RESEARCH

Fabrication and characterization of novel biocomposite based on *Sargassum vulgare* for controlling sugar beet root diseases

Noha Abdelwahab[1], Walaa Rabie[2] and Fatma Mohamed[3,4*]

Abstract

Background Safe food free from diseases is the world's goal. Excessive usage of chemical fungicides is considered the most important danger for the climate. Natural alternatives with low costs have become the best choice for sustainable agriculture.

Results In the context of researching green materials instead of chemical fungicides, the fabrication of nano-*Sargassum vulgare* and its composite with zeolite was carried out. Followed by an investigation of the efficiency of their extracts on controlling sugar beet root rot diseases caused by soil-borne pathogens *Rhizoctonia solani* (*R. solani*), *Sclerotium rolfsii* (*S. rolfsii*), and *Fusarium oxysporum* (*F. oxysporium*) throughout two successive seasons (2020/2021 and 2021/2022) under greenhouse conditions. The structure and morphology of nanosargassum and its biocomposite were characterized by FTIR, SEM, EDX, Zeta potential, and size particles. The morphological structure of biocomposite was changed from tubularly structured into layers stacked on top of each other after impregnation of zeolite into *S. vulgare,* and its size was reduced from 85 to 50 nm, which was confirmed through size particle distribution. The biocomposite was the most effective one in managing root rot disease caused by *R. solani*. It reduces disease severity (DS) and disease incidence (DI) with efficacy (91.08% and 88.89%), respectively, compared to that recorded by commercial fungicides (63.09% and 61.81%). In the same manner, the composite extract recorded the highest efficiency percentage in controlling the disease caused by *S. rolfsii* (76.04 and 55.27e was carried out. followed by an investigation of the efficiency of their extracts on controlling sugar beet root rot diseases caused by soil-borne pathogens Rhizoctonia solani (R. solani), Sclerotium rolfsii (S. rolfsii), and Fusarium oxysporum (F. oxysporium) throughout two successive seasons (2020/2021 and 2021/2022) under greenhouse conditions. The structure and morphology of nanosargassum and its biocomposite were characterized by FTIR, SEM, EDX, Zeta potential, and size particles. The morphological structure of biocomposite was changed from tubularly structured into layers stacked on top of each other after impregnation of zeolite into S. vulgare, and its size was reduced from 85 to 50 nm, which was confirmed through size particle distribution. The biocomposite was the most effective one in managing root rot disease caused by R. solani. It reduces disease severity (DS) and disease incidence (DI) with efficacy (91.08% and 88.89%), respectively, compared to that recorded by commercial fungicides (63.09% and 61.81%). In the same manner, the composite extract recorded the highest efficiency percentage in controlling the disease caused by S. rolfsii (76.04 and 55.27%), respectively, compared to fungicide (67.74 and 36.92%). All applied treatments considerably reduced DS and DI caused by *F. oxysporum*. At the same time, growth characteristics, sucrose, and TSS percentages of the root juice significantly improved when the seeds were treated with the biocomposite extract.

*Correspondence:
Fatma Mohamed
f_chem2010@yahoo.com
Full list of author information is available at the end of the article

Conclusion The newly fabricated structure of biocomposite facilitates the movement of macronutrients from the soil into the seed, which in turn improves growth characteristics and the sucrose yield quality in root juice, which is one of the most essential characters to advance the sugar industry. Therefore, the biocomposite is recommended to be a biofungicide and biofertilizer.

Keywords *Sargassum vulgare*, Zeolite, Layered bio composite, Root rot disease

Graphical Abstract
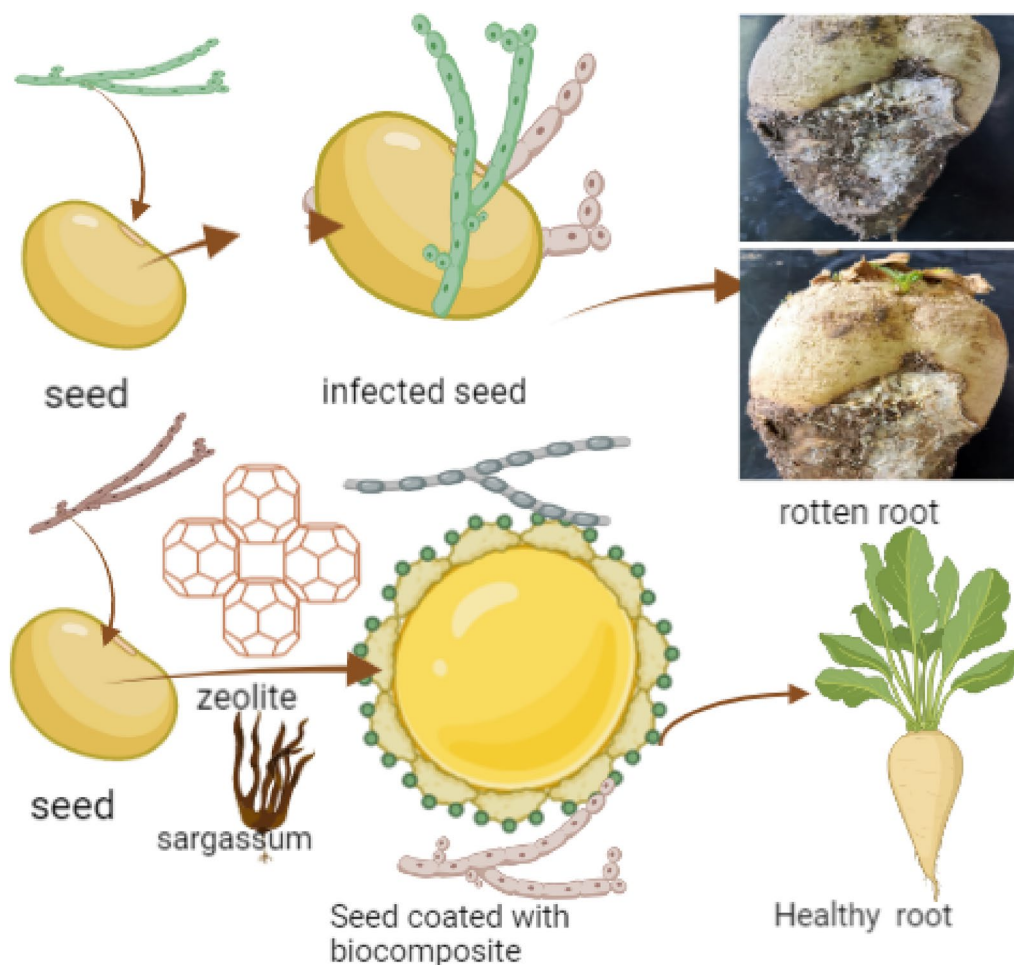
Introduction

Sugar beet (*Beta vulgaris L.*) is the main source of sugar in the temperate zones, providing approximately 30% of the world's annual sugar production [1]. Sugar beet is an indispensable and crucial sugar crop in Egypt; its area increases annually (to reach 234849.27 hectar) to bridge the nutritional gap. Egypt occupies seventh place globally in the productivity of sugar from sugar beet, producing 11.704 million tonnes during 2019 (FAO, 2020). Improving the productivity of the sugar beet crop and its sugar juice quality is one of the priorities of the Egyptian state's economic agenda.

Sugar beet root rot diseases lead to significant reductions in root yield as well as sucrose percentage and juice purity [2, 3]. In Egypt, the most destructive root rot pathogens are *S. rolfsii, F. oxysporum,* and *R. solani. Fusarium* root rot disease, caused by *F. oxysporum* f. sp. radicis-betae, causes significant quantitative and qualitative yield losses due to reduced plant population, poor growth of plants, and increased impurities in the extracted juice [4,

5]. *R. solani Kühn, a* soil-borne pathogen, dramatically affects sugar beet stands and yields, causing root and crown rot. Rhizoctonia root rot starts at or just below the soil line and sometimes lower on the tap root [6]. *S. rolfsii* appeared as the most destructive soil-borne pathogen, causing up to 50%–80% losses in crop yield and quality [7–9].

Management of root rot diseases caused by soil-borne pathogens is the most difficult aspect because of the wide host range and presence of resistant survival structures, which frequently survive for a long period in soil. Using chemical fungicides for controlling such pathogens was the predominant method [10, 11]. But on the other side, the application of such chemical fungicides, as well as chemical fertilisers, causes environmental pollution, the emergence of resistant pathogens, and different health hazards to humans and other living organisms [12]. Environmental pollution is considered the most important cause of climate change, which is one of the most important recent challenges. Therefore, finding natural alternatives that are safe and eco-friendly has become an urgent need [13]. The recent trend is to use algae, seaweeds, and natural clay as sources of eco-friendly bioactive compounds for controlling plant pathogens [14]. Seaweeds are considered a reservoir of bioactive compounds such as terpenoids, polyphenols, and lipophilic polysaccharides with several biological activities [15]. Crude extracts of seaweeds exhibit various biological activities such as biostimulant, fertiliser, and antimicrobial properties. Aqueous extract is considered to be the most cost-effective, safe, and eco-friendly one for releasing micro- and macro-elements from biomass [16]. Thus, an improvement in germination parameters was detected after treatment with an aqueous extract of *Sargassum sp.,* which qualifies it to be a promising biofertilizer [17].

Recently, it has shed light on the potential of nanofertilizers compared to other traditional ones. It was shown that they have a role in reducing environmental pollution, achieving sustainable agriculture, and ensuring a favourable environment for microorganisms, in addition to their ability to improve crop yields, decrease production costs per unit area, and facilitate storage [18]. Moreover, the usage of natural clays such as zeolite in different agricultural applications is attracting new research interest. Natural zeolites represent a broad range of microporous, crystalline aluminosilicates, inert, and nontoxic spongy minerals with physical and physicochemical properties that enable them to be used in various fields, such as agriculture [19].

Aluminium-rich zeolites are often used as desiccants. Moreover, the application of zeolite against soil-borne pathogens is considered a new disease management strategy [20]. Zeolites are described as natural carriers that have a molecular sieve action due to their open channel network [21].

All previous findings emphasized the importance of using zeolite in agricultural applications due to its ability to act as a barrier against various pathogens and a carrier of various fertilisers, with a focus on environmental safety to ensure sustainable agriculture.

Our work aims to fabricate and characterise a novel biocomposite consisting of *S. vulgare* in nanosized and zeolite forms and investigate its potency in controlling sugar beet root rot diseases, as well as improve its growth characteristics and yield quality under greenhouse conditions.

Methodology
Preparation of the tested bioagents
S. vulgare was kindly supported by the National Institute of Oceanography and Fisheries
A natural zeolite sample was delivered from a zeolite mine in the Al-Ahyuq area southwest of Taiz city, Republic of Yemen.

Nanosargassum and biocomposite
Using a PQ-N2 planetary mill (Across International Supplies Lab Equipment, USA) and agate balls (each 6 mm in diameter and 180 g, with a nanosargassum to ball mass ratio of 1:10), the ball-milled nanosargassum was created. The ball-milling machine operated in the air for 6 h at a speed of 600 rpm. Based on the ideal conditions described in the literature, these synthesis conditions were chosen [22].

Additionally, for preparing the biocomposite, equal amounts of zeolite and nanosargassum were ground in a mortar and then dissolved using an ultrasonic cleaner in 50 ml of distilled water for four hours. After filtering the biocomposite and repeatedly washing it with methanol and water (1:2), we finally dried the final product for an entire night at 60 °C.

Pathogens
Three root rot pathogens; *Fusarium oxysporum f.sp. radicis-betae*, *Rhizoctonia solani* and *Sclerotium rolfsii* that cause severe diseases of sugar beet plants were obtained from Maize and Sugar Crops Diseases Department, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt. The fungal isolates were transferred to potato dextrose agar (PDA) medium for further study.

Inoculum preparation
Five mm agar mycelia discs from a 7-day-old culture of each pathogen were inoculated in sterilised 500-ml glass bottles containing 150 g of sorghum seeds and incubated at room temperature (27.5 °C) for 15 days until sufficient

Abdelwahab *et al. Chem. Biol. Technol. Agric.*   (2023) 10:52

Page 4 of 13

growth of the fungus was captured. Thereafter, the contents of the bottles of each fungus were poured out and mixed separately to get homogenized inoculum. Soil infestation was carried out by adding fungal inoculum to sterilised potted soil at a rate of 2.5% (w/w). Pots (No. 40) were then moistened with tap water for 5 days before planting to permit the pathogens to establish themselves [23].

Preparation the aqueous extract of different treatments
100 g of different treatments (*S. vulgare*, nanosargassum, and biocomposite) were added to 1 L of distilled water and then shaken for 15 min, followed by autoclaving at 121 °C for 1 h at 1.21 kg/cm2. The resultant hot extracts were filtered through Whatman No. 40 filter paper. The filtrates (extracts) were designed as stock solutions to investigate their potency in controlling sugar beet root rot diseases [24]

Greenhouse experiment
The experiments were carried out under greenhouse conditions for the growing seasons 2020–2021 and 2021–2022 at Sids Agricultural Research Station, Beni-Suef Governorate, Egypt.

Seeds of the sugar beet cultivar Toro cv. were chosen for all experiments according to their susceptibility to soil-borne fungal pathogens. Prior to use, seeds were first rinsed with tap water, surface sterilised with 5% sodium hypochlorite, and rinsed three times with sterile distilled water. After that, seeds were coated with the extracts of different treatments, i.e., *Sargassum vulgare*, nanosargassum, and biocomposite, by addition of Tween 20 (0.5 ml per 100 ml) for 8 h. Seeds rinsed in distilled water acted as a control. On the other hand, seeds are also coated with the commercial fungicide Metalaxyl M and fludixonil (1 cm/kg). Then, the seeds were planted in pots under greenhouse conditions; ten seeds per pot and three replicates were used for each treatment.

Disease assessments
After 150 days of planting, Disease severity (DS) and Disease incidence (DI) were measured on all sugar beet plants for each replicate. Root rot severity was scored according to [25] with the following rating scale:

0: Healthy sugar beet plant.

1: No internal browning, with superficial lesions (<25%).

2: Slight internal browning (25–50%) surface covered with cankers,

3: Moderate internal browning (50–75%) cankers,

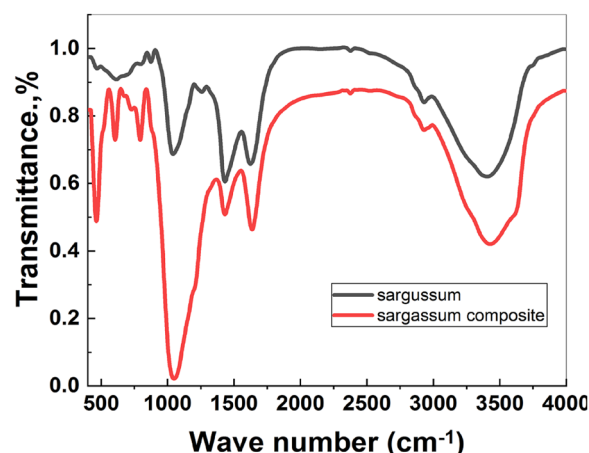4: Severe internal and external (>75%) browning.

Fig. 1 FTIR of nanosargassum and its bio composite with zeolite

$$\text{Disease severity} = \text{Sum}\left(n \times r^0\right) + \left(n \times r^1\right) + \ldots + \left(n \times r^4\right)/4\,N \times 100$$

Where, n is No. of plants in each numerical rate (r0.... r4) and N is the total No. of plants multiplied by the maximum numerical rate r4.

The disease incidence and efficacy were calculated as following:

$$\text{Disease Incidence (DI) \%} = \text{No. of infected plants} / \text{Total No. of plants} \times 100$$

$$\text{Efficacy\%} = (\text{Control} - \text{Treatment}/\text{Control}) \times 100$$

Determination of the growth characters& yield quality
After 150 days, sugar beet plants were collected and the following parameters were measured: Total weight of plant (g)/plant, root weight (g)/plant, root length (cm)/plant, and root diameter (cm)/plant, according to [26]. The determination of sucrose percentage and total soluble solids (TSS) was done according to [7]

Statistical analysis
Data were analyzed statistically using Package for the Social Sciences (SPSS) software for Windows version 25.0. All comparisons were first subjected to one-way analysis of variance (ANOVA) test and the least significant difference (LSD) was calculated at $p = 0.05$. The significant differences among treatments means were determined with Duncan's Multiple Range test at $P \leq 0.05$ [27].
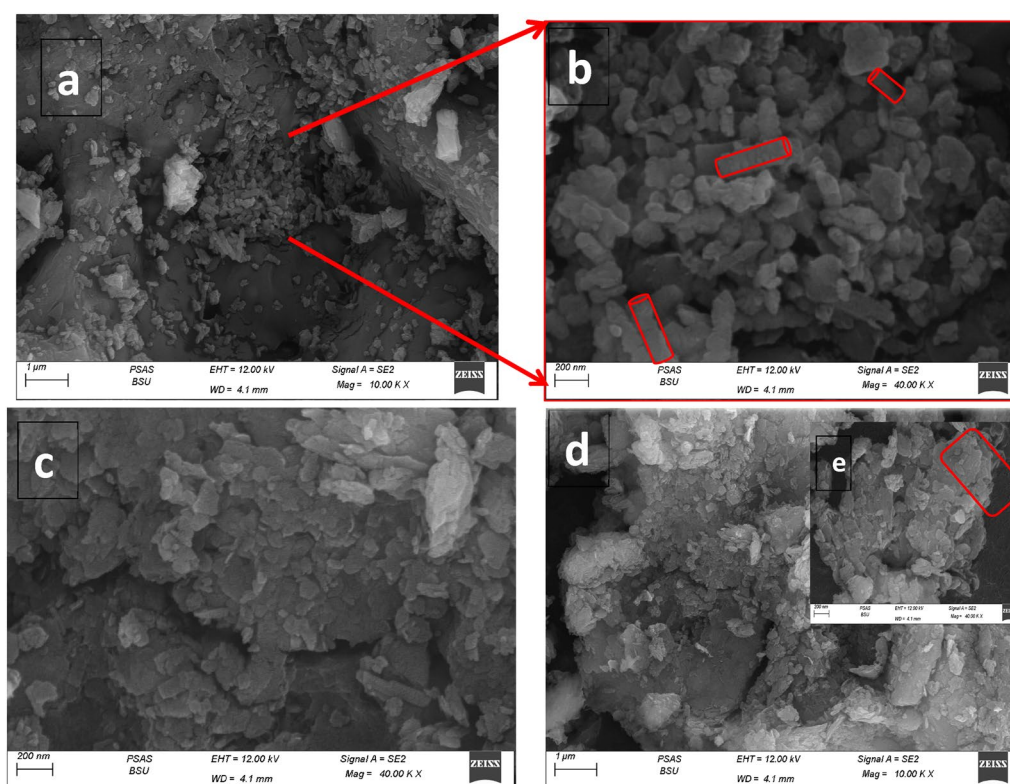
Abdelwahab *et al. Chem. Biol. Technol. Agric.*   (2023) 10:52

Page 5 of 13

Fig.2 a, **b** SEM of nanosargassum, **c**, **d**, **e** SEM of biocomposite

Results and discussion

Characterization of biocatalyst

Functional group determining tool

Infrared absorption spectroscopy is used to characterise functional groups on the surface of biocatalysts, and the resulting spectra are shown in Fig. 1. The FT-IR spectrum of nanosargassum reveals an absorption peak at 3404 cm1, which corresponds to the amine group (-NH) stretching and the hydroxyl group (-OH) of phenolic groups [28]. While the band appearing at 2935 cm1 was related to the alkyl (CH) group stretching mode, the absorption band shown at 1620 cm1 is ascribed to O–H vibration. In addition to the strong peak appearing at 1420 cm1, this is owing to the C-H mode. The band is around 1040 cm1 and was possibly caused by C-O stretching vibrations [29].

After incorporation of zeolite into the nanosargassum matrix, there are mixed bands between nanosargassum and zeolite, and a red shift appears at 3426 cm1, which corresponds to the hydroxyl group (-OH) of phenolic groups. The band at 2929 cm1 that was thought to be the stretching vibration of CH_2 groups proved the strong connection between algal function groups and active molecules of zeolite [30]. The absorption bands of the composite were seen at approximately 1000–1660

cm1, and zeolite significantly boosted the intensities of the nanosargassum characteristic peaks. The development of the novel biocomposite is confirmed because both the band shift and band disappearance are consistent with information gained using other characterization techniques.

SEM–EDS analyses

The surface morphology of nanosargassum and biocomposite was examined using scanning electron microscopy (SEM) coupled with EDS as represented in Fig. 2. The percentage of surface elements in nanosargassum is in the range of 38–40% for C, 40–43% for O, and about 4.74% for Ca and traces of As and Na and Mg elements, making it a promising carbon-rich matrix. Nanosargassum has an interconnected tubular-shaped structure with no pores or cavities. Its surface morphology appears as agglomerated homogenous particles in a tubular structure. Their average size is 85 nm which is shown in Fig. 2 a, b. While SEM of the nanosargassum/zeolite biocomposite confirmed that zeolite was impregnated as filler into the nanosargassum matrix, the surface morphology of the biocomposite appears as a layered shape due to the addition of zeolite and their size particles were
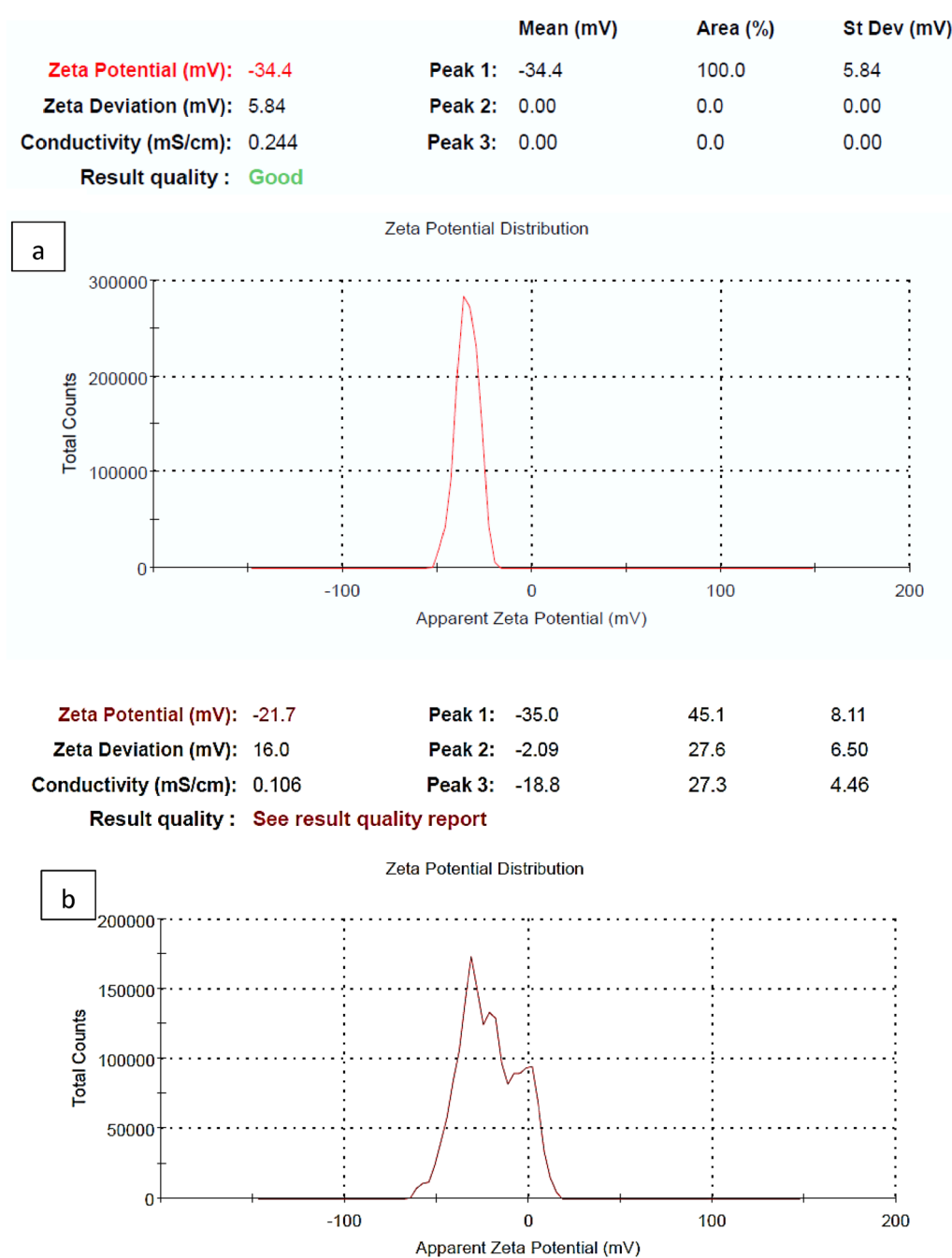
	Mean (mV)	Area (%)	St Dev (mV)
Zeta Potential (mV): -34.4	Peak 1: -34.4	100.0	5.84
Zeta Deviation (mV): 5.84	Peak 2: 0.00	0.0	0.00
Conductivity (mS/cm): 0.244	Peak 3: 0.00	0.0	0.00
Result quality : Good			

a

Zeta Potential Distribution

Zeta Potential (mV): -21.7	Peak 1: -35.0	45.1	8.11
Zeta Deviation (mV): 16.0	Peak 2: -2.09	27.6	6.50
Conductivity (mS/cm): 0.106	Peak 3: -18.8	27.3	4.46
Result quality : See result quality report			

b

Zeta Potential Distribution

Fig. 3 zeta potential of nanosargassum(**a**) biocomposite(**b**)

reduced to be 50 nm which was represented at Fig. 2c, d [31]. The layers stacked each other on the nanosargassum surface, which was observed in Fig. 2e. The hierarchically structured biocomposite surface area, which in turn facilitates the transfer and diffusion of macromolecules into the plant matrix,

The EDS analysis of the sargassum/zeolite biocomposite was as follows: 60.5 wt% O, 10% C, 5% Al, 17.6 wt% Si, 1.05 wt% Mg, 1.3 wt% K, and trace metals. We noticed that the percentage of Al and Si content increased as a result of the good incorporation of zeolite.

The zeta potential of the algal surface is an important parameter because it influences the interaction
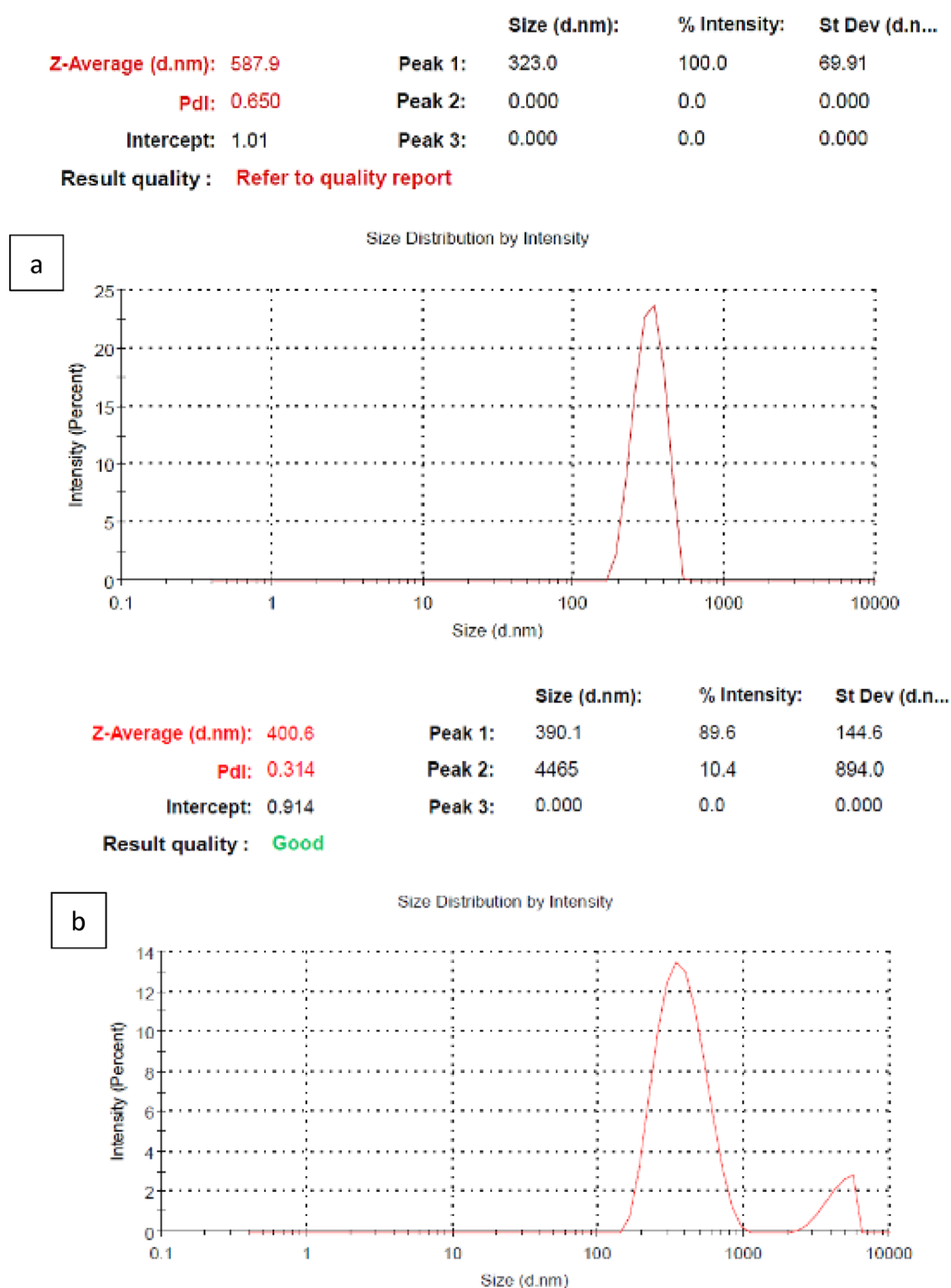
	Size (d.nm):	% Intensity:	St Dev (d.n...
Z-Average (d.nm): 587.9	**Peak 1:** 323.0	100.0	69.91
PdI: 0.650	**Peak 2:** 0.000	0.0	0.000
Intercept: 1.01	**Peak 3:** 0.000	0.0	0.000
Result quality : Refer to quality report			

	Size (d.nm):	% Intensity:	St Dev (d.n...
Z-Average (d.nm): 400.6	**Peak 1:** 390.1	89.6	144.6
PdI: 0.314	**Peak 2:** 4465	10.4	894.0
Intercept: 0.914	**Peak 3:** 0.000	0.0	0.000
Result quality : Good			

Fig.4 size particle distribution of nanosargassum (**a**) and biocomposite (**b**)

between the algal cells and gas bubbles during attachment. Figure 3 depicts the surface charge of suspended materials in water in a neutral medium. It was found that zeta potential is related to the synthesis methods of materials and the zeolite content in these materials. The nanosargassum has a negatively charged surface at -34.4 mV in neutral medium, as represented in Fig. 3 a. Generally, the negative zeta potential of the microalgal cell is caused primarily by dissociated carboxylic groups at the cell surface. [32]. A zeta potential that is highly negative indicates that the algal cells are stably dispersed in the surrounding medium. Moreover, this

Abdelwahab *et al. Chem. Biol. Technol. Agric.*   (2023) 10:52

Page 8 of 13

Table 1 Evaluation of *S. vulgare*, nanosargassum and biocomposite extract potency on controlling root rot disease caused by *R. solani* under greenhouse condition

Treatment	Disease severity			Eff%	Disease incidence			Eff%
	1st	2nd	Mean		1st	2nd	Mean	
S. vulgare	11.11	12.50	11.8 ± 4.08^{b}	70.82	22.22	66.67	44.44 ± 18.59^{ab}	44.45
Nanosargassum	8.33	8.33	8.33 ± 5.27^{b}	79.40	16.67	33.33	25 ± 17.08^{b}	68.75
Biocomposite	7.22	0.00	3.61 ± 2.73^{b}	91.08	17.78	0.00	8.89 ± 5.88^{b}	88.89
Fungicide	17.36	12.50	14.93 ± 6.1^{b}	63.09	44.44	16.67	30.56 ± 10.02^{b}	61.8
Control	40.63	40.28	40.45 ± 3.09^{a}		76.67	83.33	80 ± 7.64^{a}	

* Means ± standard deviation within a column followed by different letter(s) in the column are significantly different according to Duncan's multiple range test at $p < 0.05$. Values are mean of three replicates for each treatment as well as the control

Table 2 Evaluation of *S. vulgare*, nanosargassum and biocomposite extracts potency on controlling root rot disease caused by **S. rolfsii** under greenhouse condition

Treatment	Disease severity			Eff%	Disease incidence			Eff%
	1st	2nd	Mean		1st	2nd	Mean	
S. vulgare	40.97	45.83	43.4 ± 4.58^{b}	52.00	55.55	66.67	61.11 ± 8.24^{b}	36.92
Nanosargassum	47.22	34.70	40.96 ± 8.77^{b}	54.70	69.44	72.22	70.83 ± 6.72^{ab}	26.89
Biocomposite	21.11	22.22	21.67 ± 7.2^{c}	76.04	31.11	55.55	43.33 ± 16.22^{b}	55.27
Fungicide	25.00	33.33	29.17 ± 7.68^{bc}	67.74	38.89	83.33	61.11 ± 15.32^{b}	36.92
Control	93.33	87.50	90.42 ± 4.58^{a}		93.75	100.00	96.88 ± 3.13^{a}	

* Means ± standard deviation within a column followed by different letter(s) in the column are significantly different according to Duncan's multiple range test at p < 0.05. Values are mean of three replicates for each treatment as well as the control

Table 3 Evaluation of *S. vulgare*, nano*sargassum* and biocomposite extracts potency on controlling root rot disease caused by *F. oxysporum* under greenhouse condition

Treatment	Disease severity			Eff%	Disease incidence			Eff%
	1st	2nd	Mean		1st	2nd	Mean	
S. vulgare	0.00	4.17	2.08 ± 1.08^{b}	94.99	0.00	16.67	8.33 ± 8.33^{b}	90.30
Nanosargassum	2.77	16.67	9.72 ± 5.96^{b}	76.62	7.41	55.55	31.48 ± 17.31^{b}	63.36
Biocomposite	7.23	4.17	5.70 ± 2.00^{b}	86.29	24.78	16.67	20.72 ± 8.17^{b}	75.88
Fungicide	10.42	5.55	7.99 ± 3.66^{b}	80.79	19.44	11.11	15.28 ± 6.94^{b}	82.22
Control	33.13	50.00	41.57 ± 6.82^{a}		71.82	100.00	85.91 ± 7.19^{a}	

* Means ± standard deviation within a column followed by different letter(s) in the column are significantly different according to Duncan's multiple range test at $p < 0.05$. Values are mean of three replicates for each treatment as well as the control

negative value was due to deprotonation of surface functional groups that caused anionic characteristics in the algal cell wall (carboxylic, phosphoric, phosphodiester, hydroxyl, and amine), and the microalgae cell also produces large amounts of protein and sugar in or out of the cell membrane, which can enhance the surface electronegativity [33].

The addition of zeolite induced a lowering of the negative surface charge to -21 mV at neutral medium, as observed in Fig. 3b. This behaviour was attributed to the coverage of zeolite on the nanosargassum surface.

Also, the value of the conductivity was evaluated to be 0.24 and 0.106 mS/cm for nanosargassum and its composite with zeolite, respectively. The resultant values confirmed their noticeable stability without aggregation [34].

The incorporation of zeolite inside the nanosargassum matrix decreases significantly the particle size of the composite, which was observed through particle size distributions owing to the porous layered structure and formation of bimodal size, resulting in a smaller

Abdelwahab *et al. Chem. Biol. Technol. Agric.* (2023) 10:52

Page 9 of 13

particle size of the composite at Fig. 4a, b, which was consistent with the results of SEM [35, 36].

Disease severity and incidence

Evaluating the efficacy of *sargassum*, nanosargassum, and biocomposite as seed treatments of sugar beet seeds against root rot disease incidence was carried out in the greenhouse during seasons 2020–2021, and 2021–2022.

Data presented in Table 1 showed that biocomposite extract treatment was the most effective one used in controlling root rot disease caused by *R. solani and* hence recorded a remarkable decrease in DS and DI in both seasons, revealing the highest efficacy (91.08% and 88.89%) compared to efficacy recorded by commercial fungicide (64.09% and 61.81%, respectively). Furthermore, biocomposite extract was significantly superior for reducing root rot disease caused by S. rolfsii, with an appreciable reduction in DS and DI when compared with the other tested treatments as well as the control. It recorded efficacy of 76.04% and 55.27% compared to that determined by fungicide (67.74%) and 36.92%, respectively (Table 2). It is a promising finding, as root rot caused by *S. rolfsii* is a very destructive disease and commercial fungicides do not completely manage the disease.

On the other side, data established in Table 3 revealed that all applied treatments significantly reduced disease incidence and severity of sugar beet root rot caused by *F. oxysporum* compared with untreated control, but the plants treated with *S. vulgare* extract exhibited the highest noticeable reduction in DS and DI, with efficacy reaching 94.99% and 90.30%, respectively, as opposed to fungicide treatment (80.79% and 82.22%, respectively).

From previous data, it was clear that an extract of *S. vulgare* potentially managed root rot disease caused by F. *oxysporum, R. solani, and S. rolfsii.*

It is noteworthy that our findings are in harmony with previous studies [37, 38], which revealed that the aqueous extract of *S. vulgare* potentially inhibited the growth of *F. oxysporum and R. solani.*

Generally, the management of the disease can be a consequence of two possibilities: (1) a direct antifungal action over the phytopathogenic agent, or (2) promoting plant growth and activating the defence pathways of the plant [15].

The fungicidal activity of *S. vulgare* extract could be attributed to the presence of bioactive compounds such as phenols, terpenes, fatty acids, and acetogenins, which act singly or in combination, changing the physiological status of the fungal cells by binding their protein molecules, behaving as chelating agents, altering structural component synthesis, and destroying or weakening the permeability barrier of the cell membrane [37, 39–41].
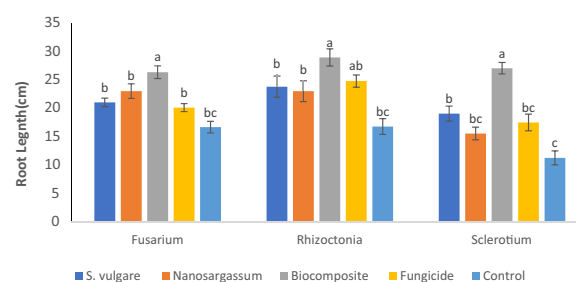
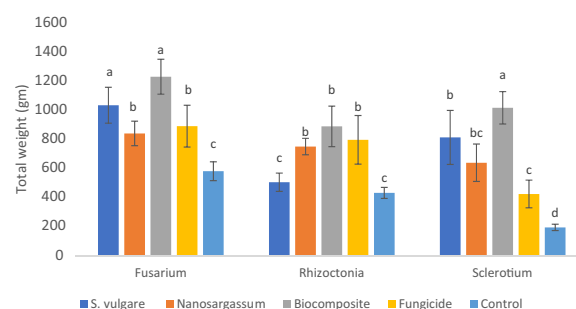**Fig.5** Effect of the different tested extracts on the total weight (g)

Fig. 6 Effect of the different tested extracts on root length (cm)

It is the first time to convert S. vulgare from its normal size to nanosized, providing brilliant properties to its activity, as shown in Tables 1 and 2. The nanostructured *S. vulgare* with an average size of 85 nm has a larger external and internal surface, a higher surface energy, and a shorter channel in comparison with the conventional microsized one. All these changes in their features make it expected to increase its antifungal activity.

The fungicidal properties of zeolite have recently attracted the attention of many researchers. Zeolite is considered a film-coating polymer, so it creates a barrier that prevents disease inoculums from directly contacting the seed surface [42]. Huge amounts of silicon in the zeolite matrix improve the mechanical and physiological properties of plants, enabling them to overcome many biotic and abiotic stresses and enhance plant resistance to diseases caused by fungal pathogens [43].

Furthermore, zeolites are recognised as highly hydrophilic sorbents because of their electrostatically charged framework and the abundance of extra-framework cations [44]. Aluminosilicate zeolites with larger pores possess a higher capacity for water than other types [45], so zeolites prevent the formation of the liquid film of water that is necessary for spore germination of many fungal pathogens [46]. Their high affinity for water is another potential advantage that makes them a promising biofungicide.
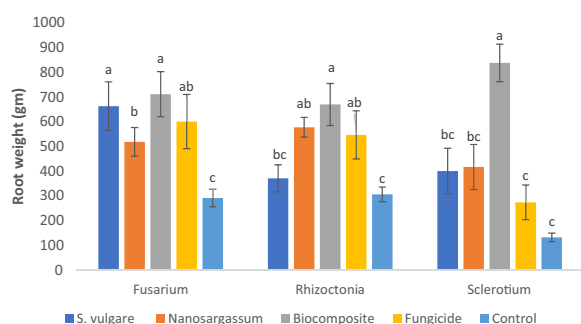
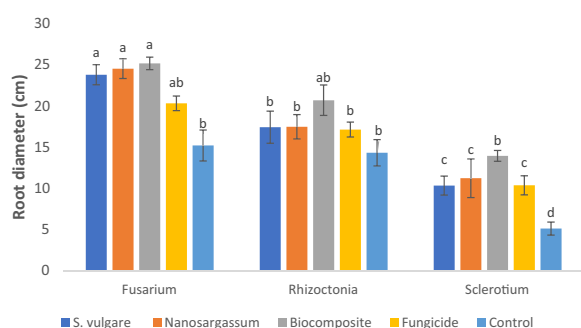**Fig. 7** Effect of the different tested extracts on root weight (g)

Fig. 8 Effect of the different tested extracts on root diameter (cm)

Unfortunately, *F. oxysporum* in our study didn't behave in the same manner and could tolerate a deficiency of water, as observed in Table 3**,** and *S. vulgare* treatment without zeolite represented the most effective one.

The fungal membrane is the vital component for guaranteeing cellular stability, and any abnormalities occurring at it can disturb cell stability, leading to a reduction in cell lifespan [47, 48], so it is considered an important target usually affected by commercial antifungal products [49, 50]**.**

The proposed mechanism of antifungal activity of biocomposite extract was illustrated as follows:

1) The antifungal potential of macroalgal extract might be returning to the fatty acids found in the extract of *S. vulgare*. Fatty acids, characterized by the presence of a methyl group at one end and a carboxyl group at the other chain end, allow their insertion into the fungal membrane, causing an increase in fluidity and, consequently, their permeability, modifying their conformational organisation, and culminating in cell death [15]**.**

2) Its activity could also be attributed to the presence of fucosterol in *S. vulgare* extract, which is similar to the structure of ergosterol, a sterol in the fungal membrane responsible for stability, deceiving the fungal membrane and interacting with it to disturb their normal regulation and increase the fluidity of the membrane components [48, 51]**.**

In the light of all of the above, the higher efficiency of biocomposite treatment in controlling root rot disease caused by *R. solani and S. rolfsii* than that treated with *S. vulgare* or nanosargassum individually, as observed in (Tables 1, 2), becomes very logical due to the expected synergistic effect between zeolite and nanosargassum.

Sugar beet growth characters

Figures 5, 6, 7, and 8 demonstrated that root length, root weight, root diameter, and total weight significantly increased by all treatments compared with untreated ones when they were planted in soil infested with the tested pathogens in the two seasons. Generally, coating sugar beet seeds with biocomposite before sowing was the pioneer treatment in improving the growth characteristics of sugar beet, which could be explained on the basis of the presence of different macronutrients in the extract of biocomposite, such as potassium, calcium, phosphorus, silica, and aluminium, as illustrated in the characterization part, which are considered key elements for the growth and productivity of the crop [52]. Potassium, for example, plays a significant role in increasing

Table 4 Effect of the different tested extracts on the percentages of sucrose and total soluble solids (TSS) in the sugar beet root juice

Treatment	F. oxysporum		R. solani		S. relfosii	
	sucrose %	TSS	sucrose %	TSS	sucrose %	TSS
S. vulgare	15.95[a]	16.65[c]	16.60[a]	18.20[b]	15.55[a]	16.80[c]
Nanosargassum	14.95[a]	15.90[c]	17.10[a]	19.00[b]	16.55[a]	18.90[b]
Biocompsite	16.85[a]	18.38[b]	17.95[a]	19.85[a]	15.30[a]	20.50[a]
Fungicide	14.00[a]	15.30[c]	16.25[a]	20.10[a]	15.98[a]	16.60[c]
Control	12.60[b]	13.10[d]	11.80[b]	17.33[c]	9.65[b]	5.60[e]

[*] Different letter(s) in the column are significantly different according to Duncan's multiple range test at p<0.05. Values are mean of three replicates for eachtreatment as well as the control

Fig.9 Effect of *S. vulgare*, Nanosargassum and biocomposite extracts on sugar beet root rot disease severity (**a**) the sugar beet grown in a greenhouse (**b**) Effect of biocomposite treatment on the growth of sugar beet plant infested by F. Oxysporum compared to non-treated one (infected control), S. Vulgare and nanosagassum treatments

the root elongation, depth, enlarging the root, and absorptive surface [53, 54].

Enhancement of the sugar beet growth characteristics is in full agreement with previous researchers [55–57]. They explained it on the basis of the presence of gibberellin, cytokinins like growth promoters, phenylacetic acid, macro- and micronutrients in the extract of *Sargassum sp., in* addition to the distinct new layered structure of the biocomposite, which enables the nutrients needed to transfer more efficiently, as illustrated in the characterization part.

Furthermore, zeolites form a permanent water reservoir, providing prolonged moisture habitat to the plant. As well as its cation exchange capacity, which is 2–3 times greater than other types of minerals found in soil [58].

Root yield quality
Sucrose % & TSS %
As shown in Table 4, higher percentages of sucrose and TSS were recorded in the root juice of the plants previously treated with the natural extracts studied. The highest percentages of sucrose and TSS were detected in the root juice of the plants whose seeds were coated with biocomposite extract before planting in soil infested with the soil-borne pathogens *F. oxysporum, R. solani, and S. relfosii* (16.85, 18.38; 17.95, 19.85; 15.30, 20.50) compared to the control (12.60, 13.10; 11.80, 17.33; 9.65, 5.60), respectively. In the same manner, a significant increase in root and sugar yield of sugar beet was previously observed when using zeolite under water-deficient conditions [59].

An increase in sucrose and TSS percentages is expected due to the extensive root system referred to above, through which the plant can deeply absorb water and nutrients from the soil, enhancing the plant's ability to form more assimilates [60].

Finally, the biocomposite has a promising effect on controlling root rot disease as well as improving growth characters when applied it on the seed of sugar beet before cultivated in green house Fig. 9a, b.

Conclusion
A novel biocomposite was fabricated by incorporating layered zeolite into the *S. vulgare* matrix with a distinguishable layered structure, which makes the transfer of macronutrients into the root easier. It exhibited significant potential in managing root rot disease caused by soil-borne pathogens in sugar beet plants. On the other side, it has a remarkable role in improving the growth character and yield quality of the tested crop. So that we are proud to find natural alternatives that can behave as a biofungicide and biostimulant at the same time, we consider it a step towards the green and fast transition as one of the outputs of COP27.

Author contributions
The contributions of all authors must be described in the following manner: The authors confirm contribution to the paper as follows: study conception and design: NA, FM; data collection: NA, FM and WR analysis and interpretation of results: FM, NA; draft manuscript preparation: FM, wR, NA. All authors reviewed the results and approved the final version of the manuscript. An author name can appear multiple times, and each author name must appear at least once. For single authors, use the following wording: The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Abdelwahab *et al. Chem. Biol. Technol. Agric.*   (2023) 10:52

Page 12 of 13

Availability of data and materials
The database used and analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author details
[1]Department of Microbiology, Soil, Water and Environment Research Institute, Agricultural Research Center, Giza 12619, Egypt. [2]Maize and Sugar Crops Diseases Department, Plant Pathology Research Institute, Agricultural Research Center, Giza 12619, Egypt. [3]Nanophotonics and Applications Lab, Faculty of Science, Beni-Suef University, Beni-Suef 62514, Egypt. [4]Materials Science Research Laboratory, Chemistry Department, Faculty of Science, Beni-Suef University, Beni-Suef 62514, Egypt.

References

1. Dohm JC, Minoche AE, Holtgräwe D, Capella-Gutiérrez S, Zakrzewski F, Tafer H, Rupp O, Sörensen TR, Stracke R, Reinhardt R, Goesmann A, Kraft T, Schulz B, Stadler PF, Schmidt T, Gabaldón T, Lehrach H, Weisshaar B, Himmelbauer H. The genome of the recently domesticated crop plant sugar beet (Beta vulgaris). Nature. 2014;505(7484):546–9. https://doi.org/10.1038/nature12817.
2. Jahan N, Sultana N, Zinat SR, Hossain I, Hossain DM. Biological control of Sclerotium rot of sugarbeet. Bangladesh J Plant Pathol. 2019;33(1&2):29–36.
3. Haque ME, Parvin MS. Sugar beet, its disease rhizoctonia root rot, and potential biological agents. AGBIR. 2021;37(1):96–101.
4. Burlakoti P, Rivera V, Secor GA, Qi A, Rio-Mendoza LD, Khan MF. Comparative pathogenicity and virulence of Fusarium species on sugar beet. Plant Dis. 2012;96(9):1291–6. https://doi.org/10.1094/pdis-10-11-0908-re.
5. Cao S, Yang N, Zhao C, Liu J, Han C, Wu X. Diversity of Fusarium species associated with root rot of sugar beet in Chin. J Gen Plant Pathol. 2018;84(5):321–9. https://doi.org/10.1007/s10327-018-0792-5.
6. Harveson, R. M. *Rhizoctonia Root and Crown Rot of Sugar Beet. 1495*, 2–4. (2008b)
7. Abd Ellatif SA, Gharieb MM, El-Moghazy SM, Abo El-Yazied MN, Bakry AM. New approach to control *Sclerotium rolfsii* induced sugar beet root rots disease by trichoderma with improved sucrose contents. J Pure Appl Microbiol. 2019;13(3):1595–604. https://doi.org/10.22207/JPAM.13.3.32.
8. Abdelaaziz F, Asmae A, Abdessalem T, El Nabila A, Slimane K, Rachid M, Said E, Nabil R, Fouad M, Zineb B, Rachid L. Biocontrol potential of plant growth-promoting rhizobacteria (PGPR) against Sclerotiorum rolfsii diseases on sugar beet (Beta vulgaris L.). Physiol Mol Plant Pathol. 2022;119:101829. https://doi.org/10.1016/j.pmpp.2022.101829.
9. Paul SK, Mahmud NU, Gupta DR, Surovy MZ, Rahman M, Islam MT. Characterization of Sclerotium rolfsii Causing Root Rot of Sugar Beet in Bangladesh. Sugar Tech. 2021;23(5):1199–205. https://doi.org/10.1007/S12355-021-00984-6.
10. Bartholomäus A, Mittler S, Märländer B, Varrelmann M. Control of rhizoctonia solani in sugar beet and effect of fungicide application and plant cultivar on inoculum potential in the soil. Plant Dis. 2017;101(6):941–7. https://doi.org/10.1094/PDIS-09-16-1221-RE.
11. Kaya R, Avan M, Aksoy C, Demirci F, Katircioǧlu YZ, Maden S. Occurrence and importance of root rots caused by fungal pathogens on sugar beet grown in Konya province of Turkey. Zuckerindustrie. 2020;145(11):674–81. https://doi.org/10.36961/si25276.
12. Ons L, Bylemans D, Thevissen K, Cammue BPA. Combining biocontrol agents with chemical fungicides for integrated plant fungal disease control. Microorganisms. 2020;8(12):1–19. https://doi.org/10.3390/microorganisms8121930.
13. Shawki K, Elsayed A, Abido W, Shabana Y. Using green chemicals and biological control agents for controlling the seed-borne pathogen fusarium moniliforme in sugar beet. J Plant Prot Pathol. 2020;11(2):63–72. https://doi.org/10.21608/jppp.2020.78905.
14. Graff KH, Raj TS. Effect of *Sargassum tenerrimum* on controlling sheath blight of rice caused by *rhizoctonia solani kuhn*. Plant Archives. 2019;19(May):1132–5.
15. Vicente TFL, Lemos MFL, Félix R. Patrícia Valentão and Carina Félix, marine macroalgae, a source of natural inhibitors of fungal phytopathogens. J Fungi. 2021;7(12):1006. https://doi.org/10.3390/jof7121006.
16. Michalak I, Chojnacka K. Algae as production systems of bioactive compounds. Eng Life Sci. 2015;15:160–76. https://doi.org/10.1002/elsc.201400191.
17. Jumadi O, Annisi AD, Djawad YA, Bourgougnon N, Amaliah NA, Asmawati A, Manguntungi AB, Inubushi K. Brown algae (Sargassum sp) extract prepared by indigenous microbe fermentation enhanced tomato germination parameters. Biocat Agri Biotechnol. 2023. https://doi.org/10.1016/j.bcab.2023.102601.
18. Manjuanatha SB, Biradar DP, Aladakatti YR. Nanotechnology and its applications in agriculture: a review. J Farm Sci. 2016;29(1):1–13.
19. Jarosz R, Szerement J, Gondek K, Mierzwa-Hersztek M. The use of zeoiltes as an addition to fertilisers—a review. CATENA. 2022. https://doi.org/10.1016/j.catena.2022.106125.
20. Kefalogianni Io, Gkizi D, Pappa E, Dulaj L. Combined use of bio control agents and zeolite as a management strategy against Fusarium and Verticillium wilt. J Int Organiz Biol Control. 2017. https://doi.org/10.1007/s10526-016-9778-4.
21. Andrea M, Amit K, Giuseppina M, Sara AB, Marika P, Francesca A, Alessandra G, Maurizio M. Zeolite Clinoptilolite: therapeutic virtues of an ancient mineral. Molecules. 2019. https://doi.org/10.3390/molecules24081517.
22. Ahmed H, Doaa R, Mohamed Sh, Khaled NM, Elsayed HAI, Mohamadi AM, Elzanaty SA, Ahmed R-S, Nofal KhS. Application of nano bio-clay composite in a scaling-up study for wastewater treatment. Bio Interface Res Appl Chem. 2021;12(5):6393–414. https://doi.org/10.3326/BRIAC125.63936414.
23. Asaf G, Bayan H, Elhanan D, Ofir D. Integrated biological and chemical control against the maize late wilt agent magnaporthiopsis maydis. Soil Syst. 2023;7(1):1. https://doi.org/10.3390/soilsystems7010001.
24. Hernández-Herrera RM, Santacruz-Ruvalcaba F, Ruiz-López MA, Norrie J, Hernández-Carmona G. Effect of liquid seaweed extracts on growth of tomato seedlings (Solanum lycopersicum L.). J Appl Phycol. 2014. https://doi.org/10.1007/s10811-013-0078-4.
25. El-Argawy E, Rahhal MMH, El-Korany A, Elshabrawy EM, Eltahan RM. Efficacy of some nanoparticles to control damping-off and root rot of sugar beet in El-Behiera Governorate. Asian J Plant Pathol. 2016;11(1):35–47. https://doi.org/10.3923/ajppaj.2017.35.47.
26. Elwakil MAR, El-Metwall MA, El-Emam NF. Green chemicals and bio-agents for controlling damping-off diseases of sugar beet and scaling up the yield and quality. Plant Pathol J. 2018;17(1):1–10. https://doi.org/10.3923/ppj.2018.1.10.
27. Duncan DB. Multiple ranges and multiple F test. Biometrics. 1955;11(1):1–42. https://doi.org/10.2307/3001478.
28. Oliveira RC, Hammer P, Guibal E, Taulemesse J-M. Characterization of metal–biomass interactions in the lanthanum(III) biosorption on Sargassum sp. using SEM/EDX, FTIR, and XPS: preliminary studies. Chem Eng J. 2014;239:381–91. https://doi.org/10.1016/j.cej.2013.11.042.
29. Susan A, Farideh N, Mahnaz M, Mansor BA, Rosfarizan M. Biosynthesis of silver nanoparticles using brown marine macroalga, *Sargassum Muticum* aqueous extract. Materials. 2013;6:5942–50. https://doi.org/10.3390/ma6125942.

Abdelwahab *et al. Chem. Biol. Technol. Agric.*   (2023) 10:52

Page 13 of 13

30. Hamd A, Dryaz AR, Shaban M, AlMohamadi H, Abu KA, Al-Ola NK, SolimanAhmed SA. Fabrication and application of zeolite/acanthophora spicifera nanoporous composite for adsorption of congo red dye from wastewater. Nanomaterials. 2021;11(9):2441. https://doi.org/10.3390/nano11092441.

31. Hamd A, Shaban M, AlMohamadi H, Dryaz AR, Ahmed SA, Abu KA, Al-Ola HR, El-Mageed A, Soliman NK. Novel wastewater treatment by using newly prepared green seaweed-zeolite nanocomposite. ACS Omega. 2022;7(13):11044–56.

32. Laamanen CA, Ross GM, Scott JA. Flotation harvesting of microalgae. Renew Sustain Energy Rev. 2016;58:75–86.

33. Hadjoudja S, Deluchat V, Baudu M. Cell surface characterisation of Microcystis aeruginosa and Chlorella vulgaris. J Colloid Interf Sci. 2010;342:293–9. https://doi.org/10.1016/j.jcis.2009.10.078.

34. Mohamed S, Fatma M, Semsem A. Production and characterization of superhydrophobic and antibacterial coated fabrics utilizing ZnO. Nanocatalyst. 2018;8:3925. https://doi.org/10.1038/s41598-018-22324-7.

35. Jiangya M, Wei X, Xue F, Lei D, Yanli K, Huiwen Zh, Kun F. Magnetic flocculation of algae-laden raw water and removal of extracellular organic matter by using composite flocculant of Fe3O4/cationic polyacrylamide. J Cleaner Prod. 2020;248:119276. https://doi.org/10.1016/j.jclepro.2019.119276.

36. Zhongxin Y, Xiaonan Zh, Yuyan L, Bei F, Yuhang Y, Nanchun Ch, Xiuli W, Qinglin X. Fabrication of KDF-loaded chitosan-oligosaccharide-encapsulated konjac glucomannan/sodium alginate/zeolite P microspheres with sustained-release antimicrobial activity. J Mol Struct. 2021;1250:131682. https://doi.org/10.1016/j.molstruc.2021.131682.

37. Ammar N, Nefzi A, Jabnoun-Khiareddine H, Daami-Remadi M. Control of Fusarium dry rot incited by Fusarium oxysporum f. sp. tuberosi using Sargassum vulgare aqueous and organic extracts. Microb Biochem Technol. 2017;9:200–8. https://doi.org/10.4172/1948-5948.1000366.

38. Khan SA, Abid M, Hussain F. Antifungal activity of aqueous and methanolic extracts of some seaweeds against common soil-borne plant pathogenic fungi. Pak J Bot. 2017;49:1211–6.

39. Peres JCF, de Carvalho LR, Gonçalez E, Berian LOS, Felicio JD. Evaluation of antifungal activity of seaweed extracts. Ciênc Agrotecnol. 2012;36:294–9. https://doi.org/10.1590/S1413-70542012000300004.

40. Bambang BS, Kumalaningsih S, Susinggih W. Polyphenol content and antioxidant activities of crude extract from brown algae by various solvents. J Life Sci Biomed. 2013;3:439–43.

41. El Shafay SM, Ali SS, El-Sheekh MM. Antimicrobial activity of some seaweeds species from Red sea, against multidrug resistant bacteria. Egypt J Aquatic Res. 2016;42:65–74. https://doi.org/10.1016/j.ejar.2015.11.006.

42. Murrieta FN, Rico JA-G, Yocupicio-Gaxiola RI, Galván DH, González JC, Petranovskii V. Zeolites as initial structures for the preparation of functional materials. J appl res Technol. 2022. https://doi.org/10.2220/icat.24486736e.2022.20.1.

43. Wang M, Gao L, Dong S, Sun Y, Shen Q, Guo S. Role of silicon on plant–pathogen interactions. Front Plant Sci. 2017;8:1–14. https://doi.org/10.3389/fpls.2017.00701.

44. Ben P, Mikhail G, Salman MS. Influence of surface modification on selective CO2 adsorption: a technical review on mechanisms and methods. Microporous Mesoporous Mater. 2021;312:110751. https://doi.org/10.1016/j.micromeso.2020.110751.

45. Melo CR, Riella HG, Kuhnen NC, Angioletto E, Melo AR, Bernardin AM. Synthesis of 4A zeolites from kaolin for obtaining 5A zeolites through ionic exchange for adsorption of arsenic. Mater Sci Eng B. 2012;177:345–9. https://doi.org/10.1016/j.mseb.2012.01.015.

46. De Smedt C, Someus E, Spanoghe P. Potential and actual uses of zeolites in crop protection. Pest Manage Sci. 2015. https://doi.org/10.1002/ps.3999.

47. Avis TJ, Bélanger RR. Specificity and mode of action of the antifungal fatty acid Cis-9-heptadecenoic acid produced by Pseudozyma flocculosa. Appl Environ Microbiol. 2001;67:956–60. https://doi.org/10.1128/AEM.67.2.956-960.2001.

48. Sahar H, Jeffrey JC. Targeting the fungal cell wall: current therapies and implications for development of alternative antifungal agents. Future Med Chem. 2019;11(8):869–83. https://doi.org/10.4155/fmc-2018-0465.

49. Ghannoum MA, Rice LB. Antifungal agents: mode of action, mechanisms of resistance, and correlation of these mechanisms with bacterial resistance. Clin Microbiol Rev. 1999;12:501–17. https://doi.org/10.1128/cmr.12.4.501.

50. Lopes G, Pinto E, Andrade PB, Valentão P. Antifungal activity of Phlorotannins against dermatophytes and yeasts: approaches to the mechanism of action and influence on Candida albicans virulence factor. PLoS ONE. 2013;8:e72203. https://doi.org/10.1371/journal.pone.0072203.

51. Tyśkiewicz K, Tyśkiewicz R, Konkol M, Rój E, Jaroszuk-Ściseł J, Skalicka-Woźniak K. Properties of Fucus vesiculosus L. supercritical fluid extract against fusarium culmorum and fusarium oxysporum. Molecules. 2019. https://doi.org/10.3390/molecules24193518.

52. Mirza Hasanuzzaman, Mohammad Anwar Hossain, Jaime A. Teixeira da Silva, Masayuki Fujita. 2012. Plant responses and tolerance to abiotic oxidative stress antioxidant defense is a key factor. In: B. Venkateswarlu, Arun K. Shanker, Chitra Shanker, M. Maheswari (Eds). Crop Stress and Its Management Perspectives and Strategies. Springer Netherlands; Dordrecht

53. Xinxiang X, Xin D, Fen W, Jianchuan S, Qian Ch, Ge T, Zhanling Z, Shunfeng G, Yuanmao J. Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. Front Plant Sci. 2020. https://doi.org/10.3389/fpls.2020.00904.

54. Wang M, Zheng Q, Shen Q, Guo S. The critical role of potassium in plant stress response. Int J Mol Sci. 2013;14(4):7370–90. https://doi.org/10.3390/ijms14047370.

55. Layek J, Ramkrushna GI, Das A, Ghosh A, Krishnappa R, Panwar AS, Azad Thakur NS, Ngachan SV, Zodape ST, Buragohain J, Mawlong B. Seaweed sap as organic bio stimulant for rice and maize production. Res Bull ICAR Com NEH Reg. 2014;82:12. https://doi.org/10.1007/s10811-017-1225-0.

56. Martin DAN, Rahmat A. Relationship of soil physicochemical properties and existence of phytophthora sp in pineapple plantations. Indonesian J Sci Technol. 2017;2(1):81–6. https://doi.org/10.1750/ijost.v2i1.

57. Siti F, Hasimah A, Norhayati D. The effect of seaweed extract (Sargassum Sp) used as fertilizer on plant growth of capsicum annum (Chilli) and Lycopersicon Esculentum (Tomato). Indonesian J Sci Technol. 2018;3(2):115–23. https://doi.org/10.17509/ijost.v3i2.12755.

58. Perez-Caballero R, Gil J, Benitez J, Gonzalez L. The effect of adding zeolite to soils in order to improve the N-K nutrition of olive trees. Preliminary results. Am J Agric Biol Sci. 2008;2:321–4. https://doi.org/10.3844/ajabssp.2008.321.324.

59. Eman Abdel Fatah M, Soha RA, Khalil. Effect of zeolite, potassium fertilizer and irrigation interval on yield and quality of sugar beet in sandy soil. J Plant Prod. 2020;11(12):1569–79. https://doi.org/10.21608/jpp.2020.149830.

60. Aly MH, All AEl, Azza AM, Mostafa SSM. Enhancement of sugar beet seed germination, plant growth, performance and biochemical components as contributed by algal extracellular products. J Agric Chem Biotechnol. 2008;33(12):8429–48. https://doi.org/10.21608/jacb.2008.200754.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.