Colegio de Postgraduados

Seaweed Extracts and Composts (*Macrocystis* spp.) as biostimulants for tomato seedlings (*Solanum lycopersicum* L.)

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ABSTRACT

Objective: To evaluate different application rates of seaweed extracts and compost derived from *Macrocystis* spp. as biostimulants in tomato plants (*Solanum lycopersicum* L.) grown under greenhouse conditions.

Design/methodology/approach: A completely randomized design with four replications was employed. The following treatments were evaluated: (1) a *Macrocystis* spp. seaweed extract obtained in the laboratory under controlled temperature and pressure conditions; (2) a Bokashi-type compost based on the same seaweed; and (3) two commercial seaweed extracts, ProalG® and NPKelp®. Synthetic fertilization and water were used as controls. All treatments were applied at three different rates.

Results: The treatments that produced the greatest foliar biomass, plant height, and stem diameter were NPKelp® at the medium rate, ProalG® at the high rate, and the laboratory-obtained *Macrocystis* spp. seaweed extract at the high rate. Regarding nutrient concentration in plant tissue, the treatments NPKelp® (medium rate), ProalG® (high rate), seaweed extract (high rate), and compost promoted the highest macronutrient concentrations.

Findings/conclusions: The use of seaweed extracts and compost as biostimulants constitutes a viable alternative for reducing the use of chemical fertilization in tomato production.

Keywords: Extract, Seaweed, Biostimulant, Tomato.

INTRODUCTION

Tomato (*Solanum lycopersicum*) is the vegetable crop that requires the greatest use of agrochemicals for field production due to the large number of pests and diseases affecting it, in addition to its high nutrient demand in the form of fertilizers. Nutrients not absorbed by plants exert adverse environmental effects, causing eutrophication as a result of nitrate losses through leaching into water bodies. This, in turn, leads to imbalances in the organisms inhabiting both soil and aquatic ecosystems. The

productivity of this crop is directly associated with the management of biotic and abiotic factors influencing plant development and, consequently, with annual economic returns (Sánchez-Rodríguez *et al.*, 2019; Kumar *et al.*, 2020). Biostimulants are substances that induce physiological and morphological responses, thereby enhancing plant adaptation, growth, and productivity, particularly under unfavorable conditions (Fornes *et al.*, 2022; Hernández-Herrera *et al.*, 2016).

They represent an alternative or complement to the synthetic management of crop production. In recent years, the use of seaweed extracts as plant biostimulants has increased considerably due to their bioactive properties, which enhance the plant's capacity to absorb nutrients, stimulate growth, protect against stress conditions, and improve resistance to pathogens (López *et al.*, 2022; Hong *et al.*, 2007; Van Oosten *et al.*, 2017; El Boukhari *et al.*, 2020). The use of seaweed extracts as plant growth stimulants offers numerous advantages, including higher germination rates, improved root system development, increased leaf area, enhanced fruit quality, and greater plant vigor (Hong *et al.*, 2007; Rayorath *et al.*, 2008; Khan *et al.*, 2009).

Conversely, seaweed-based composts constitute an excellent alternative, as they induce biostimulation and serve as high-quality organic amendments compatible with both organic and conventional production systems. The humic acids present in compost improve the physical, chemical, and biological properties of soils, thereby increasing fertility and productivity (Bellapar *et al.*, 1996). It is essential to address the environmental challenges arising from the excessive application of synthetic chemical fertilizers required for crop development by exploring and implementing integrated strategies that reduce their use. Accordingly, in the present study, seaweed-based extracts and composts were used as soil biostimulants to identify innovative solutions for optimizing agricultural productivity. To this end, the effects of three seaweed extracts and one seaweed-based compost on tomato seedling growth under greenhouse conditions were compared.

MATERIALS AND METHODS

Study site

This study was conducted in the Plant Nutrition Laboratory and greenhouse facilities of the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional (CIIDIR-IPN), Sinaloa Unit, located in Guasave, Sinaloa, Mexico, at 28° 32″48" N latitude and 108° 28″53" W longitude, at an elevation of 15 m above sea level.

Physicochemical analysis of soil, extracts, and seaweed compost

These analyses were performed on the soil, extracts, and seaweed compost in accordance with the criteria established in the Mexican Official Standard NOM-021-RECNAT-2000, published in the Official Gazette of the Federation. Soil pH and electrical conductivity were measured using methods AS-02 and AS-18, respectively (NOM-021). The percentage of organic matter was determined from organic carbon content using the Walkley and Black (1934) method, according to method AS-07 (NOM-021). Phosphorus was analyzed using the method of Olsen *et al.* (1953), and its concentration was measured with a Genesis® UV-visible spectrophotometer, corresponding to method AS-10 (NOM-

021). The determination of cations (K, Ca, Mg, and Na) and micronutrients (Fe, Cu, Mn, and Zn) was carried out using ammonium acetate according to method AS-12 (NOM-021). For K and Na measurements, a Thermo Scientific® flame spectrophotometer was used, whereas Ca, Mg, Fe, Cu, Mn, and Zn were determined with a VARIAN® atomic absorption spectrophotometer, model 50B. Finally, total nitrogen was determined using the Kjeldahl method, AS-08 (NOM-021).

Description of treatments

Three different application rates of *Macrocystis* seaweed extract produced in the laboratory using the method of Rama Rao (1991) were evaluated (Treatments T1, T2, and T3). This procedure consisted of placing 50 g of dried and ground seaweed in 1 L of distilled water under pressure (12 lb) and temperature (100 °C for 10 min). In addition, two commercial seaweed extracts were evaluated at three different rates: low (LR), medium (MR), and high (HR). ProalG®, composed of *Ascophyllum* and *Macrocystis algae*, corresponded to Treatments T4, T5, and T6, whereas NPKelp®, composed of *Macrocystis* and *Gelidium algae*, corresponded to Treatments T7, T8, and T9. Likewise, low, medium, and high rates of bokashi-type Macrocystis seaweed compost leachate were applied (Treatments T10, T11, and T12). Two controls were also included: a positive control with synthetic fertilization (urea 46-0-0) and a negative control with water only (T13 and T14, respectively) (Table 1).

Experimental design

In this experiment, a completely randomized design with four replications was used. The bioassay consisted of sowing tomato seeds in 3-L pots containing a 1:1 mixture of Lambert® peat moss and soil. The hybrid tomato seed SV8579TE from Bayer®, characterized by determinate growth and virus tolerance, was used. Two plants were grown per pot, and the experiment lasted 50 days. Treatments were carefully applied through irrigation to each pot. The aforementioned rates (Table 1) were applied at 15, 25, and 35 days after sowing

Table 1. Description of treatments used in the seaweed extract and compost experiment.

Treatment	Description
T1	Seaweed extract (*Macrocystis*) at low rate (LR): 0.21 g of seaweed
T2	Seaweed extract (*Macrocystis*) at medium rate (MR): 0.27 g of seaweed
T3	Seaweed extract (*Macrocystis*) at high rate (HR): 0.33 g of seaweed
T4	Commercial seaweed extract ProalG® (*Ascophyllum* and *Macrocystis*) at low rate (LR): 0.60 mL
T5	Commercial seaweed extract ProalG® (*Ascophyllum* and *Macrocystis*) at medium rate (MR): 0.84 mL
T6	Commercial seaweed extract ProalG® (*Ascophyllum* and *Macrocystis*) at high rate (HR): 1.08 mL
T7	Commercial seaweed extract NPKelp® (*Macrocystis* and *Gelidium*) at low rate (LR): 1.20 mL
T8	Commercial seaweed extract NPKelp® (*Macrocystis* and *Gelidium*) at medium rate (MR): 1.56 mL
T9	Commercial seaweed extract NPKelp® (*Macrocystis* and *Gelidium*) at high rate (HR): 1.92 mL
T10	Seaweed compost (*Macrocystis*) at low rate (LR): 24 mL
T11	Seaweed compost (*Macrocystis*) at medium rate (MR): 36 mL
T12	Seaweed compost (*Macrocystis*) at high rate (HR): 48 mL
T13	Nitrogen control: 6.14 g of urea

(DAS). All treatments received the same amount of water at each irrigation event, after which the response variables were evaluated.

Response variables

The variables measured for each treatment were as follows: shoot dry weight (SDW), root dry weight (RDW), plant height (PH), stem diameter (SD), root volume (RV), and foliar nutrient analysis (FNA).

To determine shoot dry weight (SDW) and root dry weight (RDW), plants and roots were placed in labeled paper bags and dried in a FELISA® oven at 72 °C for 72 h; they were subsequently weighed using an OHAUS® digital analytical balance. Plant height (PH) was measured with a graduated ruler, and stem diameter (SD) was measured using a vernier caliper. For root volume (RV), roots were washed with water, and measurements were obtained by volume displacement using a graduated cylinder filled with water. Foliar nutrient analysis (FNA) was conducted following the methodology described in the Manual of Chemical Analysis of Plant Tissue by Alcántar and Sandoval (1999).

Once dried, the samples were processed by grinding the plant tissue with a Thomas® electric knife mill. Nutrient analysis of the plant tissue was performed through wet digestion using a mixture of nitric, sulfuric, and perchloric acids. Phosphorus was then determined by the yellow vanadate-molybdate method using a Genesis® UV-visible spectrophotometer. Potassium was determined by flame emission using a Thermo Scientific® flame photometer, whereas calcium and magnesium were determined using a VARIAN® model 50B atomic absorption spectrophotometer. Finally, nitrogen concentration was obtained using the Kjeldahl method, which consists of digestion with salicylic sulfuric acid, followed by distillation and titration.

Statistical analysis

To interpret the response variables, an analysis of variance (ANOVA) was performed. Differences among treatments were assessed using Tukey's test at a significance level of $\alpha=0.05$, employing SAS software version 9.1 (SAS, 2004).

RESULTS AND DISCUSSION

Physicochemical analysis of seaweed extract and compost

The results obtained from the nutrient analysis of the seaweed extract and compost used in the bioassay are presented in Tables 2 and 3.

Evaluation of seaweed extracts and compost under greenhouse conditions

All treatments receiving seaweed extracts showed a positive effect compared with the negative control (water). Seaweed extracts not only provide small amounts of nutrients, but may also contain organic compounds such as lipids, proteins, carbohydrates, carotenoids, and phytohormones (Romero *et al.*, 2022), which contribute to plant growth. The *Macrocystis* seaweed extract obtained in the laboratory using the method of Rama Rao (1991) produced favorable results, reaching a shoot dry weight (SDW) of 9.1 g. Likewise, the medium rate of the commercial seaweed product NPKelp® resulted in a shoot dry weight (SDW) of 10.41 g,

Table 2. Nutrient composition of the *Macrocystis* seaweed extract obtained in the laboratory.

Analysis	Results	Method
Hydrogen potential (pH)	7.4	Potentiometry
Electrical conductivity (EC, mmhos/cm)	0.89	Conductometry
Organic matter (OM, %)	0.1	Walkley and Black
Nitrogen (N, %)	0.01	Kjeldahl
Phosphorus (Olsen P, ppm)	1.10	Olsen
Potassium (K, ppm)	2.25	Flame photometry
Calcium (Ca, ppm)	3.56	Atomic absorption
Magnesium (Mg, ppm)	0.64	Atomic absorption
Sodium (Na, ppm)	2.0	Flame photometry
Iron (Fe, ppm)	0.24	Atomic absorption
Copper (Cu, ppm)	0.01	Atomic absorption
Zinc (Zn, ppm)	0.05	Atomic absorption
Manganese (Mn, ppm)	0.11	Atomic absorption

Table 3. Nutrient composition of the *Macrocystis* seaweed compost.

Analysis	Results	Method
Hydrogen potential (pH)	7.5	Potentiometry
Electrical conductivity (EC, dS m^{-1})	1.45	Conductometry
Organic matter (OM, %)	0.08	Walkley and Black
Nitrogen (N, %)	0.16	Kjeldahl
Phosphorus (Olsen P, ppm)	6.5	Olsen
Potassium (K, ppm)	106	Flame photometry
Calcium (Ca, ppm)	115	Atomic absorption
Magnesium (Mg, ppm)	12.6	Atomic absorption
Sodium (Na, ppm)	10	Flame photometry
Iron (Fe, ppm)	2.01	Atomic absorption
Copper (Cu, ppm)	0.41	Atomic absorption
Zinc (Zn, ppm)	0.69	Atomic absorption
Manganese (Mn, ppm)	1.25	Atomic absorption

which did not differ statistically from the high rate of the commercial seaweed product ProalG®, with a shoot dry weight (SDW) of 10.25 g. Similarly, no statistical difference was observed with the high rate of seaweed compost, which recorded a shoot dry weight (SDW) of 8.04 g, as shown in Figure 1.

Root dry weight

For root dry weight, the treatment with the seaweed extract obtained in the laboratory recorded a root dry weight (RDW) of 2.15 g. The medium rate of the commercial seaweed product NPKelp® produced a root dry weight (RDW) of 2.43 g, which did not differ statistically from the high rate of the commercial seaweed product ProalG®, which recorded an RDW of 2.11 g. Likewise, no statistical difference was observed with

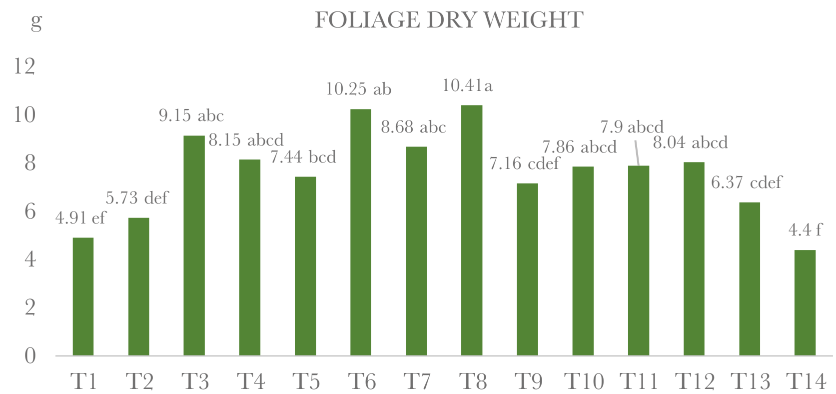

Figure 1. Shoot dry weight in the seaweed extract and compost experiment for tomato seedling production. Means followed by the same letter within each column do not differ significantly according to Tukey's test ($p \leq 0.05$).

the high rate of seaweed compost, which produced a root dry weight (RDW) of 2.4 g, as shown in Figure 2.

Plant height

For the plant height variable, the seaweed extract treatment reached 79.25 cm, whereas the medium rate of the commercial seaweed product NPKelp® resulted in a plant height (PH) of 85.5 cm, which did not differ statistically from the high rate of the commercial seaweed product ProalG® or from the high rate of the seaweed compost treatment. This is shown in Figures 3 and 4.

Stem diameter

For the stem diameter variable, the seaweed extract treatment recorded a stem diameter (SD) of 5.25 mm. In contrast, the medium rate of the commercial seaweed product NPKelp® produced a stem diameter (SD) of 5.7 mm, which did not differ statistically from the high rate of the commercial seaweed product ProalG®, with 5.87 mm, or from the high

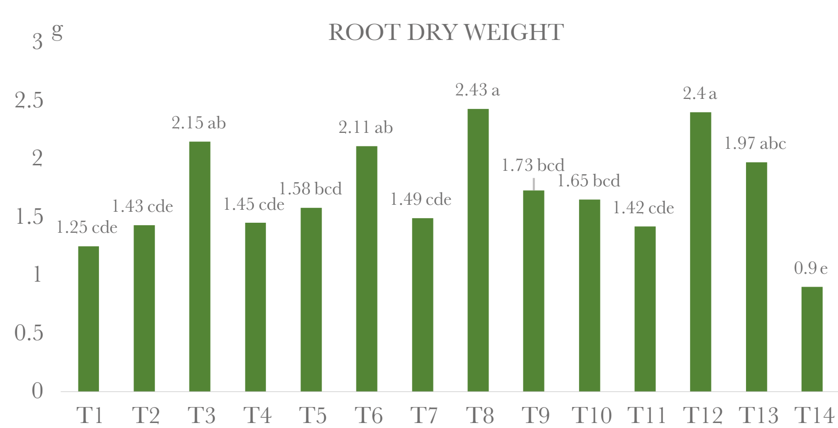

Figure 2. Root dry weight in the seaweed extract and compost experiment for tomato seedling production. Means followed by the same letter within each column do not differ significantly according to Tukey's test ($p \leq 0.05$).

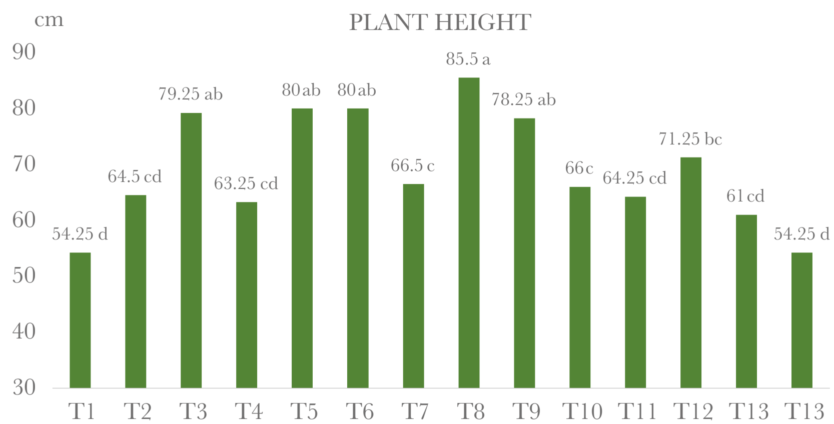

Figure 3. Plant height in the seaweed extract and compost experiment for tomato seedling production. Means followed by the same letter within each column do not differ significantly according to Tukey's test (p≤0.05).

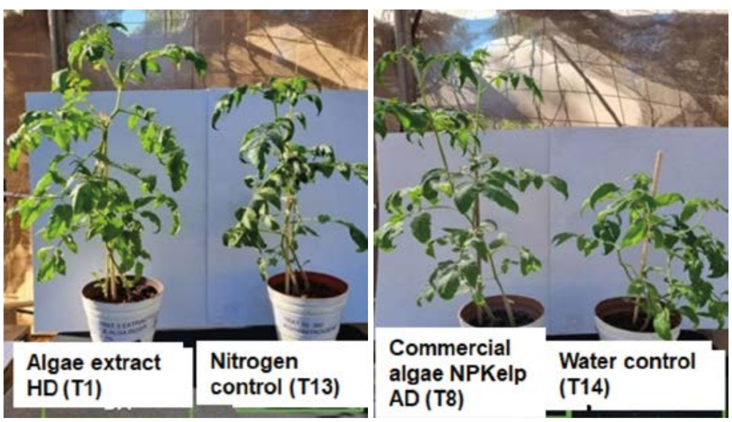

Figure 4. High rate of *Macrocystis* seaweed extract (T3) and the nitrogen control (T13) (left image). Medium rate of the commercial seaweed product NPKelp® (T8) and the water control (T14) (right image).

rate of seaweed compost, with 5.12 mm. The treatment that exhibited the smallest stem diameter was the water control, with an SD of 3.2 mm, as shown in Figure 5.

Root volume

The laboratory-obtained seaweed extract produced favorable results, reaching a root volume (RV) of 16.7 cm^3. Likewise, the medium rate of the commercial seaweed product NPKelp® resulted in a root volume (RV) of 16.2 cm^3, which did not differ statistically from the high rate of the commercial seaweed product ProalG®, with an RV of 15.0 cm^3. Similarly, no statistical difference was observed with the high rate of seaweed compost, which recorded a root volume (RV) of 14.7 cm^3. The water control exhibited the lowest root volume, with 8.0 cm^3, as shown in Figures 6 and 7.

Nutrient concentration

Regarding the macronutrient concentration in the foliage of the different treatments, the highest values were recorded for the high rate of *Macrocystis* seaweed extract (T3), with

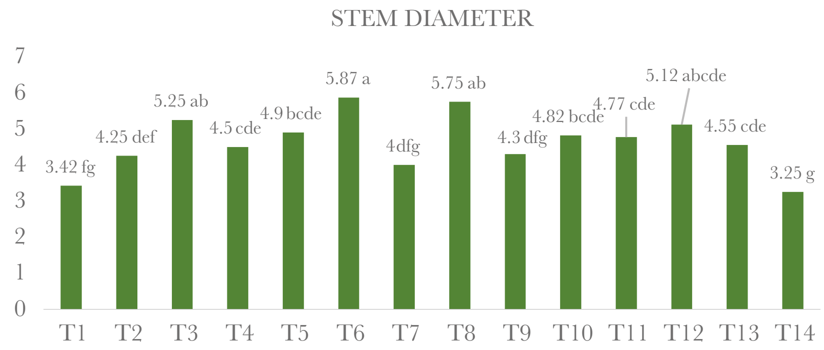

Figure 5. Stem diameter in the seaweed extract and compost experiment for tomato seedling production. Means followed by the same letter within each column do not differ significantly according to Tukey's test ($p \leq 0.05$).

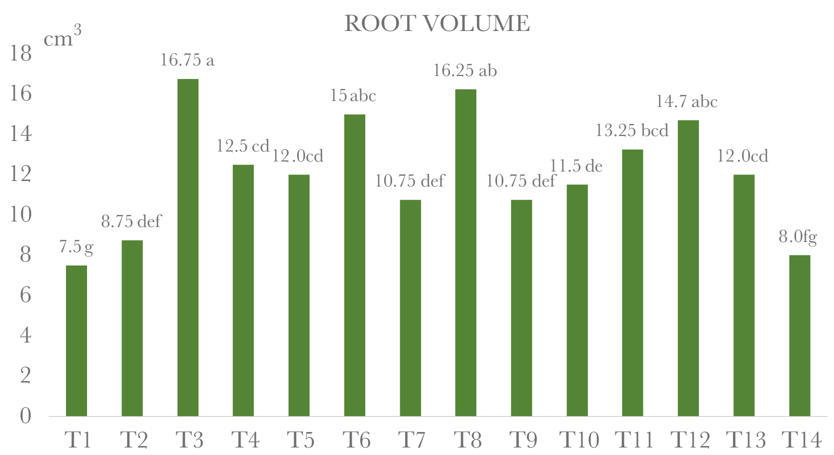

Figure 6. Root volume in plants in the experiment of seaweed extracts and compost in the production of tomato seedlings. Means followed by the same letter within each column do not differ significantly according to Tukey's test ($p \leq 0.05$).

Figure 7. Roots of tomato plants treated with extract and compost of *Macrocystis* seaweed, compared to water and nitrogen controls.

concentrations of N 3.9%, P 0.56%, K 2.6%, Mg 1.3%, and Ca 1.98%; the medium rate of the commercial seaweed product NPKelp® (T8), with N 4.5%, P 0.58%, K 2.9%, Mg 1.27%, and Ca 2.64%; and the high rate of seaweed compost (T12), with N 4.0%, P 0.54%, K 2.8%, Mg 1.31%, and Ca 1.84%. No statistical differences were observed among these treatments. In contrast, the treatment with the lowest nutrient uptake was the water control (T14), which showed N 3.24%, P 0.39%, K 1.9%, Mg 1.8%, and Ca 0.98%.

These results indicate that, although seaweed extracts directly supply only small amounts of nutrients, they enhance the plant's capacity for nutrient absorption. In a study conducted by Cole *et al.* (2016), the high total nitrogen content of seaweed-based composts was shown to exert a positive effect on sugarcane growth, demonstrating that seaweed composts can be used as an alternative nitrogen source for agricultural crop production.

Likewise, Hernández *et al.* (2014) reported that extracts prepared from *Macrocystis* seaweed were favorable for the development of terrestrial plants. In agreement with other studies, this effect has been attributed to the capacity of these extracts to enhance mineral absorption. These seaweed extracts and composts function as biostimulants in tomato plants, indicating that reducing the application of chemical fertilizers in this crop is indeed feasible. Macronutrient uptake is presented in Table 4.

Table 4. Comparison of treatment means in macronutrient analysis in foliage in experiment of seaweed extracts and compost in tomato seedling production.

Treatment	N %	P %	K %	Ca %	Mg %
T1	3.54df	0.41deg	2.46c	2.14bcdef	1.16abcd
T2	3.6cdf	0.46defg	2.45c	2.05cdef	1.27abc
T3	3.97c	0.56ab	2.64abc	1.98def	1.32abc
T4	4.09b	0.42deg	2.65abc	2.41abc	1.32abc
T5	4.20ab	0.44defg	3.04a	2.64a	1.27abc
T6	4.41ab	0.47cdef	2.82abc	2.48ab	1.18abcd
T7	4.13ab	0.40fg	2.47bc	2.16bcdef	1.14bcd
T8	4.54a	0.58a	2.93ab	2.25bcde	1.27abc
T9	4.17ab	0.45defg	2.87abc	2.16bcdef	1.27abc
T10	3.87cd	0.48cde	2.95a	1.89ef	1.39a
T11	3.83cd	0.50bc	2.97a	1.89ef	1.38ab
T12	4.07b	0.54abc	2.8abc	1.84f	1.31abc
T13	5.15a	0.41deg	2.96a	2.33abcd	1.10cd
T14	3.24f	0.39g	1.9d	1.81f	0.98d

Means with the same letter in each column do not show a significant difference according to Tukey's test ($p \leq 0.05$).
T1=*Macrocystis* seaweed extract, 0.21 g, low rate (LR); T2=*Macrocystis* seaweed extract, 0.27 g, medium rate (MR); T3=*Macrocystis* seaweed extract, 0.33 g, high rate (HR); T4=ProalG®, 0.6 mL, low rate (LR); T5=ProalG®, 0.84 mL, medium rate (MR); T6=ProalG®, 1.08 mL, high rate (HR); T7=NPKelp®, 1.2 mL, low rate (LR); T8=NPKelp®, 1.5 mL, medium rate (MR); T9=NPKelp®, 1.9 mL, high rate (HR); T10=*Macrocystis* seaweed compost, 24 mL, low rate (LR); T11=*Macrocystis* seaweed compost, 36 mL, medium rate (MR); T12=Macrocystis seaweed compost, 48 mL, high rate (HR); T13=nitrogen control, 6.14 g (urea); and T14=water control.

CONCLUSIONS

The results showed that the *Macrocystis* seaweed extract obtained in the laboratory through pressure and temperature did not exhibit statistically significant differences in the response variables evaluated when compared with the commercial seaweed extracts. Since it is produced through a simple and rapid method, it represents a more favorable cost-benefit alternative. Likewise, the composted seaweed did not show significant differences from the commercial seaweed products in the variables analyzed, despite the fact that the latter contain additional compounds. Therefore, these findings demonstrate that seaweed extracts and composts constitute an effective alternative for agricultural producers seeking to reduce the use of synthetic chemical fertilization in tomato cultivation.

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