Valorization of Seaweed Gracilaria sp. Biomass Waste into Liquid Organic Fertilizer: Assessment on Growth of Cayenne Pepper Capsicum Frutescens L.

Imam Pudoli, Sukma Budi Prasetyati and Muhammad Fadhlullah

October 24, 2022

Valorization of Seaweed *Gracilaria* sp. Biomass Waste into Liquid Organic Fertilizer: Assessment on Growth of Cayenne Pepper *Capsicum frutescens* L.

Imam Pudoli[1, 2, a)], Sukma Budi Prasetyati[1, b)], and Muhammad Fadhlullah[3, c)]

[1]*Fisheries Product Processing Department, Karawang Polytechnic of Marine and Fisheries, Karawang, West Java 41314 Indonesia*
[2]*CV Agro Niaga Utama, Karawang, West Java 41352 Indonesia*
[3]*Independent Researcher*

[c)]Corresponding author: fadhlullah.mbp@gmail.com
[a)]imampudoli2@gmail.com
[b)]sukmabudiprasetyati@gmail.com

Abstract. Seaweed processing commonly generates biomass waste either used as a low-value product or discarded. However, seaweed biomass waste still contains essential nutrients that can be recovered to generate valuable products, such as organic fertilizer. This study aims to valorize seaweed *Gracilaria* sp. biomass waste into liquid organic fertilizer to support sustainable and eco-friendly production. *Gracilaria* sp. biomass waste from Karawang, Indonesia was composted, and two liquid organic fertilizer doses were formulated (containing 0.5 and 1.0% v/v of compost liquid). The fertilizer variants were then applied to *Capsicum frutescens* L. plants and their growth parameters (plant height, relative growth rate, number of leaves, and dry weight) were evaluated. The fertilizer's physicochemical properties (organic-C, total N, P, K, and pH) were also analyzed. The growth assessment and physicochemical characteristic results were then compared to the results from control and commercial organic fertilizer. The present study showed that both seaweed biomass waste-based liquid organic fertilizer variants generated higher *C. frutescens* L. plant growth parameters than the control, with comparable outcomes to the commercial one. Although, the fertilizer's organic-C, total N, P, and K content were below the national technical standard. These findings demonstrate that seaweed biomass waste is prospective and can be studied further for liquid organic fertilizer development.

Keywords: Composting, *Gracilaria* sp., plant growth, seaweed fertilizer, zero waste

INTRODUCTION

Karawang is an area on the north coast of West Java, Indonesia known for its fisheries sector. One of the developing fisheries sector activities is seaweed cultivation, with a productivity of 757.54 metric tons in 2021 [1]. Besides the area's suitability for seaweed cultivation, the increasing trend of seaweed production is driven by the surrounding agar industries' demand [2]. It is well known that seaweed is the raw material for hydrocolloid products such as agar [3,4].

However, it is common that seaweed processing generates biomass waste due to processing residues and rejected materials. A recent case study by Fadhlullah *et al*. (2022) [2] showed that a local seaweed processing unit with a monthly processing capacity of 120 metric tons of seaweed *Gracilaria* sp. could generate 4 metric tons of biomass waste. The biomass waste is typically applied as an additional feed for local milkfish ponds, a mixture for constructing materials, or discarded. Meanwhile, the same study also showed that the *Gracilaria* sp. biomass waste still contains nutrients, i.e., proteins (13.7% DW), carbohydrates (63.2% DW), lipids (1.7% DW), and minerals

(21.5% DW). This information indicates that high-value and beneficial products can still be generated from biomass waste, thus minimizing waste.

Various studies have shown that seaweed products can be applied as a natural bio-stimulant for plant growth. They demonstrated seaweed products' ability to improve soil water holding capacity, mineral uptake from soil to plants, and plants' resistance to biotic and abiotic stress [5,6,7]. Hence, the high nutrient content of seaweed biomass waste and the bio-stimulant prospective of seaweed products drive the valorization of seaweed *Gracilaria* sp. biomass waste into liquid organic fertilizer.

The use of organic fertilizer could substitute synthetic fertilizer, which has been widely used in the agriculture sector. However, long-term use of synthetic fertilizer could cause detrimental impacts, such as water pollution, toxic metals accumulation in the soil, and soil quality cutback [8]. Seaweed-based organic fertilizer provides advantages compared to synthetic fertilizer by improving soil fertility due to humus generation, being easier to handle, and having a longer shelf-life. But most importantly, seaweed-based organic fertilizer could facilitate a sustainable and environmentally-friendly way to improve plant productivity [5].

Cayenne pepper (*Capsicum frutescens* L.) was used as a model plant in this study due to its brief cultivation period, which is suitable for plant growth assessment. Moreover, cayenne pepper is one of the important global horticulture commodities, especially in Indonesia. Cayenne pepper is commonly used as a seasoning material and ingredient in various cuisines [9]. Besides food application, cayenne pepper contains multiple vitamins and bioactive compounds, such as capsaicin and asparaginase, which have health-promoting functions [10].

This study aims to valorize seaweed *Gracilaria* sp. biomass waste into liquid organic fertilizer, thus, supporting zero waste seaweed processing as well as sustainable and eco-friendly agriculture. To achieve this aim, *Gracilaria* sp. biomass waste was composted to generate liquid organic fertilizer. Several liquid organic fertilizer doses were applied to cayenne pepper (*C. frutescens* L.), and plant growth (e.g., plant height, weight, and number of leaves) was examined. The effect of liquid organic fertilizer on plant growth was then compared to commercial organic fertilizer.

MATERIALS AND METHODS

Gracilaria sp. Biomass Waste

Gracilaria sp. biomass waste was collected from Koperasi Mina Agar Makmur's warehouse (Karawang, Indonesia) in March 2021 (rainy season). The GPS coordinates of the warehouse are 6°00'21" south (latitude) and 107°14'02" east (longitude). Seaweed biomass was identified based on morphological features according to the seaweed identification book [11]. The biomass waste was filtered through a wooden sieve (d = 55 cm) and then washed with tap water to remove impurities (shells and sand).

Composting Process

Gracilaria sp. biomass waste composting was carried out in a plastic composter (Fig. 1). The biomass waste (5 kg) was chopped and put into the composter along with 300 g of molasses, 200 mL of effective microorganisms 4 (EM4) solution, and 4 L of water [12]. The composter cap was fully closed during composting, while the compost mixture was stirred for 5-10 minutes per day until harvest. After 18 days (mature compost was indicated by alcoholic scent), the compost liquid was collected and filtered through the composter cap in a plastic container and kept at room temperature. The compost liquid was used as the stock solution for liquid organic fertilizer formulation.

Fertilizer Formulation

Five liquid organic fertilizer variants were assessed in this study. The variants were control (X_0), solution with 0.5% compost liquid (X_1), 1.0% compost liquid (X_2), 0.5% commercial organic fertilizer (X_3), and 1.0% commercial organic fertilizer (X_5) [13]. The commercial organic fertilizer used in this study was *Pupuk Organik Cair Kebun Mas* (CV. Mandiri Citra Sukses, Indonesia). Control and commercial liquid organic fertilizer served as references to seaweed-based liquid organic fertilizer. The formulation of liquid organic fertilizer variants can be seen in Table 1. The liquid organic fertilizer variants were then stored in a closed plastic container, free from sunlight exposure, and kept at low temperature (0–4°C) for physicochemical analysis and room temperature for plant application.

TABLE 1. Liquid organic fertilizer formulation

Components (mL)	Variants				
	X_0	X_1	X_2	X_3	X_4
Compost liquid	0	5	10	0	0
Commercial organic fertilizer	0	0	0	5	10
Water	1,000	995	990	995	990

Capsicum frutescens L. Seed Pre-treatment

Capsicum frutescens L. seeds were obtained from a local plant supplier in Rengasdengklok, Karawang, Indonesia. The seeds were immersed in warm water (50°C, 5 min) for sortation and germination stimulation [14]. Then, the sinking seeds were collected and kept on a wet tissue for six days. After six days, germinated seeds were transferred to polybags (d = 7 cm).

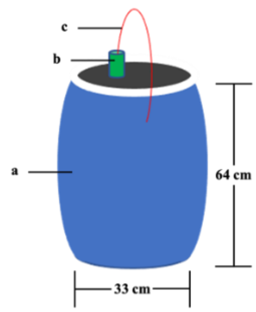

FIGURE 1. Composter illustration. Parts: a) Compost container (V = 60 L); b) Used plastic bottle (V = 330 mL); c) Plastic tube (L = 60 cm, d = 5 mm)

Experimental Design

Cayenne pepper (*C. frutescens* L.) plants were cultivated in a greenhouse from April 19th - May 26th, 2021 in Karawang, Indonesia, with GPS coordinates of 6°06'34" south (latitude) and 107°15'38" east (longitude). The plants were grown in polybags (d = 7 cm). The plant growing media used in this experiment was a mixture of soil and husk (ratio 2:1) and a total height of 5 cm. The soil (loose soil) was obtained from a local garden in Rengasdengklok, Karawang, Indonesia. The husk was acquired from a local plant supplier in Rengasdengklok, Karawang, Indonesia. Twenty plants were experimented with four replications for each treatment, complying with Equation 1.

$$t(n-1) \geq 15 \tag{1}$$

Variable t represents the number of treatments, five in this study, and variable n represents the number of replications [15].

The greenhouse comprised a polyethylene cover, bamboo frames (Fig. 2), and five compartments (partitioned by plywood), representing the number of treatments. Each compartment comprised four polybags, representing the number of replications, and each polybag was planted with one *C. frutescens* L. plant. Polybags in each compartment were rotated clock-wisely to the subsequent compartments every four days to provide homogenous conditions (e.g., light exposure and humidity) [16].

Liquid organic fertilizer was applied on plants starting on day 6 after planting in polybags. The fertilizer was sprayed on soil, stem, and leaves every four days. The plants were watered twice a day, morning and afternoon (2 L/day) [17]. The volume of liquid organic fertilizer applied was 1:100 to the water applied on that day (20 mL).

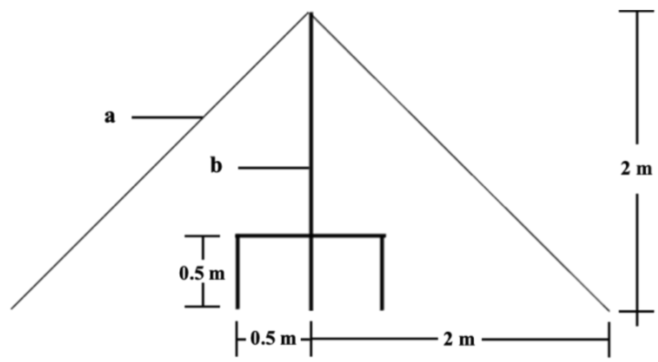

FIGURE 2. Greenhouse illustration. Parts: a) Polyethylene cover; b) Bamboo frame

Growth Assessment

Plant Height

Plant height was recorded every four days and at the end of the experiment. The height was measured using a ruler from the soil's surface up to the highest tip of the plant [18]. The data were presented as mean ± standard deviation.

Relative Growth Rate

The relative growth rate (RGR) of the plant was calculated according to Equation 2 [19].

$$RGR = \frac{\ln h_f - \ln h_i}{t_f - t_i} \tag{2}$$

Variable h_f represents the plant height at the end of the exponential growth phase, variable h_i represents the plant height at the beginning of the exponential growth phase, variable t_f represents the time at the end of the exponential growth phase, variable t_i represents the time at the beginning of the exponential growth phase.

The plant growth exponential phase was determined using the plant height curve, which is demonstrated by an increasing trend [20]. A trendline and R^2 value were applied to the expected exponential curve using Microsoft Excel software. R^2 value higher than 0.9 verifies the exponential phase determination [5].

Number of Leaves

The number of leaves was recorded during the initial and end of the experiment. The number of leaves was calculated through direct observation [18] and presented as mean ± standard deviation.

Dry Weight

At the end of the experiment, *C. frutescens* L. plants were collected and cleaned from the soil (without water). The plants were sun-dried for five days, then weighed using an analytical balance to obtain the dry weight. The data were presented as mean ± standard deviation.

Physicochemical Analysis

Physicochemical parameters of liquid organic fertilizer variants were analyzed. The parameters were pH, organic carbon (organic-C), total nitrogen (total N), phosphorus (P), and potassium (K). pH was analyzed using pH universal indicator strips (Merck, Germany). Organic-C, total N, P, and K were analyzed at a nationally accredited testing laboratory, the laboratory of Indonesian Soil Research Institute, Bogor, Indonesia by referring to the Association of Official Agricultural Chemists [21].

RESULTS AND DISCUSSIONS

This part will report and discuss Cayenne pepper (*C. frutescens* L.) plant growth due to seaweed liquid fertilizer treatments. The growth parameters include plant height, relative growth rate, number of leaves, and dry weight. Furthermore, the physicochemical properties of fertilizer variants will be presented and discussed to provide supporting explanations of fertilizer components' influence on the Cayenne pepper (*C. frutescens* L.) plant growth. At the end of this part, some insights gained from this study will be discussed to formulate a recommendation for further studies and development.

C. frutescens L. Growth

Plant Height

Fig. 3 presents the growth of each Cayenne pepper plant (*C. frutescens* L.) variant's height. All plants' heights increased from the beginning to the end of the experiment. The plants treated with seaweed liquid fertilizer (X_1 and X_2) had a higher height trend than the control (X_0) and were comparable to the commercial fertilizer-treated plants (X_3 and X_4). The plant variants with the highest to the shortest height at the end of experiment were X_2 (12.83 ± 0.25 cm), X_3 (11.85 ± 3.93 cm), X_1 (11.50 ± 1.88 cm), X_4 (10.70 ± 0.80 cm), and X_0 (7.88 ± 1.00 cm).

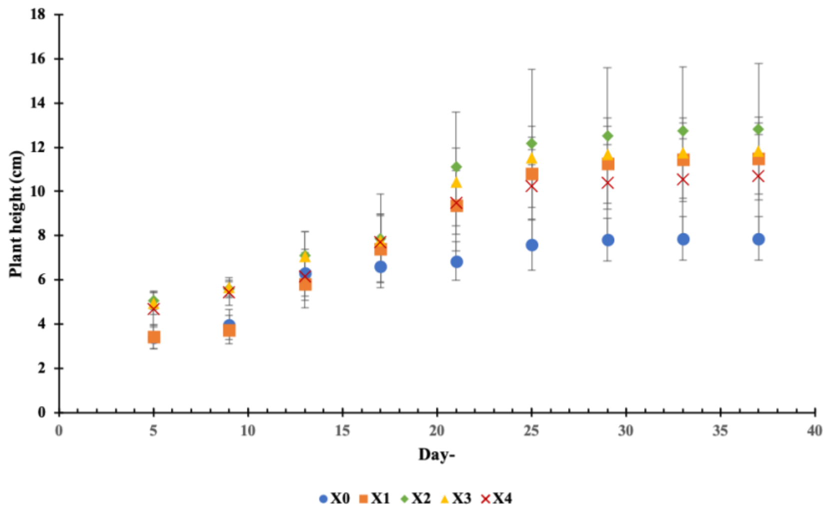

FIGURE 3. Plant height growth of each *C. frutescens* L. plant treatment

Various articles have reported the application of seaweed extracts as a biostimulant to promote pepper plant (*Capsicum annuum* L.) growth. Marhoon and Abbas (2015) [22] reported that the application of 6 mL L^{-1} commercial seaweed extract (Basfoliar Kelp SL, 6 months, foliar spray application) generated the highest plant height of two pepper plant cultivars, *C. annuum* L. cv. Flavio F1 (113.56 cm) and California wonder (85.74 cm) compared to control (83.55 and 61.73 cm, respectively). Ozbay and Demirkiran (2019) [18] found that the highest pepper plant (26.43 cm) was the one that was treated with 1.0 mL L^{-1} of commercial seaweed extract (Stimplex®, 10 weeks, substrate drench application) compared to the control (19.18 cm). Ashour *et al.* (2021) also applied 5 mL L^{-1} (0.5% v/v) of commercial seaweed extract (TAM®, 13 weeks, foliar spray application) and gained improvement in pepper plant height (88.00 cm) compared to control (67.33 cm). However, the plant treated with a higher concentration (10 mL L^{-1} or 1% v/v) had a shorter height (72.67), although it was still higher than the control [13].

Additionally, studies on seaweed extract use as a growth stimulant have been reported for other plants. Red seaweed *Kappaphycus alvarezii* liquid extract (15%, 4 months, spray application) has been applied to soybean plant (*Glycine max*), resulting in increased plant height (81.6 cm) compared to control (69.9 cm) [23]. A 10% of brown seaweed *Sargassum johnstonii* liquid extract (7 months, soil drench application) improved tomato plant (*Lycopersicon esculentum* Mill.) height (33.3 cm) compared to the control (13.2 cm) [24]. Another study applied 1.0% of green seaweed *Ulva lactuca* and 0.2% of brown seaweed *Padina gymnospora* liquid extract separately (7 weeks, soil drench application) on tomato plant (*Solanum lycopersicum* L.), yielding a plant height of 79 cm compared to control, 70 cm [25]. Spain *et al.* (2022) reported that the application of 40% red seaweed *Solieria chordalis* enzyme extract (Protamex®, 10 days) generated radish plant (*Raphanus sativus* L.) height of 3.0 cm compared to control, 2.3 cm. In contrast, a higher seaweed enzyme extract concentration (60, 80, and 100%) generated less plant height (2.6, 2.0, and 2.4 cm, respectively) [5].

Our finding was consistent with the results from previous studies. The seaweed liquid fertilizer in our study could increase the Cayenne pepper plant height compared to the control. Previous studies indicated that seaweed extract might contain macro-, micronutrients, and growth-promoting substances (e.g., auxin, cytokinin, abscisic acid, betaine, and zeatin) [13,18,22,23,25,26]. Macro- and micronutrients are involved in enzymes and coenzymes activation for cell division and enlargement, while growth-promoting substances stimulate metabolic processes also in cell division and enlargement. Thus, the cell division and enlargement processes increase plant height [22]. Macro-, micronutrients, and growth-promoting substances might also be contained in our seaweed liquid fertilizer. More discussion on seaweed waste-based liquid fertilizer will be addressed later. However, increasing seaweed extract or fertilizer concentration may not always increase plant height [5,13]. Such responses might vary with different plant species, seaweed types, and fertilizer application methods (e.g., foliar spray and soil drench) [18,24].

Relative Growth Rate

The relative growth rate (RGR) of Cayenne pepper plants treated with seaweed liquid fertilizer is presented in Table 2. By referring to the plant height growth curve (Fig. 3), most of the plant variants (X_0 - X_3) began the exponential growth phase (t_i) on day-9, except variant X_4 which began on day-5. Then, variants X_0 and X_1 stopped the exponential growth phase (t_f) on day-25, while variants X_2 - X_4 stopped on day-21. The R^2 value of all plant variants' RGR was above 0.9. Overall, the plants treated with seaweed waste-based fertilizer (X_1 and X_2) had a higher RGR (0.066 and 0.057 cm day^{-1}, respectively) compared to control X_0 (0.041). Variants X_1 and X_2 also had a higher RGR than those treated with commercial fertilizer, X_3 (0.051 cm day^{-1}) and X_4 (0.044 cm day^{-1}).

TABLE 2. The relative growth rate of *C. frutescens* L. plants

Variants	t_i (day-)	t_f (day-)	RGR (cm day^{-1})	R^2
X_0	9	25	0.041	0.9979
X_1	9	25	0.066	0.9968
X_2	9	21	0.057	0.9956
X_3	9	21	0.051	0.9984
X_4	5	21	0.044	0.9905

Our RGR results were coherent with the previous study. Gibilisco *et al*. (2020) [19] found that chickenclaws plant (*Sarcocornia perennis*) treated with brown seaweed *Undaria* sp. compost:perlite (50:50) mixture had an RGR of 0.045 g day^{-1}. Accordingly, the RGR improvement of a plant treated with seaweed compost was probably due to the nitrogen (N) content in the compost/fertilizer [19]. As can be seen later in Table 3, the N content of seaweed liquid fertilizer (X_1 and X_2) seemed higher (0.34 and 0.29%) than control X_0 (0.25%). The nitrogen function on plant growth will be discussed later.

As seen in Table 2, the different initial and final exponential growth phase observed in plant variants was possibly due to the plant's response to different fertilizer and the concentration applied [18]. All of the RGR R^2 values were above 0.9, which means that the RGR determination was verified [5]. The plant treated with 0.5% seaweed liquid fertilizer (X_1) had a higher RGR than that treated with 1.0% seaweed liquid fertilizer (X_2). However, the final height of plant variant X_2 was higher than variant X_1 (Fig. 3). This condition might occur due to the inhomogeneous plant height used at the beginning of the experiment.

Number of Leaves

The following plant growth parameter observed in this study was the number of leaves (Table 3). At the end of the experiment, the plants treated with seaweed liquid fertilizer (X_1 and X_2) had more leaves (6.50 ± 0.58 and 8.67 ± 2.08 leaves plant^{-1}, respectively) compared to control X_0 (4.25 ± 0.96 leaves plant^{-1}). Variants X_1 and X_2 also had more leaves than the plants treated with commercial fertilizer, X_3 (6.25 ± 1.50 leaves plant^{-1}) and X_4 (5.75 ± 0.96 leaves plant^{-1}).

TABLE 3. Number of leaves of each *C. frutescens* L. plant treatment

Variants	Initial day (leaves plant^{-1})	Final day (leaves plant^{-1})
X_0	4.00 ± 0.00	4.25 ± 0.96
X_1	4.00 ± 0.00	6.50 ± 0.58
X_2	4.00 ± 0.00	8.67 ± 2.08
X_3	4.00 ± 0.00	6.25 ± 1.50
X_4	4.00 ± 0.00	5.75 ± 0.96

Previous studies have indicated the effect of seaweed extract in increasing the number of leaves or branches in pepper and other plants. Marhoon and Abbas (2015) [22] applied a commercial seaweed extract (6 mL L^{-1}) on pepper plants *C. annuum* L. cv. Flavio F1 and California wonder, generating plants with 23.94 and 10.58 branches plant^{-1} compared to control, 13.93 and 6.75 branches plant^{-1}, for each cultivar. Ozbay and Demirkiran (2019) [18] reported that pepper plant *C. annuum* L. treated with a commercial seaweed extract (Stimplex®, 1.0 mL L^{-1}) had more leaves (46 leaves plant^{-1}) compared to the control (41 leaves plant^{-1}). Soybean plant (*G. max*) cultivated with seaweed *K. alvarezii* liquid extract (15%) had 8.01 branches plant^{-1} compared to 4.96 branches plant^{-1} of control [23]. Kumari *et al*. (2011) [24] also found that the tomato plant (*L. esculentum* Mill) grown with seaweed *S. johnstonii* liquid extract (10%) had more branches (11 branches plant^{-1}) compared to the control (4.3 branches plant^{-1}). Finally, the cucumber plant treated with green seaweed *Enteramorpha intestinelis* extract (0.24 mL m^{-2}, 75 days, spray application) had more leaves (27 leaves plant^{-1}) than the control (17 leaves plant^{-1}) [27]. Our findings seemed in line with the previous studies.

The increase of leaves or branches number in a plant treated with seaweed extract may also be related to the extract content. As previously discussed, seaweed extract or fertilizer may have macro-, micronutrients, and growth-promoting substances (e.g., auxin, cytokinin) [13,18,22,23,25,26]. The carbohydrates and cytokinin content may stimulate the growth of the lateral buds and vascular tissues, thus increasing the number of plant branches and leaves [22]. Additionally, fertilizer application methods (e.g., foliar spray and soil drench) may also affect branch and leaf growth stimulation. For instance, plants may have different efficiency in taking nutrients from the soil or the leaves [18,24].

Dry Weight

The last observed plant growth parameter was plant dry weight (Fig. 4). At the end of the experiment, the seaweed liquid fertilizer treated Cayenne pepper plants (X_1 and X_2) had a higher dry weight (1.85 ± 0.24 and 1.39 ± 0.71 g) than control X_0 (0.30 ± 0.00 g). The seaweed-treated plants' dry weight was also comparable with the ones treated with commercial organic fertilizer, X_3 and X_4 (1.49 ± 0.35 and 0.96 ± 0.74 g).

Most studies indicated that seaweed extract application had a trend of improving plant dry weight. For instance, the application of commercial seaweed extract (6 mL L^{-1}) on pepper plants *C. annuum* L. cv. Flavio F1 and California wonder increased their dry weight (18.11 and 16.08% DW) compared to the control (13.71 and 10.03% DW) [22]. In another study, pepper plant *C. annuum* L. treated with a commercial seaweed extract (Stimplex®, 1.0 mL L^{-1}) had an increase in dry weight (3.36 g) compared to control (2.84 g) [18]. Ahmed and Shalaby (2012) reported that treating cucumber plants with seaweed *E. intestinelis* extract (0.24 mL m^{-2}) increased plant dry weight (75 g) compared to control (66.63 g) [27]. Gibilisco *et al*. (2020) [19] found that chickenclaws plant (*S. perennis*) treated with brown seaweed *Undaria* sp. compost:perlite (50:50) mixture had more dry weight (1.01 g) than other treatments, e.g., plants treated with the 25:75 mixture (0.56 g).

Dry weight, as well as plant height, RGR, and number of leaves, is part of plant vegetative growth parameters. Therefore, plant dry weight may also be affected by macro-, micronutrients, and growth-promoting substances (e.g., auxin, cytokinin) contained in seaweed extract or fertilizer [13,18,22,23,25,26]. The available nutrients and growth-promoting substances may induce plant photosynthesis activity, thus increasing the plant shoot and root dry weight [22].

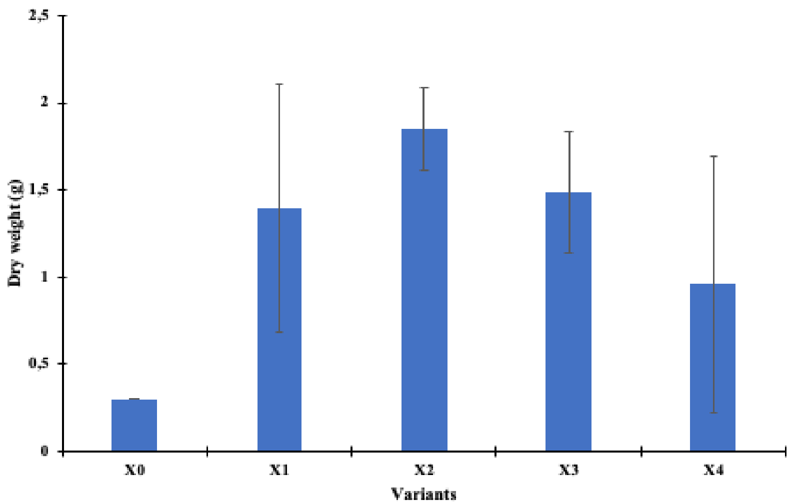

FIGURE 4. The dry weight of each *C. frutescens* L. plant treatment

Physicochemical Properties of Fertilizer

Table 4 provides the physicochemical properties of fertilizer variants applied in this study. The observed parameters were organic carbon (C), total nitrogen (N), phosphorus (P), potassium (K), and pH. The fertilizer organic-C of seaweed waste-based fertilizer (X_1 and X_2) seemed higher (0.006 and 0.010%) than control X_0 (0.004%). Fertilizer variants X_1 and X_2 had a comparable organic-C with the commercial organic fertilizer X_3 (0.008%), but lower than the commercial organic fertilizer X_4 (0.017%). The total N of seaweed fertilizer X_1 and X_2 was higher (0.34 and 0.29%) than control X_0 (0.25%) and comparable with the commercial organic fertilizer X_3 and X_4 (0.28 and 0.30%). The seaweed fertilizer X_1 and X_2 had similar P and K content with control X_0 and the commercial organic fertilizer X_3, but less than the commercial organic fertilizer X_4. In total, the NPK content of seaweed fertilizer X_1 and X_2 was higher (0.35 and 0.30%) than control X_0 (0.26%) and comparable with the commercial organic fertilizer X_3 (0.30%) and X_4 (0.38%). The pH of all fertilizer variants was between 7 - 8.

TABLE 4. Physicochemical properties of liquid organic fertilizer

Parameters	Variants					Standard*
	X_0	X_1	X_2	X_3	X_4	
Organic-C (%)	0.004	0.006	0.010	0.008	0.017	≥ 10
Macronutrients						
Total N (%)	0.25	0.34	0.29	0.28	0.30	
P (%)	5.5×10^{-4}	5.6×10^{-4}	5.6×10^{-4}	5.6×10^{-4}	1.9×10^{-3}	
K (%)	0.01	0.01	0.01	0.02	0.08	
N + P + K (%)	0.26	0.35	0.30	0.30	0.38	2 - 6
pH	8	8	8	7	7	4 - 9

*According to the Ministry of Agriculture, Republic of Indonesia [30]

Our observation agreed with previous studies that indicated the macro- and micronutrient content in seaweed extract. For instance, seaweed *K. alvarezii* extract stock contained N (0.03%), P (3.4×10^{-3}%), K (1.97%), and other nutrients (S, Ca, Mg, S, Cu, Fe, Mn, and Zn) [23]. Seaweed wracks compost (SWC), which consisted of a mixture of *Ulva* sp., *Ceramium* sp., *Dyctiota dichotoma, Corallina* sp., *Codium* sp., and *Gracilaria gracilis*, contained C (14.2%), N (1.12%), and a trace concentration of various metal (Cd, Cu, Zn, Mn, Ni, Pb, Cr, and Fe) [19].

Plants could use the organic-C in seaweed fertilizer to form their structures. C is also the key element in all organic compounds in plant metabolism. Plants could use the N content to form amino acids, proteins, and coenzymes involved in plant metabolism [28]. N is also a key composer of chlorophyll, which is important for plant photosynthetic activity and growth rate [5,19]. The P content could be used for various plant structures and metabolic functions, such as to form nucleic acids, phospholipids, and adenosine triphosphate (ATP) [28]. P could also stimulate root proliferation and increase nutrient absorption efficiency from the soil [26]. Plants could use the K content as cofactors substrate, cations in developing cell turgor, and to maintain cell electroneutrality [28]. K is also used for regulating plant water status, stomata opening, influencing meristematic growth, photosynthates translocation, and resistance to disease [26]. At last, seaweed fertilizer pH is important because it correlates with the nutrient's solubility. Nutrients (e.g., minerals, organic molecules) are mostly dissolved in a neutral pH and therefore can be absorbed by the plants [29].

As seen in Table 4, most of the seaweed fertilizer physicochemical parameters, except pH, did not meet the minimum technical requirement of organic fertilizer according to the Ministry of Agriculture, Republic of Indonesia [30]. This result is probably because the tested seaweed liquid fertilizer concentration was still too low. Nonetheless, our seaweed liquid fertilizer could still improve the vegetative growth parameters of Cayenne pepper plants (*C. frutescens* L.) as shown in the previous parts.

Study Recommendation

Based on our current findings, this study can be further progressed by adding more treatments and analyses. The plant growth parameter observed in this study belonged to the vegetative parameter, which involves plant cell division, elongation, and differentiation [31]. Moreover, generative growth parameter involving flower/fruit formation and development [31] is important to be assessed for horticultural plants such as pepper. Therefore, the generative growth parameter of Cayenne pepper plants, such as crown diameter, number of flowers, number of fruits, fruit yield, fruit weight, and fruit length/diameter, can be assessed in subsequent studies [13,18,24,27,32]. However, no pepper plant flowers nor fruits were observed at the end of the experiment. As shown in Fig. 3, the plants entered the stationary growth phase after 21 or 25 days. During the stationary phase, plants prepare to form and develop flowers/fruits [20]. Based on our observation, we suggest expanding the experiment duration in further studies to allow flowers and fruit growth. The quality aspect of growth parameters, such as leaf pigments, plant biomass nutrient content, fruit nutrients and antioxidant compounds, can also be analyzed in further studies [13,18,19,23,24,27].

As previously discussed, seaweed extract/fertilizer contains various macro-, micronutrients, and growth-promoting substances. Therefore, further studies can add more analysis of seaweed fertilizer proximate, macronutrients (e.g., Ca, Mg), micronutrients (e.g., Fe, Cu, Mn, Zn), and growth-promoting substances (e.g., cytokinin, auxin, and other phytohormones) content to provide more extensive information [13,24]. We also suggest increasing the seaweed fertilizer concentration in further studies to meet the organic fertilizer minimum requirement and testing it again for plant growth parameters. In addition, soil physicochemical parameters can be analyzed in further studies to evaluate the longevity and sustainability of seaweed fertilizer on soil quality [32].

CONCLUSION

In conclusion, this study showed that seaweed *Gracilaria* sp. biomass waste could be used to produce an organic liquid fertilizer with positive impacts on Cayenne pepper plant (*C. frutescens* L.) growth. This study also supported the prospective of seaweed waste-based organic fertilizer and displayed the further studies that can be explored towards zero waste seaweed processing, sustainable, and eco-friendly agriculture.

ACKNOWLEDGMENTS

This study was part of the first author's Associate's degree final project, under the supervision of the second and the third author. Therefore, the authors would like to acknowledge Karawang Polytechnic of Marine and Fisheries (Indonesia) for facilitating this study. The authors would also like to thank Koperasi Mina Agar Makmur (Karawang, Indonesia) for providing the seaweed biomass waste. This study received no specific grant from any funding agency in the public, commercial, or non-profit sectors. The authors declare there is no conflict of interest.

REFERENCES

1. BPS-Statistics of Karawang Regency, *Karawang Regency in Figures 2022* (BPS-Statistics of Karawang Regency, Karawang, Indonesia, 2022), pp. 227.
2. M. Fadhlullah, S. B. Prasetyati, I. Pudoli and C. Lo, 3BIO: J. Biol. Sci. Technol. Manag. **4**(1), 42–53 (2022).
3. M. Álvarez-Viñas, N. Flórez-Fernández, M. D. Torres and H. Domínguez, Mar. Drugs **17**(11), 620 (2019).
4. M. D. Torres, S. Kraan and H. Domínguez, Rev. Environ. Sci. Biotechnol. **18**, 335–388 (2019).
5. O. Spain, K. Hardouin, N. Bourgougnon and I. Michalak, Biomass Conv. Bioref. (2022).
6. K. Dziergowska, M. Wełna, A. Szymczycha-Madeja, J. Chęcmanowski and I. Michalak, Mol. **26**(22), 6917 (2021).
7. H. Hariyati, B. Ibrahim and A. Ahmad, Jurnal Ecosolum **7**(2), 67–74 (2018).
8. C. Chandini, R. Kumar, R. Kumar and O. Prakash, "The Impact of Chemical Fertilizers on Our Environment and Ecosystem," in *Research Trends in Environmental Science 2nd Edition*, edited by P. Sharma (AkiNik Publications, Delhi, India, 2019), pp. 71–85.
9. M. S. Yuliartini, A. A. N. M. Wirajaya, A. U. R. Z. Assegaf and Y. P. Situmeang, J. Phys. Conf. Ser. **1869**, 012039 (2021).
10. E. Latifah, H. A. Dewi, P. B. Daroini, E. Korlina, A. Hasyim, K. B. Andri, A. Z. Zakariya, A. Kuantariningsih, A. A. Negoro, A. L. Hakim and G. C. Luther, IOP Conf. Ser. Earth Environ. Sci. **230**, 012063 (2019).
11. H. S. Kalasariya, A Beginners Guide for Seaweeds Identification (Educreation Publishing, New Delhi, India, 2019), pp. 115–143.
12. A. Rahmah, M. Izzati and S. Parman, Buletin Anatomi dan Fisiologi dh Sellula **22**(1), 65–71 (2014).
13. M. Ashour, S. M. Hassan, M. E. Elshobary, G. A. G. Ammar, A. Gaber, W. F. Alsanie, A. T. Mansour and R. El-Shenody, Plants **10**(6), 1045 (2021).
14. E. Tjandra, *Panen Cabai Rawit di Polybag*, (Cahaya Atma Pustaka, Yogyakarta, Indonesia, 2011).
15. R. Kusriningrum, *Dasar Perancangan Percobaan dan Rancangan Acak Lengkap*, (Universitas Airlangga, Surabaya, Indonesia, 2008).
16. Nuraini, "The Effect of Methyl Jasmonate on Tomato Plant (*Lycopersicum esculentum* L.) Defense Against Armyworm (*Spodoptera litura* Fab.) Herbivory," Bachelor thesis, Bandung Institute of Technology, 2015.
17. C. Suherman, M. A. Soleh, A. Nuraini and A. N. Fatimah, Jurnal Kultivasi **17**(2), 648–655 (2018).
18. N. Ozbay and A. R. Demirkiran, Appl. Ecol. Environ. Res. **17**(2), 4361–4375 (2019).
19. P. E. Gibilisco, J. L. Lancelotti, V. L. Negrin and Y. L. Idaszkin, J. Env. Manag. **274**, 111193 (2020).
20. F. Salisbury and C. Ross, *Plant Physiology 4th Edition* (Cengage Learning, USA, 1991).
21. G. W. Latimer, Jr., *Official Methods of Analysis of AOAC International 20th Edition* (AOAC International, Rockville, USA, 2016).
22. I. A. Marhoon and M. K. Abbas, Int. J. Res. Stud. Agric. Sci. **1**(1), 35–44 (2015).
23. S. S. Rathore, D. R. Chaudhary, G. N. Boricha, A. Ghosh, B. P. Bhatt, S. T. Zodape and J. S. Patolia, S. Afr. J. Bot. **75**, 351–355 (2009).
24. R. Kumari, I. Kaur and A. K. Bhatnagar, J. Appl. Phycol. **23**, 623–633 (2011).
25. S. T. Zodape, A. Gupta, S. C. Bhandari, U. S. Rawat, D. R. Chaudary, K. Eswaran and J Chikara, J. Sci. Ind. Res. **70**, 215–219 (2011).
26. R. M. Hernández-Herrera, F. Santacruz-Ruvalcaba, M. A. Ruiz-López, J Norrie and G. Hernández-Carmona, J. Appl. Phycol. **26**, 619–628 (2014).
27. Y. M. Ahmed and E. A. Shalaby, J. Hortic. Sci. Ornam. Plants **4**(3), 235–240 (2012).
28. L. Taiz, E. Zeiger, I. M. Møller and A. S. Murphy, *Plant Physiology and Development* (Sinauer Associates Inc., USA, 2015).
29. D. Neina, Appl. Environ. Soil Sci. **2019**, 5794869 (2019).
30. Ministry of Agriculture of Republic of Indonesia, *Decree of Minister of Agriculture of Republic of Indonesia No. 261/KPTS/SR.310/M/4/2019 on Minimum Technical Requirement of Organic Fertilizer, Bio-fertilizer and Soil Conditioner* (Ministry of Agriculture of Republic of Indonesia, Jakarta, Indonesia, 2019), pp. 5.
31. M. G. Ajuru and B. E. Okoli, Int. J. Mod. Bot. **3**(2), 15–19 (2013).
32. M. Illera-Vives, S. S. Labandeira, L. M. Brito, A. López-Fabal and M. E. López-Mosquera, Sci. Hortic. **186**, 101–107 (2015).