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Effect of Different Seaweed Extracts and Compost on Vegetative Growth, Yield and Nutraceutical Quality of Cucumber fruit (Cucumis Sativus)

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Abstract: The objective of this research was to evaluate the production and phytochemical quality of cucumber fruits (Cucumis sativus), in response to the foliar application of different seaweed extracts. This study was carried out under shadow mesh conditions in the autumn - winter agricultural cycle at Instituto Tecnológico de Torreón, Torreón, Coahuila. The experimental design was completely random, using six treatments with six repetitions each. The treatments evaluated were: Macrocystis pyrifera, Bryothamnion triquetrum, Ascophyllum nodosum, Grammatophora sp., Macrocystis intergrifolia, and a control treatment with inorganic fertilization. The substrate used was a mixture of sand and vermicompost. The yield, commercial quality and phytochemical compounds of the fruit were evaluated. Results showed that yield using Steiner solution (6.75 kg m-2) was higher than that obtained with Bryothamnion triquetrum algae (6.07 kg m-2). Regarding the phenolic content, the extracts surpassed the control treatment, with Macrocystis pyrifera and Macrocystis integrifolia being statistically equal, with values of 47.37 and 43.73 mg equiv. of Ac. Gallic 100 g fresh weight, respectively. The antioxidant capacity by ABTS+ and DPPH+ methods was higher using the treatment with algae Macrocystis pyrifera with 149.4 and 454.1 µM equiv Trolox / 100 g fresh base, respectively. This treatment also presented the highest value of vitamin C with 5.07 mg / 100 g fresh base, being 27% greater than the control treatment. Algae extracts increased the quality of the fruits by obtaining the highest antioxidant capacity, making their use a viable option to minimize the application of conventional fertilizers, thereby attenuating the effects on the environment and improving the health of the population.

Keywords: *Cucumis sativus*; nutraceutical; antioxidant; ABTS+, DPPH+

1. Introduction

The production of protected vegetables is one of the main export activities in Mexico because it occupies fourth place worldwide and first place in the American continent [1]. The main crops produced are tomatoes (70%), pepper (16%) and cucumber (10%); the production of these vegetables is mainly located in the northwest (72%) and center of the country (19%) [2]. Cucumber is in great demand in the United States of America (USA) and has had an unprecedented growth in recent years. Its importation grew from 394 107 tons in 2002 to 459 242 in 2012 [3]. Of this import volume, 80% comes from Mexico, which is the main exporting country to the USA [4]. Under protected agriculture conditions, the production of cucumber is 2 to 9 times greater than in the open field, which depends on technological levels, nutrition management and the control of climatological conditions which are key factors for achieving high yields in this type of systems [5].

The nutrition of this crop is an important factor in maximizing its production. In several regions, there is an indiscriminate use of agrochemicals and the excessive cultural practices have brought serious consequences to the environment. In addition, the high costs of fertilizers in Mexico have put them out of the reach of producers, resulting in low yields, low incomes and low quality produce [6]. Along with this, in the large market of imported vegetables, there is a growing tendency among the consumer towards the acceptance of "innovative, different", suitable products that can contribute to an ever-healthier diet with less environmental impact on natural resources [7]. The implementation of biological control and organic nutrition with biofertilizers could reduce the dependence on agrochemicals and thus make the production less hazardous to the environment and the consumer. Additionally, the application of these products can reduce the use of chemical fertilizers, increase performance and stress resistance by water and temperature tensions and positively influence their growth and physiology [8].

Today, seaweed extracts (SWE) provide an alternative, as they not only contain nitrogen, phosphorus and potassium, but also present molecules with a very wide range of structures and can be composed by phytohormones or metabolically active plant extracts such as amino acids and organic acids [9]. Researchers [10,11] point out that seaweed extracts contain a wide variety of plant growth-promoting substances such as auxins, cytokinins, betaines, gibberellins, and organic substances, including amino acids, macronutrients, and trace elements that improve crop yield and quality.

SWE are natural bioactive materials soluble in water; they are also organic fertilizers that promote the germination of seeds and that increase the development and yield of crops [12]. They have been used as nutritional supplements, bio-stimulants or biofertilizers in agriculture and horticulture [13]. In recent years, the use of marine algae extracts as biofertilizers has allowed the partial substitution of conventional mineral fertilizers [14]. These can be used as liquid extracts for foliar and soil applications, or in granular form as soil improvers and fertilizer [15]. SWE have also been used to increase germination, fruit weight and yield in tomato [16]; to improve chlorophyll and carbohydrates contents, fruit diameter, yield, and vitamin C in cucumber plants, [9]; and to increase leaf area, number of leaves, fresh stems and biomass in beans [17]. In Stevia plants (*Stevia rebaudiana* Bertoni), marine algae extracts have improved some morphological, anatomical and chemical characteristics [18]. Investigation was carried out on the effects of three seaweed extracts viz., *Asparagopsis* spp, *Gelidium pectinutum* and green alga *Enteromorpha intestinalis*, commercial seaweed extract Algreen and compost on cucumber [9]. Results showed that the use of *E. intestinelis*, *G. pectinutum* or commercial seaweed extracts with compost is considered a suitable application to improve vegetative growth and yield of cucumber plants. The effect of three commercial extracts of the brown seaweed, *Ascophyllum nodosum*, on phytochemical content and yield in cabbage plants under field conditions was evaluated [19]. They found that total phenolic content was higher in all seaweed treated plants, with the highest increase recorded with AlgaeGree (3.5 l ha^{-1}). Similar increases were recorded in total flavonoid content. In another study to investigate the effect of the Seaweed Liquid Fertilizer (SLF), *Rosenvigea intricata* --with or without chemical fertilizer -- on seed germination, growth, yield and pigment content [20], it was found that 20% of SLF -- with or without chemical fertilizer -- shows a higher growth, yield, chlorophyll pigment and soil profile compared to other concentrations. A significant improvement in the size of olives and the quality of olive oil was recorded in trees sprayed with an A. nodosum extract fortified with added nitrogen and boron [21]. Anbuchezhian et al., [22], also mention that the biofertilizers derived from marine algae form great biofertilizers and improve the soil quality and yields considerably. Marine algal species *Ascophyllum*, *Ecklonia* and *Fucus* are commonly utilized as fertilizers containing amounts of nitrogen and potassium comparable to animal manure and organic fertilizers, but with a low phosphorus content. Application rates, frequency and timing of the treatments vary with species, season, geographical location, and local environmental variables. Important ancillary benefits of seaweed products for crop production include the amelioration of damage caused by insects and bacterial or fungal diseases [23].

Due to the above and based on the importance of the growing protected horticulture in the Comarca Lagunera, the objective of this research is to improve the yield and phytochemical quality of cucumber via leaf application of different seaweed extracts.

2. Materials and Methods

This study was carried out in shade mesh at the Technological Institute of Torreon (ITT), located at km 7.5 of the old Torreon - San Pedro road, Municipality of Torreon, Coahuila. The mesh is an Agro Shade model of 250 m2 with a maximum wind resistance of 120 km/h, and greater than 35 m2 load capacity. The mesh was 16X10 strands of stabilized monofilament of flat fabric at 50% shade. The structure was manufactured with materials in accordance with the Mexican standard for the design and construction of greenhouses NMX-E-255-CNCP-2008 [24].

The treatments evaluated were five biofertilizers formulated with seaweed extracts: T1 = *Macrocystis pyrifera (Macro)*, T2 = *Bryothamnion triquetrum (Bryo)*, T3 = *Ascophyllum nodosum (Asco)*, T4 = *Grammatophora* sp. (Gramma), T5 = *Macrocystis integrifolia (Macro integri)*. They were compared with a control treatment (T6) using Steiner Solution (SS).

2.1 Obtaining the seaweed extracts

Algae *Macrocystis pyrifera and Grammatophora sp.*, were collected in the Pacific Ocean off the coast of La Paz, Baja California Sur (29° 09'N, 110° 19'W), Mexico. The algae were washed with distilled water and dried for 7-10 days at room temperature. For the preparation of the extracts, the dried algae were ground in mortar and sieved. Subsequently, the aqueous extract was obtained by performing an extraction with distilled water 1:5 (w/v) for 5 h with constant agitation at room temperature. It was then centrifuged at 800 x g in a HealForce centrifuge (Beckman GS-GKR, USA) at 40 °C for 20 minutes. Subsequently, each sample was crushed in a mill and used to determine the chemical composition by undergoing acid digestion.

Organic matter, N, F, K, Mg, Bo, Zinc and Si were determined by atomic absorption spectrophotometry [25]. Then 100 g of each sample was added to 1 L of distilled water with constant stirring for 15 min followed by autoclaving at 121 °C for 1h at 1.21 kg cm^{-2} [26]. The hot extracts were filtered through a Whatman No. 40 filter paper and stored. In the case of the *Bryothamnion triquetrum, Ascophyllum nodosum and Macrocystis integrifolia* algae, commercial algae existed on the market under the name of Fulvimax^{AT}, Seaplant^{AT}, y Gaia^{AT}, respectively.

The aqueous solution was applied at 10% concentration, via Foliar spray, at an average of 150 ml per plant according to the technical recommendation for horticultural crops. The applications were started eight days after the transplant and, subsequently, every 2 weeks up until 80 days after the transplant (dds).

The chemical characteristics of the algae are presented in Table 1. The experimental design was completely randomized with six treatments and six repetitions resulting in 36 experimental units. An analysis of variance (ANOVA) and the Tukey separation test (P≤0.05) were performed using the statistical program SAS ver. 6.03 [27].

Table 1. Chemical composition of seaweed extracts evaluated in cucumber production.

Compound	*Macrocystis pyrifera*	*Bryothamnion triquetrum*	*Ascophyllum nodosum*	*Grammatophor sp.*	*Macrocystis integrifolia*
			% P/V		
Organic material	3.49000	4.15000	n.a	3.50000	2.94400
Nitrogen	0.14700	1.45000	3.00000	1.14500	0.02630

Phosphorus	0.00800	1.36000	0.10000	0.02000	0.00540
Potassium	0.07700	1.48000	5.30000	2.00000	1.31000
Magnesium	0.01360	n.a	0.15000	0.02000	0.00236
Bore	0.00061	n.a	0.0003	n.a	0.00093
Zinc	0.00013	0.00075	n.a	0.00025	0.00126
Silicium	n.a*	0.00027	n.a	n.a	n.a

Source: Technical specifications of the product. *n.a = not available.

2.2. Substrate use

The substrate was organic using the proportions 80% sand + 20% vermicompost. This substrate has been evaluated in several studies showing the best results for this vegetable [28]. The chemical and physical characteristics of the substrate are presented in Table 2.

Table 2. Chemical and physical composition of the organic substrate (sand: vermicompost) used in the evaluation of algae extracts in the shade-grown cucumber culture.

Nutrient	**Sand + Vermicompost (80:20 v/v)**		
	mg kg^{-1}		
Nitrate	13.72	Texture (sand-silt-clay)	97-1-2
Phosphorus	15.33	CEC (meq/100g)	9.00
Carbonates	3.30	pH	7.91
Potassium	198.5	OM (%)	7.04
Iron	1.76	CE (dS m^{-1})	3.21
Copper	0.49	R	2.95
Zinc	0.53	ESP	2.99
Manganese	2.91		

Source: Analyzes carried out in the Laboratory of ITT and the Coop. Agrop. of Comarca Lagunera. CEC= Cation exchange capacity, pH= Hydrogen potential, OM = Organic material, R=Rate; ESP= Exchangeable sodium percentage.

A hydroponic substrate formulated with disinfected and sterilized river sand, along with pearlite in a ratio of 80:20 (v/v) was used for the control treatment. The algae and the control treatments were established in polyethylene plastic pots, caliber 600 of 18 kg capacity.

2.3. Agronomic management of the crop

The experiment was carried out during the autumn-winter agricultural cycle. On September 1st, cucumber (*Cucumis sativus* L.) American type parthenocarpic, hybrid, Hisham-EZ 1110 was planted

in 200-well polyethylene trays using the Premier Promix P6X peat moss substrate, using one seed per cavity. The handling of the trays consisted in maintaining the relative humidity (80%) and adequate temperature (25-27 °C) for its development. The transplant to the pots took place 15 days after planting when the seedlings had a height between 5 - 7 cm and three to five true leaves. The pots were accommodated in such a way that the population density was of 4 plants per square meter in double rows separated by 30 cm, with a distance of 40 cm between pots and 1.5 m between rows.

The irrigation of the pots was on average 0.750 - 1.0 L of water per pot per day; this condition varied depending on the evaporation and environmental conditions within the shade mesh. The control treatment (SS) was irrigated with nutrient solution [29] every day applying an average of 0.750 L per pot. The solution (SS) was diluted at a rate of 30, 50, 75 and 100% concentration according to the phenological stage of the culture. Organic products were used in the control of pests and diseases, which included organic repellents. A dose of 40 mL of neem extract and garlic extract in 20 L of water was applied once a day in the morning at 8 day intervals for the control of whitefly (*Bemisia tabaci*).

The agronomic management was in accordance with the usual practices of the producer of the region. The stems were trained vertically, sustained with polypropylene agricultural raffia yarn. All buds were eliminated below 40 cm of the main stem, and later on, all lateral buds were eliminated by weekly pruning, leaving one fruit per axilla, until the plant reached 2.0 m in height.

2.4. Evaluated Variables

For the analyzes nine mature cucumber samples were taken in each treatment. The length of the fruit was determined using a metal tape, with a precision of 1 mm. A Mitutoyo digital vernier, model CD-6 " CS, with a precision of 0.01 mm was used for the diameter of the fruit in mm. The firmness of the fruits was measured using an Extech penetrometer (FHT200) with a maximum capacity of 20 kg / 44.10 lb or 196.10 Newton, and the average of two measurements per fruit was reported in Newton (N). The total soluble solids were measured with a 0 - 32% manual refractometer (Sper scientific 300001) and the results were reported in ° Brix. A model AUY Shimadzu digital balance was used to weigh the fruit in grams, with a precision of 0.1 mg. The cucumber harvest was approximately 60 days after the transplant (daT); the fruits with commercial maturity were harvested, those with smooth and straight cylindrical surfaces, a dark, uniform green color (with no yellowing), considering the A category of 3.5 - 5.0 cm in diameter and 14.0 - 16.5 cm in length, according to the Mexico Supreme Quality mark, as the norm for commercial production [30]. The yield was obtained from all harvested fruits that fulfilled this consideration. The result was expressed in grams per plant (g plant-1) and kilograms per square meter (km -2).

2.5. Samples preparation for phytochemical quality analysis

The harvested fruits were washed with drinking water for 2 minutes to remove residues and lyophilized for 5 days. Subsequently, the dry material was pulverized manually (using mortar and pestle) and stored in plastic tubes at -18 °C until extracts were obtained.

2.5.1. Obtaining extracts for phytochemicals analysis

250 mg of dry sample were mixed in 5 ml of HPLC-grade methanol in plastic tubes with screw caps, which were placed on a rotary shaker (ATR Inc., EU) for 24 hours at 20 rpm at room temperature (25 °C). Then, the tubes were centrifuged at 3000 rpm for 5 minutes and the supernatant was removed for analysis.

2.5.2. Total phenolic content

The total phenolic content was measured using a modification of the Folin-Ciocalteau method [31]. The content was calculated by means of a standard curve using gallic acid (Sigma, St. Louis, Missouri, USA) as the standard, and the results were reported in mg of equivalent gallic acid per g of fresh base sample (mg equiv AG / g BF). The analyzes were performed in triplicate.

2.5.3. Equivalent antioxidant capacity in Trolox (ABTS+ method)

The equivalent antioxidant capacity in Trolox was evaluated by the in vitro ABTS+ (2,2'-azino-bis (3-thylbenzthiozoline-6-sulphonic acid)) method published by Esparza et al. [31]. The results were reported as equivalent antioxidant capacity in mM equivalent in Trolox per g fresh base (mM equiv Trolox / g BF).

2.5.4. Equivalent antioxidant capacity in Trolox (DPPH+ method)

Also, the antioxidant capacity was evaluated through the DPPH+ (1,1-diphenyl-2-picrylhydrazil) in vitro method using a modification of the method published by Esparza et al. [31]. The results were reported as equivalent antioxidant capacity in µM equivalent in Trolox per g fresh base (µM equiv Trolox / 100 g BF).

2.6 Vitamin C content

The vitamin C content was determined using a modification of the chromatograph method cited by Esparza et al. [31]. The extract obtained was filtered through a membrane filter of 0.45 µm before being injected into high-resolution chromatography equipment (Hewlett Packard, 1200 Series, Palo Alto, Calif., USA) using the Chem Station software for CL (Agilent Technologies, Palo Alto, Calif., USA). The ascorbic acid (vitamin C) was eluted on a C18 Supelco column (150 mm x 5.0 x 0.5 cm) at a flow rate of 0.5 ml / min, using a 50:50 mixture of phosphoric acid 0.5% and methanol (chromatograph grade) as the mobile phase. The effluent was monitored at 254 nm in a diode array detector. The results were obtained using a standard curve for ascorbic acid (Sigma) and reported as mg of ascorbic acid per g fresh sample. The analyzes were performed in duplicate.

3. Results

3.1. Fruit quality

The length and diameter of the fruit, as well as the firmness and concentration of soluble solids, were better in the chemical treatment (SS), as seen in Table 3. The best treatment of algae extracts for affecting the size of the fruit, was the Bryothamnion triquetrum algae, being statistically equal to the control treatment. Regarding diameter, the Macrocystis integrifolia algae was statistically equal to the control and, with respect to SST, the Macrocystis pyrifera algae showed the lowest value (see Table 3). In the case of firmness, there were no differences between treatments. El-Sharony et al. [33], reported that the use of algae extracts is very effective for improving fruit set, fruit retention, yield and enhanced fruit quality.

Table 3. Diameter, length, total soluble solids and firmness of cucumber fruits in shaded house conditions, with foliar applications of algae extracts.

Treatment	Fruit quality		Weight	Total soluble solids
	Length	Diameter		
	cm		g fruit^{-1}	°Brix
T1(*Macrocystis pyrifera*)	13.360 d[†]	3.380 d	154.330 e	3.440 b
T2(*Bryothamnion triquetrum*)	16.430 a	4.520 c	264.660 b	4.810 a
T3(*Ascophyllum nodosum*)	14.730 c	4.640 b	223.660 c	4.590 a
T4(*Grammatophora sp.*)	15.930 ab	4.600 bc	210.330 d	4.880 a
T5(*Macrocystis integrifolia*)	15.330 bc	4.800 a	208.330 d	4.690 a

T6(Steiner Solution)	16.730 a	4.820 a	286.000 a	4.760 a
MSD	0.982	0.086	10.711	0.428
SE	0.293	0.0257	3.203	0.128
CV	3.790	1.280	4.450	4.900

† Values with equal letters within each column are statistically similar (Tukey, $P \leq 0.05$). MSD=Minimum Significant Difference; SE=Standard Error; CV=Coef. Var.

In regard to the size of the fruit, DeGannes et al. [34] have indicated that the length of the American cucumber fluctuates between 20 and 25 cm, and not under 15 cm [30]. For the diameter of the fruit, Farrag et al. [35] found an average diameter of 3.17 cm with seaweed extract; likewise, Wittwer and Honma [36] found that the diameter of cucumber fluctuates from 5.0 to 5.7 cm, and should not exceed 6.0 cm. From the results, it can be observed that the foliar applications of the algae extracts showed similar values to those obtained in the control treatment. This result can be attributed to the benefits of algae when used in horticultural crops. In this regard, Bajpai [37] indicated that algae present active organic compounds as growth regulators. Metting et al. [38] have indicated that the physiological responses derived from the application of marine algae include greater nutrient mobilization, the development of a vigorous root system, an increase in chlorophyll content, leaf area and delay in fruit senescence.

Regarding the content of total soluble solids (SST), the treatments Bryothamnion triquetrum (T2), Ascophyllum nodosum (T3), Grammatophora sp. (T4) and Macrocystis integrifolia (T1) were statistically equal to the treatment with Steiner solution (SS), with an average value of 4.76 ° Brix, and different to the treatment with Macrocystis pyrifera algae which decreased the SST by 29% (Table 3). Colapietra and Alexander [39] observed an increment of up to 17 ° Brix in a table grape crop (cv Italia) with foliar application of seaweed extracts Ascophyllum nodosum.

Similarly, Khan et al. [40] reported increments of 28% of total sugars in Perville cv Vine by applying Ascophylum nodosum. On the other hand, Kumari et al. [41] mentioned a higher concentration of total soluble sugars in the tomato crop with soil and foliar applications of seaweed extract Sagarssum johntonii.

3.2. Weight of the fruit (g fruit-1)

The weight of the American cucumber fruit should fluctuate between 300 to 400 grams. In this study, the different algae extracts caused significant differences in weight (P≤0.05), with the control treatment (SS) having the greatest weight. Regarding treatments with algae extracts, the Bryothamnion triquetrum treatment was the best, with a 7% lower weight than that of the control, but 41% higher than that of the treatment with the Macrocystis pyrifera, which obtained the lowest weight. The differences in the weight of the American cucumber found in this study may be due to different hybrids, different climate conditions and crop management. The specifications PC-021-2005 for the use of the official Mexico mark [30] establishes two types of cucumber in relation to its attributes. The fruits obtained in this study fall into the classification B (diameter 5.1-6.5 cm and length 14-16.5 cm) and, therefore, could compete in the national and International market.

3.3. Yield (g plant^{-1})

The statistical analysis for this variable shows significant differences (P≤0.05) in the yield (g plant-1), which indicates that the foliar application of the marine algae extracts influenced the yield (Figure 1). The control treatment with Steiner solution reported the highest yield, being 9% higher than the best yield obtained with the algae extracts. The treatment with the Bryothamnion triquetrum alga showed a 42% higher yield compared to the lower yield obtained with the alga Macrocystis pyrifera. The higher yield obtained with Bryothamnion triquetrum may be due to its greater effect on nutrient absorption. In this regard, Youssef et al. [42] have indicated that the higher production of

biomass and yield in cucumber plants could be attributed to the fact that the plants inoculated with biofertilizers have a greater capacity to maintain a high rate of net photosynthesis and a better nutritional status (high concentration of P, K, Mg, Fe, Zn and Mn) compared to non-inoculated plants. Likewise, Metting et al. [38] have mentioned that the physiological responses derived from the application of seaweed include greater mobilization of nutrients, the development of a vigorous root system, an increase in the chlorophyll content, leaf area and delay in the senescence of the fruit.

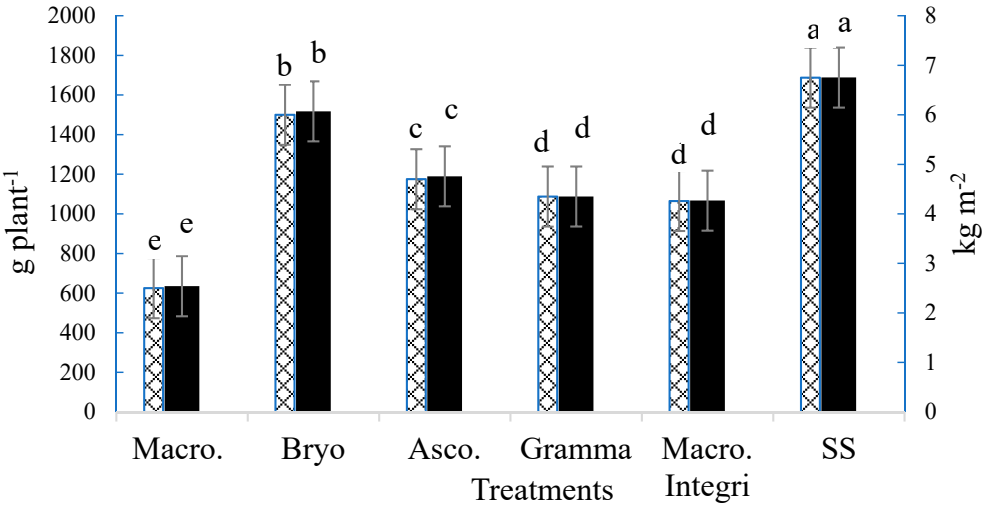

Figure 1. Effect of foliar application of seaweed extracts on the yield production (g plant^{-1} and kg m^{-2}) of cucumber plants established in shade mesh. Means followed by the same letter are not significantly different between treatments (Tukey; $P \leq 0.05$).

It was observed that the control treatment (SS) presented the highest yield per square meter (kg m-2). The treatments with algae extracts showed values between 2.54 and 6.08 kg m-2 (see Figure 1). Regarding the performance in protected systems in Mexico, by SIAP [43] reports, the average yield of cucumber is 98 t·ha-1 (9.8 kg m-2). For example, the average yield for this shade mesh culture is 17.6 kg m-2 in the state of Baja California (Mexico) [44]. In the case of the Comarca Lagunera (Mexico), with medium-tech production technology in shade mesh and fertirrigation, for six plants, the yield fluctuates between 14 -17 kg m-2 [45].

Comparing the benefits of the yields obtained in this experiment to those using chemical fertilization and algae, it can be mentioned that the latter are greater because they are friendly to the environment. The trend in the future is to produce organic cucumbers since they have a high demand by consumers. The payment of overpricing of these products in the foreign market could be higher in relation to the price of conventional products and, consequently, it would improve the cost-benefit ratio of their production.

3.4. Phytochemical quality

The phytochemical quality of the fruits (antioxidants, phenols and vitamin C) was influenced by the algae extracts ($p \leq 0.05$). Higher values were obtained with the Macrocystis pyrifera algae (Table 4). Regarding the antioxidant capacity, in both determination methods (ABTS+ and DPPH+), Macrocystis pyrifera showed the highest value, followed by Bryothamnion triquetrum. Both values were statistically different from each other and different from the control treatment, exceeding it by 30% and 4%, respectively. With the DPPH+ method, the treatment with chemical fertilization presented the lowest value. These results can be explained considering the nutrient deficiency that the substrate presents, particularly that of nitrogen for the plant. In this regard, Lorio [46] and Herms and Mattson [47] mentioned that plants produce higher amounts of sugars and secondary metabolites when they are subjected to a deficit of readily available nitrogen.

315 **Table 4.** Antioxidant capacity of cucumber produced in shade mesh with the application of different
316 nutrient solutions derived from algae, using two methods ($ABTS^+$ and $DPPH^+$).

Treatments	CAOX* (Method $ABTS^+$)	CAOX** (Method $DPPH^+$)
Macrocystis pyrifera	149.4 a	454.1 a
Bryothamnion triquetrum	110.4 b	373.9 bc
Ascophyllum nodosum	90.6 c	295.9 d
Grammatophora sp.	77.0 d	278.4 d
Macrocystis integrifolia.	120.4 b	403.5 b
Steiner Solution (SS)	105.9 b	349.7 c

317 * CAOX: Antioxidant capacity ($ABTS^+$ method), results in µM equiv Trolox / 100 g fresh base.

318 ** CAOX: Antioxidant capacity ($DPPH^+$ method), results in µM equiv Trolox / 100 g fresh base.

319 Differences between means obtained by Tukey test ($P \leq 0.05$). Values in columns with different lowercase letters
320 are statistically different ($P \leq 0.05$).

321 However, the results obtained contrast with those found by Santiago-López et al. [48] in which
322 organic sources of fertilization were used for cucumber, obtaining antioxidant capacity values of
323 779.9 to 1391.1 µM equiv Trolox / 100 g BF. On the other hand, Díaz-Méndez et al. [28] used different
324 proportions of vermicompost and obtained antioxidant capacity values between 749.9 and 1015.2.
325 Some studies have shown that high concentrations of NaCl in substrates increase the activity of
326 antioxidant enzymes [49,50]. This result has been attributed to the synthesis of phenols by plants as
327 a defense mechanism to counteract the negative effects of oxidative stress [51]. Therefore, phenolic
328 compounds are the main drivers of antioxidant activity [52]. In Table 4, the phenolic content for the
329 Macrocystis pyrifera algae had the highest value (47.37), which was expected since it generated the
330 highest antioxidant capacity.
331 Cucumber provides a large amount of C vitamin (mg / 100 g fresh base) and, in this experiment,
332 the treatments with the highest content were the algae Macrocystis pyrifera (5.07), Macrocystis
333 integrifolia. (4.23) and the control treatment (3.70) (See Figure 2). The alga Grammathosfera sp.
334 presented the lowest value -- 40% lower compared to Macrocystis pyrifera. Nagy and Pintér [53] have
335 pointed out that the positive effect of seaweed extract can be explained by the high content of high-
336 quality proteins, amino acids such as lysine and tryptophan, essential minerals, trace elements, B-
337 complex vitamins and bio-constituents, especially cytokinins.
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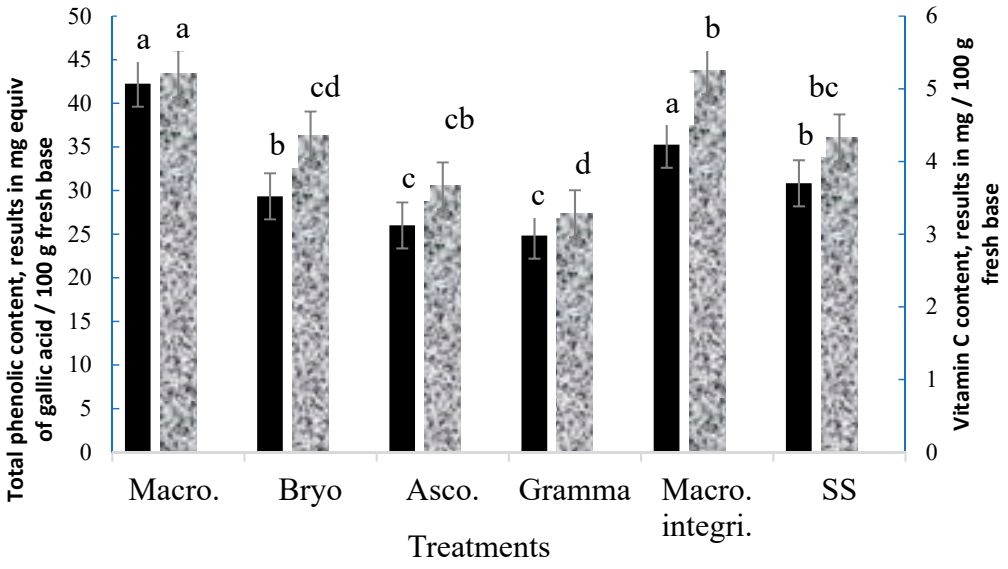

Figure 2. Total phenolic and vitamin C content of cucumber produced in shade mesh with the application of different nutrient solutions derived from algae. Differences between means obtained by Tukey test ($P \leq 0.05$). Values with different lowercase letters are statistically different ($P \leq 0.05$).

4. Conclusions

Higher yields and commercial quality were obtained in cucumber fruits using chemical fertilization, mainly due to the higher concentration of N and the ionic balance of the nutritive solution. Of the treatments with algae extracts, Bryothamnion triquetrum was superior in total soluble solids, fruit firmness, fruit size and yield. However, the highest antioxidant capacity, phenols and vitamin C were obtained with the Macrocystis pyrifera extract. The algae extracts provided some phyto-nutrients for the nutrition of the cucumber plants and increased the quality of the fruits by obtaining greater antioxidant capacity. Therefore, its use is a viable option to minimize the application of conventional fertilizers, thereby attenuating the effects on the environment and improving the health of the population.

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