A custom, low-cost, continuous flow chamber built for experimental Sargassum seaweed decomposition and exposure of small rodents to generated gaseous products

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A R T I C L E   I N F O

A B S T R A C T

Since 2011, Sargassum events have increased in frequency along the Caribbean and Atlantic coasts. The accumulation and decomposition of large amounts of Sargassum seaweed on beaches pose socio-economic, ecological, and health risks due to the emission of hydrogen sulfide (H_2S), methane, and ammonia. However, limited research exists on the emission processes and the health effects of subchronic and chronic exposure to low levels of H_2S. Additionally, the absence of emission factor data for Sargassum decomposition on-site makes health risk assessments challenging. This study aimed to create a custom chamber to simulate real-world Sargassum decomposition, exposing experimental animals to the generated gases. Metal content was analyzed, and emission rates were estimated in a controlled environment. The decomposition-exposure system replicated reported environmental gas emissions from the Caribbean region, except for NH_3. H_2S bursts were observed during the decomposition process at intervals of 2–10 days, with higher frequency associated with larger masses of decomposing Sargassum. The decomposed gas was transferred to the exposure chamber, resulting in an 80–87% reduction in H_2S concentration. The maximum H_2S emission was 156 ppm, with a concentration ranging from 50.4 to 56.5 ppm. An estimated emission rate of 7–8 g/h for H_2S was observed, and significant levels of lead, arsenic, and aluminum were found in beached Sargassum from the northeast coast of Brazil. This study's developed model provides an opportunity to investigate the effects and risks to human health associated with exposure to gases produced during the environmental decomposition of Sargassum seaweed.

1. Introduction

Since 2011, Sargassum events have increased in frequency along the Caribbean and Atlantic coasts, specifically the West African

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and Northern Brazilian coasts [1]. Fidai and cols [2]. defines a Sargassum event as the deposition of massive amounts of Sargassum seaweed on beaches, resulting in negative socio-economic and ecological implications and detrimental effects on the health of nearby communities. The genus Sargassum encompasses over 350 species of macroalgae, primarily found attached to rocks along the coast, with only a few species being pelagic (free-floating) [3]. Pelagic species form large floating masses in the open sea, providing habitat and support for various marine species. Since 2011, there has been a significant proliferation of these pelagic Sargassum species (*S. natans and S. fluitans*), leading to frequent massive beaching events [1]. Evidence suggests that climate changes, such as increased sea surface temperatures, and elevated seawater nutrient levels (ocean contamination), may be potential causes of this excessive proliferation and massive beaching; however, further studies are required for confirmation [4–8]. Due to the challenges in removing and appropriately disposing of the large quantities of Sargassum deposited on beaches, most of it accumulates and decomposes *in situ* [9]. This decomposition process of Sargassum biomass releases gases that contaminate the surrounding air [10]. Microbiota, temperature, and pH influence the decomposition process, leading to the production of by-products such as H_2S, NH_3, CO_2, and CH_4 [11]. These gases, including toxic ones like H_2S [12] and NH_3 [13], pose health risks to coastal residents and beach users [14]. Additionally, the presence of these toxic gases can endanger the health of local animals.

Recent studies have highlighted the potential health risks associated with Sargassum decomposition emissions in humans. Commonly reported symptoms among affected individuals include eye irritation, irritation of the nasal mucous membranes, headaches, nausea, and breathing difficulties [15]. Furthermore, two cases of keratoconjunctivitis have been linked to such exposures [16]. Resiere and cols [15]. reported 11,000 suspected poisoning cases associated with environmental exposure to Sargassum gas emissions in 2018. It is worth noting that information regarding occupational exposure of workers involved in Sargassum biomass removal activities is lacking, and their exposure near the source may be higher.

Despite the health risks associated with the massive influx of Sargassum and the gases emitted during the decomposition process, there is a scarcity of studies examining the emission processes and the effects of subchronic and chronic exposures to low levels of these gases. Conducting health risk assessments is also challenging due to the absence of data on emission factors and models for Sargassum decomposition *in situ* [17]. Humans studies (clinical and epidemiological) are complicated by numerous co-factors (e.g. age, nutritional status, use of medication, use of alcohol or recreational drugs, stress) that may interfere with the specific effects of exposure to gases produced by Sargassum decomposition, making difficult to establish a causal relationship.

The objective of this study was to develop a custom chamber to simulate the "real world" decomposition of Sargassum and expose experimental animals to the resulting gases. Our primary goal was to replicate the environmental conditions, enabling controlled studies on the decomposition process and its health effects. Furthermore, we analyzed the metal content and estimated emission rates in this controlled environment.
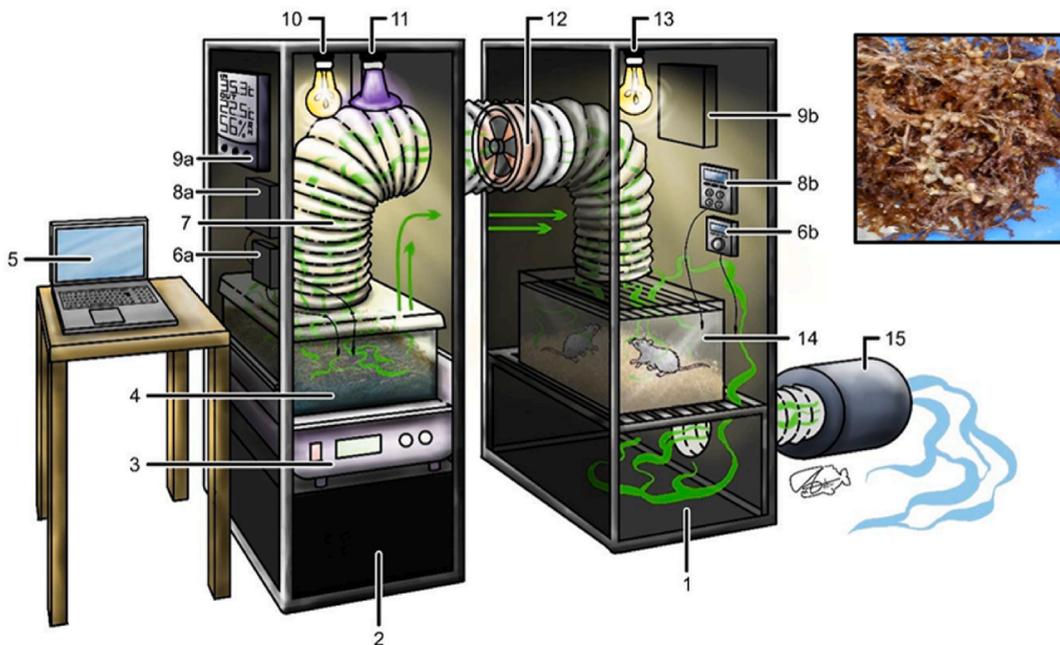
Fig. 1. Schematic illustration of the decomposing (2) and exposing chambers (1). Sargassum seaweed decomposing box (4) was accommodated on an orbital shaker (3) and through a ventilation tube connected to a fan (12) emission were transferred to the exposure chamber were animals were maintained (14). Light-dark cycle was created with a lamp for indoor grow (10) and heat generated by a ceramic lamp (11). A regular lap was used to light the animal chamber (13). Temperature, humidity and gas concentrations were monitored daily using digital monitor (9) and gas sensors for CO, O_2, H_2S (6) and CH_4 and NH_3(8). Data generated by the sensors and monitors were monitored and stored in a notebook (5) connected to the system. Carbon air filter for exhaustion (15). In the detail box a picture of the fresh Sargassum collected and used in this study (Sargassum natans VIII).

2. Materials and methods

2.1. System design

Our system comprises two chambers positioned side by side: one for the decomposition of Sargassum biomass and the other for exposing small experimental animals. Briefly, the gases generated in the decomposition chamber are conveyed to the exposure chamber, where the animals are housed, with the assistance of an exhaust fan to prevent alterations in Sargassum decomposition emissions. Fig. 1 provides a schematic illustration of the chambers. To construct the chambers, commercially available indoor plant grow chambers were utilized (Model Basic Garden Highpro, dimensions 160 cm × 40 cm x 40 cm) (Fig. 1, items 1 and 2). These chambers are user-friendly, cost-effective, and equipped with multiple vents to accommodate various ventilation configurations and exhaust systems. They also feature sealed openings for the installation of monitoring, lighting, and heating systems.

2.1.1. Decomposition chamber

We employed a closed system for the Sargassum decomposition process. A plastic box (dimensions 20 cm × 26 cm x 21 cm) was utilized, with a 3 cm layer of beach sand placed at the bottom, upon which the Sargassum mass was positioned (Fig. 1, item 4). The box was not completely sealed, featuring an opening at the top to allow gas exhaust through a ventilation tube (Fig. 1, item 7). Additionally, two small openings were created for twice-daily seawater spraying. The ventilation tube connected to the exposure chamber facilitated gas conduction. To aid the process, an exhaust fan (model brand) with a flow rate of 107 m^3/h was employed in the exhaust duct, creating positive pressure and directing the gases to the exposure chamber (Fig. 1, item 12). The decomposition box was placed on a low-speed orbital shaker (Fig. 1, item 3) to induce water movement near the sand and facilitate gas release. Gas sensors (AKSO®, SP2nd-NH$_3$ and MULTIGAS PRO) were employed to monitor the concentrations of H$_2$S, NH$_3$, CH$_4$, CO, and O$_2$ in both the decomposition box and exposure chamber. Limits of detection and resolution of the gas sensors are depicted in Fig. 2. Temperature and humidity were continuously monitored using digital humidity/temperature monitors in both chambers (Fig. 1, items 6 and 8). The temperature of the Sargassum seaweed mass was measured once daily in the morning using an infrared thermometer. For artificial light and heat, LED lamps simulating sunlight (Fig. 1, item 10) and ceramic heat lamps (Fig. 1, item 11) were utilized. A light-dark cycle of 12/12 h was implemented, with the heating lamps active only during the light period.

2.1.2. Exposure chamber

Within the exposure chamber, a plastic shelf was placed to accommodate three animal cages side by side (Fig. 1, item 14), ensuring consistent exposure conditions regardless of cage position. The opening of the decomposition chamber's exhaust duct was positioned 30 cm above the animals. Gas concentrations, temperature, and humidity in the exposure chamber were monitored using the aforementioned digital humidity/temperature monitor, and gas sensors located directly above the cages. To prevent contamination of the ambient air outside the exposure chamber, air exhaustion was carried out through a carbon air filter located at the base of the structure (Fig. 1, item 15).

2.2. Chamber testing

To test the chamber's functionality, three experiments were conducted using varying masses of Sargassum. The first two experiments (EXP1 and EXP2) utilized 4 kg and 6 kg of Sargassum, respectively. In the third experiment (EXP3), 10 kg of Sargassum was used in the plastic box. The experiments commenced on day 1, defined as the day when the Sargassum biomass was placed in the decomposition box and the heating and light cycle was initiated. During the dark period, the heating lamps were turned off, maintaining the temperature at 21 °C (laboratory room temperature). Gas (H$_2$S, NH$_3$, CH$_4$, CO, and O$_2$) monitoring, along with humidity and temperature measurements, began on the same day and continued for 28, 30, and 90 days. These durations periods were chosen to align with the recommendations of OECD (Organization for Economic Co-operation and Development) test guidelines for Subacute and Subchronic inhalation toxicity testing (Test no. 412 and 413) [18].

Hydrogen sulfide (H$_2$S), commonly known as sulfidric gas, was selected as the reference gas due to its association with the health impacts of massive Sargassum landings and decomposition in the Caribbean region. The exhaust system was activated to assess gas levels in the exposure chamber during the second (EXP2) and third (EXP3) experiments.

Gas	Limits of detection	Resolution
O$_2$	0-30% Vol	0,1% Vol
H$_2$S	0 -100ppm	1ppm
NH$_3$	0-100ppm	1ppm
CH$_4$	0 a 5% (0-2500ppm)	0,01%
CO	0-1000ppm	1ppm

* AKSO®, SP2nd-NH$_3$ and MULTIGAS PRO

Fig. 2. Gas sensors* specification
* AKSO®, SP2nd-NH$_3$ and MULTIGAS PRO.

2.3. Sargassum samples

The Sargassum samples used in this study were collected from Porto de Galinhas beach (−8.491205, −35.001764) in the state of Pernambuco, Brazil. The identification of Sargassum species was based on their morphology (Fig. 1, detail box), and our samples were primarily composed of *Sargassum natans VIII* [19]. A total of 20 kg of fresh Sargassum seaweed and 6 L of surrounding seawater were collected for the purpose of hydrating the Sargassum during the decomposition process.

2.4. Estimates of H$_2$S emission rates

The emission rates of H$_2$S were determined by multiplying the ventilation rates (fan) with the daily mean H$_2$S concentrations (Ni et al., 2000). The H$_2$S concentration in parts per million (ppm) was converted to milligrams per cubic meter (mg/m^3) using the following formula (a).

(a) concentration (mg/m3) = 0.0409 x concentration (ppm) x molecular weight (34.08 g/mol).

2.5. Elemental analysis of Sargassum seaweed samples

A random sample of 200 g of fresh Sargassum seaweed was collected at the same site and divided into 50 g subsamples. Excess seawater was drained off before storing the samples in 50 ml Falcon tubes, which were kept refrigerated until analysis. For metal content characterization, the samples were lyophilized and ground using a laboratory ball mill (Retsch model PM200). Analysis was conducted using X-ray fluorescence (Thermo Scientific model Niton™ XL3t XRF Analyzer).

3. Results

3.1. Sargassum decomposition emissions

In the first experiment, decomposition emissions started on day 10, while in the second and third experiments, they started on days 7 and 9, respectively. In all three experiments, there was an initial surge of CO emissions before H$_2$S emission. Fig. 3 (A-C) graphically represents the daily mean gas emissions during the experimental periods for all three experiments. During the decomposition process, bursts of H$_2$S release occurred at intervals of 2–10 days, with a higher frequency observed when a larger mass of Sargassum seaweed
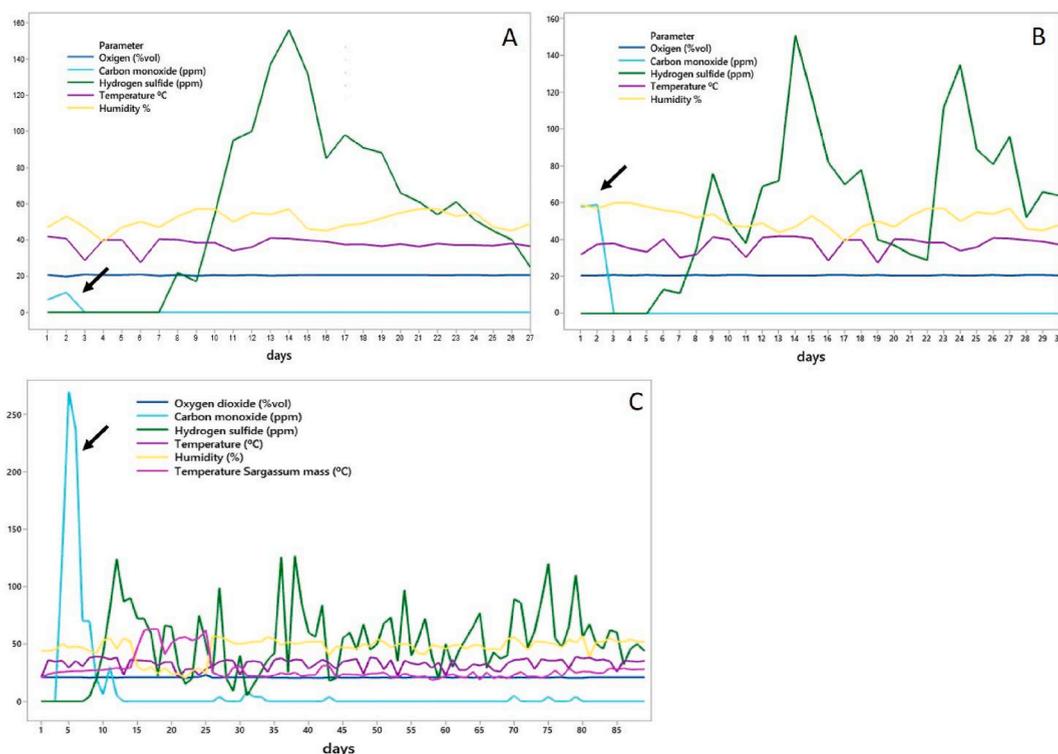
Fig. 3. Graphic representation of mean daily gas concentration during EXP1 (A), 2 (B) and 3 (C). A CO surge (arrow) precedes the beginning of H$_2$S gas generation, during the process of decomposition peak releases are observed.

was decomposing. In experiments 1 and 2, the maximum emissions of H_2S were 156 ppm and 151 ppm, with a daily mean concentration of 54.7 and 56.5, respectively. The third experiment lasted 90 days, and a peak concentration of 121 ppm of H_2S was observed. Mean, median, standard deviation (SD) and coefficient of variation (CV) of daily temperature, humidity, and the gases concentrations are presented in Table 1. Only in the third experiment, a low concentration of CH4 was observed after 50 days. NH_3 emissions were not detected in any of the experiments.

3.2. H_2S concentration in animal exposure chamber

Gas concentrations in the exposure chamber was measured for the second and third experiments, as animals were being exposed simultaneously (health effects resulting from animal exposure are not within the scope of this study). Table 1 presents the daily mean concentration of gases (O_2, CO, H_2S, CH_4) inside the decomposing and exposure chambers, as well as the mean values of temperature and humidity. NH_3, CH_4, and CO were not detected. In the exposure chamber, the concentration of H_2S was reduced by approximately 80–87%. Fig. 4 (A-B) provides a graphical representation of the H_2S concentration in the decomposing chamber and the exposure chamber for EXP 2 and EXP 3 showing differences between the emission source and the exposure scenario in our model.

3.3. Emission rates

The daily H_2S emission rates for the three experiments are presented in Fig. 5. The mean daily emissions for EXP1, EXP2, and EXP3 were 7.87 g/h, 8.43 g/h, and 7.52 g/h, respectively.

3.4. Sargassum seaweed elemental content

The results of elemental concentration in Sargassum seaweed are presented in Table 2. The table provides mean values (in ppm), standard deviations (±SD), and coefficients of variation (CV) for each element. Noteworthy concentrations include lead (Pb) with a mean of 11.2 ppm, aluminum (Al), with a mean concentration of 3658.51 ppm and arsenic (As) with a mean of 10.62 ppm.

Table 1
Mean, standard deviation (SD), coefficient of variation (CV), median and maximum and minimum values of daily temperature, humidity and gases concentrations in the decomposing and exposure chambers for the 3 experiments. EXP1 = 28 days, EXP2 = 30 days and EXp3 = 90 days.

	Parameter	Mean	SD	CV %	Median	Max
28 days	O_2 (%vol)	20,5	0,2	1,2	20,6	20,9
	CO (ppm)	0,7	2,5	369,8	0,0	11,0
	H_2S (ppm)	54,7	46,7	85,4	54,0	156,0
	CH4 (%vol)	nd	nd	nd	nd	nd
	Temperature (°C)	37,6	3,3	8,8	37,9	41,8
	Humidity (%)	50,8	4,8	9,4	50,0	57,0
30 days	O_2 (%vol)	20,7	0,2	0,8	20,6	20,9
	CO (ppm)	3,9	14,8	380,6	0,0	59,0
	H_2S (ppm)	56,5	41,6	73,6	58,0	151,0
	CH_4 (%vol)	nd	nd	nd	nd	nd
	Temperature (°C)	37,3	4,3	11,4	38,7	41,9
	Humidity (%)	51,7	5,4	10,5	52,5	60,0
30 days exposure chamber	O_2 (%vol)	20,7	0,1	0,6	20,6	20,9
	CO (ppm)	nd	nd	nd	nd	nd
	H_2S (ppm)	7,3	5,8	78,4	8,0	18,0
	CH_4 (%vol)	nd	nd	nd	nd	nd
	Temperature (°C)	23,3	0,6	2,7	23,4	25,1
	Humidity (%)	51,6	6,6	12,9	50,5	62,0
90 days	O_2 (%vol)	20,8	0,3	1,5	20,9	23,1
	CO (ppm)	9,7	40,9	419,3	0,0	270,0
	H_2S (ppm)	50,4	30,9	61,3	50,0	127,0
	CH_4 (%vol)	0,02	0,04	209,85	0,00	0,20
	Temperature (°C)	32,8	4,7	14,5	34,6	39,1
	Humidity (%)	46,8	8,7	18,6	49,0	57,0
90 days exposure chamber	O_2 (%vol)	20,6	0,1	0,7	20,6	20,9
	CO (ppm)	nd	nd	nd	nd	nd
	H_2S (ppm)	9,7	6,4	66,2	9,0	38,0
	CH_4 (%vol)	nd	nd	nd	nd	nd
	Temperature (°C)	24,6	2,7	10,8	25,0	32,6
	Humidity (%)	54,2	5,2	9,6	54,0	69,0
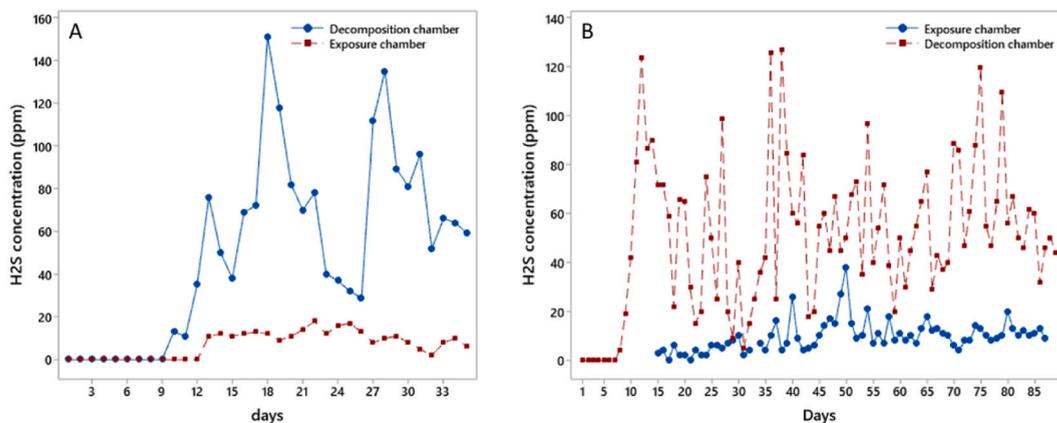
Fig. 4. Daily mean concentration of H$_2$S in the decomposition and exposure chamber showing differences between the levels in the emission source and exposure levels during the 30 days (A) and 90 days (B) experiments.
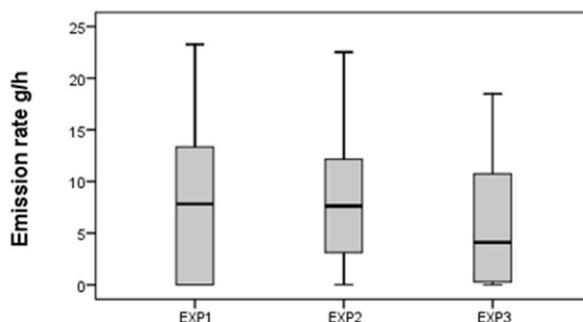
Fig. 5. H$_2$S mission rates observed in the three experiments.

4. Discussion

Our decomposing-exposure system successfully replicated the environmental gas emissions reported in the Caribbean region, with the exception of NH$_3$. Environmental concentrations of H$_2$S in Martinique, as indicated by Resiere and cols [14,15], ranged from 0.1 to 0.9 ppm, with a minimum of 0 ppm and a maximum of 11.1 ppm. The Air Quality Report outside France from 2021 revealed that in certain regions of Martinique, the number of days exceeding the limits of 5 ppm and 1 ppm of H$_2$S can reach 50 and 500 days, respectively. No exceedance of NH$_3$ levels was observed [18].

Table 2
Elemental concentration in Sargassum seaweed.

Element	Mean (ppm)	±SD (ppm)	CV
Al	3658.51	1994.48	55%
Si	23773.95	957.64	4%
S	65357.01	675	1%
Cl	257423.24	1447.52	1%
K	4519.71	95.62	2%
Ca	77303.38	913.68	1%
Sc	140.91	29.64	21%
Ti	230.1	32.98	14%
Fe	2705.11	87.85	3%
As	10.62	3.65	34%
Rb	158.59	4.9	3%
Sr	1029.73	10.57	1%
Zr	30.93	5	16%
Nb	7.73	2.6	34%
Mo	13.4	2.75	21%
Pb	11.2	4.55	41%
Bi	89.46	9.15	10%
Th	21.78	3.52	16%

In 2015, H_2S concentrations ranging from 0.1 to 1 ppm, and occasionally reaching concentrations of 0–5 ppm with peaks at 10 and 15 ppm were detected [10]. Environmental levels of H_2S vary greatly between days and years, depending on environmental conditions and the volume of deposited Sargassum seaweed, according to reports from the French Agency of Public Health and the Martinique Observatory of Air Quality (https://www.madininair.fr/).

In our study, patterns of gas emission also varied over time. These variations could be explained by organic matter consumption, temperature fluctuations, photodegradation and changes in bacterial populations [20]. All these factors influence the biogeochemistry of elemental cycling, particularly, for elements such as sulfur and arsenic. The decomposition of organic matter releases sulfur compounds, contributing to the emission of H_2S. Additionally, changes in temperature and bacterial populations can affect the activity of microbial communities involved in sulfur and arsenic transformations, influencing their cycling dynamics in the environment [20].

Additionally, we have to consider that changes and differences in emission could be explained by photodegradation of dissolved organic matter [21,22]. After carbon dioxide (CO_2), carbon monoxide (CO) is the second most prevalent result of dissolved organic matter photodegradation, however it is still unclear how it is formed [23]. CO production from dissolved organic matter is significant in distant ocean locations or in conditions with high inputs of terrestrial dissolved organic matter. Recently, Ossola e cols [22] based on the results from Stubbins and cols [21], proposed that lignin, also present in Sargassum seaweeds [24], is an environmentally relevant precursor of CO. Ossola and cols [22]. suggest that the methoxy aromatic groups of lignin serve as the carbon source for the photochemical synthesis of CO from dissolved organic matter.

Differences in H_2S concentrations between experiments could also be attributed to the mass of the Sargassum used, which increased the thickness of the Sargassum layer in the decomposition box. Emissions in the decomposition chamber and the exposure chamber differed significantly, with a mean reduction of 80–87% in H_2S concentration. The mean concentration of H_2S in the exposure chamber was 7.3 ppm with a maximum of 18 ppm in the 30-day experiment, and 9.7 ppm with a maximum of 38 ppm in the 90-day experiment. Daily mean concentrations varied greatly, similar to environmental conditions [14,15]. A few days before the onset of H_2S production, a surge in carbon monoxide (CO) occurs. Production lasts for a few days and then diminishes. CO production can be abiotic (photodegradation) and related to temperature and pH-induced decomposition, or it may be linked to the present microbiota. Biological CO production may also be associated with the aerobic degradation of chlorophyll and heme-containing compounds or the anaerobic degradation of organic matter [25,26].

The elemental composition of our samples is similar to that found by Rodriguez-Martinez and cols [27] in samples of *Sargassum fluitans* and *natans* collected from the Mexican Caribbean coast. However, in our samples, detectable amounts of P (phosphorus), Mg (magnesium), Mn (manganese), U (uranium), and V (vanadium) were not found. This can be attributed to the trajectory of the Sargassum mass and the presence of these metals in ocean water, as these algae are known to bioabsorb metals [27,28]. Arsenic and lead were detected in our samples, with mean concentrations of 10.62 ppm (SD ± 3.65) and 11.2 ppm (SD ± 4.55), respectively. In contrast, As concentrations in Sargassum samples from the Mexican Caribbean Sea ranged from 24 to 172 ppm, while lead was present in extremely low concentrations [27]. Aluminium content was high, with a mean concentration of 3658 ppm. Rodríguez-Martínez and cols [27] also found aluminum in pelagic Sargassum, with a maximum detected concentration of 500 ppm. The elements detected in our samples could also be attributed to biosorption, as our samples were collected on the beach 1–2 days after stranding [29]. The metal content detected in our Sargassum samples could also be a reflection of sea contamination and/or a consequence of the recent worst oil spill in Brazilian history, which occurred in September 2019 [30]. Elemental analysis of crude oil from this disaster collected in Alagoas indicated high levels of Hg (mercurium), As, Cd, Pb, and Zn (zinc), while in seawater, Hg, Cd, Pb, and Cu (copper) exceeded the maximum limit concentration established by the National Environment Council of Brazil (CONAMA) [31,32]. The contamination of Sargassum seaweed by metals is a health concern, given its potential use as animal feed or its disposal in landfills, which could subsequently contaminate soil and groundwater.

There are currently no available estimates of H_2S emission rates from Sargassum seaweed decomposition in natural environmental conditions. In our experiment, we estimated an emission rate of 7–8 g/h for H_2S. Considering the area of the plastic box (520 cm^2) used for decomposing the Sargassum seaweed, we can calculate an emission rate of 192.3 $g/h/m^2$. However, further field studies are needed to determine how this calculated emission rate correlates with actual emission rates in real environmental conditions. Knowledge of emission rates is crucial for health risk assessment studies and implementing preventive measures.

Occupational exposure to high levels of H_2S has been well-documented, with associated health effects described. However, as noted by Resiere and colsc [14,15,17], subacute and chronic exposure to low levels of H_2S is not well-studied. Evidence indicates that the majority of medical visits related to Sargassum decomposition emissions are due to neurological (80%), digestive (77%), and respiratory (69%) disorders. In the French West Indies, the exposure period to Sargassum decomposition gas emissions lasts nearly 3 months per year [15].

The development of animal models and exposure systems that replicate real environmental conditions is of utmost importance, as it enables researchers to elucidate complex biological mechanisms that impact development, behavior, and health. Experimental models have played a vital role in understanding the effects of exposure to urban air pollution, passive exposure to marijuana smoke, and noise pollution [33–35]. Human studies alone are insufficient to uncover certain mechanisms and associations between environmental exposures and health effects, as manipulating certain conditions (e.g., nutrition, stress) known to interact and interfere with effects is not feasible. Additionally, animal models help us better comprehend the variability observed in epidemiological studies and distinguish between correlational and causal impacts, allowing for the identification of direct and indirect effects as well as the manipulation of intrinsic and extrinsic factors [36].

Therefore, the decomposition chamber and exposure model developed in this study present an opportunity to investigate further the effects and risks to human health resulting from exposure to gases produced during the decomposition of beached Sargassum seaweed.

5. Conclusion

Our study provides valuable insights into the gas emissions and biogeochemistry of elemental cycling during the decomposition of beached Sargassum seaweed. The observed variations in gas emissions over time, influenced by factors such as organic matter consumption, temperature fluctuations, photochemical degradation and changes in bacterial populations, highlight the dynamic nature of this process. The detection of arsenic and lead in the seaweed samples raises concerns about potential contamination and associated health risks. Further research is warranted to determine more precisely emission rates, investigate the effects of prolonged exposure to low gas levels, and assess the broader environmental implications. By addressing these knowledge gaps, we can enhance our understanding of Sargassum seaweed decomposition and develop effective strategies to mitigate its impact on human health and the environment.

In summary, this study contributes to the understanding of the complex dynamics involved in the decomposition of beached Sargassum seaweed and its associated gas emissions. The findings underscore the need for continued research to unravel the intricacies of elemental cycling and the potential risks posed by contaminants. These insights can inform decision-making processes aimed at safeguarding human health and devising appropriate management strategies to mitigate the environmental consequences of Sargassum seaweed decomposition.

Author contribution statement

Thamires Silva: Performed the experiments; Dunia Waked: Performed the experiments; Ana Bastos: Performed the experiments; Gabriel Gomes: Conceived and designed the experiments; José Veras Closs: Conceived and designed the experiments; Fernando Tonin: Conceived and designed the experiments; wrote the paper.

João Rossignolo: Conceived and designed the experiments; Analyzed and wrote the paper.

Karina do Valle Marques,:Analyzed and interpreted the data and wrote the paper.

Mariana Veras:Conceived and designed the experiments, analyzed and interpreted the data and wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Mariana Matera Veras reports financial support was provided by Fundação de Amparo a Pesquisa do Estado de São Paulo FAPESP.

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