CONTRIBUTION 7.3

Sargassum In The Caribbean: Challenges And Opportunity For Blue Growth Based On The Circular Economy Approach

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Abstract

Since 2011, the mass of Sargassum in the Caribbean has increased dramatically and resulting in more than three times the normal amount of this seaweed in the region. In 2022, the mass of Sargassum in the region had a record of around twenty-two million tons in July and a similar figure is expected in 2023. Sargassum has a role in the marine ecosystem by providing fish nurseries, shelter for sea turtles and absorption of carbon dioxide. However, large volumes of this seaweed have a negative impact on the tourism sector, fishing industries, coral reefs and other coastal ecosystems, and the health of coastal residents.

In 2020 the New Zealand Ministry of Foreign Affairs and Trade funded a three-year collaborative project, which is being implemented by Plant & Food Research (PFR) of New Zealand and the Caribbean Regional Fisheries Mechanism (CRFM), to address Sargassum seaweed influxes in affected Caribbean countries. The project has four activity areas: raw material safety testing and harvesting operations review, product and process development, product commercialization strategy development and outreach and supply chain development.

The raw material safety testing was done using Sargassum collected in Belize, Barbados, Jamaica, and Dominican Republic. The results confirmed the findings of previous studies that Sargassum has elevated levels of Arsenic, Cadmium and Lead, with concentrations above the maximum allowable limits for human food and animal feed. For the second activity, the project team reviewed twenty-three potential products derived from Sargassum to identify the most suitable for product development and commercialization within the context of the Caribbean environment. Based on the results of the raw material safety testing; the technologies required for harvesting, product development and production; market competition; and regulatory standards in respect of the end-products, the project team selected three products: liquid fertilizer, compost and building materials. The selection of the three products was guided by the circular economy principle of minimum waste generation, mitigation of heavy metal content in accordance with international regulations, and contribution to blue growth in the Caribbean region.

Laboratory trials to produce liquid fertilizer and compost started in May 2023. The results obtained will define the operational conditions for production at pilot plant scale of the prototype products and value chains in 2024.

KEYWORDS: Sargassum, Value Chains, Blue Growth

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INTRODUCTION

Sargassum seaweed (*Sargassum natans and S. fluitans*) is a brown macroalgae that forms large floating mats in the ocean, particularly in the Atlantic. It is a natural part of the marine ecosystem providing habitat and food for various species. For example, it provides critical habitat, food supplies, protection, and breeding grounds for several marine species, including turtles and fish species such as the gray triggerfish, amberjacks, and mahi mahi. Sargassum has, however, been an issue of major concern in the Caribbean since 2011, when widespread blooms in the Atlantic Ocean and massive accumulations started affecting coastal areas and livelihoods in the Caribbean and West Africa regions (Kershaw, 2017; Franks *et al*., 2016; Hinds *et al.,* 2016; Wang *et al*., 2019; Oxenford *et al.* 2021). The blooms and beaching are seasonal, usually occurring from March-April through August-September each year, although the season may start earlier and continue until November or December, as was the case in 2018 and 2019. Since 2011, the Sargassum phenomenon has been a subject of keen interest and the focus of several regional, national and local initiatives due to its recurring presence, concerns regarding its negative socio-economic, environmental and health impacts on coastal ecosystems communities the region, and a desire to harvest and utilize it for commercial purposes.

At the global level, Smetacek and Zingone (2013), reported that there has been an overall increase in green and golden seaweed 'tides' within recent years. Dai *et al* (2023) also reported that coastal algal blooms have expanded and intensified over the past two decades. The Sargassum blooms are believed to be driven by a several factors including eutrophication of the Atlantic Ocean and Caribbean Sea arising from agricultural runoff, wastewater discharge, deforestation, and Saharan dust which contribute to excess nutrients in the ocean; as well as, warmer ocean temperatures and changes in ocean currents due to climate change (Franks *et al*., 2016; Wang *et al*., 2019; Leatherman, 2021).

The blooms being experienced in the Caribbean since 2011, are novel and unprecedented and seem to be increasing in magnitude over time (Wang *et al*., 2019; UNEP-CEP, 2021). They have negatively affected livelihoods and wellbeing of coastal communities, and national and regional economies through diversion of funds for clean-up and dumping, reduce profitability and loss of economic opportunities to fishers, hoteliers and other businesses operating in the affected coastal areas.

Sargassum is a naturally occurring marine, marine alga that contains hundreds of elements and compounds and can therefore be used in a variety of ways to benefit society. For example, it can be used as an organic fertilizer or soil conditioner to enrich soil quality and promote plant growth; building material for low-cost housing; a source of renewable bio-energy for electricity generation; a source of carbon sequestration; it is high in cellulose and hemicellulose, which are raw materials used in manufacturing paper product; it contains alginic acid, which can be used as a thickener and emulsifier in the food industry; and the genetic material may hold potential for biotechnological research and applications.

A recent study by Transparency Market Research (2021) estimated the global value of the algae market at USD$20.16 billion in 2021, and they expect it to grow at a compound annual growth rate of 10.9% per year between 2022-2031, to USD$55.67 billion by the end of 2031. It is therefore not surprising that regional governments and local entrepreneurs have been exploring ways of taking advantage of the Sargassum blooms to develop products and generate income and jobs.

Given the recurring blooms and large biomass of Sargassum available in the coastal waters, notwithstanding the spatial and temporal variation in the blooms, the harvesting and valorization of Sargassum biomass is an option for managing its negative impacts and

generating positive economic benefits that should be fully explored. From the beginning of the recent large influxes in the region entrepreneurs and other entities have been viewing the blooms as an opportunity for entrepreneurship and have been exploring potential ways of creating innovative products and value chains, and generating jobs and income from the Sargassum.

Since 2020, the CRFM and Plant and Food Research of New Zealand have been working together to implement the "Sargassum Products for Climate Resilience Project" (hereinafter referred to as the Project) which aims to mitigate the environmental and economic impacts of Sargassum in the region through the creation of technologies and value chains from the biomass. The Project which is funded by the New Zealand Ministry of Foreign Affairs and Trade (MFAT) has four main components as follows: (1) raw material safety testing and harvest operations review; (2) product and process Development; (3) product commercialization strategy development; and (4) outreach and supply chain development. The basic approach of the project is to collect fresh Sargassum at sea and use it as raw material for safe, innovative products based on the circular economy concept, with the aim of total utilization and recycling of the Sargassum, thus reducing waste to a minimum. The Sargassum and any residue remaining after processing will neither be left to decompose and release toxic gases, nor would other toxic elements such as arsenic and cadmium be reintroduced into the environment – all will be utilized in a safe manner.

THE PROJECT

The project aims to mitigate the environmental and economic impacts of *Sargassum* seaweed. An initial step was to evaluate a range of different possibilities and technologies that would not require extremely large infrastructure inputs but would provide new opportunities for local businesses and start-ups. Another important driver was to develop a circular appraoch to managing the compost – that is to reduce any compost going to waste. This first step identified opportunities for developing fertilizers or production enhancers from *Sargassum*, with the any left-over *Sargassum* used for soil conditioners, including compost. Additional opportunities identified include industrial option such as using this remaining Sargassum material for construction bricks. A key step in this phase is the identification of the chemical components of the *Sargassum* and its variability with sampling location and year – this influences any further use of the *Sargassum*.

The next step is the product development - exploring methods of extracting and developing liquid fertilizer or enhancers from the *Sargassum*. This includes laboratory trials to develop a product, and then testing these in glasshouse and field trials. These steps also have important consequences on the remining Sargassum product and its potential use for compost of building materials. Once a process is identified that produces a reliable and effective product, the next step is scaling up production and commercializing with local businesses.

Here we report on initial findings from sampling Sargassum in different locations and years, as well as the first steps in laboratory trials to develop a fertilizer or plant enhancer for production.

Samples collection and analysis

Samples of Sargassum were collected in different areas of the Caribbean, and the main goal was to have samples covering the four cardinal Caribbean regions, i.e., north, south, east and west. The countries selected were Belize (western Caribbean), Barbados (eastern Caribbean), Jamaica (south-central Caribbean) and Dominican Republic (north-central Caribbean). Figure 1 shows the locations of the countries where the Sargassum samples were collected.

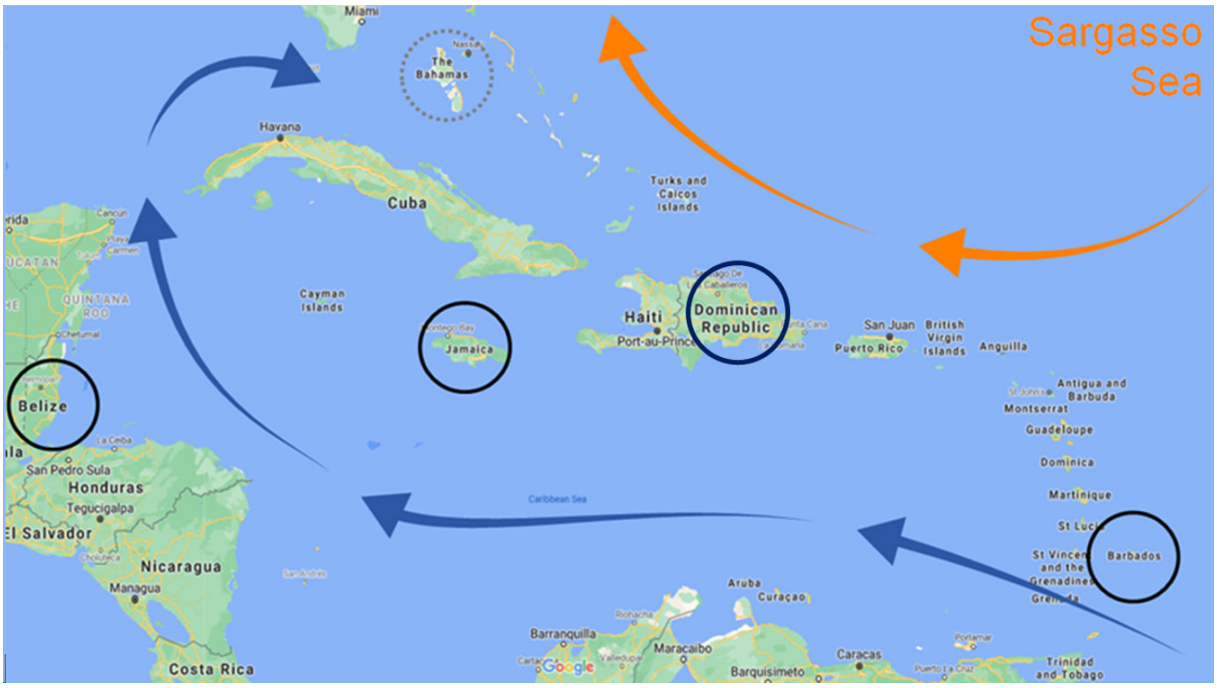

Figure 1. Caribbean countries where the Sargassum samples were collected.

The Caribbean Regional Fisheries Mechanism (CRFM) and The New Zealand Institute for Plant and Food Research Limited (PFR) established partnerships with local universities, research organizations, private companies, and government ministries to assist with the sample collection and processing of the Sargassum. Two samples collection were done, one between July-September 2021, with 33 samples, and the second one August-October 2022 with 20 samples. After the Sargassum samples were collected, they were washed with fresh water and dried to be sent for chemical analysis.

Several chemical analyses were required to evaluate the content of some heavy metals and other elements. The heavy metals analyzed were Arsenic (As), Lead (Pb), Cadmium (Cd) and the elements measured were Calcium (Ca), Chromium (Cr), Iron (Fe), Magnesium (Mg), Sodium (Na), Titanium (Ti), Zinc (Zn), Potassium (K), Nitrogen (N), Phosphorus (P), Sulphur (S) and Carbon (C).

The heavy metals content was assessed to know how the Sargassum could be used as a raw material to make different products without exceeding the maximum allowable limits (MAL) for soil, human, or animal products. The elements analyzed were the ones that are essential for animal feed and/or plant stimulant. Minerals such as Nitrogen (N), Phosphorus (P), and Potassium (K) are necessary for animal feeds, for fertilisers and composts. Iron (Fe), calcium (Ca), magnesium (Mg), zinc (Zn), are also essential minerals in most of the animal diets and should therefore be considered for any animal feed applications. The results for heavy metals and minerals are shown in Table 1 and Table 2.

Table 1. Average of heavy metals content, in bracket, and observed range of heavy metals content for Sargassum samples collected by the Activity June-September 2021 from Barbados, Belize, and Jamaica and August-October 2022 from Jamaica and Dominic Republic. The concentrations are in on a dry weight basis.

Country	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)	Lead (mg/kg)
Barbados 2021	**(27.7 ± 13.4)** **15.6 – 73.3**	**(1.1 ± 0.1)** **0.8 – 1.6**	**0.01**	**(0.3 ± 0.1)** **0.3 – 0.4**
Belize 2021	**(70.9 ± 4.6)** **52.2 – 99.3**	**(1.0 ± 0.1)** **0.9 – 1.3**	**0.01**	**(0.09 ± 0.01)** **0.07 – 0.12**
Jamaica 2021	**(30.5 ± 1.0)** **29.3 – 31.3**	**(0.6 ± 0.1)** **0.6 – 0.7**	**0.01**	**(0.6 ± 0.1)** **0.48 – 0.67**
Jamaica 2022	**(62.9 ± 5.7)** **41.7 – 82.5**	***(0.5 ± 0.1)*** ***0.4-0.6***	***0.01***	***(0.3 ± 0.2)*** ***0.1-0.6***
Dominic Republic 2022	**(89.3 ± 3.6)** **81.4 – 105.3**	***(0.4 ± 0.1)*** ***0.3-0.5***	***0.01***	***0.1***

According to the results in Table 1, the Arsenic concentrations were notably different between the countries selected. Also, Arsenic concentrations were the highest for all the heavy metals evaluated and this has been reported in several papers (Devault *et al.,* 2020; Alleyne *et al*., 2023). The concentrations of the rest of the heavy metals were more consistent within the countries.

Arsenic, cadmium, mercury and lead are environmental pollutants that can accumulate and contaminate the food chain. Maximum Allowable Limits (MAL) of these metals for products to be used in agricultural soils, for human consumption and animal feeds are shown in Table 3.

Table 2. Mineral contents for Sargassum evaluated in the different countries. The concentrations are in mg/kg on a dry weight basis.

Species	Belize 2021	Jamaica 2021	Barbados 2021	Jamaica 2022	Dominic Republic 2022
Ca	51,198.05	36,693.05	54,086.76	68,538.20	35,443.09
Cr	0.34	1.58	0.41	0.32	0.54
Fe	40.27	102.80	91.54	26.42	64.33
Mg	9,404.36	9,582.40	7,794.95	12,162.03	6,919.76
Na	14,843.86	2,218.97	2,458.99	2,598.42	8,257.62
Ti	0.01	0.01	0.01	0.01	0.01
Zn	6.80	12.27	6.39	3.34	21.56
K	63,075.00	3,114.85	3,520.22	17,386.41	64,569.61
N*	13,090.75	9,506.51	10,750.88	9,830.14	8,705.07
P	1,181.09	394.28	522.33	537.32	881.49
S	12,242.74	12,167.32	13,612.22	12,298.82	14,827.96
Total organic C	35.33	41.30	47.84	30.77	27.02

Ca= Calcium, Cr= Chromium, Fe= Iron, Mg= Magnesium, Na= Sodium, Ti= Titanium, Zn= Zinc, K= Potassium, N= Nitrogen, P= Phosphorus, S= Sulphur and C= Carbon.

Table 3. Maximum allowable limits (MAL) for soil, human, or animal products.

Element	Maximal Allowable Limits (MAL) (mg/kg)*			
	Agricultural soil	Animal feeds	Human food	Human supplements
Arsenic (As)	20.0	40.0	3.0	3.0
Cadmium (Cd)	1.5	1.0	0.5	0.5
Mercury (Hg)	6.6	0.1	0.1	0.01
Lead (Pb)	350	10.0	5.0	3.0

* Guidelines for human food and supplements were from the French Agency for Food Safety (AFSSA) and Council of the European Union (EC); guidelines for animal feed and agricultural soil were from the Council of the European Union, The European Community and China's Environment Protection Agency guidelines on concentration for soil Pb to protect human from health risk.

Considering the MAL values display in Table 3 and the results in Table 1, it is evident that the concentrations of arsenic in the Sargassum are limiting it to be used directly in soil or huma/ animal applications. However, the Sargassum can be used in the applications listed early by processing or mixing it with other ingredients to achieve concentrations below the MAL. In the case of Cd, Hg, and Pb, their concentrations in the Sargassum would not be restricted it for the applications listed.

The contents of Ca, Mg, K and N in Sargassum, see Table 2, suggest that it could be used as an ingredient in the formulation of animal feed. Although, the proportion of Sargassum in the diet formulation must ensure that the arsenic content is below the MAL.

Products development

An exhaustive literature review, including patents, was done to look for potential applications of Sargassum (or similar seaweed) derived products that were currently in the market. A list of 33 products was generated and they were compared in terms of their end-product value; the technological complexity and infrastructure necessary to produce them in a circular economy approach and minimum waste; their global market size and the intensity of the market; and regulations on heavy metal concentrations. Based on these criteria, three products were selected: Sargassum liquid fertilizer/ plant growth enhancer, compost, and building materials. Figure 2 shows the block diagram to produce the target Sargassum products.

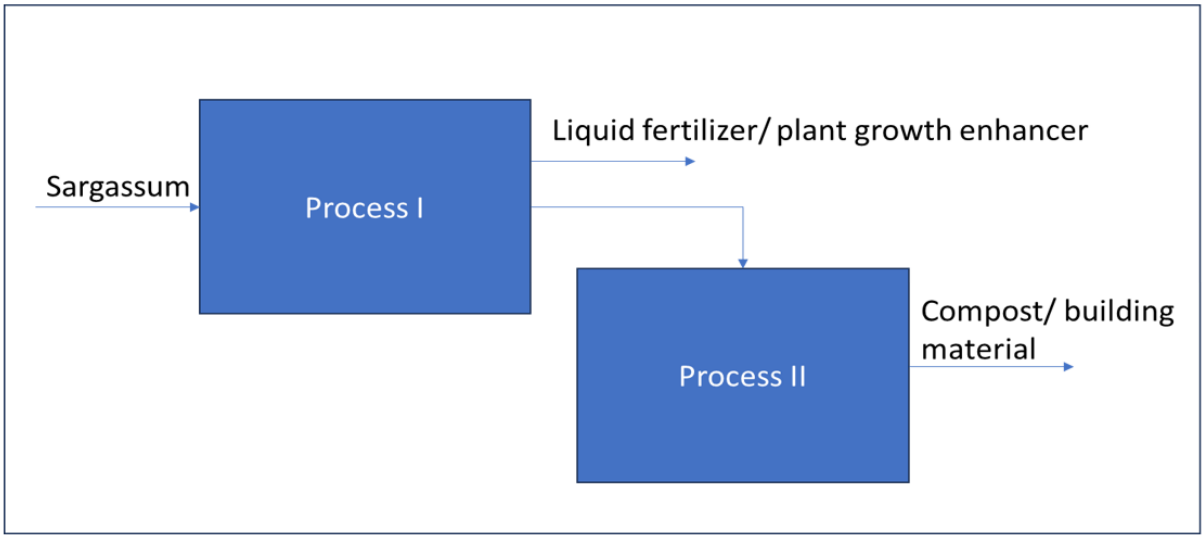

Figure 2. Circular economy and minimum waste approach for the target Sargassum products.

For the development of the Sargassum products several tests have been done at laboratory scale. The goal of the laboratory tests is to obtain the physicochemical and process parameters to be used for scaling up the products to pilot and industrial scales.

Laboratory tests for the Sargassum liquid fertilizer/ plant growth enhancer

Laboratory trials to develop a liquid plant growth enhancer from Sargassum seaweed commenced in May 2023 at the University of the West Indies, Cave Hill Campus Barbados (UWI-Barbados). A total of 46 kg Sargassum seaweed was collected from Consett Bay, St. John, Barbados, at an approximate distance of 1 mile offshore. Two-thirds of the seaweed harvested (estimated at 31 kg wet weight) was delivered to the Caribbean Agriculture Research and Development Institute (CARDI) for cleaning and drying, in accordance with the step-by-step guidelines outlined in the manual provided**.** The remaining bags of fresh Sargassum seaweed were transported to UWI-Barbados for washing and same-day analysis. Figure 3 shows the Sargassum collection and processing.

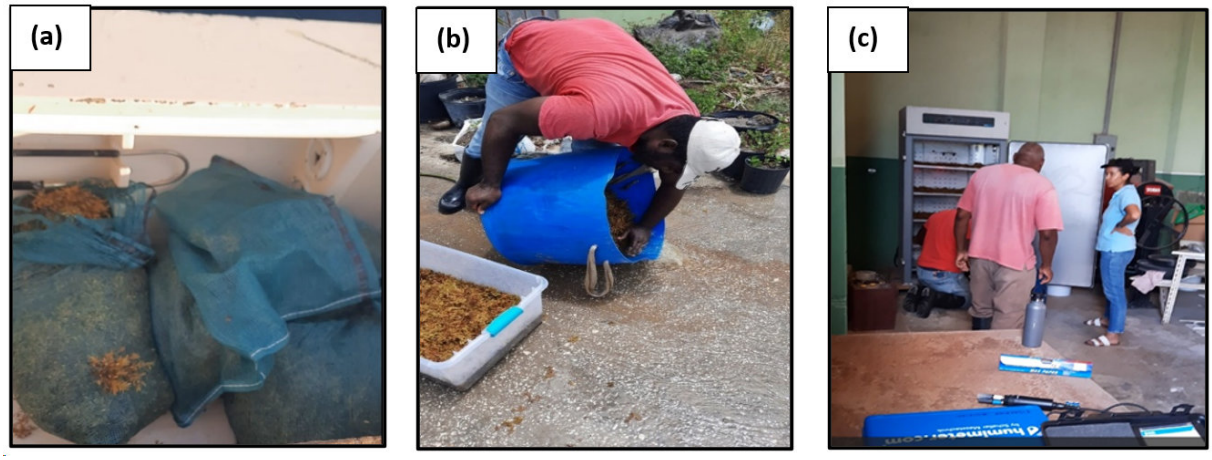

Figure 3. (a) Sargassum collected from Consett Bay, St. John, Barbados; (b) Sargassum sorting and washing at CARDI; (c) Oven drying Sargassum seaweed at CARDI.

During six weeks of laboratory trials, four (4) different extraction systems were investigated. The systems evaluated were three (3) enzymes and one control without enzyme addition. The Sargassum/liquid ratio and extraction time were constant for all the extractions. For the enzyme systems, the quantities, temperature, and pH values were recommended by the enzyme supplier.

The volume of liquid extract yielded from the three (3) enzyme-induced extraction processes evaluated was 25-60% greater than that derived from the control experiment, see Figure 4. The dry matter content of the liquid extracts ranged from 30-35% across all the systems studied, with visible sedimentation deposited at the bottom of the storage container when the liquid extract was left to stand for 10-15 minutes. Noteworthy, enzymes addition to Sargassum accelerated the breakdown of recalcitrant lignocellulose to fermentable sugars, thereby altering the chemical structure and reducing fibrous texture of the residual solid fractions relative to the virgin biomass (Houfani *et al.*, 2020; Guo *et al.,* 2023). Refer to Figure 4.

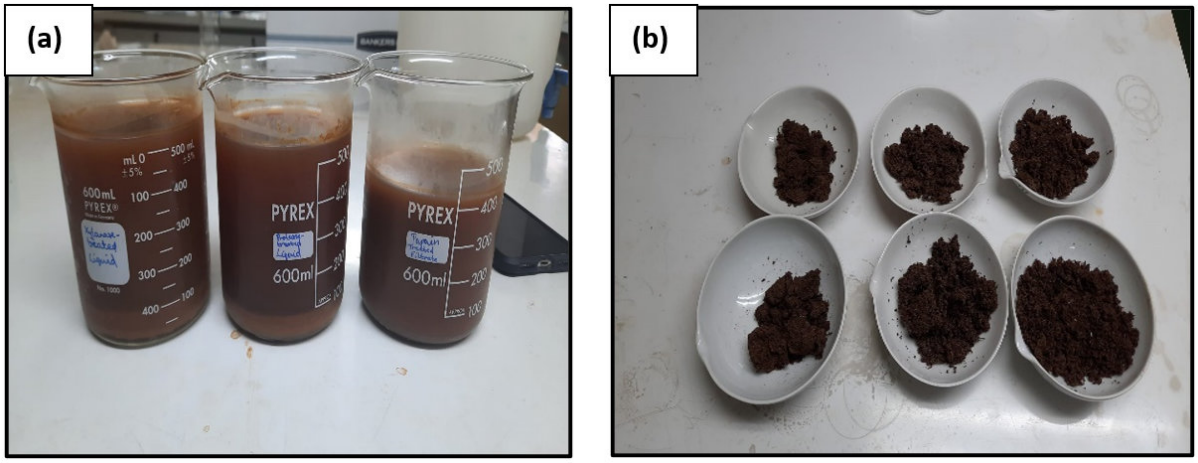

Figure 4. (a) Liquid extract yields: the two beakers in the left with enzymes and the beaker at the right the control and (b) Solid Sargassum residue recovered after 2-hours of enzymatic liquid extraction.

The liquids obtained for the different extractions were analyzed for macronutrient (NPK) content, see Figure 5 below.

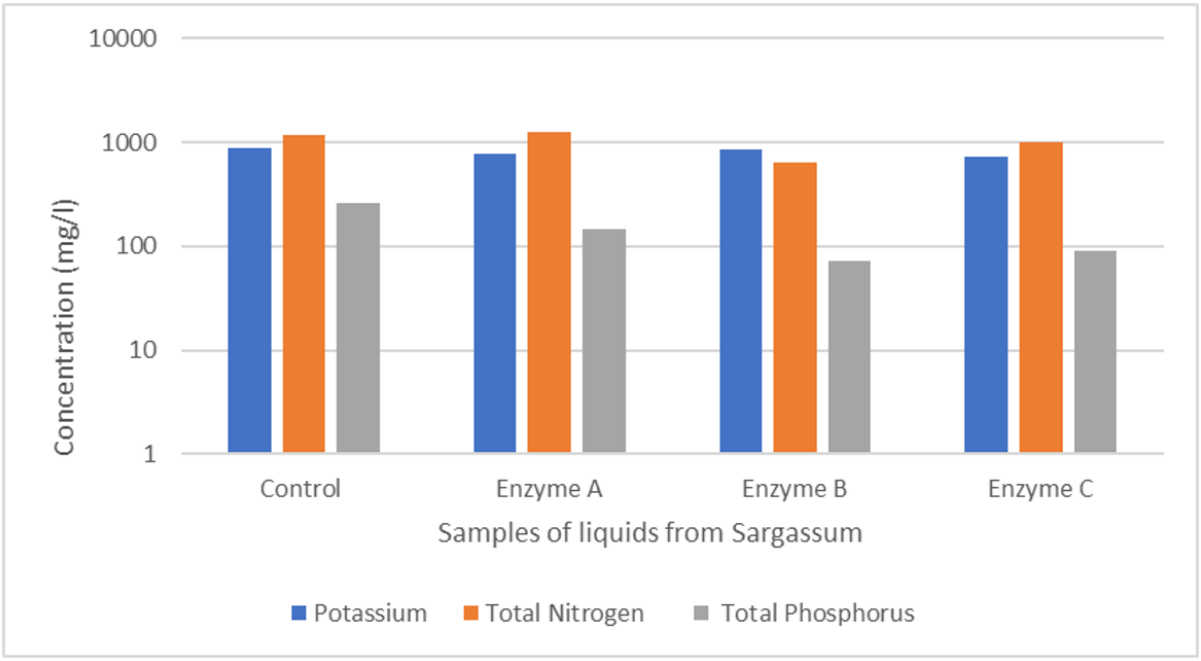

Figure 5. NPK content in the liquid Sargassum extractions.

From the results shown in Figure 5, the Nitrogen (N) content was the highest in the four Sargassum extraction systems evaluated, followed by Potassium (K) and Phosphorus (P). The NPK ratios of fertilizers and plant growth enhancers are important to support plant health and productivity. Heavy metal analysis of the liquid extracts was also conducted to determine the concentrations of arsenic (Ar), lead (Pb) and cadmium (Cd). The results are reported in Figure 6.

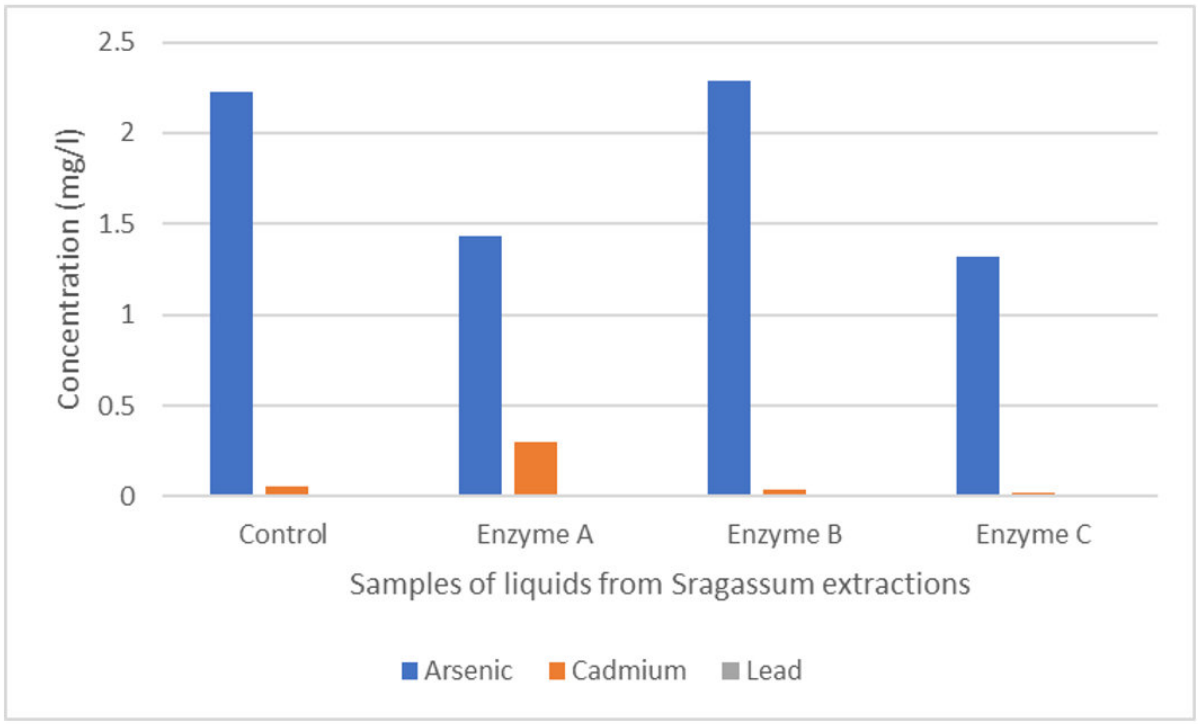

Figure 6. Heavy metals content in the samples of liquid Sargassum extractions

Arsenic (Ar) was the most abundant heavy metal in the Sargassum liquid extractions evaluated, while the lead (Pb) concentration was below the detectable limit (see Figure 6). Collectively, the concentration of all detected metals was below the maximum allowable limits for agricultural soils: arsenic at 5 mg/l; lead at 750 mg/l; and cadmium at 1 mg/l (Tóth *et al*, 2016). This positive result suggests safety of the liquid extracts for use as a fertilizer or biostimulant, as far as the studied metals are concerned. Nevertheless, further analysis on the arsenic present in Sargassum is warranted to understand its speciation and potential toxicity. This point was emphasized in a recent publication by the Centre for Resource Management and Environmental Studies, UWI-Barbados which indicates that pelagic Sargassum in Barbados is composed primarily of toxic inorganic arsenic, a result not influenced by Sargassum influx events or the seaweed growth site (Alleyne *et al.*, 2023).

Presently, the four Sargassum extraction liquids are under evaluation in a greenhouse trial at CARDI and the one with the best performance will be optimized and scaled-up in pilot plant production. Given the project's strong focus on circular economy, the residual solids from Sargassum liquid extraction will also be assessed for utilisation in compost or as building material.

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