rates and farming practices in local
SERVICES
Adequate nutrition, health, education, sanitation and social protection services, with healthy food environments that support good diets.
-Seaweed incorporation in diet, its' health benefits education, availability in local market and at affordable prices.
Enabling determinants
RESOURCES
Sufficient resources – including environmental, financial, social and human resources – to enable children's andwomen's right to nutrition
-Increased income education and employment through income from seaweed farming
NORMS
Positive social and cultural norms and actions to enable children's and women's right to nutrition
-Encouraging incorporation of non-conventional micronutrient and food sources; edible seaweed and demystifying misconception through education increasing its acceptability in local community.
GOVERNANCE
Good governance – to enable children's and women's right to nutrition
-Government support in central and county levels in encouraging and supporting increased seaweed farming of various edible species in more coastal communities, support incorporation to local and international markets with good market price to increase income, involvement of local and private sector in decision making and support increased education on further seaweed research and exploitation as food source among other uses

Figure 2.1: UNICEF conceptual framework on Maternal and Child Nutrition(modified by researcher)

Source: UNICEF*; Determinants of Maternal and Child Nutrition United Nations Children's Fund;* 2020. p. 3.

2.2 Blue economy

United Nations' (UN) second goal of sustainable developmental goals aims to promote sustainable agriculture, improve nutrition, end hunger and achieve food security (Blue Economy Committee Report, 2016-unpubl;UNGA, 2015). UN projects that food production may need to increase to 70% by the year 2050 to feed 2.5 billion additional humans (UNDESA, 2018). For this reason, various multisectors are teaming up to examine the future of health and nutrition by creating food from alternate non-conventional sources such as Algae nutrition.

Blue Economy (BE) is an ocean-based economic model largely dependent on coast and marine ecosystems and is recognized by UN in advancing sustainable development through the 2030 Agenda for Sustainable Development goals (UNGA, 2015). Aquaculture industry has steadily and rapidly grown to meet this demand (Little *et al.*, 2016; FAO, 2018) Algae, case in point seaweeds are some of the ocean resources that have begun to be exploited more globally as food sources of the future to feed the growing human population. This is due to their rich nutritional composition of macro and micronutrients, (Tiwari &Troy,2015).

Seaweed industry has more than doubled in the last decades producing about 30 million tons annually and becoming a multi-billion-dollar industry (MacMonagail *et al*., 2017; FAO, 2018). Exploiting blue economy for food resources will equally contribute towards moving Kenya closer to its vision 2030 of achievement of Food Security (SBEC, 2019).

2.3 Seaweed

Seaweeds are plant-like organisms that form the biomass in the tidal zones and are the largest group of consumed algae, there exists over 10,000 species (Rindi *et al.*, 2011). The main phyla of seaweed are: Chlorophyta (green algae), Rhodophyta (red algae), Phaeophyceae (brown algae) and blue-green algae (Guiry & Guiry, 2019). Seaweed habitats including reef flats, bays, coves, rocky wave exposed areas or on the edge of the reef and are found occurring in different tidal zones. Green seaweed species such as *Chaetomorpha, Codiumand Caulerpa* occur majorly in the intertidal zone (Roy,2020). The tidal or upper subtidal zones areinhibited by the brown algae such as *Turbinaria, Sargassum, Dictyota and Laminaria.* Red species also occur in the subtidal waters, these include *Eucheuma, Gracilaria, Gelidiella,Acanthophora and Ceramium* (Mwalukumbi,2022). The Kenyan seaweed flora recorded in past researches are approximately 386 species; about 56 of Phaeophyceae, 116 of Chlorophyta and 214 of Rhodophyta. Included as well is an additional 19 infraspecific taxa (Bolton *et al*.,2007;Vieira *et al*.,2021). Among countries and island on the Indian Ocean, Kenya is ranked 11th out of 66 countries in seaweed biodiversity (Bolton *et al*.,2007; Msuya *et al*.,2022).

2.3.1 Edible seaweed

Algae are found occurring in both fresh and marine waters. Most edible seaweeds are marine algae whereas the toxic algae inhabit fresh waters. Among 10,000 species of macroalgae, the worldwide consumed 'sea vegetables' are as few as 200 species (Guiry & Morrison, 2013; Guiry & Guiry, 2017; Pereira & Neto, 2015). Today edible seaweeds are popular in most continents. Seaweed used as a staple date as far as 400 BC in Asian countries of Japan, Korea and China (Collins et al.,2016). Around 21 species of seaweed are used as an everyday meal in Japan, they are consumed in dried or fresh forms as well as ingredients in food., they are also consumed as salads, curry, soup, jam as well as in processed forms. Some species use date as far as from the 8th century (Subba Rao *et al*., 2010).

Common edible seaweed are such as Nori (*Porphyra*), Wakame (*Undaria*), Kombu (*Laminaria japonica*), Irish moss (*Chondrus crispus*) etc (Table 2.1) (Peñalver *et al*.,2020). *Caulerpalentillifera* is majorly cultivated in Asia (Paul *et al*., 2013). Edible seaweeds have beenapproved and marketed in Europe as vegetables as well as condiments. (Kilinc *et al*., 2013; Mendes *et al*., 2022). In Japan among 20 different species of seaweed are consumed, Wakame (*Undaria* spp), Kombu (*Laminaria* spp) and Nori (*Porphyra* spp) being the major ones. Nori normally sold as thin dried sheets is a vegetarians and vegans favorite as it contains more Vitamin B_{12} and less Iodine in comparison to other seaweed types like Kelp which on the other hand is a rich source of vitamins C and A (Hamid *et al*., 2015).

For centuries, coastal communities especially in Asian countries have been exploiting seaweed as food due to its numerous nutritional benefits and reduced cases of MNDs have been noted but not so in Kenya (Brownlee*et al.*,2012), with increased knowledge and awareness of availability of these non-conventionalmicronutrient sources and their compositions, the communities of the Kenyan coast as well as the country at large can exploit seaweeds' nutritional benefits.

Table 2.1 Edible seaweed species and their common names

Red algae	Green algae	Brown algae	Fuvales
-*Carola *(Callophyllis spp)*	-Chorella *(Chorella spp)*	-Kelp (Laminariales)	-Bladderwrack *(Fucus vesiculosus)*
-Carrageen moss *(Mastocarpus stellatus)*	-Gutweed *(Ulva intestinalis)*	-Arame *(Eisenia bicyclis)*	-Channelled wrack *(Pelvetia canaliculate)*
-Dulse *(Palmaria palmata)*	**-*Sea grapes or green caviar** ***(Caulerpa lentillifera)***	-Bladderlocks *(Alaria esculenta)*	-Hijiki or Hiziki *(Sargassum fusiforme)*
Eucheuma** ***(Eucheuma spinosum) (Eucheuma cottonni)	***Sea lettuce** ***(Ulva spp.)***	-Cochayuyo *(Durvillaea antarctica)*	**-*Limu Kala** ***(Sargassum fusiforme)***
-*Gelidiella ***(Gelidiella acerosa)***		-*Ecklonia cava*	-*Sargassum cinetum*
-*Ogonori ***(Gracilaria) Gravilaria edulis Gracilaria corticatsa***		-Kombu *(Saccharina japonica)*	-*Sargassum vulgare*
-Grapestone *(Mastocarpus papillatus)*		-Oarweed *(Laminaria digitata)*	**-*Sargassum swartzii**
****Hypnea***		-Sea palm *(Postelsia palmaeformis)*	-*Sargassum myriocysum*
-Irish moss *(Chondrus crispus)*		-Sea whip *(Nereocystis luetkeana)*	-Spiral *wrack (Fucus spiralis)*
-Laverbread *(Porphyra laciniata/Porphyra umbilicalis)*		-Sugar kelp *(Saccharina latíssima)*	-Thongweed (Himanthalia elongata)
- Gim *(Pyropia)*		-Wakame *(Undaria pinnatifida)*	**-*Ectocarpales**
-Nori *Porphyra)*		-Hiromi*(Undaria undarioides)*	-Mozuku *(Cladosiphon okamuranus)*
		-Grapestone *(Mastocarpus papillatus)*	

***Edible seaweed species found at the Kenyan coastline according to the algae data base (www.algaebase.org)**

2.3.2 Micronutrient composition

Seaweeds are considered food for the future due to their richness in nutrients, both macro and micro (Kilinc *et al.*, 2013, Kimona *et al.*,2017). Micronutrient composition variations among seaweed species are as a result of factors such as seaweed phylum, origin, seasonal, environmental, physiological and geographical conditions (Appendix 1&II) (Circuncisão *et al.*, 2018). Seaweeds have a higher ability to concentrate rare earth element than terrestrial plant due to their cell wall polysaccharide which is of a different structure. They possess numerous metal ion binding sites making mineral content in seaweeds high, affinity for each element varies in different seaweed species (Connan & Stengel,2011). Mineral and Vitamin levels may also vary in same seaweed species, this is influenced by phylum, stages of life cycle and age of seaweed (Appendix I&II) (Pereira,2011 Peñalver *et al.*,2020;).

Micronutrient of high nutritional value found in most edible seaweeds include fatty acids, Vitamin B_{12}, Omega 3 and 6, Selenium, Iodine and dietary fiber (Peña- Rodríguez *et al.*,2011;

Gil *et al*.,2014). Seaweeds are also vegetable sources of calcium, with content ranging from 7% to 25% (Peñalver *et al*.,2020).

Fortification of wheat and maize based bread with Sargassum spp have been noted to increase the proportion of absorbed iron, its iron content being 156 mg per 100g of dry weight (Garcia-Casal *et al.,* 2018). Vitamin content varies according to species; Vitamin A content in 5g of dried *Ulva rigida* is approximately 14.5 μg whereas Fucus spiralis contains 70.5 μg (Taboada *et al*., 2010; Paiva *et al.*, 2014). Content in vitamin C varies from 0.41 mg in Ascophyllum nodosum to 9.24 mg in *Undaria pinnatifida*. In Ulva spp folate varies from 7.5 μg to 5400 μg (Taboada *et al.,* 2010)

VitaminD_3 contentofdryweightin Fucusspiralis is0.83 mg/100 gand1.05 mg/100 g in Porphyra spp(Paiva *et al*., 2014). Seaweed is among the few vegetablesources of Vitamin B_{12}. Vitamin B_{12} content in 4g of dried purple laver contains 77.6 μg /100 g suppling an RDA of 2.4 μg/day (Watanabe *et al.*,2014).

Iodine levels in varies among species, from 0.06 mg/100 g of dry weight in *Ulva lactuca* , 624.5 mg/100 g of dry weight in *Laminaria digitata* to only 80 μg/5g portion of Porphyra tenera. In Japan, iodine intake levels are high varying from 0.1 to 20 mg/d exceeding the upper tolerable limits (Zava & Zava, 2011).

2.3.2.1 Importance of micronutrients found in seaweed

Vitamin B_{12} in *Porphyra species* is mostly prescribed in ageing effects therapy, anemia and in treatment of chronic fatigue (El-Beltagi *et al.*,2022). *Himanthalia elongata, Palmariapalmata* contains Vitamin C that plays numerous roles such as strengthening the immunesystem, activation of iron absorption in the intestinal, aids in conjunctive tissue formation, regenerating Vitamin E and in trapping free radicals (Mwalukumbi,2022). *Fucus species* contain Vitamin E that inhibits low density lipoproteins oxidation and formation of prostaglandins and thromboxan in the arachidonic acid chain (Mwalukumbi,2022). Iodine found in most brown species such as *Fucus vesiculosus, Laminaria species, Undaria pinnatifidahe* have traditionally been used for goiter treatment (Holdt, 2011). *Undariapinnatifida, Laminaria spp. Saccharina spp* among other seaweeds *are* packed with calcium are recommended tovulnerable persons exposed to risk of calcium deficiency such as expectant mothers, adolescents and the elderly (Biris-Dorhoi *et al*.,2020).

Flavonoids, carotenoids and antioxidants such as vitamins A, C and E protect cells from being damaged by free radicals (Mikami & Hosokawa, 2013; Chia *et al*, 2015). Fucoxanthin a carotenoid in brown seaweed such as wakame has been shown to protect cell membranes, reduce blood sugar levels and body fat, aiding in weight loss. (Mikami *et al.*, 2017). It also helps aids in alleviating the risk of type 2 diabetes through controlling blood sugar levels (Mikami *et al* 2017). Seaweed promotes gut health due to its rich source of fiber as well as in the reduction of blood cholesterol levels (Shirosak,2011;Holscher,2017). Fucans, carbohydrates in seaweed may help also prevent blood clotting (Magalhaes et al.,2011).

2.3.3 Bioavailability of seaweed micronutrients

Bioavailability varies among seaweed species. About 5.2g of *dulse* powder, 2.3g of dried sea lettuce or 6g of dried *nori* provides 100% of daily require intake levels of Iron. With these exceptions, other seaweeds do not provide more bioavailable Iron per gram of dry matter than spinach due to low Iron absorption efficiencies in the seaweeds (Flores *et al*., 2015). *Nori* and sea lettuce have higher Iron content and absorption efficiencies hence provides more bioavailable Iron per gram dry matter than spinach. Vitamin C is also noted to increase Iron bioavailability in *nori* and sea lettuce (Flores *et al*., 2015). Vitamin B12 in *chlorella* and *nori* were found to be bioavailable by significantly improving Vitamin B12 status when fed to Vitamin B12 deficient rats (Madhubalaji *et al*.,2021). Iodine bioavailability in two different locations were found varying and at high percentages in two seaweed of, *gracilariaverrucos*a and *laminaria hyperborea* (Circuncisão *et al*.,2018). Vitamin bio-availability mayalso be impacted by processing methods as drying of *Porphyra* species inactivates Vitamin B12 (Watanabe *et al*, 2014). *Undaria pinnatifida* (wakame) has a high protein bioavailability of 85-90%(Holdt, 2011).

2.3.4. Seaweed as nutraceutical

Recent studies have shown that seaweeds can be referred to as nutraceuticals or functional foods, as they possess other dietary benefits other than their nutrient content. (Misurcova *etal.*, 2011). Metabolites with biological activity in seaweed have been used in therapeuticproducts production (Davis & Vasanthi, 2011; Zerrifi *et al*., 2018). Seaweeds are a source of phytochemical constituents with potential health benefit and used for nutraceutical developments (Holdt & Kraan, 2011; Brown *et al.*, 2014). The bio-active compounds such as polysaccharides are explored for their biological activities and functional properties such as antiviral, antidiabetic, antiinflammatory, antimicrobial, antitumor, anticoagulant, cytotoxic, anti-HIV and anti-Alzheimer’s activity *in vitro* (Nagarajan & Mathaiyan, 2015). Carotenoids, tocopherols and polyphenols in seaweed serve as antioxidants, inhibitors or suppressors of free radical generation.

Polyphenol compounds known for their potential biological activities are common in brown and red seaweeds (Abirami & Kowsalya, 2017). These are such as *H. elongrata*, *Euchema cottonii,Sargassum muticum* and *Ecklonia cava* (Rajauria *et al*., 2012). Omega 3 and 6 acids found in *Porphyra spp.* (brown algae) have been noted to prevent diabetes, cardio-vascular diseasesand osteoarthritis (Holdt, 2011). Green and Red seaweeds contain high protein content, an average of 10-30 % of the dry weight, for instance *dulse* and *nori* can contain high protein ranges of 35% to 47% of the dry matter, respectively (Peñalver *et al,*2020). *Wakame* contains a high biological protein value due to a high bioavailability of 85-90% and a high essential amino acids balance (Holdt, 2011).

2.3.4.1 Other uses of seaweed

Anciently seaweeds have been used as fertilizers, dyes, fodder and folk remedies. Alginate, carrageenan and agar are hydrocolloids, polysaccharide extractives found in red and brown seaweed. Their gelling properties have been utilized in foods, biotechnological and pharmaceutical applications (Rhein-Knudsen *et al*., 2015; Zollman, 2019). *Ascophyllum,Macrocystis, Laminaria, Alaria, Palmaria and Pelvetia* species are some of seaweeds usedas fodder. Species of *Gelidium, Gracilaria, Pterocladia, Gelidiella, Ahenpeltia* and *Acanthopeltis* are agarophytes, while those of *Laminaria, Macrocystis, Ascophyllum, Durvillea, Ecklonia* and *Sargassum* species are alginophytes. *Carrageenophytes* includespecies of *Chondrus, Gigartina, Sarcothalia, Eucheuma* and *Kappaphycus.* Seaweed has contributed to green fuel alternatives through bio-diesel production (Abomohra *et al*., 2016; Chye *et al*., 2018). It has also been used as indicators and bio-filters to reduce toxic materials such as metal content thus reducing pollution in aquatic environments containing (Lim *et al* 2015).

2.3.5 Seaweed aquaculture

Over the last fifty years, economic importance and demand for seaweed has been on the rise, surpassing the ability to supply requirements from natural wild stock. Decline in the global seaweed production from wild harvest has been noted, attributing to only five percentage of the global seaweed production. Over 90% of market demand is now being produced by the cultivation industry (FAO 2010, 2011, 2012). Numerous seaweed species are known to exist but only a few are used in aquaculture of seaweed, these include: brown algae such as *Saccharina japonica* and *Undaria pinnatififida*, as well as red algae *Kappaphycus alvarezii,Eucheuma striatum* (carrageenophytes), *Gracilaria*/*Gracilariopsis* and *Porphyra* species (FAO, 2017).

Cultivation first began in Philippines and the first two species majorly farmed commercially due to their economic importance and uses were *Eucheuma denticulatum* and *Kappaphycusalvarezii.* These species are often farmed for their phycocolloid and carrageenan properties,their use in food, pharmaceutical and cosmetic industries and account for over 80% of world's carrageenan production (Rupert *et al*.,2022; Hayashi*et al*., 2010).Its commercial value per unit mass of $523 per wet metric ton is the highest in comparison to other aquacultured species. Kelp is $141 per wet ton, *Gracilaria*, $273 per wet ton, *Kappaphycus* /*Eucheuma*, $172 per wet ton and *Sargassum*, $460 per wet ton (FAO,2017). Countries such as Tanzanian, Madagascar,South Africa Fiji, Morocco, Namibia, Senegal, Kiribati and Mozambique have/had adopted commercial cultivation due to increasing global demand for seaweed extracts (Msuya *et al*., 2022). Compared to opportunity cost of activities such as fishing, coastal inhabitants have reported seaweed aquaculture to be a low capital investment venture with high return rates ranging from 78% to over 100% per annum (Valderrama *et al*., 2013). Gazi Bay and Kibuyuni in southern coast were one of the chosen pilot sites for commercial eucheumoid cultivation in Kenya (Wakibia *et al*., 2011).

Culture technique

The fixed off-bottom technique is commonly used for eucheumoid cultivation where seaweed cuttings are stocked on polypropylene ropes of about 5 meters long and 4 millimeter in diameter. The cuttings are then tied to the rope using plastic straws at intervals of 25 cm. In order to maintain the farms, epiphytes are removed and loose stakes, ropes and cuttings tightened at least every fortnight. The seaweed is ready for harvest after six weeks, the stocked ropes are untied and the water drained.This technique is efficient as installation is simple with low maintenance and material cost (Wakibia *et al*., 2011).

2.3.6 Risks associated with seaweed consumption

Heavy metals is one of the major concerns about seaweed consumption, seaweed accumulates heavy metal coming from contaminated aquatic environment through adsorption in concentrated amounts on the surface of its tallus (Lim *et al*., 2015; Desideri *et al*,2016). Possible heavy metals exposure includes Arsenic, Lead, Cadmium, Aluminium, Mercury, Nickel, Silicon, Tin etc (Kimona *et al*.,2017). The types and concentration of metals vary with species, ecology, growth phase and habitat. In dried seaweed products tested, 8.5g of seaweed consumed contained 0.2% to 6.7% tolerable weekly intake of Arsenic, Mercury, Lead and

Cadmium (Hwang *et al*, 2010). Bio-absorption rate of heavy metals varies between species such as the high levels of 0.2-0.5 mg/kg of dry weight of Cadmium in *Laminaria japonica* as compare to *Laminaria digitata* were observed (Zhao *et al.*,2012; Desiderie *et al.*,2016). Perennial speciessuch as *Ulva* and *Halimeda* species accumulate numerous types of metals in their tissues hence their safety for use in aquaculture feeds need to be determined beforehand (Mutia &Matern, 2018).

Some seaweed species contain potentially toxic Arsenic levels with total content ranging from 4.1 to 111.0 µg/g. Majority of Arsenic present as inorganic Arsenic content (arsenosugars) with levels below 1.0 µg/g such as *Laminaria digitata*, *Fucus spiralis (*brown seaweed*)*, *Porphyra umbilicalus*, *Chondrus crispus* (red seaweed) and *Ulvaprolifera* and *Ulva lactuca (*green seaweed). *Laminaria digitata*, contained levels of 36 to131 µg/g of dry weight while in contrast, *Laminaria japonica* contained below maximum limits of 0.16 to 0.58 mg/kg (Feldmann *et al,* 2011; Desideri *et al*.,2016; Ronan *et al*., 2017; Taylor & Jackson, 2016). Species of *Gracilaria* are affected by bio-accumulation of Cadmium in the ocean (Ardiyansyah *et al*., 2019). Cadmium intake in concentrated amounts is allegedly linked to Iron deficiency (Silver, 2013). *Laminaria digitata* can contain large and potentially dangerous amounts of Iodine that could poses a risk of impaired thyroid function in daily consumption (Michikawa *et al*., 2012). In Japan, daily average intake is about 1,000-3000 µg, above tolerable upper limits (Zava & Zava, 2011). This is countered by cooking seaweed with goitrogen containing foods such as broccoli, cabbage, bok choi and soy. The phytochemicals in these foods compete with iodine thus inhibiting excess uptake by the thyroid gland (Zava & Zava, 2011).

CHAPTER THREE

3.0 RESEARCH DESIGN AND METHODOLOGY

3.1 Study design

A combination of a cross sectional and comparative experimental study design was used. Comparative experimental design where by seaweeds growing along the Kenyan coastline and those cultivated were sampled from selected areas, analyzed for presence of micronutrients and heavy metals and comparison in the levels made.

3.2. Study setting

3.2.1 Geographical location

Lying in the tropical zones and bordering Somalia and Tanzania to the north and south respectively, the Kenyan coastline stretches about 640km in length extending from Kiunga, Lamu county to the north (1. 41ºS) to Vanga Kwale county to the south (4.40ºS). Parallel to the coastline and lying about 0.5 to 1.5 km offshore, is a continuous fringing coral reef platform. Tana River and Sabaki River are the main rivers discharging their waters into the Indian Ocean. Six counties make up the Kenyan coast, Lamu, Kilifi, Mombasa, Tana River, Taita taveta and Kwale County. All except Taita Taveta lie on the Kenyan coastline. Mombasa County is approximately 275 km^2 and has a 32km coastline. It is made up of the island, mainland, Tudor and Makupa creeks as well as Kilindini and Port Reitz (65 km^2) (Figure 3.1). Kilifi County begins from 'mto' Kilifi and extends southwards to Mtwapa creek with a coastline distance of 265km. It consists of the Mida and Kilifi creek. The coastline is majorly sandy beaches such as those found in Malindi and Watamu, renowned tourist destinations. Kwale County has a coastline south of Mombasa and consists of smaller islands such as Chale, Wasini and Funzi. Gazi Bay (4^o25'S, 39^o30'E) in Kwale county is a mangrove system fed by freshwater from nearby rivers. Slave caves, forests, the coastal beaches and marine ecosystems are commonattractions in Shimoni. The shores in Kibuyuni (4^o38'S, 39^o20'E) in Shimoni has a large flat intertidal reef and this is where the pilot seaweed farms were established (Chesori,2015).

3.2.2 Demographics

Population of counties along the coastline is Mombasa-,1208,333, Kwale -866,820, Kilifi 1,453,787, Lamu-143,920, Tana River-351,943 (KNBS, 2019). Major ethnic communities of the coastal counties include the Mijikenda, Swahili, Arabs and a significant presence of the Kamba tribe among other small communities. Agriculture, fishing, trade and tourism are among the major economic activities. Majority of population are Christians and Muslims. Kibuyuni is one of the areas in Kwale County are where seaweed farming is practiced, majority of seaweed farmers reside there and in the surrounding villages (Mirera *et al*.,2020).

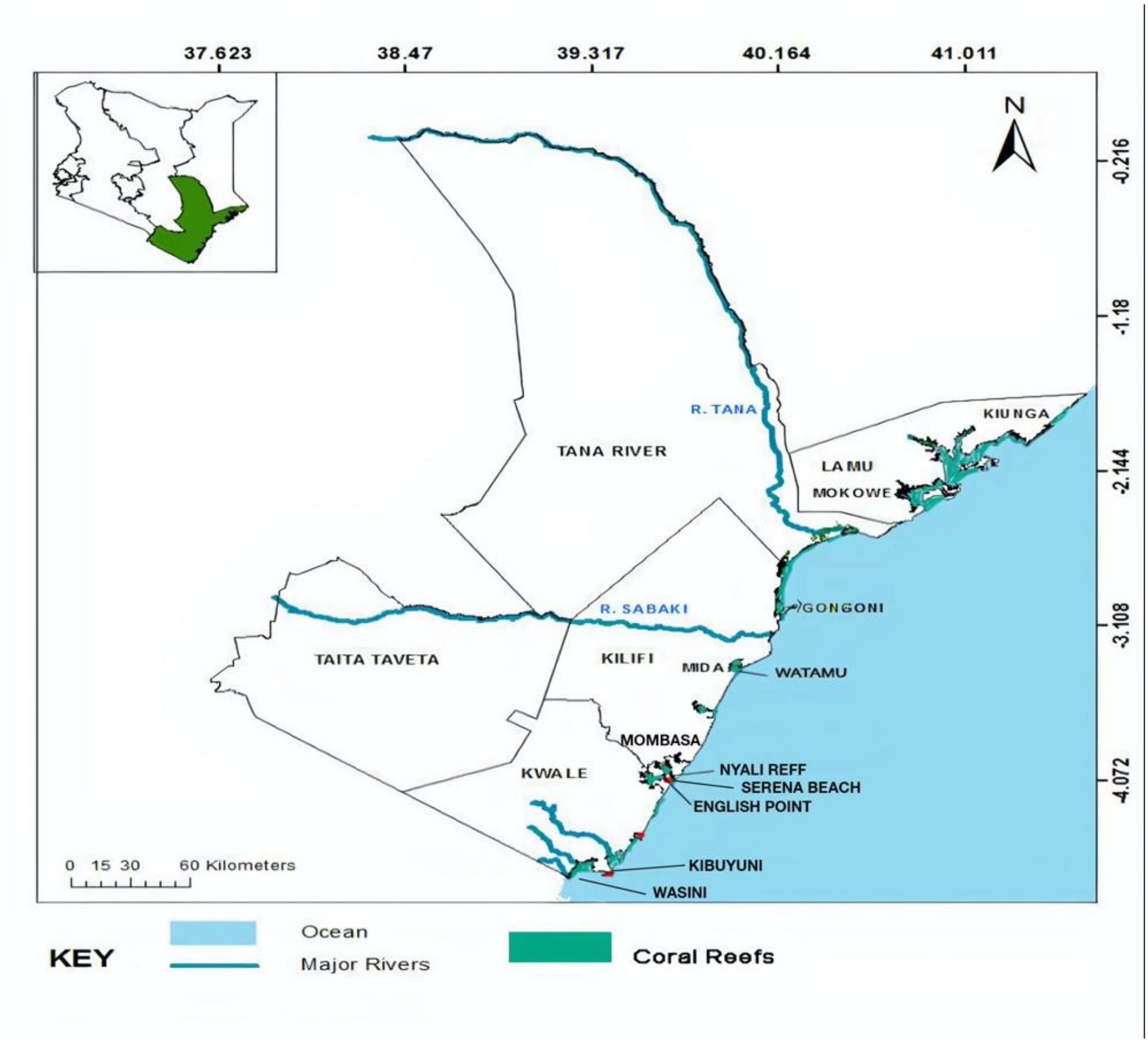


Figure 3.1 : The Kenyan coastline showing coral reef, rivers and study locations
Source: (https://www.google.com/maps/kenya)

3.2.3 Study population

In Kenya seaweed cultivation was established in coastal villages of Kwale County (Nyundo,2017). The study population included households from five villages where seaweed farmers in Kwale county resided, that is Kibuyuni, Fikirini, Kijiweni, Magogoni and Wasini. The study population also included edible seaweed species found growing wildly in three (Mombasa, Kilifi, Kwale) out of the five counties of the Kenyan coastline, that is Kwale (Kibuyuni beach), Mombasa (Nyali reef beach, Serena beach, English point) and Kilifi (Watamu beach) counties, as well as seaweed species being farmed in Kibuyuni.

3.3 Sampling design

Purposive sampling was employed to selected coastal counties where seaweed samples were collected. These counties made up the sampling clusters whereby seaweed samples were obtained from three out of six coastal counties. In each cluster, samples were collected through simple random sampling from the selected sites. Purposive sampling design was also used in selection of the seaweed farming population as seaweed farming in Kenya is currently practiced majorly in Kwale County. Selected seaweed farming villages were the sampling units where households in the villages were randomly selected.

3.3.1 Selection criteria

Inclusion criteria

Edible seaweed samples collected from sampling units(wild growing and farmed) and households in seaweed farming villages

Exclusion criteria

Seaweed samples that were not edible and households that did not practice seaweed farming

3.3.2 Sample size

Sample size of study population is estimated using the Fischers' formula where; $\mathbf{N=Z^2pq/d^2}$, Z^2=level of significance (1.96=95%), p=prevalence at 50%, q=(1-p), d^2=degree of accuracy (0.05=5%)=(1.96^2 x0.5x0.5)/0.05^2 =384.16=385. Since seaweed farming population is finite hence= $\mathbf{n^0 = n/(1+(n-1)/N)}$=385/(1+(385-1)/1000) =278.

The study drew due to financial constrains a sample size of 175 participants from the seaweed farming villages of Kibuyuni, Fikirini, Kijiweni, Magogoni and Wasini who formed the study population where a member of every household was interviewed. The study population also comprised of seaweed that grew wildly along the Kenya coastline collected from the 5 different beaches of English point, Nyali reef, Serena beach (Mombasa county), Kibuyuni beach (Kwale county) and Watamu beach (Kilifi County) and seaweed species that were farmed in Kibuyuni village.

3.4. Sampling procedure

Purposive sampling of study populations of seaweed farmers and seaweed sampling sites of Kwale, Mombasa and Kilifi counties was employed. Random sampling of seaweed was employed in the specific seaweed sampling sites in each county, this included Nyali Reef beach, Serena beach and English Point beach(Mombasa country), Kibuyuni beach (Kwale county) and Watamu beach (Kilifi county). Participants from households in the villages where seaweed farmers reside in Kwale County were also randomly selected to participate in the interviews (Figure 3.2).

Wildly growing seaweeds were randomly collected from the sample sites in each cluster with the help of professional seaweed research team from Kenya Marine and Fisheries Research Institute (KEMFRI). They included various seaweed species comprising of Red, Brown and Green edible seaweed phyla. Euchemoid seaweed species comprising of green and brown *Kappaphycus alvarezii* (cottonii) and *Euchuma spinosun* (Green and Brown phyla), the majorspecies cultivated in the seaweed farms, were also randomly sampled.

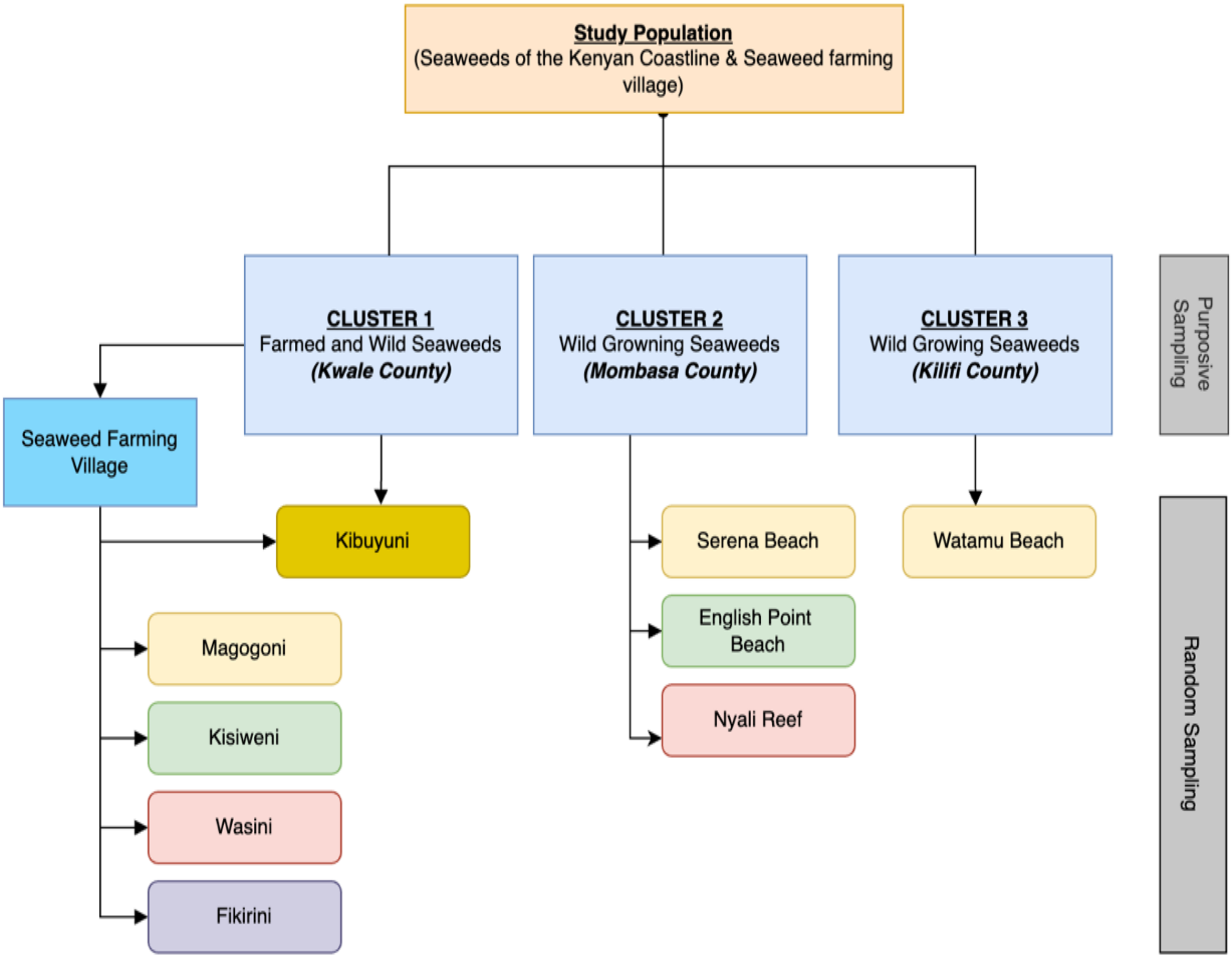


Figure 3.2: Sampling schema of the study population sampling sites

3.5 Data collection

Qualitative and quantitative methods of data collection was used to collectprimary data of socio-demographic characteristics and seaweed consumption patterns as well as to determine micronutrient and heavy metal levels in edible seaweed samples respectively. Laboratory experiments were conducted to determine micronutrient levels in edible seaweed samples. Interviews were also conducted at household levels to collect socio-demographic characteristics and seaweed consumption patterns.

3.5.1 Socio-demographic characteristics data collection

Socio-demographic data of the study population was collected through interviewing 175 participants from households in each of the five villages where seaweed farmers resided.

Guided by a semi-structured questionnaire, the researcher asked the participants questions and the responses were later recorded in the Open Data Kit (ODK) application in a smart phone for ease in data entry and conversion to numerical data.

Data collection in the study population

Source: Pictures taken by researcher Mercy Nelima during research (permission obtained)

3.5.2 Seaweed consumption patterns data collection

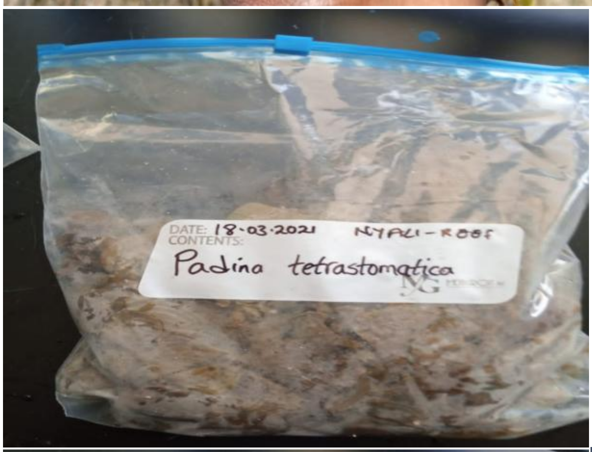
This was collected through a food frequency recall whereby a Food Frequency Questionnaire(FFQ) was administered to the 175 participants from households in each of the five villages. Respondents were asked whether they do or have consumed seaweed, the amount and number of times consumed, in which form consumed etc.

Fresh seaweed salad and cooked seaweed

Source: Pictures taken by researcher Mercy Nelima during research (permission obtained)

3.5.3 Micronutrients and heavy metals data collection

This data was obtained through laboratory analysis of seaweed samples collected from five beaches along the Kenyan Coast; English point, Nyali Reef and Serena beaches in Mombasa county, Kibuyuni beach in Kwale county and Watamu beach in Kilifi county. Micronutrients that were analyzed from the seaweed samples included Vitamins; fat-soluble vitamins (A and D) and water-soluble vitamins (B_9 and B_{12}). Minerals analyzed were Iron, Zinc and Iodine. Heavy metals analyzed wereLead, Cadmium, Nickel and Mercury. Ultraviolet Spectrophotometry (UV/VIS) was used to analyse vitamin A, B_9, B_{12} and High Performance Liquid Chromatography (HPLC) for vitamin D whereas Mineral and heavy metals were analyzed using Atomic Absorption Spectrophotometry (AAS).


DATE: 18·03·2021 NYALI-REEF
CONTENTS:
Padina tetrastomatica


DATE: 18·03·2021 NYALI-REEF
CONTENTS:
Gracilaria sarlicornea


DATE: 18·03·2021 NYALI-REEF
CONTENTS:
Ulva lactuca


DATE: 18·03·2021 NYALI-REEF
CONTENTS:

Edible seaweed species data collection

Source; pictures taken by researcher Mercy Nelima during research (permission obtained)

Sample preparation

All fresh seaweed samples were washed in respective sites in sea water to remove all extraneous matters such as epiphytes, shells, associated fauna and adhering sand particles. Samples were also washed in fresh water to remove salt on the surface. Fresh wild and farmed seaweed samples were then stored in a cooler and transported to KEMFRI laboratories in Mombasa for botanical identification and naming. Analysis of micronutrient and heavy metals parameters was then done at University of Nairobi and Jomo Kenyatta University laboratories. All collected samples were coded and labeled for easy of identification and handling (Table 3.1)

Table 3.1: Sample codes and their corresponding species name

MOMBASA COUNTY				KWALE COUNTY		KILIFI COUNTY	
ENGLISH POINT (Ep)=16 Brown seaweed (Phaeophyceae) 17.3.2021		**NYALI REEF(Nr)=13 Brown seaweed (Phaeophyceae) 18.3.2021**		**KIBUYUNI (Ki)=16 Brown seaweed (Phaeophyceae) 26.3.2021**		**WATAMU(W)=9 Brown seaweed (Phaeophyceae) 27.3.2021**	
EpB1	*Sargassum polycystum*	**NrB1**	*Sargassum ilicifolium*	**KiB1**	*Sargassum oligocystum*	**WB1**	*Sargassum oligocystum*
EpB2	*Sargussum aquifolium*	**NrB2**	*Sargassum oligocystum*	**KiB2**	*Sargussum aquifolium*	**WB2**	*Sargussum aquifolium(limited)*
EpB3	*Turbinaria decurrens*	**NrB3**	*Turbinaria ornata(limited)*	**KiB3**	*Padina tetrastromatica*	**WB3**	*Padina tetrastromatica*
EpB4	*Turbinaria conoides*	**NrB4**	*Turbinaria conoides(limited)*	**KiB4**	*Dictyota dichotoma*	**WB4**	*Turbinaria ornata*
EpB5	*Dictyota dichotoma*	**NrB5**	*Turninaria decurrens*				
EpB6	*Padina tetrastromatica*	**NrB6**	*Dictyota cervicornis(limited)*				
		NrB7	*Padina Tetrastomatica*				
Green seaweed (Chlorophyta)		**Green seaweed (Chlorophyta)**		**Green seaweed (Chlorophyta)**		**Green seaweed (Chlorophyta)**	
EpG1	*Ulva reticulata*	**NrG1**	*Ulva reticulata*	**KiG1**	*Ulva reticulata(limited)*	**WG1**	*Ulva reticulata(limited)*
EpG2	*Ulva lactuca*	**NrG2**	*Ulva lactuca*	**KiG2**	*Ulva lactuca(limited)*	**WG2**	*Ulva lactuca*
EpG3	*Ulva fasciata(limited)*	**NrG3**	*Ulva fasciata(limited)*	**KiG3**	*Ulva pulchra*	**WG3**	*Caulerpa fastigiata*
EpG4	*Ulva intestinalis*						
EpG5	*Caulerpa lentifera(limited)*						
EpG6	*Caulerpa toxifolia*						
Red seaweed (Rhodophyta)		**Red seaweed (Rhodophyta)**		**Red seaweed (Rhodophyta)**		**Red seaweed (Rhodophyta)**	
EpR1	*Gracilaria salicornia*	**NrR1**	*Gracilaria salicornia*	**KiR1**	*Gracilaria salicornia*	**WR1**	*Gracilaria salicornia*
EpR2	*Gracilaria corticata*	**NrR2**	*Gracilaria corticata*	**KiR2**	*Gracilaria corticata*	**WR2**	*Hypnea cornuta*
EpR3	*Hypnea cornuta*	**NrR3**	*Hypnea cornuta*	**KiR3**	*Gracilaria verrucosa*		
EpR4	*Hypnea musciformis*			**KiR4**	*Hypnea cornuta*		
				KiR5	*Soliera robusta*		
				KiR6	*Eucheuma spinosum(wild)*		
SERENA BEACH(S)=4 Brown seaweed (Phaeophyceae) 19.3.2021				**FARMED(F)=3**			
SB1	*Sargassum*			**KiRF1**	*Kappaphychus*		

	aquifolium				*alvarezii(eucheuma cottonii)(Red)*		
SB2	*Sargassum ilicifolium*			**KiGF2**	*Eucheuma spinosum(Green)*		
SB3	*Turbinaria conoides*			**KiBF3**	*Eucheuma spinosum(brown)*		
SB4	*Padina tetrastromatica*						

Research tools

Reagents and chemical used were of analytical grade. Equipment used included; AAS machine (BUCK scientific model: 210 VGP), UV/VIS machine (PERKIN ELMER, Lambda 2), HPLC machine (KNAUER Model pump EA4300.Detector E4365) glassware, crucible, measuring, cylinder, incubator, furnace, weighing scale

3.5.3.1 Vitamin Analysis of edible seaweed samples by UV/ViS/HPLC

Vitamin A (β-carotene) analysis by UV/ViS

Sample preparation

Vitamin A in the samples were extracted using modified version of the methods used by Jadoon et al., and Musara & Nyagura. Briefly, the plant sample were ground using a mortar and pestle and 5 g of sample was extracted by refluxing with 1g of ascorbic acid and with 10 mL of methanol, sample in glass tube was protected from light to prevent oxidation. It was then saponified (to break down lipid globules in which the fat-soluble vitamin is bound) by 15 mL of 50% KOH, vortexed for 1 minute then incubating in a water bath at 45℃ for 2 hours. After refluxing, 50 ml of water was added and fat-soluble vitamin extracted three times with 10ml hexane. The organic layer was recovered using a separating funnel and evaporated to dryness in an oven at 37℃. The residue was then re-dissolved in 5ml of 10% methanol and topped to 10mL with distilled water. The samples were then kept in dry clean vials and stored in the fridge at 4℃ waiting for analysis using UV-visible light spectrophotometer. The absorption spectrum of vitamin A is between 300 and 350 nm, with peak absorbance at 328 nm (Jadoon *et al.*, 2013; Musara & Nyagura, 2017).

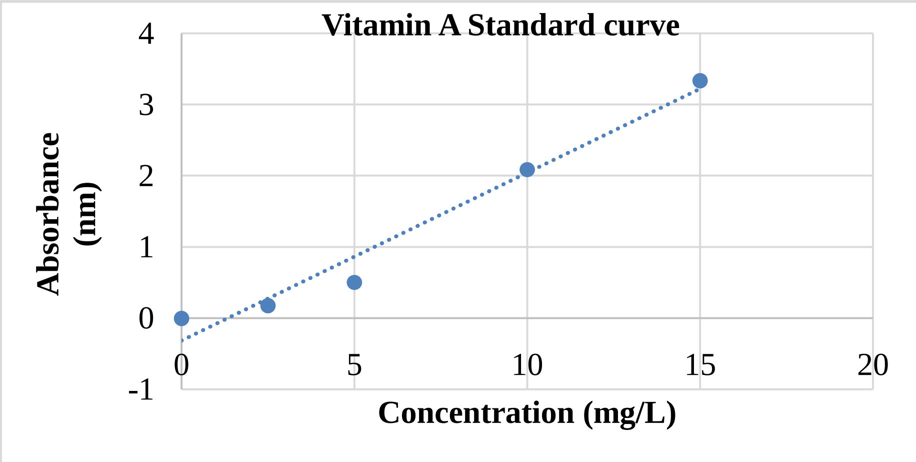


Figure 3.3: Vitamin A Standard curve

Vitamin B_9 (Folate) analysis by UV/ViS

Sample Preparation

5g of ground plant samples were extracted for Vitamin B_9 using 50 ml of methanol and saponified using 15ml KOH, 10ml of 50% ethanol and 1g ascorbic acid at 45℃ for 1 hour and filtered into clean vials. 100mg Folic Acid standard, was precisely weighed and put to a 100ml volumetric flask then dissolved with methanol. The final volume was then filled with distilled water, yielding a solution with a concentration of 1000mg/l. A working standard of 100mg/l was prepared by diluting 0.1ml of the stock solution to 10 ml with distilled water (Kshirsagar *et al.*, 2017; Modupe *et al.*, 2020).

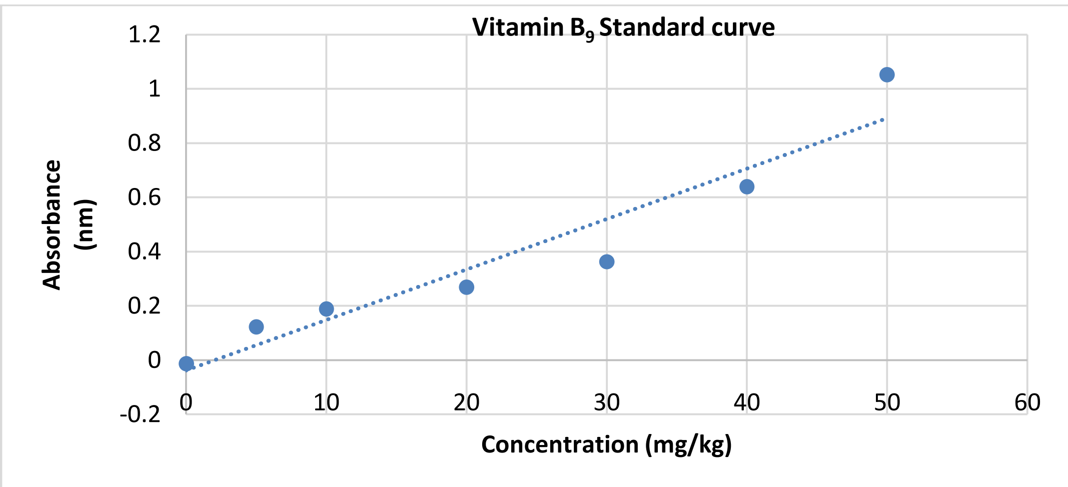


Figure 3.4: Standard curve for Vitamin B_9

Vitamin B_{12} (cyanocobalamin)

The concentration of cyanocobalamin was determined using UV/Vis by comparing the plant extracts with standards of known concentrations using the maximum absorbance at 361 nm according to Birgit Schelling, Mettler Toledo method (Schelling, *n.d.*).

Sample preparation

5g of sample was extracted by refluxing in 50% methanol at 60℃ for 2 hours cooled and filtered into clean vials.

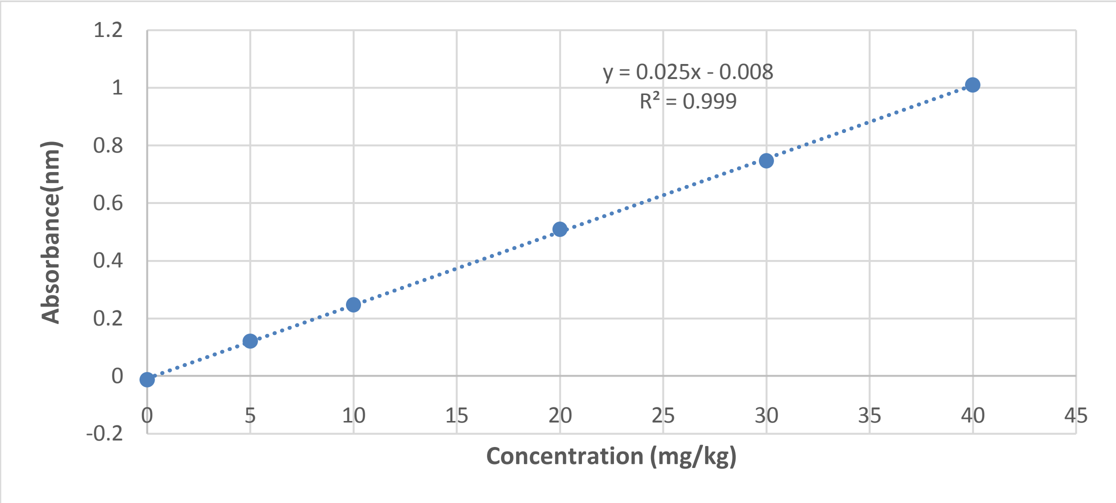


Figure 3.5 : Vitamin B_{12} Standard curve

Standards preparation

In spectrophotometry the concentration of a substance is directly proportional to the absorbance. It was thus possible to determine the quantity of Vitamin A, B_{12} and B_9 respectively using their standards at maximum wavelength of absorbance of 328, 361 and 283 nm respectively. The standard for analysis of vitamins were prepared as follows; Vitamin A; 0, 2.5, 5, 10 and 15mg/l, Vitamin B_9; 0, 5, 10, 20, 30, 40, and 50mg/l, and Vitamin B_{12}; 0, 5,10, 20, 30 and 40mg/l. The standard curves were prepared by transferring 3ml of the respective standards to a quatz cuvette and the standards measured at the wavelength corresponding to the peak absorbances. The stock standards were prepared and the working standards prepared by serial dilution. Water was used as a blank. All experiments were carried out in triplicates and the results expressed as mean ± standard deviation (SD) in mg/L/kg using the equation below.

$$Concentration\ per\ kg = \frac{Measured\ concentration\ \left(\frac{mg}{L}\right) x\ 1000\ g}{weight\ of\ sample}$$

Vitamin D (ergocalciferol) analysis of edible seaweed using HPLC

A high-performance liquid chromatograph Knauer, equipped with a diode array detector and a ChemStation data acquisition system, was used. The chromatographic separation was performed on a reversed-phase Eurospher C18 100 × 3.0 mm, 3 µm particle size column at 35°C using acetonitrile–water (99:1, v/v) as a mobile phase at a flow rate of 1 mL/min. The injection volume was 50 µL, depending on the type of the preparation. The detection was carried out at 265 nm (Keyfi *et al*.,2018).

Reagents and chemicals

Vitamin D_2 (98%, CAS No. 67-97-0) and 30% solution of hydrogen peroxide (H_2O_2) were purchased from Sigma-Aldrich (Steinheim, Germany). Sodium hydroxide (NaOH), hydrochloric acid (HCl), formic acid (HCOOH) and orthophosphoric acid (H_3PO_4) were obtained from Merck (Darmstadt, Germany). Both acetonitrile and methanol of HPLC grade were from Sigma-Aldrich. Micro filters 0.2µm.

Sample Preparation:

A sample of 0.5 g was mixed with 20 ng internal standard (Cholecalciferol-D_3), adding 4 mL water, 16 mL pyrogallol ethanolic solution (2g/100mL) and 8 mL of KOH (50%) solution. The mixture was then saponification at 70^{o}C for 1 hour mixing periodically. After cooking to room temperature, liquid-liquid extraction was done with 12 mL hexanes mixed and then hexane layer washed with 8mL water. From the extract 6mL was taken, blow dried with nitrogen at 30^{o}C and then reconstitute with 5ml acetonitrile. The solution was then filtered with 0.2-micron membrane filter before injection (Keyfi *et al*.,2018;Yang*et a*l.,2017).

Standard preparation

Working standards solution was prepared by dissolving 10.0 mg of Vitamin D_2 into 100.0 mL methanol and diluted to 1,000 µL with methanol to form stock solution. (Keyfi *et al*.,2018). The stock solution was mixed and diluted with acetonitrile to obtain a series of standard calibration solutions. Calibration linearity plot was generated by plotting concentration (ppb) against peak area. Calibration ranged from 0.002 to 0.2 mg/kg (AOAC,2017).Vitamin D_2 peak was eluted at 6.6 minutes. Vitamin D_3 which was also detected to be present and was eluting at 7.2 minutes Results were expressed as mean± SD.

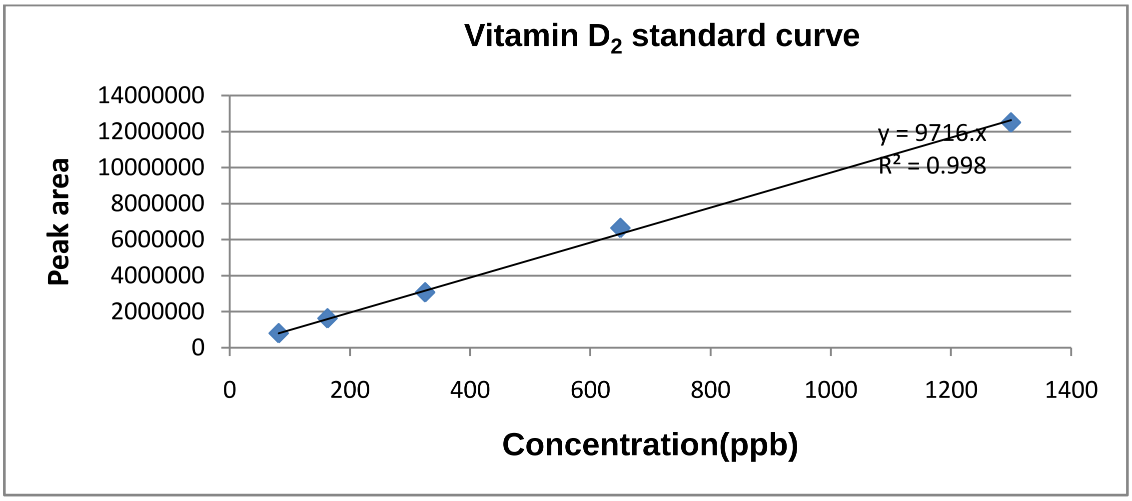


Figure 3.6: Vitamin D_3 standard curve

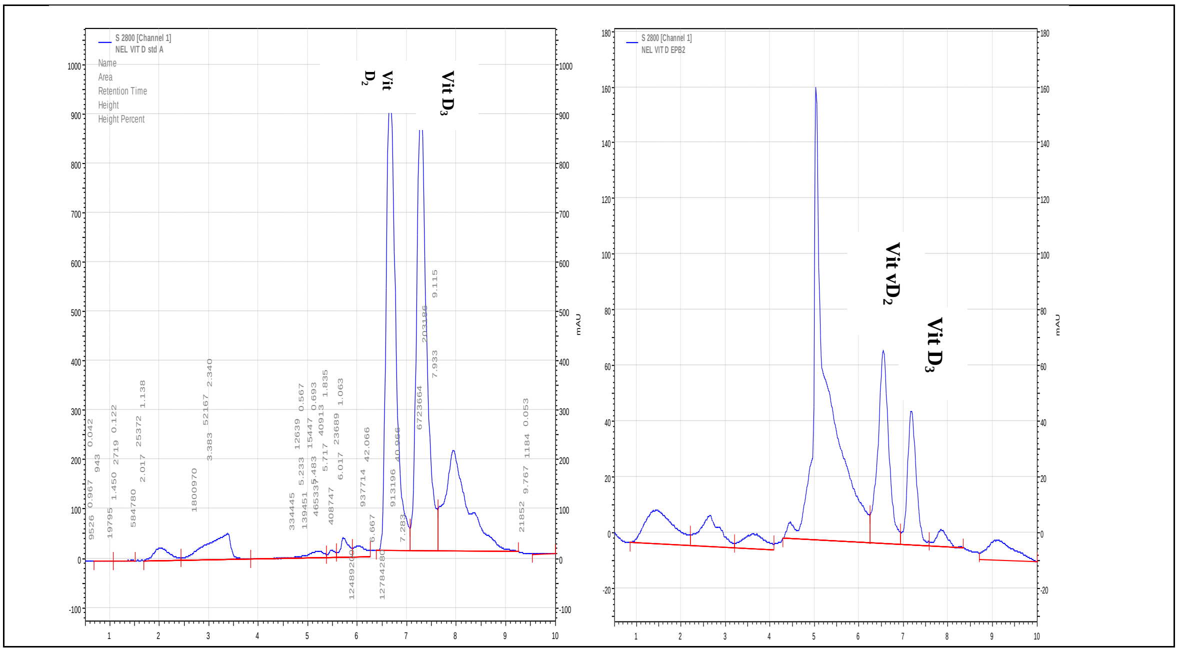


Figure 3.7: Chromatogram showing Vitamin D presence in standard solution and one of the seaweed samples (EPB2).

3.5.3.2 Minerals and Heavy metal analysis of edible seaweed samples by Atomic A

Minerals determination of edible seaweed samples

Ash determination and digestion

2-4g of sample was weighed into a porcelain crucible. Ashing was then done with a Bunsen burner (low flame) and this continued in a muffle oven at 500^{o}c-600^{O}C until a light gray or white ash of constant weight is obtained. Ash content of the sample was then calculated.

10mls of 20% HCL was added to the ashed sample in the crucible**.** It was then heated on a hot plate to boiling**.** The boiled ash was let to cool and filtered using filter paper into 50mls volumetric flask**.** The filtrate was topped up to the mark of 50mls with distilled water and mixed well. Minerals were read using Absorption Atomic Spectrophotometer using various respective standards (Iron-248.3nm, Zinc-213.9nm and Iodine-203nm). Answer was given in Ppm or mg/kg (AOAC.,2019; Paul *et al*.,2014).

Calculation

$$\frac{\textit{Graph constant of respective metal} \times \textit{Absorbance} \times \textit{Dilution factor (50)}}{\textit{Sample Weight}}$$

Heavy metals determination of edible seaweed samples

Wet digestion method

Removal of organic matter by digestion with acid

1g of ground sample was weighed in a beaker. 20mls of acid was then added (3 parts perchloric acid and 1-part Nitric Acid) and left on the bench overnight. This was then placed on a hot plate (sand bath) and digested till the fumes clear. White fumes showed that all organic matter was digested. Filter paper was wet with water and beaker contents filtered into 50mls volumetric flask and mixed. Using the various metal standards, the absorbance of the various heavy metals was read using Atomic Absorption spectrophotometer (Lead -217nm, Nickel-232nm, Mercury-253.7nm Cadmium-228.8nm).As for mercury determination, the diluted ash was subjected to vapor generation before being read in Atomic Absorption spectrophotometer. Answer was given in Ppm and converted to mg/kg (AOAC.,2019;Paul *et al*.,2014).

Calculation

$$\frac{\textit{Graph constant of respective metal} \times \textit{Absorbance} \times \textit{Dilution factor (50)}}{\textit{Sample Weight}}$$

3.6 Data Analysis

Data analysis was done using Statistical Package for Social Science version 23 (SPSS 23.0). Continuous variables were presented as mean ± standard deviation, and categorical variables as frequency (n) and percentage (%).ANOVA and t-test and was used for comparison of variables of micronutrient and heavy metals levels present in the various categories of seaweed and location found as well as socio-demographic and seaweed consumption patterns. p values of <0.05 was considered statistically significant (Reddy,2019).

CHAPTER FOUR

4. RESULTS

4.1 Socio-demographic characteristics of the study population at the Kenyan Coast

The researcher conducted interviews among 175 seaweed farmers from five different villages of Kwale County, Dindimu location, Mzizima Sub-location where seaweed farmers resided. Almost half of the study population were from Kibuyuni (46.3%), followed by Magogoni (33.1%), Kijiweni (17.1%) then Wasini (2.3%) and Fikirini (1.1%). Socio-demographic characteristics explored included; (Table 4.1)

4.1.1 Respondents and Gender of Kenyan Coast study population

Majority of the respondents were household heads (HHH) (60%) while minority were relative to HHH (1.7%), depicting a significant difference (p-value=0.001).There were more female respondents (68%) compared to males (32%) with a significant difference of **(p-value=0.014)** (Table 4.1).

4.1.2 Age of Kenyan Coast study population

Majority of the respondents (37.7%) were between the ages of 30-40 years and very few (1.7%) were below 20 years depicting a significant difference **(p-value=0.021)** The respondent aged 20-30 years and 40-50 were slightly over a fifth (26%) and few were over 50 years(8.6%)(Table 4.1).

4.1.3 Marital Status of Kenyan Coast study population

Majority of seaweed farmers were married (46.3%), singles were quarter (25.7%), then the widowed (14.9%) and divorced (13.1%). There was a significant difference the married who were majority and the divorced who were minority **(p-value=0.046)**(Table 4.1).

4.1.4 Education Level of Kenyan Coast study population

There was a significant difference **(p-value=0.017)** between majority of respondents who attained upper primary (41.1%) and minority who attained tertiary education (1.2%). Those who had no formal education (30.3%), followed by slightly less than a fifth (19.4%) completed lower primary while those who completed secondary school (8.0%) (Table 4.1).

4.1.5 Occupation of Kenyan Coast study population

Majority of the respondents were farmers (96%) while only 3% had businesses other than farming (fishing, trading etc) and 1% were in formal employment. There was a significant difference (**p-value=0.003**) between seaweed farming and other occupations. (Table 4.1).

Table 4.1: Socio-demographic characteristic of study population at the Kenyan coastline.

Demographic Characteristics of study population	%(N=175)	p-value
Respondents		
HHH	60	**0.001**
Spouse	22.9	
Daughter	6.3	
Son	9.1	
Relative	1.7	
Gender		
Female	68	**0.014**
Male	32	
Age		
<20	1.7	**0.021**
20-30	26.3	
30-40	37.7	
40-50	25.7	
>50	8.6	
Marital status		
Married	46.3	
Single	25.7	**0.046**
Widowed	14.9	
Divorced	13.1	
Education level		
No formal education	30.3	**0.017**
Lower primary	19.4	
Upper primary	41.1	
Secondary	8.0	
Tertiary/Collage	1.2	
Occupation		
Farmers	96	
Employed	1	**0.003**
Other businesses	3	

4.2 Seaweed farming and consumption patterns of the Kenyan Coast study population

The study sort to determine the seaweed farming and consumption patterns by exploring the seaweed farming practices by seaweed farmers at the Kenyan coastline, the type, form and frequency of seaweed consumption patterns, reason stated for not consuming seaweed and the perception of seaweed cost and income generated from seaweed farming by study population of the Kenyan coastline.

Seaweed farms

Seaweed culture technique-seedlings on the rope

Dried and fresh harvested Eucheuma spp seaweed

Seaweed value addition

Source; pictures taken by researcher Mercy Nelima during research (permission obtained)

4.2.1 Seaweed farming practices by seaweed farmers at the Kenyan coastline

Almost all the respondents, (98.9%) had heard about seaweed as 97.1% were practicing seaweed farming while only 2.9% were not. There was a significant difference (p=0.009)between seaweed farmers and non-seaweed farmers. About three quarters of the respondents (74.7%) practiced seaweed farming for income generation while 2.9% for domestic consumption. Slightly over a fifth (22.4%) practiced for both income generation and food for home consumption. There was a significant difference (p-value=0.043) between those who practiced seaweed farming for consumption and those who practiced for other reasons (Table 4.2).

4.2.2 Type, form and frequency of seaweed consumption patterns by the study population at the Kenyan coastline

Majority of respondents (98.9%) were aware that seaweed is edible, of these respondents 69.7% of them consumed it. Among the ones who consumed seaweed 59.5% respondents consumed all the three types (Red, Brown and Green) of edible *Eucheuma* species followed by 25.6% who only consumed the Brown type, 14% consumed the Green type and only 0.9% consumed the Red type. There was no significant difference in the type of edible seaweed being consumed (p-value=0.061).

Consumption/use by respondents was inform of juice (9%) and cooked salad (5%) while it was dominantly used to make (75%) soap and shampoo(11%),use of seaweed for other purposes other than consumption purposes was high depicting a significant difference (p-value=0.018). Slightly over a half (52.1%) consuming seaweed less than once per week, while slightly over a third (34.7%) consuming more than once per week and few (13.2%) consumed seaweed once a month. There was no significant difference (p-value=0.15) However, when seaweed was consumed, in terms of servings per day, about three quarters (74.4%) consumed a serving of 50-100 grams per day, showing significant difference (p-value=0.034) from slightly over a fifth who consumed (23.1%) less than 50 grams per day and very few (2.5%) who consumed more than 100 grams per day. Majority of the ones who consumed seaweed preferred consuming it in cooked form (63.6 %) as compared to eating it dried (19.8%) or fresh (15.7%) and only few (0.9%) consumed in all cooked, dried and fresh forms showing no significant difference (p-value=0.239)(Table 4.2).

4.2.3 Reason stated by the respondents for not consuming seaweed at the Kenyan coastline

Among the non-consumers of seaweed, lack of knowledge(59.9%) on whether seaweed could be consumption was the major reason stated of not consuming seaweed, showing a significant difference (0.033) from other reasons of fear of contamination (21.7%), unpleasant taste (16.7%) and few perceived seaweeds as having an unpleasant smell (1.7%).A significant difference (p-value=0.004) was observed. In regards to the perception of smell, 66% of the respondents like the smell of seaweed, 27% were indifferent while only 7% did not like the smell. There was no significant difference (p-value=0.769)(Table 4.2).

4.2.4 Study populations' perception of seaweed farming cost and income generation at the Kenyan Coastline

Most respondent found the purchase price of Kenya shillings(Ksh) 50 per kg of farmed seaweed being sold in the area to be almost equally fair (49.4%), cheap (48.9%) and very few (1.7%) found it costly significantly different (p-value=0.48).The income generated from seaweed sales per harvest ranged from KES10,000-20,000. Slightly less than half of the study households (47.6%) obtained KES 10,000-20,000 from seaweed per harvest. Slightly over a third (36.5%) of the seaweed farmers earned less than KES10,000 per harvest and less than a fifth (15.9%) earned over KES 20,000 (Table 4.2).

Table 4.2 Seaweed farming and consumption patterns of the Kenyan coastline study population

Seaweed farming and consumption patterns	%	p-value
Seaweed farming		
Seaweed farmers	97.1	**0.009**
Non-seaweed farmers	2.9	
Reason for seaweed farming		**0.043**
Income generation	74.7	
Consumption	2.9	

Income generation and consumption	22.4	
Type of seaweed consumed		
All	59.5	0.061
Brown	25.6	
Green	14	
Red	0.9	
Frequency of seaweed consumption		
Less than once per week	52.1	0.15
More than once per week	34.7	
Once per month	13.2	
Serving of seaweed per gram/day		
< 50 grams	23.1	**0.034**
50-100 grams	74.4	
>100 grams	2.5	
Income from seaweed farming per harvest (Ksh.)		
<10,000	36.5	0.18
10,000-20,000	47.6	
>20,000	15.9	
Form of seaweed consumption/use		**0.018**
Juice	9	
Cooked salad	5	
Soap	75	
Shampoo	11	
Reason stated for not consuming seaweed		
Lack of knowledge	59.9	**0.033**
Fear of contamination	21.7	
Unpleasant taste	16.7	
Unpleasant smell	1.7	
Perception of seaweed smell		
Liked the smell	66	0.769
Indifferent about the smell	27	
Did not like the smell	7	
Type of seaweed consumed		
Red	0.9	
Green	14	
Brown	25.6	
All	59.5	
Form of seaweed consumed		0.239
Fresh	15.7	
Dried	19.8	
Cooked	63.6	
All	0.9	
Perception of cost of seaweed		**0.48**
Cheap	48.9	
Fair	49.4	
Costly	1.7	

4.3. Distribution of socio-demographic characteristics by seaweed consumption patterns of the study population at the Kenyan Coast

The sex of the seaweed consumers was positively associated (p-value=0.004) with level of knowledge of the nutritive value of the different types of seaweeds (where female (68%) who majorly practiced seaweed farming, were more knowledgeable than male). The age of the respondents (majority middle-aged 30-40 years) was significantly associated with the seaweed farming practice (p-value=0.003), reason for Household (HH) practicing seaweed farming (p-value=0.004), consuming large quantities of serving per day (p-value=0.042) and cost of seaweed per kg (p-value=0.009). Marital status was significantly associated with reason for HH practicing seaweed farming (p-value=0.005) and knowledge of seaweed nutritive value (p-value=0.003) (as 74.7% HH practiced seaweed farming to sustain the livelihood of their families through income generation due to this, know a little more about seaweed). Education level (where 90.8% of respondents hadn't attained above secondary level) was associated with reason for household practicing seaweed farming (p-value=0.001), not consuming seaweed (p-value=0.017), knowledge of nutritive value (p-value=0.023) and finally consuming seaweed because increased of knowledge of nutritive value (p-value=0.004). The occupation of the respondent was association with practices of seaweed farming as 97.1% were seaweed farmers (Table 4.3).

Table 4.3: Distribution of seaweed consumption patterns by socio-demographic characteristic of study households

Seaweed consumption patterns	Sex	Age	Marital Status	Education Level	Occupation
Practice seaweed farming	0.329	**0.003***	0.507	0.409	**0.000***
Reason for HH practicing seaweed farming	0.205	**0.004***	**0.005***	**0.001***	0.840
If consume seaweed	0.461	0.126	1.000	0.302	1.000
If not consume, why not	0.623	0.290	0.053	**0.017***	0.315
If edible, which type	0.061	0.122	0.592	0.081	0.064
Frequency of consumption	0.220	0.625	0.705	0.070	0.229
Serving per day	0.668	**0.042***	0.482	0.101	0.717
Form of consumption	0.065	0.276	0.611	0.358	0.094
Smell perception of seaweed	0.500	0.071	0.515	0.079	1.000
Knowledge of nutritive value	**0.004***	0.795	**0.003***	**0.023***	0.256
Cost of seaweed per (kg)	0.734	**0.009***	0.256	0.094	0.649
Likelihood of consumption with increased nutritional knowledge	0.504	0.064	0.716	**0.004***	0.305

***Indicated significant difference(p-value<0.05)**

4.4. Edible seaweed species found along the Kenyan Coastline

A total of 58 seaweed samples were collected from the 5 beaches along the Kenyan coastline; 34 from Mombasa county,16 from Kwale and 9 from Kilifi county (Table 3.1). Mombasa county contributed 57% of seaweed samples collected while Kwale contributed 28% and 15% came from Kilifi county.A total of 28 edible seaweed were identified, among them, 3 were farmed edible seaweed species collected in Kibuyuni seaweed farms. Among the edible seaweed species, 11 were from the Phaeophyceae class (Brown seaweed) comprising of the genus; S*argassum, Turninaria, Dictyota, Padina and Eucheuma, 9* were from Chlorophyta class (Green seaweed) comprising of genus, U*lva* and C*aulerpa* and *Eucheuma* and 8 speciesfrom Rhodophyta class (Red seaweed) comprising of genus *Gracilaria, Hypnea, Soliera* and *Eucheuma* as seen (Table 4.4).

Table 4.4:Distribution of edible seaweed species collection according to group found at the Kenyan Coastline

Phaeophyceaen=11 (Brown colour)	**Chlorophyta n=9 (Green colour)**	**Rhodophyta n=8 (Red colour)**
1. Sargassum polycystum	*1.Ulva reticulata*	*1.Gracilaria salicornia*
2. Sargassum ilicifolium	*2.Ulva lactuca*	*2.Gracilaria corticata*
3. Sargassum oligocystum	*3.Ulva fasciata*	*3.Gracilaria verrucosa*
4. Sargussum aquifolium	*4.Ulva pulchra*	*4.Hypnea cornuta*
5. Turbinaria decurrens	*5.Ulva intestinalis*	*5.Hypnea musciformis*
6. Turbinaria ornata	*6.Caulerpa fastigiata*	*6.Soliera robusta*
7. Turbinaria conoides	*7.Caulerpa lentifera*	*7.Eucheuma spinosum(wild)*
8. Dictyota dichotoma	*8.Caulerpa toxifolia*	*8.Eucheuma cottonii (Kappaphychus alvarezii-farmed)*
9. Dictyota cervicornis	*9.Eucheuma spinosum(farmed)*	
10. Padina tetrastromatica		
11. Eucheuma spinosum(farmed)		

4.4.1 County seaweed contribution according to phyla in the study population

Mombasa county contributed more brown seaweed type(65.4%) in comparison to Kwale (19.2%) and Kilifi (15.4%). Kwale and Mombasa county had the same proportion of the Red type (43.8%) as compared to Kilifi county (15.4%), Kwale (22.5%) and Kilifi (18.8%) contributed almost the same proportion of green type whereas Kilifi county contributed the least of all types of seaweed types. However, there was no significant difference in the differing proportions between and within the counties (p-value=0.357).

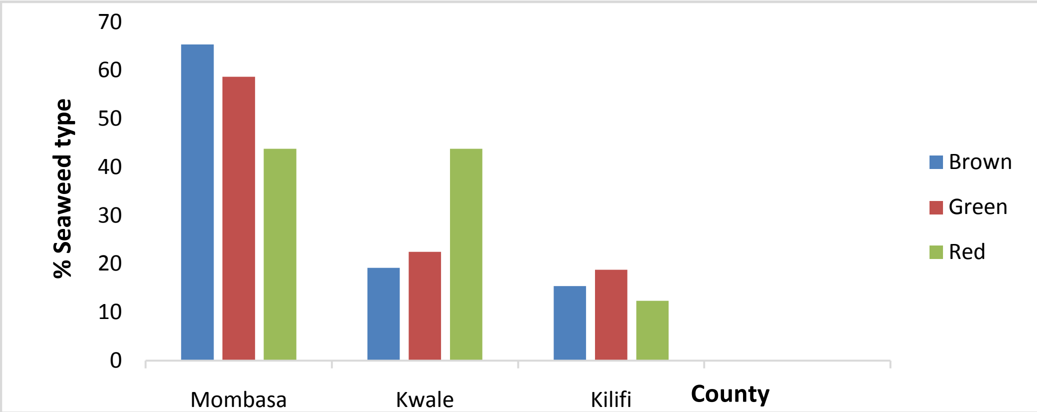


Figure 4.1:County contribution of edible seaweed found at the Kenyan coastline according to color

4.4.2: County contribution of vitamins in edible seaweed found along the Kenyan coastline

Kilifi county had seaweed with the highest mean levels (µg/100g) of Vitamin B_{12} (464.9±203.6), Vitamin B_9 (63.6 ±25.3), Vitamin A (146±49.7) and Vitamin D (33.4±30.2).There was a significance difference in the levels of Vitamin B_{12} (p-value=0.031),Vitamin A (p-value=0.047), and Vitamin D (p-value=0.006), found in the 3 different counties. (Table 4.5).

Table 4.5:Distribution of Vitamins and Mineral levels in edible seaweed phyla according to counties at the Kenyan coastline

County/micronutient (µg/100g)	Mombasa county	Kwale county	Kilifi county	p-Value
Vitamin B_{12}	269.2±286.2	176.7±203.6	464.9±203.6	**0.031***
Vitamin B_9	43.6±45.5	59.8±118.9	63.6±25.3	0.649
Vitamin A	101.1±88.1	63.8±69	146.0±49.7	**0.047***
Vitamin D	16.4±21.9	1.04±0.58	33.4±30.2	**0.006***
County/micronutient (mg/kg-DW)				
Iron	268.3±208.3	269.9±154.6	104.1±37.5	***0.047**
Zinc	55±60.1	43.4±29.7	43.9±14.1	0.068
Iodine	38.5±38.0	41.2±39.2	20.9±12.4	0.399

4.4.3: County contribution of minerals in edible seaweed found along the Kenyan coastline

Highest mean levels (mg/kg) of Iron (269.9±154.6) and Iodine (41.2±39.2) were observed in Kwale county. Seaweed collected from Mombasa county had highest mean levels of Zinc (55±60.1). There was a significance (p-value=0.047) of mean Iron level between and within seaweed samples collected when comparison was made in relation to all three counties where seaweed was collected. There was also a significant difference between mean Iron levels of seaweed species found in Mombasa county and Kilifi county (p-value 0.018) and between Kwale county and Kilifi county (p-value 0.03) (Table 4.5).

4.4.4 Mean Vitamins levels in seaweed types found at the coastline of Kenya

Levels(µg /100g) of Vitamin B_{12} (306.5±287.9) and Vitamin D (18.8± 24.3) were highest in the Green seaweed type while Vitamin B_9 (73.0±122.3) and Vitamin A (102.4±104.8) were highest in the Red seaweed type. However, there was no significant(p-value=0.156) in the mean Vitamin levels between and within the seaweed types (Table 4.6).

Table 4.6: Micronutrients quantities in edible seaweed phyla found at the Kenyan coastline

County/micronutient µg /100g	Brown Seaweed	Green Seaweed	Red Seaweed	p-Value
Vitamin B_{12}	257.5±222.9	306.5±287.9	268.5±320.9	0.846
Vitamin B_9	44.4±37.1	40.2±35.0	73.0±122.3	0.352
Vitamin A	93.8±72.5	99.6±74.0	102.4±104.8	0.942
Vitamin D	15.9±20.9	18.8±24.3	13.5±27.2	0.852
County/micronutient (mg/kg-DW)	**Brown Seaweed**	**Green Seaweed**	**Red Seaweed**	**p-Value**
Iron	249.9±200.2	201.6±190.1	274.0±158.6	0.536
Zinc	47.3±28.1	53.3±60.8	51.3±61.5	0.924
Iodine	33.4±32.8	41.0±34.1	38.5±44.8	0.796

4.4.5 Mean Minerals level in seaweed types found at the coastline of Kenya

Highest contribution (mg/kg-DW) of Iron was from the Red seaweed type with a mean of 274±158.6 followed by the Brown type with a mean of 249.9±200.2 and 201.6±190.1. Green seaweed type contributed a mean of 53.3±60.8 of Zinc close to the Red one at 51.3±61.5 and 47.3±28.1 from the Brown type. Majority of Iodine was contributed by the Green type with a mean of 41±34.1 followed by the Red 38.5±44.8 and finally the Brown type 33. ±32.84.There was no significant difference among the various seaweeds phyla when it came to micronutrient content (Table 4.6).

4.4.6 Mean quantity levels of micronutrients in edible seaweed species found at the Kenyan coastline.

Frequently occurring genus/species among the Red phyla was *Gracilaria* sp and *Hypnea cornuta* and among the Brown phyla was *Turbinaria* sp, S*argassum aquifolium* and *Padina tetrastomatica.* The genus *Ulva* was dominant among the Green phyla. Farmed *Eucheuma cotonii (Kappaphychus alvarezii)* had the highest levels of Vitamin B_{12} (696.6µg/100g) and Vitamin A (298.6µg/100g), whereas *Hypnea cornuta* had the highest levels of Vitamin B_9 (153.1µg/100g). *Caulerpa fastigiata* recorded the highest level of Vitamin D (77.63µg/100g). In terms of minerals, *Ulva intestinalis* recorded highest levels of Iron(637.85mg/kg). Mean levels of Vitamin A were also high in Farmed *Eucheuma cotonni* (298.6 µg/100g) and *Turbinaria ornate* (221.9µg/100g) as compared to low levels in farmed *Eucheuma spinosum* (28.7µg/100g) and *Soliera robusta* (26.1µg/100g).

Caulerpa taxifolia had highest level of Zinc (277.74 mg/kg) and Iodine (142.8 mg/kg). Farmed *Eucheuma* genus recorded higher levels in vitamins as compared to the wildly growing one, however they were much lower in mineral levels. There was no sign significant difference (p-value=0.079) in micronutrients quantity levels within and between edible seaweed species in the different phyla (Table 4.7).

Table 4.7: Mean quantity levels of micronutrients found in edible seaweed species found at the Kenyan coastline

Species name	No of species found	Vitamin B_{12}(µg /100g)	Vitamin B_9(µg /100g)	Vitamin A(µg /100g)	Vitamin D(µg/100g)	Iron(Fe) (mg/kg) -DW	Zinc(Zn) (mg/kg) - DW	Iodine(I) (mg/kg)-DW
Red								
Gracilaria corticata	3	28.30	81.7.	78.97	2.83	401.08	115.28	81.33
Gracilaria salicornia	4	34.86	46.4	116.37	16.21	280.12	22.29	34.02
Gracilaria verrucosa	1	6.35	12.5	37.3	1.44	342.50	47.17	28.92
Hypnea cornuta	4	32.91	**153.1**	129.48	27.71	258.39	44.22	28.24
Hypnea musciformis	1	1.88	15.7	28.1	6.27	473.80	31.01	-
Eucheuma spinosum(wild-	1	1.85	7.6	30.5	1.45	123.30	47.50	27.50

red)								
Soliera robusta	1	1.106	3.6	26.1	-	222.92	17.01	5.55
Eucheuma cotonii-(Kappaphychus alvarezii)-farmed	1	**69.61**	45.	**298.6**	-	61.14	57.95	36.48
Brown								
Sargassum aquifolium	5	33.17	63.1	107.14	7.36	218.95	36.44	20.91
Sargassum ilicifolium	2	15.18	26	63.6	7.40	202.83	49.75	20.03
Sargassum oligocystum	2	5.32	29	36.05	5.38	321.14	35.46	24.13
Sargassum polycystum	1	17.77	14.	28.1	8.13	255.49	41.61	20.86
Turbinaria conoides	3	40.04	51.5	131.57	5.15	74.63	38.20	18.46
Turbinaria decurrens	2	4.02	14.	53.6	48.82	306.13	23.11	33.88
Turbinaria ornata(limited)	2	67.26	55.0	221.9	75.28	148.41	33.63	22.44
Dictyota cervicornis(limited)	1	9.30	54.9	250	39.35	578.70	114.81	75.72
Dictyota dichotoma	2	4.91	11.7	32.6	1.47	395.28	88.13	100.53
Eucheuma spinosum (brown)-farmed	1	**36.54**	10.3	28.7	2.01	131.55	23.92	38.46
Padina tetrastromatica	5	18.25	73.3	71.54	9.9	297.68	59.91	34.27
Green								
Ulva fasciata	2	31.25	60.3	122.55	13.28	106.96	39.50	29.31
Ulva intestinalis	1	8.38	18.5	40.8	6.33	**637.85**	39.94	41.12
Ulva lactuca	4	33.73	40.9	97.88	11.41	255.52	34.35	28.24
Ulva pulchra	1	18.07	37.4	48.9	1.23	112.52	31.65	33.69
Ulva reticulata	4	30.41	35.4	118.63	26.97	184.07	35.34	47.31
Caulerpa fastigiata	1	68.07	**81.8**	155.2	**77.63**	112.24	60.67	-.
Caulerpa taxifolia	1	39.94	61.6	73.5	8.23	103.60	**277.74**	**142.87**
Eucheuma spinosum(Green)-farmed	1	36.19	67.5	137.1	0.46	78.48	29.87	19.87

4.5 Heavy metals content in Seaweeds found at the Kenyan coastline

Four heavy metals, Lead, Cadmium, Mercury and Arsenic were tested in the edible seaweed species sampled. Traces of Lead and Cadmium were found in all seaweed species while

Mercury was only found in seaweed species sampled in English point beach Mombasa county. Arsenic was not detected in all seaweed samples. Mean (mg/kg) Lead levels (0.774±0.659) were highest in seaweed species found in Kilifi county whereas mean Cadmium levels (0.021±0.026) were highest in Mombasa county. There was no significant difference in heavy metal levels of seaweed samples in all the three counties. However, when comparison was made between and within seaweed samples collected in the 2 counties of Mombasa and Kilifi (p-value 0.035) and Kilifi and Kwale (p-value=0.031)significant difference was noted (Table 4.8).

Mean (mg/kg) Lead levels (0.56±0.488) were highest in Brown seaweed type whereas mean Cadmium levels (0.025±0.036) were Highest in Green seaweed type. However, there was no significant difference in the mean heavy metal levels of seaweed types collected (Table 4.8).

Table 4.8: Distribution of Mean levels of heavy metal by seaweed phlya and study counties.

Heavy metal content (ppm/mg/kg-DW)	**Mombasa County**	**KwaleCounty**	**Kilifi County**	**p-Value**
Lead	0.444±0.355	0.399±0.316	0.774±0.659	0.068
Cadmium	0.021±0.026	0.017±.017	0.003±0.001	0.179
Heavy Metal content (ppm/mg/kg-DW)	**Brown**	**Green**	**Red**	**p-Value**
Lead	0.560±0.488	0.462±0.449	0.378±0.204	0.387
Cadmium	0.013±0.014	0.025±0.036	0.018±0.014	0.265

4.5.1 Mean heavy metal levels in seaweed species found at the Coastline of Kenya

Caulerpa taxifolia recorded the highest levels of both Lead (2.0575mg/kg) and Cadmium (0.123mg/kg). Mercury was detected in only 4 varieties of seaweeds found at English Point beach in Mombasa county; *Gracilaria corticata* (0.735 mg/Kg) from Red phyla, *Ulva reticulata* (0.0405mg/Kg), *Caulerpa lentifera* (limited) (0.0395mg/Kg) and *Caulerpa taxifolia* (0.0650 mg/Kg) from the Green phyla. Arsenic metal was not detected in any of the seaweed. Significant difference in mean cadmium levels (p-value=0.023) was noted between and within the species group but not in mean Lead levels (p-value=0.108) (Table 4.9).

Table 4.9: Mean levels of heavy metals in edible seaweed species found at the Kenyan coastline

Species name	No. of species found	Cadmium (ppm/mg/kg-DW)	Lead (ppm/mg/kg-DW)
Red			
Gracilaria corticata	3	0.0265	0.3687
Gracilaria salicornia	4	0.0292	0.3160
Gracilaria verrucosa	1	0.0251	0.3335
Hypnea cornuta	4	0.0049	0.5295
Hypnea musciformis	1	0.0408	0.3040
Eucheuma spinosum(wild)	1	ND	0.2955
Eucheuma cotonii(red)(Kappaphychus alvarezii)-farmed	1	0.0012	0.1305
Soliera robusta	1	0.0169	0.2685
	16		
Brown			
Dictyota cervicornis(limited)	1	0.0160	1.3135
Dictyota dichotoma	2	0.0253	0.8688
Eucheuma spinosum(brown)-farmed	1	0.0072	0.2545
Padina tetrastromatica	5	0.0058	1.027
Sargassum aquifolium	5	0.0152	0.3926
Sargassum ilicifolium	2	0.0116	0.4800
Sargassum oligocystum	2	0.0246	0.2948
Sargassum polycystum	1	0.0307	0.2735
Turbinaria conoides	3	0.0041	0.3123
Turbinaria decurrens	2	0.0593	0.2983
Turbinaria ornata	2	0.0018	0.4928
	26		
Green			
Ulva fasciata	2	0.0070	0.3098
Ulva intestinalis	1	0.0362	0.3365
Ulva lactuca	4	0.0275	0.4403
Ulva pulchra	1	0.0038	0.2530
Ulva reticulata	4	0.0227	0.2985
Caulerpa fastigiata	1	0.0036	0.5215
Caulerpa lentifera(limited)	1	0.0089	0.3345
Caulerpa taxifolia	1	**0.1230**	**2.0575**
Eucheuma spinosum(Green)-farmed	1	0.0050	0.3205
	16		

***ND-Not detected**

CHAPTER FIVE

5.0 DISCUSSION

5.1 Socio-demographic characteristics of the study population of the Kenyan coastline

5.1.1 Gender of study population of the Kenyan coastline

The current study established that the highest proportion of seaweed farmers were women with an increased knowledge of seaweeds nutritive value due to their involvement in seaweed farming than men. In many developing countries, seaweed farming is mostly practiced by women indicated by several studies (Mirera *et al.*, 2020; Msuya & Hurtado, 2017; Nyundo, 2017). Their resilience in the sector is considered a key factor in spearheading the seaweed industry as well as optimizing the quality of life (Msuya *et al.*, 2022). Msuya went on to explain that disparity in proportion was explained by men majorly being involve in other trading activities that give quick or instant cash as they needed money on a daily basis to fend for the families. Men also saw seaweed farming as having slow returns and required more patience when it came to the farming process, this trait was majorly exercised by women (Msuya *et al.*, 2022).

5.1.2 Age and education level of study population at the Kenyan coastline

Majority of the respondents in the study who practiced seaweed farming solely for income generation was found to be over 30 years category. This corresponds to the various studies that asserted that the average age of seaweed farmers was 37.04 years (Zamroni *et al.*,2011). Further studies established that the mean age of seaweed cultivators were 40 years with the lowest age recorded being 19 years (Odhiambo *et al.*,2021, Nyawade *et al.*, 2021) Another study in Indonesia further supported this finding by exploring livelihood features of seaweed farming households and found majority of the respondents being in the age bracket of 25-49 years of age (Rahim *et al*., 2019).

Majority of the study households had a low level of education. However, despite the HHH influence in determining the level of involvement in the type of farming, education level and income status might play a role in people's involvement, likelihood of consumption and increased nutritive knowledge (Odhiambo *et al.*, 2020; Zamroni *et al*.,2011). Majority of households along the coastal parts of Kenya are characterized by low education (Mtsweni *et al.*,2020; Nyawade *et al.*, 2021). This may be attributed to high unemployment rates thus low incomes. High economic potential of seaweed products (Zamroni *et al.*, 2011) can play a role in alleviation of this.

5.1.3 Economic benefits of seaweed farming at the Kenyan coastline

Most of the middle-aged respondents practiced seaweed agriculture for the purpose of income generation with a small proportion of the farmers practicing it for home consumption, Nyawade et al,2021 established similar findings where seaweeds were harvested for both income generation and home consumption. Seaweed farming is promoted to the coastal rural community to uplift their poverty (Campbell *et al*.,2019; Rimmer *et al*.,2021).

The current cost per Kg (USD 0.41) of harvested seaweed was higher than a few years back where a kilogram was lower than USD 0.25 (Msuya *et al*.,2022) Monthly income in rainy season in a study done in Rota Island averages to USD 94 (Mariño *et al*.,2019). Studies supported seaweed farming to have high economic returns due to short culture cycle and simple low-cost farming technologies deployed (Garcia-Poza *et al*., 2020). If dependence on purchase would shift to multiple buyers due to increased consumption of more variety of edible seaweed species and use by the local population in addition to export, this would see further increase in prices of seaweed and consequently improved livelihoods of the farmers(Ahmed *et al*., 2022).

5.2 Seaweed consumption patterns by the Kenyan coastline study population

Respondents who consumed seaweed consumed all the three seaweed types especially *Kappaphycus alvarezii* and *Eucheuma spinosum* that were majorly cultivated in the area but hardly the other edible seaweed types growing wildly. As in other studies, seaweed species commonly cultivated in Kenya, Tanzania, and Mozambique include *Kappaphycus alvarezii, Eucheuma denticulatum*, and *Kappaphycus striatum* with their production volume in the region estimated to be over 15000 tons of dry matter every year (Msuya *et al.*, 2014).

In the current study, majority of the seaweed farmers still utilized seaweed traditionally for soap with low consumption rate. When consumed the cooked form of seaweed was preferred. Studies have shown that the consumption rate in Africa is not as common compared to Asian countries, particularly China, Japan, and Korea (who consume seaweed in all its forms) as seaweed has not been embraced as traditional food (Probst, 2015). In France, the main European seaweed consumer, consumption is in form of seaweed vegetables (Fleurence, 2016).

The major of respondents attributed low seaweed consumption rate to lack of knowledge of its consumption and nutritive value followed by fear of contamination. Several studies had similar findings, where lack of know-how of incorporation to human diet and the food safety concern related to seaweed is associated with microbial contamination such as presence of Salmonella species, bio-accumulating toxic heavy metals such as Arsenic, and cadmium from the water bodies and pesticide residues. (Banach *et al*., 2020; Casas-Beltrán *et al*., 2020; Ii, 2015; Perryman *et al.*, 2017; Warguła *et al*., 2021;Young *et al*.,2022).

Few of the respondents were affected by its smell and taste as they found both to be relatively pleasant. A study that sort to find out whether consumers wanted seaweed in diet; evaluating emotional responses to food containing seaweed, participants' purchase-intent scores were highest for bread and dried seaweed, which they associated with positive emotions. They also believed seaweed could be added to fish, savoury, and cereal grains-based foods. (Moss & McSweeney, 2021).

The study established an association between increased likelihood of consumption to increased seaweed purchase and consumption by the local population with improved knowledge and education on more edible seaweed types, its nutritive value and ways of incorporation in diet .This was in line with the study by Young et al, where consumers wanted more promotion and environmental sustainability of seaweed products to improve knowledge and seaweed consumption (Young *et al*.,2022).

5.3 Micronutrient content of edible seaweed species found at the Kenyan coastline.

5.3.1 Vitamin content of edible seaweed species found at the Kenyan coastline.

Vitamins content of seaweeds found in the three counties were found to be different. Seaweed species found in Kilifi country recorded highest mean levels of all vitamins of interest but the vitamin content varied according to species while the minerals did not differ much. As in various studies, micronutrient composition variations among seaweed species are as a result of factors such as seaweed phylum, origin, seasonal, environmental, physiological and geographical conditions (Villares *et al.*,2013). Variation in Vitamin B_{12} levels in various edible seaweed species is seen in other studies where dried green laver (*Enteromorpha* sp.) and purple laver (*Porphyra* sp.) most widely consumed edible algae, contained substantial amounts of Vitamin $B_{12.}$. *Enteromorpha sp* contain approximately 63.6 μg/100 g dry weight and *Porphyra* sp Vitamin B_{12} levels range from 32.3 μg/100 g -133 μg/100g dry weight (Watanabe *et al*.,2014).

Variation in Vitamin A levels is also seen in various studies that show Vitamin A content in 5g of dried *Ulva rigida* to be approximately 14.5 μg whereas *Fucus spiralis* contains 70.5 μg /100g (Taboada *et al*., 2010; Paiva *et al*., 2014). Vitamin B_9 (folate) variation in range was also observed in other studies where *Ulva* spp Folate levels (Vitamin B_9) vary from 7.5 μg to 5400 μg /100g (Taboada *et al*., 2010) Vitamin D_3 content were detected at very low levels and other species not. Such results were seen in studies where dry weight in *Fucus spiralis* is 0.83 mg/100 g and1.05 mg/100 g in *Porphyra* spp (Paiva *et al*., 2014).Vitamin D_3 was also detected in fresh Kombu (0.01 μg /100 g) in a study done in Australia (Hughes *et al*., 2018).

High Vitamin B_{12} levels were noted in farmed Edible seaweed species. Vitamin B_{12} is majorly found in animal sources, seaweed is one of the few non-animal sources. In other studies levels vary from 63.58 μg and from 32.26 to 133.8 μgper 100 g of dry weight, in *Enteromorpha* spp and *Porphyra* spp respectively (Cherry *et al*.,2019;Watanbe *et al*., 2014). Vitamin B_{12} is a great alternative to individuals on vegan diets as seen in a study that monitored children that practiced a vegan diet from 4 to 10 years, their Vitamin B_{12} status was in good levels and this was attributed to Nori *(Porphyra* spp) intake (Cherry *et al*.,2019). In another study it was quoted that feeding dried purple laver (nori) to vitamin B12-deficient rats significantly improves Vitamin B12 status(Cho & Rhee.,2019). Other studies state that species limited levels or inactive / analog form of Vitamin B_{12} due to differences in structure (Watanbe *et al*., 2014).

5.3.2 Mineral content of edible seaweed species found at the Kenyan coastline.

In the current study, Iron was identified to be the major mineral composition in the sampled edible seaweed species. Iron levels varied from very low to quite high levels (mg/kg) in farmed seaweeds. High iron concentrations in all the three groups was noted in another study with *Ulva* spp being predominant in Iron levels being with respect to red macroalgae (*Porphyra* spp.),however significant variations being noted to occur among same species found in different locations (Circuncisão *et al.*,2018).In a study where several seaweeds were analysed for Iron concentration, ten of thirteen seaweeds analyzed contained more Iron than spinach. Iron content ranged from 73 to 3490 μg/g dry matter (Flores *et al*.,2015).Another study sort to determine whether there would be an increase in hemoglobin levels when seaweed was incorporated in chocolates, the results registered high levels scores of

56mg/100g and Iron was bioavailable at 11.8mg levels thus increased hemoglobin levels (Banu and Mageswari,2015). In another study, Iron was detected in *Gracilaria corticata* and was found to be 64.4mg (Reka *et al*.,2017).

In the study, Zinc (mg/Kg) level were found to be high in some species and relatively low in others. A study that sought to incorporate seaweed in biscuits found *Dictyota* sp. having highest levels of Iron (314.25 mg/100g dw) and Zinc (50.69 mg/100g dw) contents, but the lowest Cadmium (0.20 mg/100g dw) and Lead (0.02 mg/100g dw) contents thus was able to be incorporated (Mwalukumbi,2022)

Iodine levels in seaweed varies among species, the range about 137 mk/Kg. This variation is seen in various studies where iodine levels reported for *Ulva* sp.(23.3mg/kg), *F.spiralis* (232.7mg/kg), *L. ochroleuca* (883.5mg/kg) and *G. vermiculophylla* (46.7mg/kg) dry weight. Desideri *et al*.,2016 found that 3.3 g of *Laminaria digitata* would provide 4017% of the tolerable daily intake for iodine and suggested that habitual intake of seaweed with an Iodine content exceeding 45 mg/kg of dry weight could impair thyroid function (Desideri *et al.*,2016). The presence of Iodine in brown seaweed has been traditionally used to treat goiter (Probst, 2015).

Overally, the edible seaweed species in the study had high levels of micronutrient of interest and this is supported by other similar studies that have shown high macronutrients and micronutrient composition of majority of edible seaweed species recommended for nutritionally vulnerable groups such as pregnant women making it an alternative remedy for food security constraints (Ramu *et al.,* 2020).

5.4 Heavy metals safety of edible seaweed found at the Kenyan coastline

Heavy metal contamination of seaweeds especially with Lead and Cadmium was moderately high in some species as compared to others. Lead levels were highest in seaweed species found in Kilifi county whereas Cadmium levels were highest in species sampled from Mombasa county. Species from Mombasa country had high level of contamination compared to samples from Kilifi and Kwale, this could be attributed to more industrial activity and poor sewage systems in Mombasa county (Okuku *et al*.,2011) Major concern about seaweed consumption is exposure to heavy metals such as Cadmium,Arsenic, Lead and Mercury (Desideri *et al*.,2016,Kimona *et al.*,2017) The contamination of seaweeds with heavy metals depends on habitat or ecology. Other studies have shown varying concentrations of Cadmium concentrations, around Asia, Europe and America (Filippini *et al*.,2021).

In the study majority of the Lead levels in seaweed species were below maximum allowable limit of 0.5mg/kg for Lead in vegetable set by WHO (Lee *et al*.,2022; Hwang *et al*.,2010). However, Cadmium levels were higher than limit set by WHO, JESFA, and FAO of 0.025mg/kg. (Musa *et al*., 2017) in a substantial number of species. *Caulerpa taxifolia* among the green type was noted to contained highest levels that exceeded acceptable limit of both Lead and Cadmium. In other studies, species of *Gracilaria* are affected by bio-accumulation of Cadmium in the ocean (Ardiyansyah *et al*., 2019) whereas other studies reported low levels of toxic compounds Cadmium, and Lead in seaweed species (Soares *et al*.,2020),supporting the varying levels among species as seen in the study.

Mercury was detected in a few varieties of red seaweed phyla and these were all above the maximum concentration of mercury 0.01 mg/kg set by WHO. Studies show *Ulva* spp have an anionic polysaccharide that enables them accumulate heavy metals, removing them from contaminated waters to the seaweed tissue (Schijf & Ebling, 2010)

Arsenic was not detected in all seaweed sample, in the study. This was in contrary to other studies that found Arsenic content with levels below 1.0 µg/g in *Laminaria digitata*, *Fucus spiralis*, *Porphyra umbilicalus*, *Chondrus crispus* (red seaweed) and *Ulvaprolifera* and *Ulva lactuca (*green seaweed). *Laminaria digitata*, contained levels ranging from 36 to131 µg/g of dry weight while in contrast, *Laminaria japonica* contained below maximum limits of 0.16 to 0.58 mg/kg (Feldmann *et al*, 2010; Desideri *et al*.,2016; Ronan *et al*.,2017; Taylor & Jackson, 2016). In another study where10 categories of 180 seaweed samples were tested, (kelp, sea mustard, laver, agar, sea lettuce, seaweed fulvescens, gulfweed, sea staghorn, sea string, hijiki) concentrations ranged from 1.3 mg kg^{-1} in agar to 145mg kg^{-1} in hijiki. Arsenic though in low concentrations was detected in all seaweed samples except for approximately half of the agar samples (Kim *et al*.,2020).

Heavy metals have similar origin with their increased concentrations associated with their marine ecosystem, (Khandaker *et al.*, 2021) asserted that although most studies show that the levels of heavy metals may be within tolerable limits, greater value of possible hazard quotient of non-carcinogenic risks indicates potential adverse health effects as a result of long term consumption of seaweeds (Chesori,2015). This attribute is buttressed by the non-biodegradability aspect of the heavy metals and their ability to accumulate in seaweed. However, studies have also reported that the heavy metal contents in seaweed can be reduced by special treatments during preparation and processing. For instance, inorganic arsenic has been reported to reduce by 20%-60% under soaking, washing, and boiling treatments (Yang *et al.*, 2016).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Objective 1 and 2

Association was established between sociodemographic characteristics and seaweed consumption patterns. Gender roles are part of the seaweed farming with middle aged women and few men playing a central part in farming and value addition of seaweed. Majority of those involved in seaweed farming practice it for income generation rather than home consumption, this could be attributed to low income and education levels noted in the coastal study population. Seaweed consumption was only seen in the middle-aged population and not much in younger population who are majorly affected by micronutrient deficiencies. Despite their mild awareness of seaweed being edible, low consumption and utilization of edible seaweeds of the Kenya Coastline as food source was noted. This majorly attributed limited knowledge of its nutritive value and lack of knowhow in seaweed incorporation in diet much more than fear of contamination or its smell and taste properties. Association was established between increased likelihood of consumption with increased nutritive knowledge of seaweed as a micronutrient food source.

Objective 3

Brown seaweed phyla were found to be predominant with the red and green species accounting only up to a quarter each of the coastal seaweed population at the Kenyan coastline. Seaweed species found at the coastline were found to contain all micronutrient of studied and in high levels in majority of the seaweed species. The micronutrient contents of these seaweed species vary from one region to another with some species exhibiting high micronutrient levels than others and above recommended daily intake. However, Vitamin D_3 levels were substantially high in only few edible seaweed species.

Objective 4

Traces of Lead and Cadmium were found in most of the edible seaweed species but were below the maximum permissible limit in most of the edible species. Mercury traces were found in only four of the edible species and no Arsenic was found in any of the edible seaweed species

6.2 RECOMMENDATIONS

Increased knowledge and education to the local community in Kenya on exploration of seaweed as an alternative macro and micronutrient sources and on ways of incorporation in diet, in turn increase local purchase for purposes of consumption and consequently improving acceptability in the Kenya as in the Asian and western countries.

Exploring more research on increased nutritive value of various edible seaweeds found in the country. Increasing research on processing, value addition and incorporation in existing local market and local therapeutic and complementary diets for both children and adult consumption (e.g. through baking, salt substitute, rap-arounds, as fortificants etc) thus improving its acceptability by the Kenyan population.

Exploring seaweed farming of more edible seaweed species other than Eucheuma *spp* at the Kenyan coast. Regulatory bodies in the country need to set recommended guidelines for permissible heavy metal content in edible seaweeds by doing so, the nutritional and medicinal values of these seaweeds will be exploited.

To avoid negative connotation that comes with the word ‘weed’, regulatory bodies could consider reviewing the name to of categorizing edible seaweeds under “sea plants” or “sea vegetable” to increase acceptability. Removing heavy metals through such processes as bio-adsorbent techniques could also be explored

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APPENDICES

Appendix I: Mineral composition of some edible seaweed species (mg/100g-1 DW)(Pereira,2011 Peñalver et al.,2020;).

Species	Na	K	P	Ca	Mg	Fe	Zn	Mn	Cu	I
Chlorophyta (Green seaweed)										
Caulerpa lentillifera	8917	700 -1142	1030	780 -1874	630 -1650	9.3-21.4	2.6-3.5	7.9	0.11-2.2	-
C.racemosa	2574	318	29.71	1852	384 -1610	30-81	1-7	4.91	0.6-0.8	-
Ulva lactuca	-	-	140	840	-	66	-	-	-	-
U. rigida	1595	1561	210	524	2094	283	0.6	1.6	0.5	-
Phaeophyceae (Brown Seaweed)										
Fucus Vesiculosus	2450 -5469	2500 -4322	315	725 -938	670 -994	4-11	3.71	5.5	<0.5	14.5
Himanthalia elongata	4100	8250	240	720	59	59	-	-	-	14.7
Laminaria digitata	3818	11,579	-	1005	659	3.29	1.77	<0.5	<0.5	-
Saccharina japonica	2532 -3260	4350 -5951	150 -300	225 -910	550 -757	1.19-43	0.89-1.63	0.13 -0.65	0.25 -0.4	130 -690
S. latissima	2620	4330	165	810	715	-	-	-	-	15.9
Sargassum fusiforme	-	-	-	1860	687	88	1.35			43.6
Undaria pinnatifida	1600 -7000	5500 -6810	235 -450	680 -1380	405 -680	1.54 -30	0.944	0.332	0.185	22-30
Rhodophyta (Red seaweed)										
Chondrus crispus	1200 -4270	1350 -3184	135	1350 -3184	600 -732	4-17	7.14	1.32	<0.5	24.5
Gracilariaspp.	5465	3417	-	402	600	3.6-5	4.35	-	-	-

					-732					
Palmaria palmata	1600 - 2500	7000 - 9000	235	560 - 1200	170 - 610	50	2.86	1.14	0.376	10-100
Porphyra tenera	3627	3500	-	390	565	10-11	2-3	3	<0.63	1.7
P.umbilicalis	940	2030	235	330	370	-	-	-	-	17.3
P. yezoensis	570	2400	-	440	650	13	10	2	1.47	-

Appendix II: Vitamin content of some edible seaweed species (mg/100g edible portion) (Pereira,2011;Peñalver et al.,2020).

Species	**A**	**B_1Thiamine**	**B_2Riboflavin**	**B_3Niacin**	**B_5Pantothenic**	**B_6 Pyridoxin**	**B_7 Biotin**	**B_{12}Cobalamin**	**C Ascorbic acid**	**E**	**Folic acid**
Chlorophyta (Green seaweed)											
Caulerpa Lentillifera	0.05	0.02	1.09	-	-	-	-	1	2.2	2	--
Codium fragile	0.527	0.223	0.559	-	-	-	-	-	<0.223	-	-
Ulva lactuca	0.017	<0.024	0.533	98*	-	-	-	6*	<0.242	-	-
Ulva pertusa	-	-	-	-	-	-	-	-	30-241**	-	-
Ulva rigida	9581	0.47	0.199	<0.5	1.70	< 0.1	0.012	6	9.42	19.7	0.108
Phaeophyceae (Brown seaweed)											
Alaria esculenta	-	-	0.3-1*	5*	-	0.1*	-	-	100-500*	-	-
Fucus vesiculosus	0.307	0.02	0.035	-	-	-	-	-	1.4124	-	-
Himanthalia elongata	0.079	0.020	0.020	-	-	-	-	-	28.56	-	0.176 - 0.258
Laminaria digitata	-	1.250	0.138	61.2	-	6.41	6.41	0.0005	35.5	3.43	-
Laminaria ochroleuca	0.041	0.058	0,212	-	-	-	-	-	0.353	-	0.479
Saccharina japonica	0.481	0.2	0.85	1.58	-	-	0.09	-	-	-	-
Saccharina latissima	0.04	0.05	0.21	-	-	-	-	0.0003	0.35	1.6	-

Undaria pinnatifida	0.04-0.22	0.17-0.30	0.23-1.4	2.56	-	0.18	-	0.0036	5.29	1.4-2.5	0.49
Rhodophyta (Red seaweed)											
Chondrus crispus	-	-	-	-	-	-	-	0.6-4*	10-13*	-	-
Gracilaria spp.	-	-	-	-	-	-	-	-	16-149**	-	-
Gracilaria changii	-	-	-	-	-	-	-	-	28.5	-	
Palmaria palmata	1.59[1]	0.073-1.56	0.51-1.91	1.89	-	8.99	-	0.009	6.34-34.5	2.2-13.9	0.267
Porphyra umbilicalis	3.65	0.144	0.36	-	-	-	-	0.029	4.212	-	0.363
Porphyra yezoensis	16000***	0.129	0.382	11	-	-	-	0.052	-	-	-

[2] *** expressed as ppm; ** expressed as mg%; *** expressed as I.U.**