Invasive aquatic plants as a mixed substrate with Red Ferralitic soil in vegetable seedbeds

Plantas acuáticas invasoras como un sustrato mezclado con suelo Ferralítico Rojo en semilleros de hortalizas

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ABSTRACT

The composition of the substrates in the vegetable seedbed phase is important for subsequent transplanting. The aim of this study was to evaluate the use of dry mass of the invasive aquatic plants *Pistia stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms as a substrate mixed with Red Ferralitic soil for seedbeds of tomato and pepper. To plant tomato and pepper seeds, 300 alveoli were prepared with a mixture of Red Ferralitic soil with different proportions of dry mass of *P. stratiotes* (0.5% and 1.0%) and *E. crassipes* (2.0% and 4.0%). At 28 and 40 d after sowing, 30 seedlings per treatment were selected and the average length and diameter of the stem and primary root (cm) were measured. The Dickson quality index was determined in order to select the best treatment. The average stem length was greater in seedlings treated with *P. stratiotes* (0.5%) and *E. crassipes* (2.0%) and the diameter was greater in tomato seedlings treated with *P. stratiotes* (1.0%) and pepper seedlings with *P. stratiotes* (0.5%); this showed significant differences from the rest of the treatments. The maximum length and diameter of the primary root varied between treatments for both vegetables. The best treatments for the initial growth of tomato and pepper were those when Red Ferralitic soil and dry mass of *P. stratiotes* (0.5% and 1.0%) and *E. crassipes* (2.0%) were used as a mixed substrate.

Key words: *Eichhornia crassipes*, *Pistia stratiotes*, seedlings, Dickson quality index, tomato, pepper.

RESUMEN

La composición de los sustratos, en la fase de semillero de hortalizas, es importante para su posterior trasplante. El objetivo de este estudio fue evaluar el uso de masa seca de las plantas acuáticas invasoras *Pistia stratiotes* L. y *Eichhornia crassipes* (Mart.) Solms como sustrato mezclado con suelo Ferralítico Rojo en semilleros de tomate y pimiento. Para plantar semillas de tomate y pimiento se prepararon 300 alvéolos con una mezcla de suelo Ferralítico Rojo y diferentes proporciones de masa seca de *P. stratiotes* (0,5% y 1,0%) y *E. crassipes* (2,0% y 4,0%). Luego de 28 y 40 d de siembra respectivamente, se seleccionaron 30 plántulas por tratamiento y se les midieron la longitud y diámetro promedio del tallo y de la raíz primaria (cm). Se determinó el índice de calidad de Dickson para seleccionar el mejor tratamiento. La longitud promedio del tallo fue mayor en las plántulas tratadas con *P. stratiotes* (0,5%) y *E. crassipes* (2,0%) y el diámetro fue mayor en las plántulas de tomate tratadas con *P. stratiotes* (1,0%) y de pimiento con *P. stratiotes* (0,5%), mostrando diferencias significativas con el resto de los tratamientos. La longitud máxima y el diámetro de la raíz primaria variaron entre tratamientos para ambas hortalizas. Los mejores tratamientos para el crecimiento inicial de tomate y pimiento fueron aquellos donde se utilizó suelo Ferralítico Rojo y masa seca de *P. stratiotes* (0,5% y 1,0%) y *E. crassipes* (2,0%) como sustrato mezclado.

Palabras clave: *Eichhornia crassipes*, *Pistia stratiotes*, plántulas, Dickson quality index, tomate, pimiento.

Introduction

The consumption of vegetables is associated with the quality of human health due to their high contribution of vitamins and minerals that support adequate blood pressure, body mass, and prevent the risk of strokes and certain types of cancer (Quiñones-López, 2023; Reyes, 2023). Tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum* L.) are among the most important vegetable crops (Reyes-Pérez *et al*., 2018; Rodríguez-Delgado *et al*., 2021) for human health.

The tomato is native to the Andean mountains. The ancestors of this species grew in the Colombian wilderness, Ecuador, Bolivia, Peru, and the Atacama region of Chile, on both slopes of the Andes and in the Galapagos Islands

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(Sims, 1980). Also, pepper is one of the vegetables most in demand by consumers. It is the one with the highest economic value (Reyes-Pérez *et al*., 2018). China, the USA, and Turkey are the largest producers of pepper worldwide (Alarcón-Zayas, 2013). In Cuba, it is the most important crop and is grown in all provinces for local consumption and export. The Amalia tomato variety produces numerous large fruits and is highly valued (Moya *et al*., 2009).

The genus *Capsicum* is native to the tropical zone of Central and South America and is made up of several species (Barboza & Bianchetti, 2005; Del Valle-Echevarría *et al*., 2019). Five of these species are used as vegetables, including *C. annuum* (Ibiza *et al*., 2012; Pino *et al*., 2011), and several varieties, including variety True Heart (*i.e*., *C. annuum* var. True Heart). The pepper is recognized worldwide as one of the most important vegetables because of its high nutritional content and the profits it yields to the producer (Rodríguez-Delgado *et al*., 2021). In several countries of the Americas, including Cuba, pepper is the second most important vegetable (after tomato) and widely accepted among the population of the continent (Barrios *et al*., 2005).

Globally, the demand and production cost of inorganic fertilizers has increased (Tang *et al*., 2022), obligating farmers to search for alternatives to obtain the necessary organic and/or environmentally friendly fertilizers. An interesting organic option for an organic fertilizer substrate could be the use of invasive aquatic plants *Pistia stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms found in artificial freshwater lagoons in the province of Ciego de Ávila, Cuba (Hernández-Fernández *et al*., 2023).

Although these aquatic plants cannot be used for large-scale crops, they could benefit seedbeds and crops grown in urban, family, and community agriculture (Honmura, 2000; Sondang *et al*., 2021; Wamba *et al*., 2012). Today, in Ciego de Ávila, *P. stratiotes* is not used for anything; and, although it does not directly affect human populations, its excessive proliferation in the lagoon must affect the flora and fauna that inhabit it. This plant also has a negative impact on migratory water birds, which used the lagoon when it was not yet covered by *P. stratiotes* (personal observation). Only the leaves of *E. crassipes* are used in crafts, which means that their roots remain in the water, thus ensuring their immediate reproduction. These plants constitute an accessible raw material, since they are extracted and deposited on the shores of La Turbina lagoon (affecting the aesthetic value of the site) or, as a final destination, they are sent to landfills without prior treatment, putting nearby groundwater or surface water at risk. The aim of this research was to evaluate the use of the dry mass of the invasive aquatic plants *P. stratiotes* L. and *E. crassipes* (Mart.) Solms as a substrate mixed with Red Ferralitic soil for the seedbeds of tomato and pepper.

Materials and methods

This research was carried out at the Center of Bioplants of the Maximo Gomez Baez University in the province Ciego de Avila, located between the provinces of Sancti Spíritus and Camagüey in central Cuba. The soil used was Ferralitic Red soil according to the Cuban soil classification (Hernández-Jiménez *et al*., 2015). This soil is the predominant soil in the province of Ciego de Ávila (González-Domínguez *et al*., 2019). The soil has low phosphorus (P) and potassium (K) content (González-Domínguez *et al*., 2019) and has the following concentration of chemical elements determined by energy-dispersive X-ray fluorescence spectrometry (EDXRF) (Tab. 1).

TABLE 1. Chemical elements present in the Ferralitic Red soil used in the seedbeds where the tomato (var. Amalia) and pepper (var. True Heart) seeds were sown.

Chemical elements	Soil (%)	Soil (mg kg^{-1})
Al	6.23 ± 0.77	
As		6.08 ± 0.76
Br		17.7± 3.3
Ca	2.58 ± 0.13	
Cr		> 280 (487)
Cu		115 ± 21
Fe	> 6.74 (7.1)	
K	0.350 ± 0.050	
Mg	1.17 ± 0.16	
Mn		1670 ± 120
Mo		2.83 ± 0.84
Na	< 0.15	
Ni		> 130 (480)
P		> 1100 (1130)
Pb		15.2 ± 2.3
S		< 83,5
Si	23.4 ± 1.6	
Ti		6450 ± 400
Zn		105.0 ± 7.3

Experiment preparation and design

To obtain dry mass (DM), *P. stratiotes* plants were collected in the Vista Alegre artificial freshwater lagoon (21°51'9" N, 78°46'39" W, 0.013 km^2 area), and *E. crassipes* in La Turbina lagoon (21°50'51" N, 78°45'43" W, 0.086 km^2 area), in the municipality of Ciego de Ávila. Leaf and root samples were first washed with tap water and then distilled water. Afterwards, they were placed in a drying house for 30 d at an average temperature of 30 ± 1°C. The plant samples were then placed in a Boxun oven at 70 ± 1°C for a period of 48 h. The constant DM obtained was crushed to 2 µm particle size. The phosphorus (P) and potassium (K) concentrations of *P. stratiotes* and *E. crassipes* were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES) (iCAP 6000 ICP Spectrometer, Thermo Fisher Scientific, USA). Total nitrogen (TN) was determined in the plant samples by the salicylic acid-thiosulfate modification of the Kjeldahl method and included determination of $N\text{-}NO_3$ and $N\text{-}NO_2$ (Dhaliwal *et al*., 2014) (Tab. 2). The heavy metals present in the DM of *P. stratiotes* and *E. crassipes* were below the maximum permissible limits established by EU regulations (Serra, 2019). To determine the DM doses, the criterion of Rodríguez-Chow and Trujillo-Mendoza (2013) on the proportions of N, P and K for tomato seedlings was used. The criteria of Álvarez and Pino (2018) were also considered, regarding the absorption of macronutrients, in the first 35 d of pepper cultivation.

Three hundred alveoli (volume of each alveolus 30 cm^3) were prepared in four polystyrene trays, each divided into three sections, filled with a mixture of Ferralitic Red soil and different amounts of dry mass (DM) of *P. stratiotes* and *E. crassipes* (Tab. 2). Five sections with 30 alveoli per section were considered. On May 1, 2023, two seeds of tomato were sown in each of the 150 alveoli, and two seeds of *C. annuum* were sown in each of the 150 alveoli in another group. The viability of tomato seeds was 94%. The viability of pepper seeds was 98%. Seed viability was determined by flotation separation (Solís-Sandoval *et al*., 2019).

During the day, the average temperature was 29.9°C, the maximum temperature was 36.0°C, and the minimum was 20.8°C. During the night, the average ambient temperature was 24.5°C, the maximum was 28.2°C, and the minimum was 20.4°C. During the study, the experimental units received an average photosynthetic photon flux density of 326.57 µmol m^{-2} s^{-1} with a maximum of 2548.90 µmol m^{-2} s^{-1} and a minimum of 0.199 µmol m^{-2} s^{-1}, depending on the time of the day.

Analysis of the experimental units

The percentage of emergence of the tomato and pepper plants was analyzed, taking into account the number of seeds sown and those that germinated per day. For this purpose, each emerging seedling was counted from the first day of emergence until the number of emerged seedlings was constant. For tomatoes, it was from May 9 to May 20, 2023, while, for peppers, it was from May 12 to May 26, 2023. After 28 d (tomato) and 40 d (pepper) of seed sowing, 15 experimental units were randomly selected until reaching 30 seedlings per treatment. The seedlings were selected from the central part of each treatment area to avoid the border effect (Fig. 1).

Once the roots of seedlings were washed to remove traces of soil and each seedling had been drained, the length of the stem (cm) and the primary root (cm) were measured with a ruler. Stem diameter was measured with an OWT 30311 digital caliper (mm). The seedlings were then placed in an oven (IF-3D, Cuba) at 60±1°C until a constant dry mass weight (g) was obtained. To determine the dry mass of the aerial part and the root of each tomato and pepper seedling, an analytical digital balance was used.

The Dickson quality index (DQI) (Eq. 1) of the data was determined (Acevedo-Alcalá *et al*., 2020; Dickson *et al*., 1960; Domínguez-Liévano & Espinosa-Zaragoza, 2021). The highest DQI matches the best treatment.

$$\text{DQI} = \frac{\text{Total dry mass (g)}}{\dfrac{\text{Stem height (cm)}}{\text{Stem diameter (mm)}} + \dfrac{\text{Aerial part dry mass (g)}}{\text{Root dry mass (g)}}} \quad (1)$$

TABLE 2. Treatments applied using a mixture of Ferralitic Red soil with dry mass (DM) of *Pistia stratiotes* and *Eichornia crassipes*.

Number of alveoli	Preparation of the alveoli	Soil (g)	Concentration of N, P, and K in the dry mass of *P. stratioites* and *E. crassipes* (mg g^{-1})		
			N	P	K
30	Soil without plant addition (control)	19.0			
30	Soil + *P. stratiotes* (0.1 g DM) (0.5%)	18.9	24.9 ± 2.0	5.0 ± 0.1	22.5 ± 0.2
30	Soil + *P. stratiotes* (0.2 g DM) (1.0%)	18.8			
30	Soil + *E. crassipes* (0.4 g DM) (2.0%)	18.6	19.5 ± 0.8	1.9 ± 0.1	14.6 ± 1.2
30	Soil + *E. crassipes* (0.8 g DM) (4.0%)	18.2			

Soil + *P. stratiotes* (0.1 g DM) (0.5%): 0.1 g DM of *P. stratiotes* represent 0.5% of substrate; Soil + *P. stratiotes* (0.2 g DM) (1.0%): 0.2 g DM of *P. stratiotes* represent 1.0% of substrate; Soil + *E. crassipes* (0.4 g DM) (2.0%): 0.4 g DM of *E. crassipes* represent 2.0% of substrate; Soil + *E. crassipes* (0.8 g DM) (4.0%): 0.8 g DM of *P. stratiotes*, represent 4.0% of substrate.

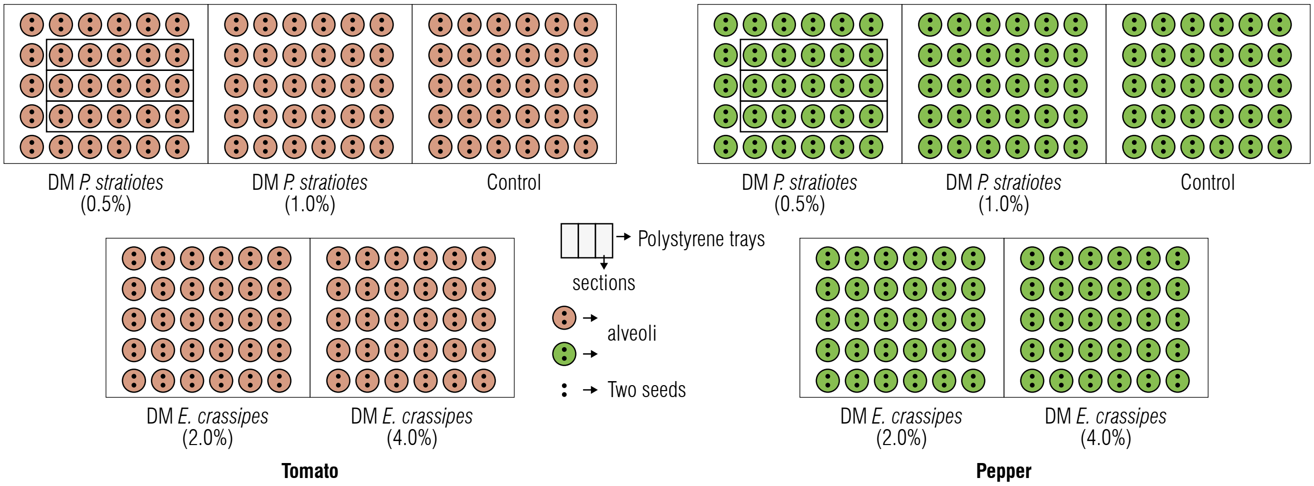

FIGURE 1. Experimental design in tomato and pepper seedbeds. DM: dry mass.

Statistical analysis

Since the data did not have a normal distribution (Shapiro-Wilk test), the non-parametric Kruskal-Wallis test was performed to detect differences in the morphological characteristics of the tomato and pepper seedlings from one treatment to another and to determine the most feasible treatment. When significant differences were present, the Wilcoxon test was applied to determine with which treatments the differences were obtained. Statistical analyses were performed using the R software version 3.1.2 (R Core Team, 2018) and the Vegan package (Oksanen *et al*., 2005).

Results and discussion

The emergence of tomato seedlings was approximately at 5 d, and that of pepper at 12 d (Fig. 2). The percentage emergence of the tomatoes ranged from 65.0 to 85.0% and that of pepper from 40.0 to 80.0%. No significant differences between the control and the treatments with DM of *P. stratiotes* (0.5% and 1.0%) and DM of *E. crassipes* (2.0% and 4.0%) were observed.

The different treatments with DM of *P. stratiotes* and *E. crassipes* used as substrate in the seedbeds did not directly affect the percentage of emergence, since there were no significant differences among the treatments used for the tomatoes nor among those used for the pepper plants. However, the emergence of seedlings is one of the key stages for the success of plant establishment. Temperature, moisture, aeration, and compaction of the substrate are the determining factors for a successful emergence (Porta-Siota *et al*., 2021). In this research, it is assumed that the

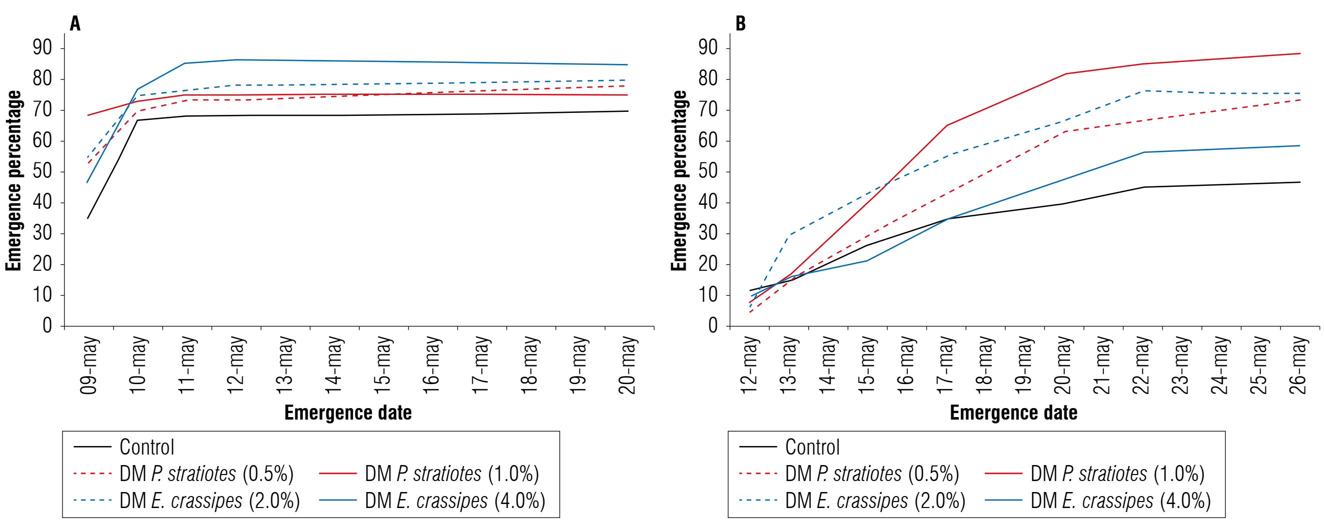

FIGURE 2. A) Percentage emergence of tomato seedlings (var. Amalia) (*P-value*=0.1947). B) Percentage emergence of pepper seedlings (var. True Heart) (*P-value*=0.06849). The *P-value* was determined according to the Kruskal-Wallis test. DM: dry mass.

characteristics of the substrates applied were different for the DM of *P. stratiotes* and *E. crassipe*s with respect to those of the control substrate; and these could influence the physiological processes of the seedlings that increased their emergence percentage, but without significant differences between them.

The optimal air temperature for tomato is between 16°C and 28°C, and that emergence occurs within 5 to 8 d if exposed to sunlight (López-Marín, 2017). For the germination of *Capsicum spp*., the optimal air temperature is 24°C and the optimal photosynthetic photon flux 230 μmol m^{-2} s^{-1} (Pine *et al*., 2018). The *C. annuum* seed takes a fairly long time to germinate and emerge, during which light is not decisive, and the optimal air temperature to achieve good results is around 30°C (Saavedra del Real, 2019). In our study, the tomato seeds emerged in the optimal range of air temperature and time (Lopez-Martín, 2017), while those of pepper emerged at an average air temperature above the one suggested by Pino (2018) and below the one stated by Saavedra del Real (2019). The average photosynthetic photon flux density was above the one suggested by Pino (2018).

Morphological characters of tomato seedlings

After 28 d of culture, the average height of tomato seedlings was 9.8 ± 0.9 cm in the control treatment, while that of the treatments where the substrate of the invasive aquatic plants was used varied between 10.5 ± 0.5 cm and 12.1 ± 0.6 cm. The highest value was obtained in the treatment with DM from *P. stratiotes* (0.5%) and *E. crassipes* (2.0%) (Figs. 3A and 4). The average stem diameter varied between 1.9 ± 0.2 mm and 2.5 ± 0.1 mm. The highest value was obtained in the treatment with DM of *P. stratiotes* (1.0%) (Figs. 3B and 4).

Tomato seedlings also had morphological variations in the length and diameter of the primary root between treatments. The average root length ranged from 8.6 ± 1.0 cm to 10.6 ± 0.8 cm. The highest value was from the treatment with DM of *E. crassipes* (2.0%) (Fig. 3C). The average root diameter was between 1.5 ± 0.1 mm and 2.1 ± 0.2 mm. The highest value was obtained in the treatment with DM of *P. stratiotes* (1.0%) (Fig. 3D).

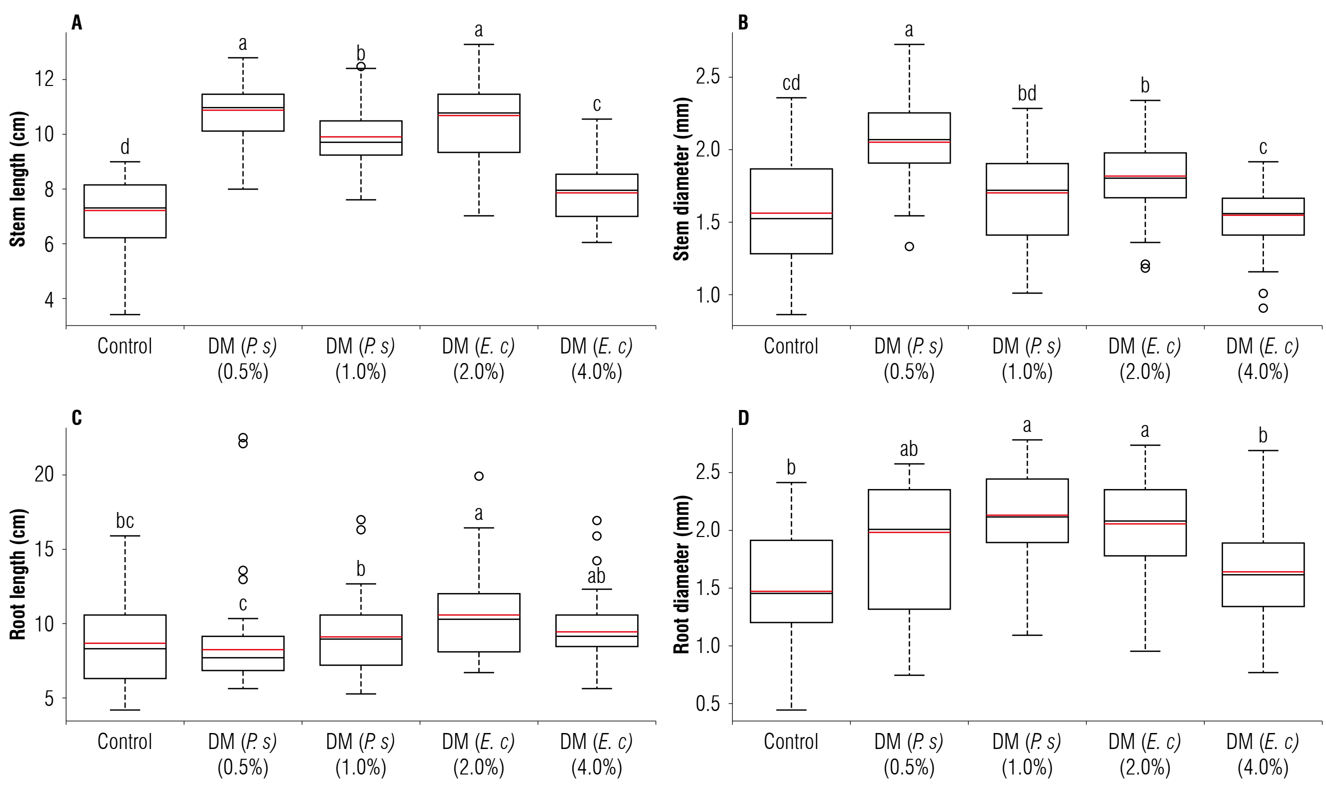

FIGURE 3. A) Stem length after tomato (var. Amalia) (*P-value*=7.247e^{-05}); B) stem diameter (*P-value*=9.377e^{-11}); C) root length (*P-value*=0.004532); D) root diameter (*P-value*=4.889e^{-05}). DM: dry mass, *P.s: P. stratiotes*, *E.c: E. crassipes*. *P*-values were determined according to the Kruskal-Wallis test. Each box represents 50% of the data. Black lines inside boxes represent a median. Red lines inside the boxes represent a mean. Dotted line at the ends=maximum and minimum values. Circles=atypical values. Different letters indicate significant differences between treatments according to the Wilcoxon test. Confidence interval was 95%.

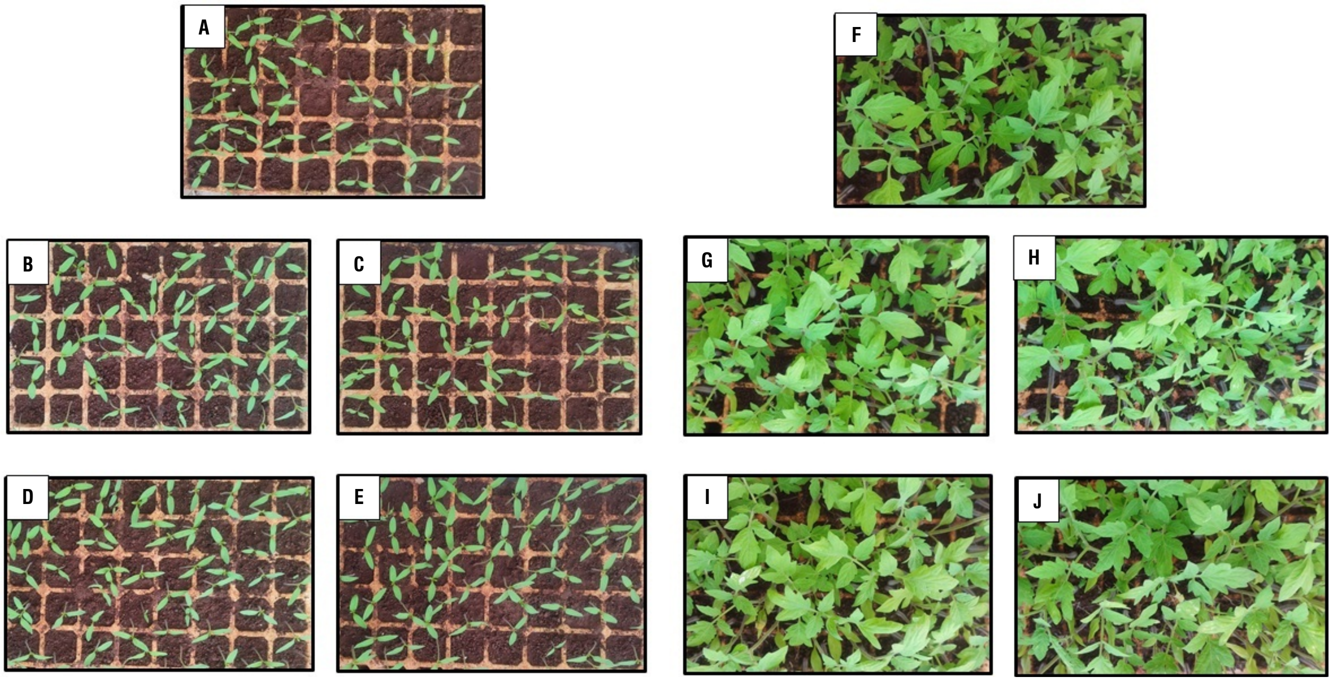

FIGURE 4. Tomato seedbeds (var. Amalia). A-E: 7 d after sowing. F-J: 28 d after sowing. (A and F) control=Ferralitic Red soil (RFS); (B and G) substrate=RFS+*P. stratiotes* DM 0.5%; (C and H) substrate=RFS + *P. stratiotes* DM 1.0%; (D and I) substrate=RFS + *E. crassipes* DM 2.0%; (E and J) substrate=RFS + *E. crassipes* DM 4.0%. DM: dry mass.

The dry mass (g) of the aerial parts of the tomato seedlings with *E. crassipes* DM treatment (2.0%) was the one with the highest mean value when compared to the control and the rest of the treatments. The dry mass (g) of the root was greater in the treatments with DM of *P. stratiotes* (0.5%) and with DM of *E. crassipes* (2.0%) (Tab. 3).

TABLE 3. Average dry mass (DM) of the aerial parts and the roots of tomato seedlings (var. Amalia) with the different treatments. Aerial part (*P-value*=3.284e-^{07}). Roots (*P-value*=1.231e^{-06}).

Treatments	Dry mass of the aerial part (g)	Dry mass of the roots (g)
Soil without MS (Control)	0.07±0.01^{d}	0.01±0.002^{c}
Soil + DM of *P. stratiotes* (0.5%)	0.15±0.02^{b}	0.03±0.009^{a}
Soil + DM of *P. stratiotes* (1.0%)	0.15±0.01^{b}	0.02±0.002^{b}
Soil + DM of *E. crassipes* (2.0%)	0.18±0.01^{a}	0.03±0.003^{a}
Soil + DM of *E. crassipes* (4.0%)	0.13±0.01^{c}	0.02±0.002^{b}

The *P-values* were determined according to the Kruskal-Wallis test. Different letters indicate significant differences between the treatments according to the Wilcoxon test.

The stem length of the tomatoes showed significant differences for all treatments when compared to the control. The values achieved with the DM of *E. crassipes* were similar to those obtained by Luna-Murillo *et al.* (2015) after 30 d of culture; they used, among other treatments, *E. crassipes* as organic fertilizer. However, the values for both stem length and diameter were below those of Fernández-Delgado *et al.* (2021) using different treatments. Specifically, stem diameter was greater in the treatments with DM of *P. stratiotes* (1.0%) and *E. crassipes* (2.0%). The average maximum length of the primary root was obtained with the treatment of DM of *E. crassipes* (2.0%) and did not show significant differences with respect to the treatment with DM of *E. crassipes* (4.0%) and with the rest of the treatments and the control. Root diameter was greater in the treatment with DM of *P. stratiotes* (1.0%), showing significant differences when compared to the control and the treatment with DM of *E. crassipes* (4.0%).

Morphological characters of pepper seedlings

After 40 d of culture, the average height of the control pepper seedlings was 7.0 ± 0.5 cm, while that of the treatments varied between 7.8 ± 0.3 cm and 10.8 ± 0.4 cm. The greatest value was obtained in the treatment with *P. stratiotes* DM (0.5%) and with *E. crassipes* DM (2.0%) (Figs. 5A and 6). The average stem diameter varied between 1.5 ± 0.1 mm and 2.0 ± 0.1 mm. The greatest value was obtained in the treatment with *P. stratiotes* DM (0.5%) (Figs. 5B and 6).

Pepper seedlings also had morphological variations between treatments for the length and thickness of the primary roots. The mean root length ranged from 6.0 ± 0.7 cm to 9.4 ± 0.8 cm. The highest value was obtained in the treatment with *P. stratiotes* DM (1.0%) (Fig. 5C).

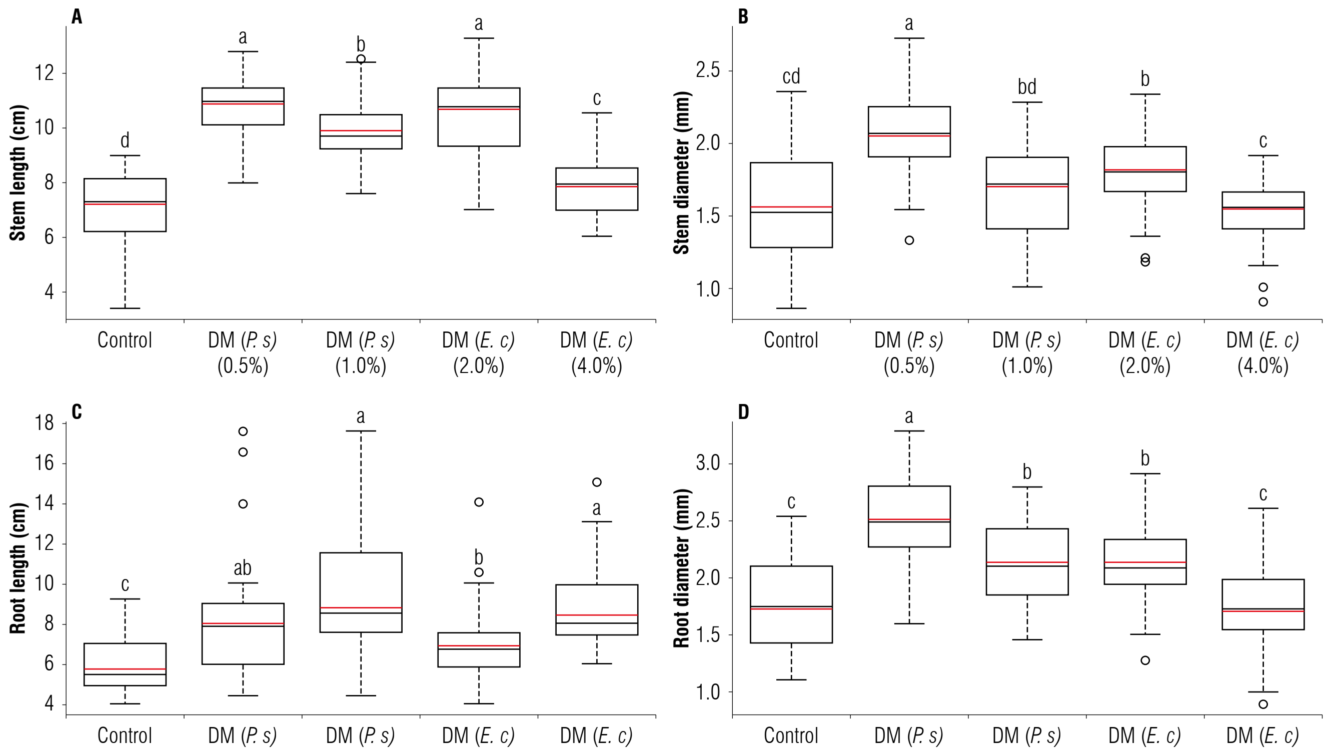

FIGURE 5. A) Stem length of pepper seedlings var. True Heart (*P-value*$<2.2e^{-16}$); B) stem diameter (*P-value*$=9.284e^{-09}$); C) root length (*P-value*$=9.724e^{-08}$); D) root diameter (*P-value*$=3.487e^{-10}$). DM: dry mass; *P.s*: *P. stratiotes*, *E.c*: *E. crassipes*. *P-values* were determined according to the Kruskal-Wallis test. Different letters indicate significant differences between treatments according to the Wilcoxon test; the box represents 50% of the data; black line inside the box=median; red line inside the box=mean; dotted line ends=maximum and minimum values; circles=atypical values; confidence interval was 95%.

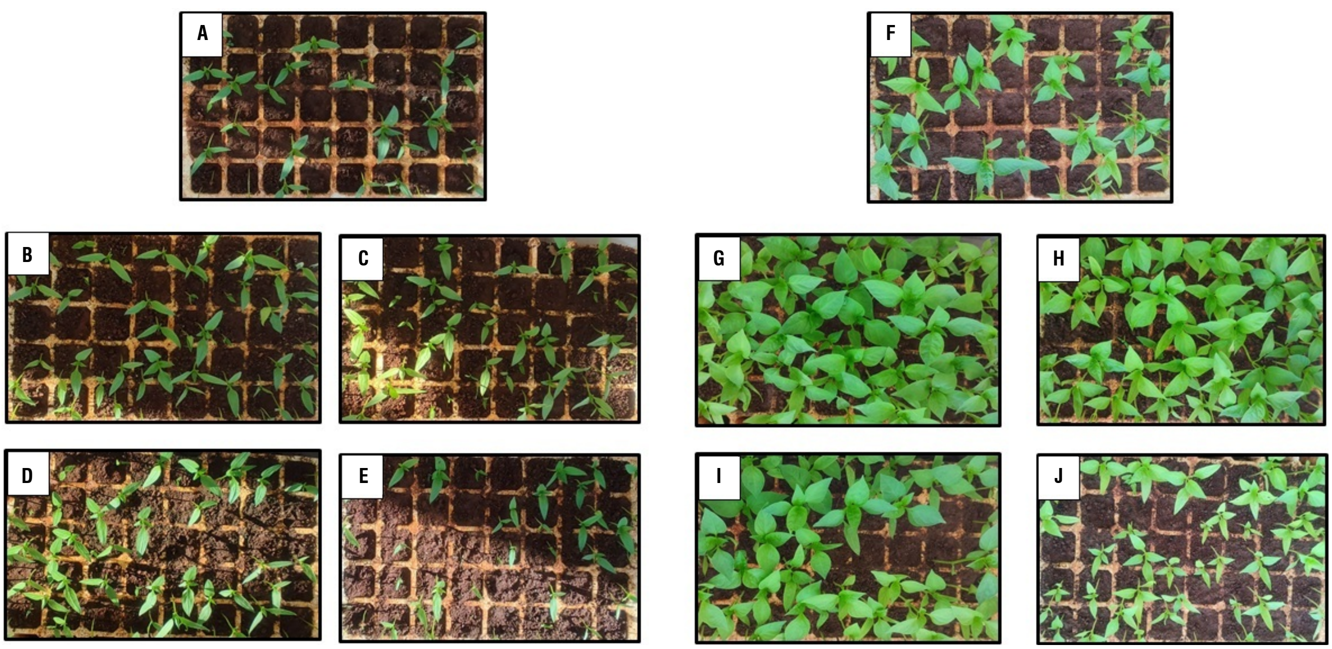

FIGURE 6. Pepper seedbeds var. True Heart. (A-E) 14 d of sowing; (F-J) 40 d after sowing; (A and F) (control=Ferralitic Red soil (RFS); (B and G) substrate=RFS + DM of *P. stratiotes* 0.5%; (C and H) substrate=RFS+DM of *P. stratiotes* 1.0%; (D and I) substrate=RFS+DM of *E. crassipes* 2.0%; (E and J) substrate=RFS+DM of *E. crassipes* 4.0%.

The mean root thickness was between 1.7 ± 0.2 mm and 2.5 ± 0.2 mm. The highest value was obtained in the treatment with *P. stratiotes* DM (0.5%) (Fig. 5D).

The dry mass (g) of the aerial part of the *C. annuum* seedlings for the treatment with DM of *P. stratiotes* (1.0%) and for DM of *E. crassipes* (2.0%) had the highest mean values with respect to the control and the remaining treatments. The treatments with DM of *P. stratiotes* (0.5% and 1.0%) and with DM of *E. crassipes* (2.0%) showed the same values in terms of the dry mass (g) of the root of *C. annuum* seedlings (Tab. 4).

TABLE 4. Average dry mass (DM) of the aerial part and the roots of pepper (var. True Heart) with different treatments. Aerial part (*P-value*= $1.743e^{-08}$). Roots (*P-value*= $2.029e^{-06}$).

Treatments	Dry mass of the aerial part (g)	Dry mass of the roots (g)
Soil without MS (Control)	0.07 ± 0.01^{c}	0.01 ± 0.002^{c}
Soil + DM of *P. stratiotes* (0.5%)	0.11 ± 0.01^{b}	0.03 ± 0.005^{a}
Soil + DM of *P. stratiotes* (1.0%)	0.13 ± 0.01^{a}	0.03 ± 0.005^{a}
Soil + DM of *E. crassipes* (2.0%)	0.13 ± 0.01^{a}	0.03 ± 0.005^{a}
Soil + DM of *E. crassipes* (4.0%)	0.07 ± 0.01^{c}	0.02 ± 0.003^{b}

The *P-values* were determined according to the Kruskal-Wallis test. Different letters indicate significant differences between treatments according to the Wilcoxon test.

The stem length of pepper for all treatments showed significant differences when compared to the control. These values were higher than those obtained by Silva *et al.* (2018) in pepper seedlings with commercial Plantmax and PlantHort II substrate (between 6.38 and 8.25 cm) and lower than those obtained with PlantHort III substrate (12.13 cm). However, the values were above those recorded by Álvarez-Romero *et al.* (2022) between 4.07 cm and 4.37 cm for pepper seedlings grown with natural light (Painita, Yolo, and 13LR62100 varieties). However, Hernández-Huerta *et al.* (2023) obtain higher values of pepper stem length (var. Jalapeño) in all their treatments. Regarding stem diameter, the values were similar to those obtained by Silva *et al.* (2018) (1.4 mm and 2.5 mm), Álvarez-Romero *et al.* (2022) (1.9 mm and 2.0 mm), and Hernández-Huerta *et al.* (2023) (1.1 mm and 2.5 mm). For the lengths of the primary root, all treatments had significant differences when compared to the control, with values similar to those achieved by Hernández-Huerta *et al.* (2023) of 6.8 cm and 9.1 cm. For root thickness, treatments with DM of *P. stratiotes* (0.5% and 1.0%) and with *E. crassipes* (2.0%) resulted in the highest values, with significant differences with respect to the treatment with DM of *E. crassipes* (4.0%) and the control.

The dry mass values of the aerial parts and the roots of pepper seedlings were within the range recorded by Silva *et al.* (2018) in pepper seedlings using commercial substrates Plantmax, PlantHort II, and PlantHort III (between 0.02 g and 0.11 g aerial part and between 0.01 g and 0.04 g root). However, Hernández-Huerta *et al.* (2023) obtained higher values of dry mass from the aerial parts and roots of pepper seedlings.

Dickson quality index (DQI) for tomatoes and peppers

Regarding the DQI for tomatoes, we obtained average values between 0.008 and 0.02. We obtained the highest values with the treatment with DM of *E. crassipes* (2.0%), not significantly different from the treatments with DM of *P. stratiotes* (0.5% and 1.0%) (Fig. 7A). Regarding the DQI for pepper, we obtained average values between 0.008 and 0.017. The highest values for the treatments with *P. stratiotes* DM (0.5%) that did not show significant differences were *P. stratiotes* (1.0%) and *E. crassipes* (2.0%) DM treatments (Fig. 7B).

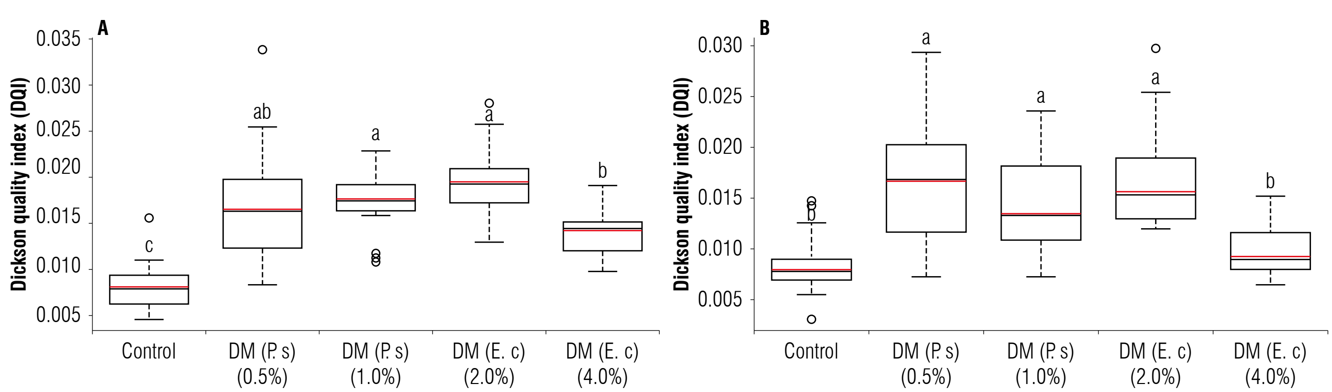

FIGURE 7. Dickson quality index (DQI). A) tomato (var. Amalia) (*P-value*= $2.343e^{-08}$); B) pepper (var. True Heart) (*P-value*= $2.21e^{-06}$). DM: dry mass, *P.s*: *P. stratiotes*, *E.c*: *E. crassipes*. *P-values* were determined according to the Kruskal-Wallis test. Different letters indicate significant differences between treatments according to the Wilcoxon test. The box represents 50% of the data. The black line inside the box is the median. The red line inside the box is the mean. Dotted line ends are maximum and minimum values. Circles are the atypical values. Confidence interval is 95%.

For tomato, the DQI was higher with the treatment with DM of *E. crassipes* (2.0%), so it was the most feasible and did not show significant differences with respect to the treatments with DM of *P. stratiotes* (0.5% and 1.0%). According to Rodríguez-Chow and Trujillo-Mendoza (2013), the soil used did not meet the P and K needs of tomatoes, so it can be inferred that the treatment with DM of *E. crassipes* (2.0%) and with DM of *P. stratiotes* (1.0%) covered these needs. However, factors such as the quality of irrigation water, the type of irrigation, and climate have played a role (López-Marín, 2017; Rodríguez-Chow & Trujillo-Mendoza, 2013).

DQI for pepper was higher in the treatment with DM of *P. stratiotes* (0.5%) that indicated that it was the best treatment and did not show significant differences with respect to the treatments with *P. stratiotes* DM (1.0%) and with DM of *E. crassipes* (2.0%). Indeed, this could have been the case, because although the soil contained most of the macronutrients necessary for the first 35 d of culture, according to the criteria of Álvarez & Pino (2018), they were not enough to cover the real needs of the species. The pepper is a vegetable with a high nutrient demand, which varies depending on the type of soil, the quality of irrigation water, and the climate (Álvarez & Pino, 2018). The treatment with DM of *E. crassipes* (4.0%) contained excessive macronutrients for peppers at the initial growth stage, which could have affected the quality of the seedlings.

The DQI values in peppers were in the range obtained by Álvarez-Romero (2022) in pepper seedbeds with red light and different substrates (between 0.01 and 0.03), but the values were below the values obtained in the seedbeds with blue light and different substrates (between 0.03 and 0.09). They were also within the range of values obtained by Silva *et al.* (2018), although these authors record maximum values between 0.02 and 0.03 with commercial substrates Plantmax, PlantHort II, and PlantHort III. Furthermore, they are lower than those reported by Hernandez-Huerta *et al.* (2023) in their study on the increase in the growth of pepper (between 0.018 and 0.040). In addition, our results were lower than those by Anjos *et al.* (2017) for the culture of pepper variety Morron with sunlight (0.06). The differences between the results of this study and the previous ones may be given by the variations of the environmental conditions, the type of substrate, and the variety used.

Conclusions

The best treatments for the initial growth of the tomato variety Amalia were those in which Ferralitic Red soil was used as a substrate, with DM of *P. stratiotes* at 1.0% and DM of *E. crassipes* at 2.0%. For the initial growth of pepper variety True Heart, the best treatments were those in which Ferralitic Red soil and DM of *P. stratiotes* at 0.5% or 1.0% and DM of *E. crassipes* at 2.0% were used as substrate. These results show that the invasive aquatic plants *P. stratiotes* and *E. crassipes*, far from having a negative impact on humans, can become an opportunity for sectors of economic importance, such as agriculture.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

LHF and YA designed the experiment and formulated the research goal and developed the methodology and research activity planning. LHF wrote the initial draft. RGZ, AJM and JCLF contributed to the data analysis. All authors reviewed the final version of the manuscript.

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