Research Article

Biocontrol Potential of Red Sea Algae *Liagora farinosa* and *Galaxaura elongata* Against *Meloidogyne incognita* on Tomato

Marwa M. El-Deriny[1,2*], Sahar H. Abdel-Baset[2], Doaa A. Abou El-Atta[3] and Sandy E. Hammad[2]

[1]The Egyptian Nematology Reference Lab (ENR Lab) and Genetic Diversity of Microbial Plant Pathogens Reference Lab, Agricultural Research Center (ARC), Giza, Egypt; [2]Nematode Diseases Research Dept., Plant Pathology Research Institute, Agricultural Research Center (ARC), Giza, Egypt; [3]Cotton and Field Crops Mites Dept., Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.

Abstract | Tomato cultivation suffers significant financial losses due to the root-knot nematode (*Meloidogyne incognita*), while chemical nematicides pose health and environmental hazards. The effectiveness of methanolic extracts from two red algae, *Liagora farinosa* and *Galaxaura elongata*, which were gathered from Egypt's Red Sea, were examined as long-term biocontrol agents in this work. In greenhouse tests, tomato plants infected with 1000 or 2000 *M. incognita*-second stage juveniles (J_2) were treated with algal extracts at concentrations of 0.5%, 1%, and 2%. The plant growth parameters, nematode suppression, and biochemical reactions were assessed. The findings showed that both algal species considerably improved plant growth: *G. elongata* at 0.5% raised fresh weight by 58.9%, while *L. farinosa* at 2% increased shoot dry weight by 101.25%. Both extracts decreased root galling and nematode reproduction. Additionally, algal treatments increased the amount of crude protein, carbohydrates, defensive phenolics, and nutrient absorption (N, P, and K) in leaves. These results demonstrate that extracts from *L. farinosa* and *G. elongata* are effective, environmentally friendly substitutes for controlling *M. incognita*, improving tomato resistance and supporting the objectives of sustainable agriculture.

Received | September 26, 2025; **Accepted** | January 04, 2026; **Published** | March 06, 2026
***Correspondence** | Marwa M. El-Deriny, The Egyptian Nematology Reference Lab (ENR lab) and Genetic Diversity of Microbial Plant Pathogens Reference Lab, Agricultural Research Center (ARC), Giza, Egypt; **Email:** marwaelderiny@gmail.com
Citation | El-Deriny, M.M., S.H. Abdel-Baset, D.A.A. El-Atta and S.E. Hammad. 2026. Biocontrol potential of red sea algae *Liagora farinosa* and *Galaxaura elongata* against *Meloidogyne incognita* on tomato. *Pakistan Journal of Nematology*, 44(1): 23-33.
DOI | https://dx.doi.org/10.17582/journal.pjn/2026/44.1.23.33
Keywords | Root-knot nematode, Red algae, Nematicidal activity, Nutrient uptake, Sustainable agriculture

Introduction

A vital crop with enormous economic value, tomatoes (*Solanum lycopersicum*) produce over $100 billion in fresh and processed markets each year and supply vital nutrients like vitamins and lycopene (Yong *et al*., 2023). Tomato has been widely grown for both domestic and commercial consumption due to its rich phytonutrient content (Costa and Heuvelink, 2018), which includes ascorbic acid, retinol, folate, potassium, carotenoids (β-carotene, lycopene, and phytoene), polyphenols, and glycoalkaloids (Chaudhary *et al*., 2018). Lycopene is the most researched carotenoid, and the phytonutrients in tomatoes account for a major portion of their unique nutritional value (Górecka *et al*., 2020). An

estimated 374097.6 feddan of tomatoes were grown in Egypt in 2023, yielding 16.5 tons per feddan, for a total production of 6211015.96 tons, according to FAO statistics (FAO, 2023). However, by reducing production by 30 to 80% due to the formation of root galls, which hinders the intake of nutrients and water and slows growth, root-knot nematodes cause significant financial losses (Jones *et al*., 2013). Severe infestations can result in complete crop failure; losses from tomatoes alone are estimated to be between $40 and $60 billion annually worldwide because of decreased fruit quality, secondary pathogen infections, and increased control expenses (Elling, 2013). According to Álvarez-Ortega *et al.* (2019), root-knot nematodes may survive in a wide range of climatic zones, from temperate to tropical, and parasitize a broad variety of plants.

In order to control plant parasitic nematodes (PPN), synthetic chemical nematicides with active ingredients like carbofuran and methyl bromide have been used extensively in the past. However, several of these chemicals have been taken off the market because they are hazardous to human health and the environment (Haydock *et al*., 2006). As a result, there is a growing effort to look for "natural" nematode control and take integrated pest control strategies into consideration (Peiris *et al*., 2020; Waisen *et al*., 2020). Given that rising soil temperatures enable many PPN to multiply more quickly, leading to population booms and more plant damage, this is especially crucial in the face of global warming.

The use of seaweed extracts in crops and soils has lately drawn attention as a sustainable and environmentally benign way to manage PPN numbers, and more especially, root-knot nematode populations. Seaweed extracts from sustainable sources have been utilized as soil conditioners and fertilizers for many years. Although their main purpose has been to promote the growth of roots and shoots, they are also believed to have a biostimulant impact on plants, and enhancing their tolerance to both biotic and abiotic stress (Khan *et al*., 2009). The enormous potential of these marine organisms for the management of sub-tropical and tropical root-knot nematodes may be revealed by advancements in diving and cultivation techniques as well as the recycling of seaweed wastes (Santaniello *et al*., 2017).

The 5000–6000 species of red algae (Rhodophyta) are primarily multicellular marine algae, which includes several prominent seaweeds (Thomas, 2002). According to the literature review, marine red algae are abundant in phenolic chemicals, particularly bromophenols. According to reports, phenolic compounds have a variety of biological effects, such as vasodilator, antimicrobial, anti-inflammatory, and antioxidant properties (Mayer and Hamann, 2005).

Fucoidans may be more abundant in red and green algae (Olsson *et al*., 2020). Although their precise mechanism of action is unknown, these substances may give plants a "bio-stimulant-like effect" and boost their resistance to abiotic stressors and pathogens (Vera *et al*., 2011). According to some research, seaweed extracts may have nematicidal effects because they made *M. incognita*, *M. javanica*, and *M. acrita* immobile in motility tests (Nour El-deen and Issa, 2016; Ghareeb *et al*., 2019). A common theme in many publications is the idea that seaweeds can make plants more resistant to pests and diseases. This idea was recently shown in Arabidopsis, where applying *Ascophyllum nodosum* reduced the number of pathogenic bacteria-colony forming units (CFUs) linked to plant tissue by triggering the expression of genes linked to plant defense responses, such as PR-1 expression (Cook *et al*., 2018).

In conjugation with the global movement towards sustainable agriculture, the results of this study may help create eco-friendly methods for controlling the root-knot nematode (*Meloidogyne incognita*) and increasing crop yields. A promising strategy for lowering dependency on chemical inputs while enhancing plant resilience and health is the use of red algae as biostimulants and biocontrol agents. This study also emphasizes the significance of investigating natural resources, such marine algae, for inventive solutions to problems in agriculture.

Materials and Methods

Preparation of the algae

Liagora farinosa and *Galaxaura elongata* samples were taken from Marsa Allam Red Sea and it had been carefully cleaned with fresh water to get rid of any clinging debris or related biota then placed in polyethylene bags. After removing the epiphytes from the algae with distilled water and cleaning it with a brush, it was dried in a hot air oven set at 60 °C for two days. The samples were mechanically crushed

into a powder using an electrical mixer (Manilal *et al*., 2009).

Algae identification

The Marine Science Department, Faculty of Science, Suez Canal University, Ismailia, Egypt, performed the morphological identification of the obtained isolates according to Borgesen and Fremy (1936).

Algal extract preparation

The crude extracts were weighed as 100 grams of the dry weight and each algal species was soaked in 1000 milliliters of the methanolic solvent for 48 hours. The mixture was then filtered and concentrated under decreased pressure using a rotary evaporator. *Liagora farinosa* and *Galaxaura elongata* methanolic extracts were applied in three concentrations: 0.5% (0.5 g/100 ml water), 1.0% (1 g/100 ml), and 2.0% (2 g/100 ml).

Preparation of nematode inoculum

Using the modified nematode extraction method described by Hussey and Barker (1973), nematode eggs were extracted from the roots of the collected galled tomato plants. To remove the soil particles, tap water was used to wash the roots then they were cut into 1-cm pieces and put in a glass bottle with a 0.5% solution of sodium hypochlorite (NaOCl). The egg masses were manually shaken robustly for three minutes in order to separate them from the roots. To get rid of the organic waste from the eggs, the suspension containing it was subsequently passed through sieves of varying diameters. To dispose of the remaining NaOCl, the suspension that was still on the 400 Mesh sieve was then thoroughly cleaned with tap water for five minutes and the recovered eggs suspension was put in a beaker. Additional eggs were extracted using the same procedure, and they were subsequently incubated at 25°C for 48 hours. Live freshly hatched juveniles (J2s) were separated from dead juveniles or unhatched eggs using the modified Baermann approach.

Greenhouse experiment

The 30-day-old tomato seedlings (cv. Elisa) were placed in plastic pots with a diameter of 30 cm and filled with 1:1 autoclaved clay and sand soil combination, two seedlings in each pot. The plants were reduced to one seedling per pot after a week. Five days later, newly hatched *M. incognita* second-stage juveniles (J2) at two different levels (1000 J_2 and 2000 J_2/pot) were inoculated in holes that were 5–7 cm deep and 2 cm in diameter around the seedling, along with untreated control. Twenty milliliters of the methanolic extracts of *L. farinosa* and *G. elongata* were applied to the plants as a soil drench three days later at the aforementioned concentrations. Four pots for every algal extract concentration, however, were free of nematodes. Plants were watered as needed while four pots were treated with Oxamyl (24% L), a common nematicide, at a rate of 0.1 ml per pot. In addition, four pots of each nematode level (1000J2 and 2000J2) were used as controls. Four pots of untreated, uninoculated plants were used as the control group. Pots were set up in a greenhouse with four replicates in a randomized completely block design.

Data collection

Plants were carefully taken out of the pots after 45 days of infection, where both the roots and shoots were removed. The fresh and dry weights of shoot and fresh weight of roots were measured, along with their lengths. The quantity of flowers and leaves was also counted. Under a stereo microscope, the number of galls and egg masses on each plant root system was counted. The Goodey Method (1957) was used to extract juveniles from the soil in each pot. The final population (Pf) was divided by the initial population (Pi) to determine the reproductive factor (Rf).

Biochemical analysis

The leaf samples were dried in an oven set to 70 °C, and then they were coarsely powdered and wet digested. The methods outlined by Mertens (2005a, b) and Agrilasa (2002) were used to measure the amounts of N, P, and K in leaves, respectively.

Phenolic contents estimation

One gram of fresh tomato leaves from each treatment were quickly and randomly cut into tiny pieces and macerated for ten minutes in 95% boiling ethanol. The macerated material was placed in soxhlet unit using 75% ethanol extraction solvent. The extraction process was restarted twelve hours later. Ethanol extracts were filtered and then evaporated until no more ethanol remained. The dry residue was dissolved in 5 milliliters of 50% isopropanol. Total phenols were measured following the guidelines provided by Simons and Ross (1971). In a test tube, 0.25 milliliters of hydrochloric acid and 0.2 milliliters of the sample extract were mixed together, then the mixture was boiled for approximately ten minutes. Following cooling, 1 ml of the Folin reagent and 5 ml

of a 20% sodium carbonate solution were added, and the combination was diluted with 10 ml of distilled water. A spectrophotometer was used to measure the density of the blue color that was produced at 520 nm after 30 minutes, using chatichole as a blank and a standard. Phenol concentration was measured in milligrams per gram of fresh weight per minute.

Crude protein and total carbohydrate estimations

Bradford's Method (1976) was applied to evaluate crude proteins. Additionally, the procedures of Je (1962) were used to determine the total carbohydrate content.

Data analysis

Analysis of variance (ANOVA) (Gomez and Gomez, 1984) followed by Duncan's multiple range tests (Duncan, 1955) were used to statistically examine the data in order to compare means.

Result

Table 1 shows the effects of two red algae (*L. farinosa* and *G. elongata*) on the development response of tomato seedlings infected or not with the root-knot nematode *M. incognita*, in comparison to the chemical nematicide Oxamyl. All treatments significantly improved plant growth parameters to varying degrees, regardless of the tested concentrations. *Liagora farinose* + 2000 J2s (N2) treatment at concentrations of 0.5 or 2% showed a notable improvement in plant fresh weight (56.6 and 55.29%, respectively) and plant dry weight (82.38 and 101.25%, respectively) for infected plants. However, the highest total plant fresh weight (58.9%) and a notable increase in shoot dry weight (77.98%) were obtained with *G. elongata* + 2000 J2s at a 0.5% concentration. Conversely, Oxamyl chemical treatments were less effective; Oxamyl + 1000 J2s (N1) and Oxamyl + 2000 J2s resulted in only moderate fresh weight increase of the shoots (17.9 and 12.44%) and dry weight (35% and 35.22%), respectively. Almost all treatments with red algae extracts resulted in a higher number of leaves. Several algal treatments, particularly at the 2% concentration, significantly improved flowering where treatment with *L. farinosa* + 2000 J2s at 2% resulted in 3.66 flowers followed by treatment with *G. elongata* + 2000 J2s at 2% which resulted in 2 flowers.

The ability to improve both vegetative and reproductive growth was demonstrated by the fact that *G. elongata* and *L. farinosa* at 0.5% concentration generated the most leaves (11) and flowers (8), while *L. farinosa* at 1% concentration produced the highest increase in total plant fresh weight (26.51%) for uninfected plants.

Algal treatments continuously surpassed the control group, especially in terms of flowers production, despite the latter's moderate growth parameters.

The nematicidal effects of each treatment on development of *M. incognita* infecting tomato plants are shown in Table 2. In comparison to untreated controls (N1 and N2 alone), both *L. farinosa* and *G. elongata* substantially decreased nematode reproduction. Higher algae concentrations (2%), among the evaluated treatments, were more successful in lowering gall formation and nematode development. *Liagora farinosa* + N2 treatment decreased total nematodes to 1280.8 (compared to N2 alone = 4350.6), galls to 77 (compared to N2 = 196.5), and egg masses to 53 (compared to N2 = 139). Likewise, a 2% concentration of *G. elongata* + N1 reduced the overall number of nematodes to 1022.3 (compared to N1 = 3180.3) and galls to 65 (compared to N1 = 150), as well as the egg masses to 36.8 (compared to N1 = 99.3).

Nematodes were almost completely eradicated by chemical treatment (Oxamyl+N1= 346.1 total nematodes, 20 galls and 9.5 egg masses). However, algae particularly at 2%, showed biologically equivalent suppression. Although damage was generally increased by higher nematode inoculum (N2), algae were still able to provide resilient control, indicating their potential as environmentally friendly alternative substitutes for chemicals.

The percentage of nitrogen in tomato leaves, an essential nutrient for plant growth and protein synthesis, is shown in Figure 1. In comparison to the control and chemical treatment (Oxamyl), the nitrogen concentration in uninfected plants was higher after treatments with red algae, *G. elongata* and *L. farinosa*. Higher concentration (2.0%) of each alga was likely more effective at improving nitrogen content than lower concentrations. This rise suggests that treatments with algae enhance the intake and usage of nitrogen, which is necessary for the proper growth of plants. Lower nitrogen levels in only nematode treatment indicated less effective nutrition uptake or availability.

Table 1: *Impact of two red algae (Liagora farinosa and Galaxaura elongata) on growth of tomato cv. Elisa infected or not infected with M. incognita under greenhouse conditions.*

Treatments	*Con. (%)	Plant growth parameters									
		Length (cm)		Fresh weight (g)			% In-crease	Shoot dry weight (g)	% In-crease	Number of leaves	Number of flowers
		Shoot	Root	Shoot	Root	Total plant					
Infected											
L. farinosa +N1	0.5	73.0^{a-c}	20.66^{cd}	25.50^{b-d}	4.90^{gh}	30.4^{d-g}	32.75	2.36^{f-i}	31.11	9.90^{ab}	0.00^{g}
L. farinosa +N1	1	73.0^{a-c}	20.33^{cd}	21.60^{f-h}	6.60^{e-g}	28.3^{f-h}	23.58	2.26^{h-j}	25.55	8.66^{a-c}	1.00^{e-g}
L. farinosa +N1	2	70.6^{a-d}	24.33^{a}	23.40^{c-f}	7.50^{d-f}	30.9^{c-g}	34.93	2.70^{b-h}	50.00	8.30^{bc}	1.33^{e-g}
L. farinosa +N2	0.5	73.6^{a-c}	20.33^{cd}	26.70^{a-c}	7.33^{d-f}	34.0^{a-d}	56.60	2.90^{a-e}	82.38	9.00^{a-c}	0.66^{e-g}
L. farinosa +N2	1	68.0^{b-e}	20.00^{cd}	19.90^{g-i}	10.53^{a}	30.4^{d-g}	40.00	2.11^{ij}	32.70	7.33^{c}	0.00^{g}
L. farinosa +N2	2	69.0^{b-e}	20.00^{cd}	27.53^{ab}	6.20^{e-g}	33.7^{b-d}	55.29	3.20^{a}	101.25	9.00^{a-c}	3.66^{bc}
G. elongata +N1	0.5	68.6^{b-e}	23.66^{ab}	22.20^{e-h}	6.00^{e-g}	28.3^{f-h}	23.58	2.53^{d-i}	40.55	8.66^{a-c}	0.33^{fg}
G. elongata +N1	1	75.0^{ab}	19.33^{d}	24.00^{c-f}	8.80^{a-d}	32.9^{b-e}	43.66	2.70^{b-h}	50.00	8.60^{a-c}	1.00^{e-g}
G. elongata +N1	2	68.0^{b-e}	20.60^{cd}	25.73^{b-d}	9.70^{a-c}	35.4^{ab}	54.58	2.35^{f-i}	30.55	8.30^{bc}	1.33^{e-g}
G. elongata +N2	0.5	68.0^{b-e}	20.00^{cd}	24.56^{b-f}	10.00^{ab}	34.5^{a-c}	58.90	2.83^{a-f}	77.98	9.00^{a-c}	0.66^{e-g}
G. elongata +N2	1	71.3^{a-c}	22.60^{a-c}	21.76^{f-h}	8.80^{a-d}	30.6^{d-g}	41.00	2.29^{g-j}	44.02	8.00^{bc}	0.00^{g}
G. elongata +N2	2	70.6^{a-d}	20.33^{cd}	22.50^{d-h}	8.00^{b-e}	30.6^{d-g}	41.00	2.41 $^{e-i}$	51.57	8.33^{bc}	2.00^{de}
Oxamyl+ N1		71.3^{a-c}	20.60^{cd}	22.20^{e-h}	4.80^{gh}	27.0^{gh}	17.90	2.40^{e-i}	35.00	8.33^{bc}	1.00^{e-g}
Oxamyl+ N2		69.0^{b-e}	19.30^{d}	19.50^{g-i}	4.90^{gh}	24.4^{hi}	12.44	2.15^{ij}	35.22	8.33^{bc}	0.66^{e-g}
N1 alone		60.0^{fg}	20.60^{cd}	19.20^{hi}	3.70^{h}	22.9^{i}	----	1.80^{jk}	-----	8.00^{bc}	0.00^{g}
N2 alone		54.0^{g}	16.50^{e}	17.90^{i}	3.80^{h}	21.7^{i}	-----	1.59^{k}	----	7.33^{c}	0.00^{g}
Uninfected											
L. farinosa	0.5	70.0^{a-d}	20.00^{cd}	25.70^{b-d}	6.50^{e-g}	32.2^{b-f}	8.05	3.10^{a-c}	10.70	11.00^{a}	8.00^{a}
L. farinosa	1	67.0^{c-f}	21.00^{b-d}	29.70^{a}	8.00^{b-e}	37.7^{a}	26.51	3.00^{a-d}	7.14	9.33^{a-c}	3.00^{cd}
L. farinosa	2	64.0^{d-f}	21.00^{b-d}	22.70^{d-g}	7.70^{c-e}	30.4^{d-g}	2.01	2.60^{c-i}	----	11.00^{a}	3.66^{bc}
G. elongata	0.5	63.0^{ef}	24.00^{a}	23.90^{c-f}	4.80^{gh}	28.7^{fg}	---	3.30^{a}	17.80	11.00^{a}	8.00^{a}
G. elongata	1	71.0^{a-d}	20.00^{cd}	26.20^{bc}	5.40^{f-h}	31.6^{b-g}	6.04	3.30^{a}	17.80	11.00^{a}	5.00^{b}
G. elongata	2	71.0^{a-d}	24.00^{a}	24.80^{b-f}	9.00^{a-d}	33.8^{a-d}	13.42	2.85^{a-f}	1.780	10.00^{ab}	5.00^{b}
Control	-	76.6^{a}	21.60^{a-d}	25.30^{b-e}	4.50^{gh}	29.8^{e-g}	-----	2.80^{a-g}	-----	9.00^{a-c}	1.66^{d-f}
L.S.D 5%	-	7.24	2.817	3.373	2.137	3.90		0.51		2.56	1.44

*N1= 1000 J2s, N2= 2000 J2s of M. incognita. *Con.= red algae concentration. Each value presented the Mean of four replicates. Means in each column followed by the same letter(s) significantly are not different (p≤0.05) by Duncan's multiple range test.*

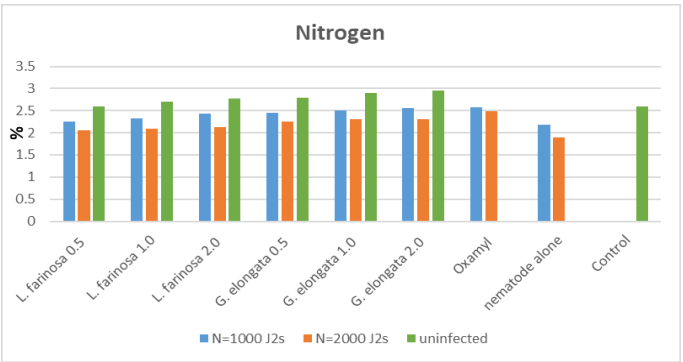

Figure 1: *Percentage of Nitrogen in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

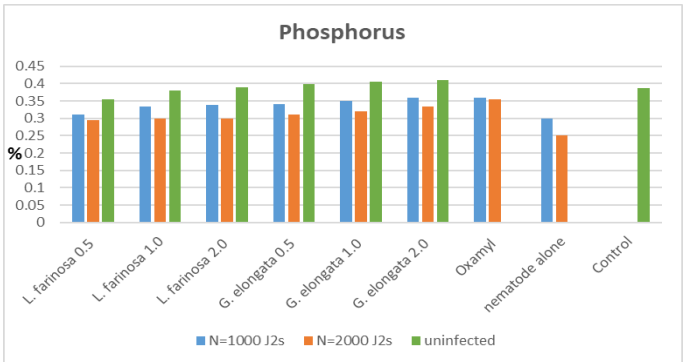

Figure 2: *Percentage of Phosphorus in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

Table 2: *Impact of two red algae (Liagora farinosa and Galaxaura elongata) on the reproduction of M. incognita infecting tomato cv. Elisa under greenhouse conditions.*

Treatments	*Con. (%)	Nematode population in			Total nematode population	***RF	Number of galls	****RGI	Number of egg masses	****EI
		Soil / pot	Root							
			**D. S	Females						
L. farinosa +N1	0.5	2095.0^{de}	31.5^{b-d}	81.5^{cd}	2208.0^{cd}	2.21	113.0^{cd}	5	65.8^{de}	4
L. farinosa +N1	1	1850.0^{e}	25.8^{b-f}	70.0^{c-f}	1945.8^{d}	1.95	88.5^{d-g}	4	59.5^{d-f}	4
L. farinosa +N1	2	1300.0 ^{f}	22.3^{e-g}	49.3^{g}	1371.6^{e}	1.37	63.0^{g}	4	39.3^{gh}	4
L. farinosa +N2	0.5	2337.5^{cd}	29.8^{b-e}	77.8^{c-e}	2445.1^{c}	1.22	93.0^{d-f}	4	62.3^{d-f}	4
L. farinosa +N2	1	2062.5^{de}	28.3^{b-e}	83.0^{c}	2173.8^{cd}	1.09	101.5^{c-e}	5	70.0^{cd}	4
L. farinosa +N2	2	1202.5^{fg}	12.8^{hi}	65.5^{d-g}	1280.8^{e}	0.64	77.0^{e-g}	4	53.0^{e-g}	4
G. elongata +N1	0.5	1815.0^{e}	16.3^{g-i}	59.0^{fg}	1890.3^{d}	1.89	73.8^{fg}	4	45.0^{gh}	4
G. elongata +N1	1	1800.0^{e}	25.0^{c-f}	62.5^{e-g}	1887.5^{d}	1.89	74.8^{e-g}	4	49.0^{f-h}	4
G. elongata +N1	2	955.0^{g}	17.5^{f-h}	49.8^{g}	1022.3^{e}	1.02	65.0^{g}	4	36.8^{h}	4
G. elongata +N2	0.5	2450.0^{c}	32.8^{bc}	105.5^{b}	2588.3^{c}	1.29	127.8^{bc}	5	80.8^{c}	4
G. elongata +N2	1	1870.0^{e}	23.0^{d-g}	78.3^{c-e}	1971.3^{d}	0.99	96.0^{d-f}	4	64.5^{de}	4
G. elongata +N2	2	1012.5^{fg}	12.3^{hi}	59.0^{fg}	1083.8^{e}	0.54	69.5^{fg}	4	48.3^{f-h}	4
N1 alone		3025.0^{b}	33.8^{b}	121.5^{b}	3180.3^{b}	3.18	150.0^{b}	5	99.3^{b}	4
N2 alone		4100.0^{a}	74.3^{a}	176.3^{a}	4350.6^{a}	2.18	196.5^{a}	5	139.0^{a}	5
Oxamyl+ N1		322.5^{h}	7.8^{i}	15.8^{h}	346.1^{f}	0.35	20.0^{h}	3	9.5^{i}	2
Oxamyl+ N2		212.5^{h}	12.0^{hi}	23.3^{h}	247.8^{f}	0.12	29.0^{h}	3	12.5^{i}	3
L.S.D 5%		324.7	8.7	17.02	433.99	-	27.4	-	14.1	-

*N1= 1000 J2s, N2= 2000 J2s of M. incognita. *Con.= red algae concentration, **D. S= Development stages *** RF= (Reproduction Factor) = nematode initial population/ nematode final population. ****Root gall index (RGI) or egg-masses index (EI) was determined according to the scale given by Taylorand Sasser (1978) as follows: 0= no galls or eggmasses, 1= 1-2 galls or eggmasses , 2= 3-10 galls or eggmasses, 3= 11-30 galls or eggmasses, 4= 31-100 galls or eggmasses and 5= more than 100 galls or eggmasses. Each value is the mean of four replicates. Means in each column followed by the same letter(s) significantly are not different (p≤0.05) by Duncan's multiple range test.*

The amount of phosphorus, a nutrient necessary for energy transfer and photosynthesis, in tomato leaves is shown in Figure 2. The nematode-alone treatment (especially at N2) showed the lowest phosphorus content. The most effective concentration of each alga was the higher one (2%). This increase shows an improvement in the uptake and utilization of phosphorus, which is essential for the plant's metabolic activities. Only the phosphorus levels of the nematode-treated plants decreased, indicating a decrease in nutrient availability or uptake efficiency.

Figure 3 shows the proportion of potassium, an essential nutrient for water regulation and enzyme activation, in tomato leaves. All concentrations of both algal species (*L. farinosa* and *G. elongata*) are expected to increase potassium levels in infected plants. The effect is likely concentration-dependent, with the 2.0% application rate showing higher potassium levels than the 0.5% rate for both algal species. The potassium content was significantly affected by treatment with different concentrations of *L. farinosa* + N1. Improved nutrient uptake and stress tolerance are suggested by plants treated with algae having higher potassium contents. Lower potassium levels in the nematode-alone treatment suggested less food availability and weakened stress reactions.

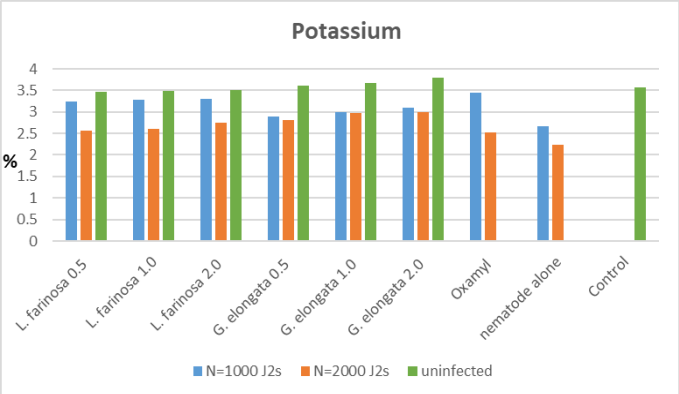

Figure 3: *Percentage of Potassium in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

Percentages of total carbohydrates in tomato leaves infected with *M. incognita* under various treatment conditions is displayed in Figure 4. Compared to the control group, the addition of red algae in uninfected plants had a substantial impact on the amount of carbohydrates. The algae *G. elongata* generally outperformed *L. farinosa*, especially at higher concentrations. Lower percentages of carbohydrates were seen in untreated controls and infected treatments (nematode alone), indicating that algal treatments increased plant metabolic activity even in the presence of nematode stress.

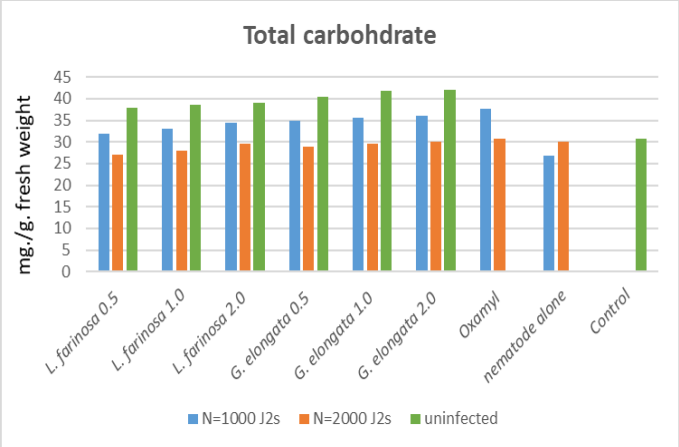

Figure 4: *Total carbohydrates content in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

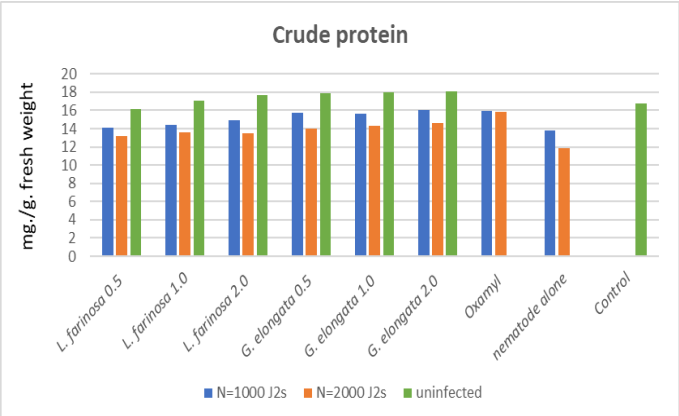

Figure 5: *Crude protein content in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

The crude protein content of tomato leaves, which is closely correlated with nitrogen availability, is displayed in Figure 5. In comparison to nematode-only treatment, the combination of *G. elongata* and *L. farinosa* at different concentrations probably resulted in higher crude protein levels. The effect is likely concentration-dependent, meaning that 2.0% concentration resulted in higher protein levels than 0.5% concentration for both algal species. This implies that treatments with algae improve protein synthesis, which benefits plant resistance and growth.

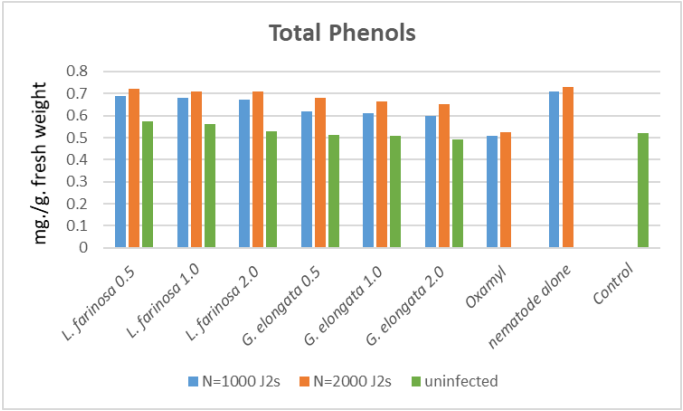

Figure 6: *Total phenols content in tomato leaves infected or un-infected with M. incognita as a result of treatment with two red algae (Liagora farinosa and Galaxaura elongata) and chemical treatment (Oxamyl). Each algal extracts were at concentrations of 0.5%, 1%, and 2%.*

The total phenol content of tomato leaves, which is a measure of the defense and stress response of plants, is depicted in Figure 6. In contrast to the chemical (Oxamyl) and control treatments, the application of *L. farinosa* and *G. elongata* probably raised the levels of total phenols. Since phenols are known to aid in plant defense against infections, a higher phenol concentration in plants treated with algae indicates improved resistance to nematode infection. It was found that the phenol concentration was high in the nematode-only treatment. Phenol levels were lower in the chemical treatment and control group, suggesting less robust stress responses.

Discussion

There is no denying that using chemical nematicides to eradicate plant parasitic nematodes has a negative impact on people, animals, and the environment. As a result, the need for safe, sustainable, and effective alternatives to get rid of this kind of pests has grown. The results of this study showed that applying two red algae at different concentrations resulted in a considerable decrease in the population of the root-

knot nematode *M. incognita* in soil and roots under greenhouse conditions. Even in the presence of nematode infection, *L. farinosa* and *G. elongata* both markedly enhanced tomato plant growth metrics including plant length, fresh weight, dry weight, and flower production. This outcome is supported by research by Kumar *et al.* (2024), which found that seaweed and products produced from it have been used to boost immunity, promote plant development, and lessen biotic and abiotic stressors. Studies on the brown seaweed *Ascophyllum nodosum* have shown that it can improve nutrient uptake, root development, and overall plant vigor in a variety of crops (Khan *et al.*, 2009).

Improved growth metrics in infected plants relative to untreated plants showed that the administration of *L. farinose* and *G. elongate* lessened the detrimental effects of *M. incognita* on tomato plants. This implies that algae might have nematode-suppressive or nematicidal effects. Previous studies have demonstrated that some algal extracts can lessen root galling and prevent nematode multiplication. Sargassum, for example, has been shown in trials to be helpful in reducing nematode populations and enhancing plant health (Rahman *et al.*, 2020). Additionally, Belmouden *et al.* (2025) concluded that the extracts of *Sargassum vulgare* and *Cystoseira humilis* attained the maximum juvenile mortality (83 %) after 72 hours. Also instead of additionally, *S. vulgare* exhibited the highest inhibition of egg hatching (82%). According to phytochemical analysis, *S. vulgare* showed strong nematicidal activity despite lower compound concentrations, whereas *C. humilis* had the highest levels of total phenolics and flavonoids.

As suggested by Ali *et al.* (2019), seaweed extracts may be somewhat effective in reducing PPN fecundity and abundance, mostly in lab and greenhouse environments. Because seaweeds contain special compounds like fucoidans and alginates, which may act as elicitors to prime plants for future pathogen defense, the literature suggests that seaweed extracts may be useful to protect plants against biotic stress, even though the exact mechanism of action for such phenomena is largely unknown. A plant may be better able to protect itself from pests and diseases if its health is improved by using fertilizer to increase nutrition. In this case, using seaweed extracts may frequently help to lengthen the roots and guarantee that the plant has access to more nutrients. Three substances were obtained from the chromatographic fractionation of the chloroform extract of *L. farinosa* collected from the Red Sea: methyl-β-D-xylopyranoside (1), glycerol-2-α-D-glucopyranoside (2), and thymidine (3) (Hammoda *et al.*, 2007).

The red sea algae *G. elongata* is regarded as a source of bioactive chemicals since it may generate a wide range of secondary metabolites with a wide range of biological activity. Red algae contain compounds that have been found to have antimicrobial, antiviral, antifungal, and antioxidant properties (Abdel-Raouf *et al.*, 2017).

It could be logical to speculate that a reduced hatching rate might be the cause of lower adult and J2 abundances, and hence, less obvious galling. The most crucial factor to consider may not be dosage rates but rather application timing, as different dosage rates sometimes appeared to have minimal impact on RKN populations (Williams *et al.*, 2021). Overall, *M. incognita* population reduction was greatest when seaweed was applied. A plant's capability to effectively react to PPN attack through mechanisms like reallocating resources to shoots, producing defensive phytohormones like jasmonic acid, and/or strengthening roots may be partially responsible for this, as may the production or lack of nematode-repelling volatile organic compounds (VOCs) (Da Silva *et al.*, 2019).

Improved nutrient uptake and stress tolerance are suggested by the higher levels of nitrogen, phosphorus, and potassium in plants treated with algae. This outcome is supported by research by Solorzano-Chavez *et al.* (2019), who found that applying *K. alvarezii* extract to rice plants' roots improved their uptake of N and K, which raised the plants' levels of amino N. Increased plant defense mechanisms against nematode infection are indicated by the rise in total phenol content in plants treated with algae. This outcome supports the findings of Lola-Luz *et al.* (2014), who found that adding seaweed extract significantly increased the amount of health-promoting phenolics and flavonoids in broccoli.

Seaweed extracts (SEs) have been investigated as natural biocontrol agents, soil conditioners, and biofertilizers in light of the growing trend toward organic and sustainable farming. They are essential for boosting plant development, soil health, and resistance

to pests, illnesses, and abiotic stresses such drought, salinity, and extremely high or low temperatures (Singh *et al*., 2025).

Conclusion

Indeed, seaweed extracts may be utilized to treat RKN infections, and when compared to alternative approaches they may provide less expensive methods of *Meloidogyne* treatment. Although the exact mechanism is unknown, this raises an intriguing research question. The findings of this study represent promising results for the use of seaweed for purposes other than biostimulants. After more investigation, seaweeds might be utilized in integrated pest management programs on a variety of crops to lessen RKN damage in addition to acting as a soil conditioner. Seaweed is an intriguing option for PPN control since it can be harvested sustainably, is safe to use, and has no known negative environmental effects. This is particularly true in light of the removal of synthetic nematicides from the market of pesticides. Future studies could examine the processes via which of these algae work, improve application techniques and assess how well they work with other crops and in the field.

Novelty Statement

The novelty of this work lies in domenstrating the use of extract from the red algae Liagora farinosa and Galaxaura elongata as a sustinable tool for Meloidogyne incognita management in tomato cultivation

Funding
No fund was received for this study.

Ethical approval
None-applicable

Author's Contribution

Conceptualization:E-DMM,A-BSH,.Methodology: E-DMM, A-BSH, and HSE. Reviewing: E-DMM, A-BSH, and HSE. Statistical analysis: E-DMM, AE-ADA and HSE. Editing and writing original draft: E-DMM, A-BSH, AE-AD and HSE.

Generative AI and AI-assisted technology statement
he author(s) declare that no Generative AI was used in the creation of this manuscript

Conflict of interest
There authors have declared no conflict of interest.

References

Abdel-Raouf, N., Al-Enazi, N.M. and Ibraheem, I.B., 2017. Green biosynthesis of gold nanoparticles using *Galaxaura elongata* and characterization of their antibacterial activity. Arabian J. Chem., 10: S3029-S3039. https://doi.org/10.1016/j.arabjc.2013.11.044

Agrilasa, 2002. AGRI Laboratory Association of Southern Africa. In: Handbook on Feeds and Plant Analyses. Pretoria, South Africa: AGRILASA.

Ali, O., Ramsubhag, A. and Jayaraman, J., 2019. Biostimulatory activities of *Ascophyllum nodosum* extract in tomato and sweet pepper crops in a tropical environment. PLoS One, 14: 1–19. https://doi.org/10.1371/journal.pone.0216710

Álvarez-Ortega, S., Brito, J.A. and Subbotin, S.A., 2019. Multigene phylogeny of root-knot nematodes and molecular characterization of *Meloidogyne nataliei* Golden, Rose and Bird, 1981 (Nematoda: Tylenchida). Sci. Rep., 9(1): 11788. https://doi.org/10.1038/s41598-019-48195-0

Belmouden, M., Bouftini, K., Braimi, A., El-Aissaoui, B., Bourassen, M., Sabir, I. and Rchid, H., 2025. Moroccan brown algae as a source of bionematicidal against root-knot nematode (*Meloidogyne* spp.). J. Natl. Pestic. Res., 100135 https://doi.org/10.1016/j.napere.2025.100135.

Borgesen, F. and Fremy P., 1936. Marine algae from the Canary Islands especially from teneriffre and gran. Canaria: I-Chlorophyceae, II Phaeophyceae, 111- Rhodophyceae, 1V-Cyanophyceae. Det. Kg I. Denske Videnskabernes.

Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analyt. Biochem., 72(1-2): 248-254. https://doi.org/10.1016/0003-2697(76)90527-3

Chaudhary, P., Sharma, A., Singh, B. and Nagpal, A.K., 2018. Bioactivities of phytochemicals present in tomato. J. Food Sci. Technol., 55(8): 2833-2849. https://doi.org/10.1007/s13197-018-3221-z

Cook, J., Zhang, J., Norrie, J., Blal, B. and Cheng, Z.,

2018. Seaweed extract (Stella Maris®) activates innate immune responses in *Arabidopsis thaliana* and protects host against bacterial pathogens. Mar. Drugs, 16(7): 221. https://doi.org/10.3390/md16070221

Costa, J.M. and Heuvelink, E.J.T.B., 2018. The global tomato industry. In: Tomatoes. Wallingford UK: CABI. pp. 1-26. https://doi.org/10.1079/9781780641935.0001

Da Silva, J.C.P., Campos, V.P., Barros, A.F., Pedroso, L.A., de Freitas Silva, M., de Souza, J.T. and de Medeiros, F.H.V., 2019. Performance of volatiles emitted from different plant species against juveniles and eggs of *Meloidogyne incognita*. Crop Prot., 116: 196-203. https://doi.org/10.1016/j.cropro.2018.11.006

Duncan, D.B., 1955. Multiple range and multiple F tests. Biometrics, 11(1): 1-42. https://doi.org/10.2307/3001478

Elling, A.A., 2013. Major emerging problems with minor *Meloidogyne* species. Phytopathology, 103(11): 1092-1102. https://doi.org/10.1094/PHYTO-01-13-0019-RVW

FAO, 2023. FAOSTAT Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL.

Ghareeb, R.Y., Adss, I.A., Bayoumi, S.R. and El-Habashy, D.E., 2019. The nematicidal potentiality of some algal extracts and their role in enhancement the tomato defense genes against root knot-nematodes. Egypt. J. Biol. Pest Contr., 29(1): 53. https://doi.org/10.1186/s41938-019-0153-5

Gomez, K.A. and Gomez, A.A., 1984. Statistical procedures for agricultural research. John wiley and sons.

Goodey, J.B., 1957. Laboratory methods for work with plant and soil nematodes.

Górecka, D., Wawrzyniak, A., Jędrusek-Golińska, A., Dziedzic, K., Hamułka, J., Kowalczewski, P.Ł. and Walkowiak, J., 2020. Lycopene in tomatoes and tomato products. Open Chem., 18(1): 752-756. https://doi.org/10.1515/chem-2020-0050

Hammoda, H.M., Badr, J.M. and Youssef, D.T., 2007. Three antioxidant compounds of the red alga *Liagora farinosa*. Nat. Prod. Sci., 13(2): 140-143.

Haydock, P.P., Woods, S.R., Grove, I.G. and Hare, M.C., 2006. Chemical control of nematodes. In: Plant nematology. Wallingford UK: CABI. pp. 392-410. https://doi.org/10.1079/9781845930561.0392

Hussey, R.S. and K.R. Barker., 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp. including a new technique. Plant Dis. Rep., 57: 1925-1928.

Je, H., 1962. Determination of reducing sugars and carbohydrates. Methods Carbohyd. Chem., 1: 380-394.

Jones, J.T., Haegeman, A., Danchin, E.G., Gaur, H.S., Helder, J., Jones, M.G. and Perry, R.N., 2013. Top 10 plant-parasitic nematodes in molecular plant pathology. Mol. Plant Pathol., 14(9): 946-961. https://doi.org/10.1111/mpp.12057

Khan, W., Rayirath, U.P., Subramanian, S., Jithesh, M.N., Rayorath, P., Hodges, D.M. and Prithiviraj, B., 2009. Seaweed extracts as biostimulants of plant growth and development. J. Plant Growth Regul., 28(4): 386-399. https://doi.org/10.1007/s00344-009-9103-x

Kumar, G., Nanda, S., Singh, S.K., Kumar, S., Singh, D., Singh, B.N. and Mukherjee, A., 2024. Seaweed extracts: Enhancing plant resilience to biotic and abiotic stresses. Front. Mar. Sci., 11: 1457500. https://doi.org/10.3389/fmars.2024.1457500

Lola-Luz, T., Hennequart, F. and Gaffney, M., 2014. Effect on yield, total phenolic, total flavonoid and total isothiocyanate content of two broccoli cultivars (*Brassica oleraceae var italica*) following the application of a commercial brown seaweed extract (*Ascophyllum nodosum*). Agric. Food Sci., 23(1): 28-37. https://doi.org/10.23986/afsci.8832

Manilal, A., Sujith, S., Kiran, G.S., Selvin, J., Shakir, C., Gandhimathi, R. and Panikkar, M.V.N., 2009. Biopotentials of seaweeds collected from southwest coast of India. J. Mar. Sci. Technol., 17(1): 10. https://doi.org/10.51400/2709-6998.1979

Mayer, A.M. and Hamann, M.T., 2005. Marine pharmacology in 2001–2002: Marine compounds with anthelmintic, antibacterial, anticoagulant, antidiabetic, antifungal, anti-inflammatory, antimalarial, antiplatelet, antiprotozoal, antituberculosis, and antiviral activities; affecting the cardiovascular, immune and nervous systems and other miscellaneous mechanisms of action. Compar. Biochem. Physiol. C: Toxicol. Pharmacol., 140(3-4): 265-

286. https://doi.org/10.1016/j.cca.2005.04.004

Mertens, D., 2005a. AOAC official method 922.02. Plants preparation of laboratory sample. Official Methods of Analysis, 18th ed. Gaitherburg, Maryland: AOAC.

Mertens, D., 2005b. AOAC Official method 975.03. Metal in plants and pet foods. Official Methods of Analysis, 18th ed. Gaitherburg, Maryland: AOAC.

Nour El-Deen, A. and Issa, A., 2016. Nematicidal properties of some algal aqueous extracts against root-knot nematode, *Meloidogyne incognita in vitro*. Egypt. J. Agronematol., 15(1): 67-78. https://doi.org/10.21608/ejaj.2016.57484

Olsson, J., Toth, G.B. and Albers, E., 2020. Biochemical composition of red, green and brown seaweeds on the Swedish west coast. J. Appl. Phycol., 32(5): 3305-3317. https://doi.org/10.1007/s10811-020-02145-w

Papenfuss, G.F., 1968. A history, Catalogue and bibliography of Red Sea Benthic Algae. Israel J. Bot., 17: 1-118.

Peiris, P.U.S., Li, Y., Brown, P. and Xu, C., 2020. Fungal biocontrol against *Meloidogyne* spp. in agricultural crops: A systematic review and meta-analysis. Biol. Contr., 144: 104235. https://doi.org/10.1016/j.biocontrol.2020.104235

Rahman, A.F.S.H.A.N., Noreen, R.U.B.I.N.A., Shafique, H.A., Shah, H. and Ara, J., 2020. Evaluation of systemic defense responses in soybean induced by *Sargassum ilicifolium* and endophytic *Pseudomonas aeruginosa* against root knot nematode. Int. J. Biol. Res., 8(1): 11-20.

Santaniello, A., Scartazza, A., Gresta, F., Loreti, E., Biasone, A., Di Tommaso, D. and Perata, P., 2017. *Ascophyllum nodosum* seaweed extract alleviates drought stress in Arabidopsis by affecting photosynthetic performance and related gene expression. Front. Plant Sci., 8: 1362. https://doi.org/10.3389/fpls.2017.01362

Simons, T.S. and Ross, A.F., 1971. Changes in phenol metabolism associated with induced systemic resistance. Phytopathology, 61(10): 1261-1265. https://doi.org/10.1094/Phyto-61-1261

Singh, A., Sharma, K., Chahal, H.S., Kaur, H. and Hasanain, M., 2025. Seaweed-derived plant boosters: revolutionizing sustainable farming and soil health. Front. Soil Sci., 5: 1504045. https://doi.org/10.3389/fsoil.2025.1504045

Solorzano-Chavez, E.G., Paz-Cedeno, F.R., de Oliveira, L.E., Gelli, V.C., Monti, R., de Oliveira, S.C. and Masarin, F., 2019. Evaluation of the *Kappaphycus alvarezii* growth under different environmental conditions and efficiency of the enzymatic hydrolysis of the residue generated in the carrageenan processing. Biomass Bioenergy, 127: 105254. https://doi.org/10.1016/j.biombioe.2019.105254

Taylor, A.L. and Sasser, J.N., 1978. Biology, identification and control of root-knot Nematodes (*Meloidogyne* spp.) Coop. Pub. Dept. Plant Pathol., North Carolina State Univ. and U.S. Agency Int. Dev. Raleigh, N.C. 111 pp.

Thomas, D., 2002. Seaweeds in the life series. The natural History Museum, London. ISBN0565091751.

Vera, J., Castro, J., Gonzalez, A. and Moenne, A., 2011. Seaweed polysaccharides and derived oligosaccharides stimulate defense responses and protection against pathogens in plants. Mar. drugs, 9(12): 2514-2525. https://doi.org/10.3390/md9122514

Waisen, P., Cheng, Z., Sipes, B. S., DeFrank, J., Marahatta, S.P. and Wang, K.H., 2020. Effects of biofumigant crop termination methods on suppression of plant-parasitic nematodes. Appl. Soil Ecol., 154: 103595. https://doi.org/10.1016/j.apsoil.2020.103595

Williams, T.I., Edgington, S., Owen, A. and Gange, A.C., 2021. Evaluating the use of seaweed extracts against root knot nematodes: A meta-analytic approach. Appl. Soil Ecol., 168: 104170 https://doi.org/10.1016/j.apsoil.2021.104170.

Yong, K.T., Yong, P.H. and Ng, Z.X., 2023. Tomato and human health: A perspective from post-harvest processing, nutrient bio-accessibility, and pharmacological interaction. Food Front., 4(4): 1702-1719. https://doi.org/10.1002/fft2.299