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Research Article

Potential Impacts of Carbon Tube and Silicon Oxide Nanoparticles on Growth, Yield and Antioxidant System of Soybean Plant

[1]Maha Mohamed Shater Abdallah, [2]Abd El-Samad Mahmoud Younis, [2]Bakry Ahmed Bakry, [1]Hala Mohamed Safwat El-Bassiouny and [1]Amany Abd El-Mohsen Ramadan

[1]Department of Botany, Agricultural and Biological Research Division, National Research Centre, 33 El Bohouth Street, P.O. Box 12622, Dokki, Giza, Egypt

[2]Department of Field Crops Research, Agricultural and Biological Research Division, National Research Centre, 33 El Bohouth Street, P.O. Box 12622, Dokki, Giza, Egypt

Abstract

Background and Objective: Nanotechnology has proposed a new generation of environmental treatment technologies that can be cost-efficient solutions for several of the most challenging environmental problems. This study was designed to evaluate the response of soybean plants to Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) under sandy soil conditions. **Materials and Methods:** Field experiment during two successive summer seasons of 2017 and 2018 was carried out to study the effect of 10, 20, 30 and 40 mg L^{-1} foliar application of CNTs and SiO_2-NPs on growth, some biochemical changes and yield of soybean. Data statistically analyzed using the analysis of variance procedure of split-plot design and means compared using LSD technique. **Results:** Foliar application of CNTs or SiO_2-NPs at different concentrations increased significantly growth characters, photosynthetic pigments, some osmoprotectants, indole acetic acid and phenolic contents of soybean plants. The increase in plant growth parameters reflected a reduction in oxidative damage due to the increase in antioxidant enzymes (catalase and superoxide dismutase), however, malondialdehyde and peroxidase decreased. Different treatments markedly increased the seed yield and its nutritional value (total carbohydrates, protein and oil percentages) compared to the control. Experimental treatments exhibited also a marked reduction in saturated fatty acids levels particularly palmitic acid, while it increased unsaturated fatty acids. **Conclusion:** Generally, the findings imply that CNTs or SiO_2-NPs have a positive role in preserving important physiological and biochemical functions that reflected positively on soybean plant growth and seeds yield when grown under sandy soil conditions.

Key words: Carbon nanotubes, silicon oxide nanoparticles, soybean, fatty acids, antioxidant enzymes, sandy soil

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Corresponding Author: Amany Abd El-Mohsen Ramadan, Department of Botany, Agricultural and Biological Research Division, National Research Centre, 33 El Bohouth Street, P.O. Box 12622, Dokki, Giza, Egypt

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

New innovations in nanotechnology supply information and technological areas for several applications in different fields (medical science, electronics and defense industries) increasing day by day. More recently, the field of nanotechnology is scoped by plant scientists, particularly for the application of nano-materials like appliances of agrochemicals or biomolecules in plants with large potency to promote crop productivity[1]. It is credible to dispute that the potentiality and advantages of NMs application in plant sciences and agriculture are yet not completely utilized because of several brief bottlenecks in terms of dose and creation of safe nanoparticles which improve plant growth and development are still needed[2]. Information on the accurate techniques of nanoparticle uptake and mobilization in plants is still lack[3]and the absence of multi-specialties tactic important for the designing and application of nanotechnology in plants.

Recently, nanotechnology is also gaining interest because of the requirement to improve diminished ancient systems to enhance seed germination, growth and plant protection to environmentalstresses[4]. Nano fertilizers can be described as nanomaterial which has the ability to supply one or more nutrients to the plants in order to increase their growth and productivity[5]. Use of nano fertilizers can be considered as one of the promising approaches to increase the productivity and growth of the plants to overcome the ever-increasing food demands. Carbon Nanotubes (CNTs) are major parts of nanotechnology having unique properties including specific electrical, mechanical and thermal characteristics. Carbon nanotubes have a diameter of several nanometers that gave it the cylindrical structures which consisting of rolled graphene sheets. So, carbon nanotubes might differ in diameter, length, the regularity of the rolled graphite sheet and the number of layers. Further uptake and interaction with the biological system may be enhanced with the crystalline tubular structure for the outer diameters compared to the non-crystalline relatively larger carbon materials, CNTs[6,7]. The CNTs have been shown that are able to absorb and remove organic and inorganic contaminants from water[8]. Numbers of CNTs have lately acquired importance because of their potential applications in the regulation of plant growth. So, the literature illustrates the positive and negative influences on different plant species, depending on CNT kind and concentration, growth conditions and plant species[9].

Epstein[10] recorded that silicon is the most common metalloid on earth which is the second most abundant element in the earth's crust after oxygen. For plants, silicon came in between the essential and nonessential elements as it is not required for the survival of most plants. It was observed that silicon used by plants to strengthen their cell walls; the family *Equisetaceae* plants were not survived in nutrient solutions lacking silicon[10]. In the presence of silicon, plants are found to benefits and are better adapted to different environmental stress conditions[10,11].

Soybean (*Glycine max* L.) is a *Fabaceae* family annual plant. It contains valuable amounts of protein, lipids, carbohydrate and mineral elements. Protein and lipids the tool of soybean's commercial value. After purification, soybean oil becomes edible and use in the food industry. Soybean seeds have about 18% oil and its meal used as a protein source in livestock and poultry feeds[12].

Therefore, the present work was aimed to evaluate the influence of the foliar application of Carbon Nanotubes(CNTs)and Silicon oxide Nanoparticles (SiO_2-NPs) materials to alleviate the adverse effects of environmental stress and keeping away from harmful influences on seed yield quantity and quality of soybean plants grown under sandy soil conditions.

MATERIALS AND METHODS

Study area: A field experiment was carried out at the Experimental Station of National Research Centre, (Latitude 30°30'1.4''N, Longitude 30°19'10.9'' E and mean altitude 21 m above sea level) at Nubaria district, El-Behera Governorate, Egypt (North Africa; represents arid or semi-arid region) during two successive summer seasons of 2017 and 2018.

Chemicals: Carbon nanotubes (CNTs) and Silicon Oxide nanoparticles (SiO_2-NPs) in the present work were supplied from Sigma-Aldrich. Soybean (*Glycine max* (L.) Merr.) seeds of Giza-111 variety were obtained from Agricultural Research Centre, Giza, Egypt. The soil of the experimental site was sandy. Mechanical, chemical and nutritional analysis of the experimental soil is reported in Table 1 according to Chapman and Pratt[13].

Research protocol: The experimental design of this trial was a split-plot design with three replications. Where Carbon Nanotubes (CNTs) and Silicon Oxide Nanoparticles (SiO_2-NPs) occupied the main plots and their concentrations foliar spraying at rates of 0, 10, 20, 30 and 40 mg L^{-1} were allocated at random in the subplots. Soybean (*Glycine max* (L.) Merr.) seeds were inoculated just before sowing with the specific rhizobium bacteria inoculants at the rate of 920 g ha^{-1}. Soybean seeds were sown in the first week of May in both seasons in rows 3.5 m long with the distance between rows of 60 cm apart. The plot area was 10.5 m^2 (3.0 m width×3.5 m

Table 1: Some physical and chemical characteristics of the experimental soil

Seasons	Constant depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture class	pH	EC (dsm^{-1})	SP	Organic matter (%)
2017	00-30	40.7	44.6	10.7	4.0	Sandy	7.84	11.76	32	0.40
	30-60	38.2	43.0	13.8	5.0	Sandy	7.89	5.79	27	0.07
2018	00-30	38.7	42.6	13.7	5.0	Sandy	7.95	1.59	23	0.38
	30-60	36.5	38.1	17.8	7.6	Sandy	7.85	1.81	25	0.32
Seasons	Constant depth (cm)	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^{-+}	K^{+}	$CaCO_3$ (%)
Anions and cations ($meqL^{-1}$) content of the experimental site										
2017	00-30	-	0.50	8.40	1.11	1.80	0.90	7.10	0.20	1.00
	30-60	-	0.60	8.00	1.40	2.10	1.50	6.20	0.20	6.00
2018	00-30	-	0.32	12.70	1.98	4.00	1.80	9.00	0.20	1.90
	30-60	-	0.45	15.40	2.15	5.60	2.00	10.20	0.20	1.30

length). The normal agricultural practices were applied as recommended in the district. The seeding rate was 120 kg ha^{-1}. Pre-sowing, 360 kg ha^{-1} of Calcium superphosphate (15.5% P_2O_5) was used. Nitrogen was applied after emergence in the form of ammonium nitrate 33.5% at a rate of 180 kg ha^{-1} in six equal doses. Potassium sulfate (48% K_2O) was added at two equal doses of 144 kg ha^{-1}. Irrigation was carried out using the new drip irrigation system once every 5 days for 2 hrs. Foliar application of different concentrations of Carbon Nanotubes (CNTs) and Silicon oxide (SiO_2-NPs) Nanoparticles was carried out twice at the vegetative stage after 30 and 45 days from sowing. Plant samples were taken after 60 days from sowing for measurements of growth characters and some biochemical parameters.

Growth measurements: The morphological traits measured were shoot length (cm), number of branches and leaves/plant, fresh and dry weight of shoot (g $plant^{-1}$), root length (cm) and fresh and dry weight of root (g $plant^{-1}$). Water content was determined according to Henson *et al.*[14] using the following formula:

$$WC = 100 \times \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}}$$

Biochemical analysis: Some biochemical tests carried out including photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids and total pigments) in fresh leaves using the method of Lichtenthaler and Buschmann[15]. Indole acetic acid content were extracted and analyzed by the method of Larsen *et al.*[16]. Phenolic content was measured as described by Diaz and Martin[17]. Free Amino Acids (FAA) was extracted according to Vartainan *et al.*[18] and determined with the ninhydrin reagent method described by Yemm and Cocking[19]. Proline content was extracted and calculated according to Bates *et al.*[20]. Total Soluble Sugars (TSS) were extracted according to Homme *et al.*[21] and assayed according to Yemm and Willis[22]. Enzyme extracts were prepared according to the method of Chen and Wang[23]. Catalase (CAT, EC 1.11.1.6) and Superoxide dismutase (SOD, EC 1.12.1.1) activity was detected by Chen and Wang[23]. Peroxidase (POX, EC 1.11.1.7) activity was evaluated according to Kumar and Khan[24]. The level of membrane damage was estimated by measuring malondialdehyde (MDA) according to Hodges*et al.*[25]. The determination of total carbohydrates was carried out according to Herbert *et al.*[26]. Total protein concentration was determined according to the method described by Bradford[27]. The oil content of soybean seeds was determined according to the procedure reported by AOAC.[28]. As the quality of the oil depends on the proportion of different fatty acids, their composition was determined quantitatively by gas-liquid chromatography according to the method described by Fedak and De La Roche[29].

Yield measurements: With signs of full maturity stage appearance yield and its attributes, plant height (cm), number of branches/plant, biological yield/plant(g), root lengths (cm), root weight (g), number of pods/plant, 100-seed weight (g), seed yield (ton ha^{-1}) and oil yield (kg ha^{-1}) were recorded.

Statistical analysis: Combined analysis of the two growing non-significant seasons was carried out using the analysis of variance procedure of split-plot design according to Snedecor and Cochran[30]. Treatments means were compared according to the Least Significant Difference Test (LSD) at 0.05 levels.

RESULTS

Changes in growth parameters: Data presented in Table 2 showed the significant influence of the foliar application of various concentrations (10, 20, 30 and 40 mg L^{-1}) of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs)on growth criteria of soybean plants. When compared to the control plants CNTs or SiO_2-NPs significantly increased all the morphological character (shoot length, number of branches and leaves/plant, root length, fresh and dry weights of the shoot, fresh, dry weights of root and water content. Exposure of soybean plants to CNTs at the rate of 30 mg L^{-1} induced significant ($p<0.05$) increase in growth parameters except for the number of branches/plant.

Changes in photosynthetic pigments: The effect of CNTs and SiO_2-NPs (10, 20, 30 and 40 mg L^{-1}) on photosynthetic pigment contents of soybean plants is presented in Fig. 1a-d. The results observed that either CNTs or SiO_2-NPs significantly increased chl.a (Fig. 1a), chl.b (Fig. 1b), carotenoids (Fig. 1c) and total pigment contents (Fig. 1d) compared to the control plant. Meanwhile, SiO_2-NPs revealed superiority than CNTs in improving photosynthetic pigments of soybean plants under sandy soil conditions, except when 30 mg L^{-1} was applied. The maximum contents of the photosynthetic pigments were obtained with foliar spraying of both SiO_2-NPs and CNTs at 20 mg L^{-1} compared to the control and other concentrations of treated plants.

Changes in osmoprotectants content in leaves: Data recorded in Fig. 2a-d showed that foliar application of soybean plants either with CNTs or SiO_2-NPs induced accumulation of osmoprotectants (a) Total Soluble Sugar (TSS), (b) Proline

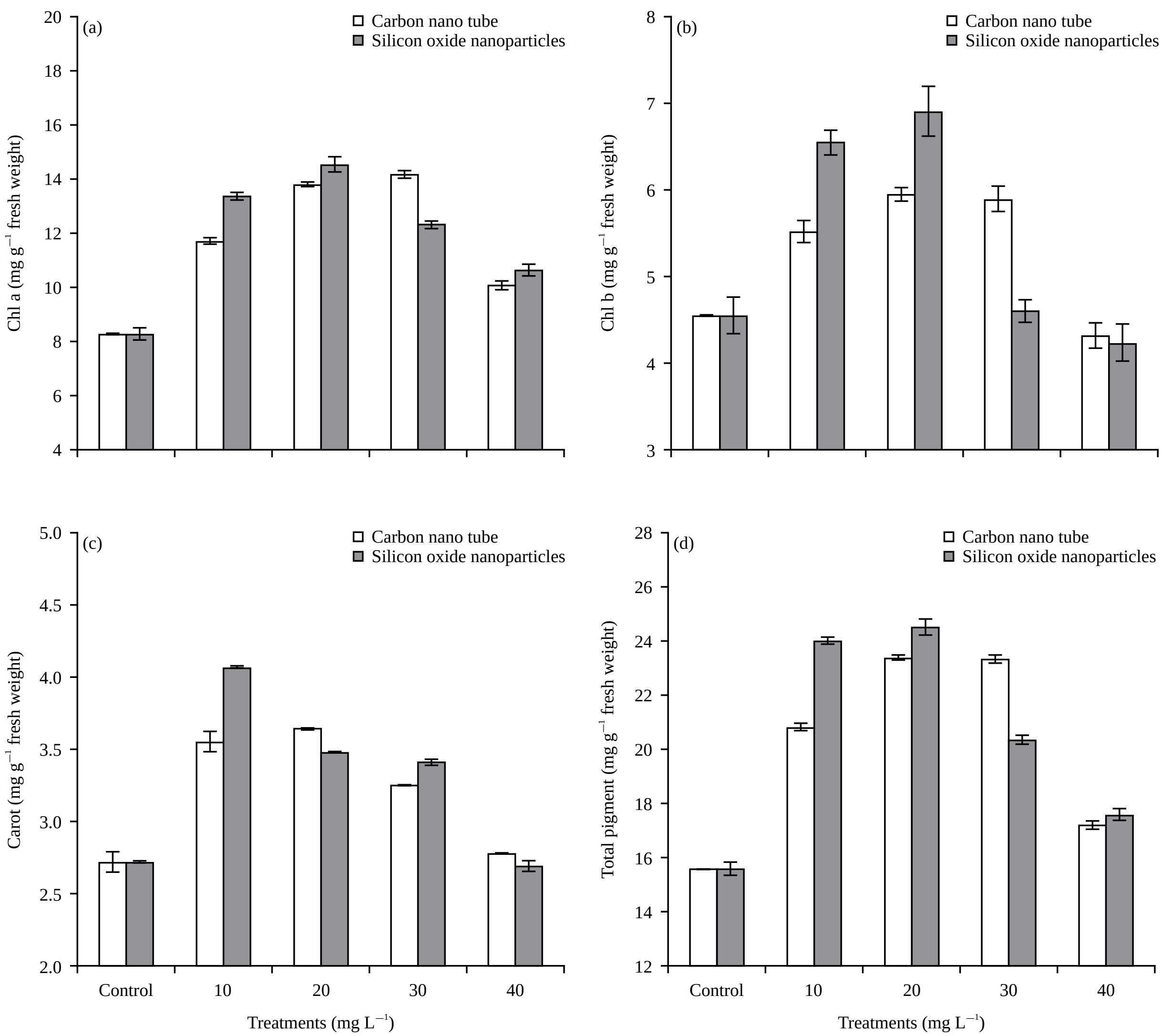


Fig. 1(a-d): Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs)at different levels on photosynthetic pigments

(a) Chlorophyll a (LSD at 5% 1.27), (b) Chlorophyll b (LSD at 5% 0.53), (c) Carotenoids (LSD at 5% 0.19) and (d) Total pigments contents (mg g^{-1} fresh weigh) (LSD at 5% 1.84) of soybean plants. Each value represents the Mean±standard error (n = 3)

Table 2: Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels on growth parameters of soybean plants

Materials (mg L^{-1})	Shoot length (cm)	Number of branches/plant	Number of leaves/plant	Shoot fresh weight (g)	Shoot dry weight (g)	Water content (%)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)
Control	40.67±0.33	1.00±0.0	14.00±0.58	18.17±0.40	6.99±0.08	61.53±0.43	16.05±1.15	1.45±0.05	0.85±0.02
CNTs									
10	51.33±1.67	2.67±0.33	29.67±0.33	32.42±0.90	11.06±0.24	65.89±0.25	17.67±0.88	1.85±0.45	0.92±0.08
20	53.00±4.04	3.33±0.21	36.00±1.15	41.67±0.71	13.02±0.53	86.75±0.41	22.03±0.58	3.13±0.16	1.44±0.03
30	56.33±0.33	3.00±0.19	39.00±2.00	47.63±1.93	16.62±1.76	65.11±0.55	25.04±1.53	4.24±0.11	3.55±0.25
40	46.67±2.85	3.00±0.14	30.33±0.33	34.69±0.25	12.64±0.17	63.56±0.67	22.33±1.20	3.56±0.23	1.45±0.16
SiO_2-NPs									
10	41.67±1.20	1.00±0.0	19.33±0.33	31.52±3.14	11.45±0.18	63.67±0.72	21.20±0.58	3.47±0.13	2.97±0.10
20	46.00±1.00	3.67±0.33	24.00±0.58	32.79±1.28	10.25±0.10	68.74±0.36	23.00±0.58	2.74±0.07	1.84±0.04
30	44.00±0.85	2.67±0.26	23.67±1.45	27.38±2.04	9.14±1.00	66.62±0.47	24.67±1.20	2.61±0.13	1.43±0.09
40	43.67±0.33	2.33±0.21	20.33±0.67	24.73±0.50	9.06±0.25	63.36±0.48	24.00±0.58	2.20±0.18	1.27±0.06
LSD 5%	5.35	0.95	2.61	4.70	2.00	4.86	N.S	0.56	0.34

Each value represents the mean±standard error (n = 3)

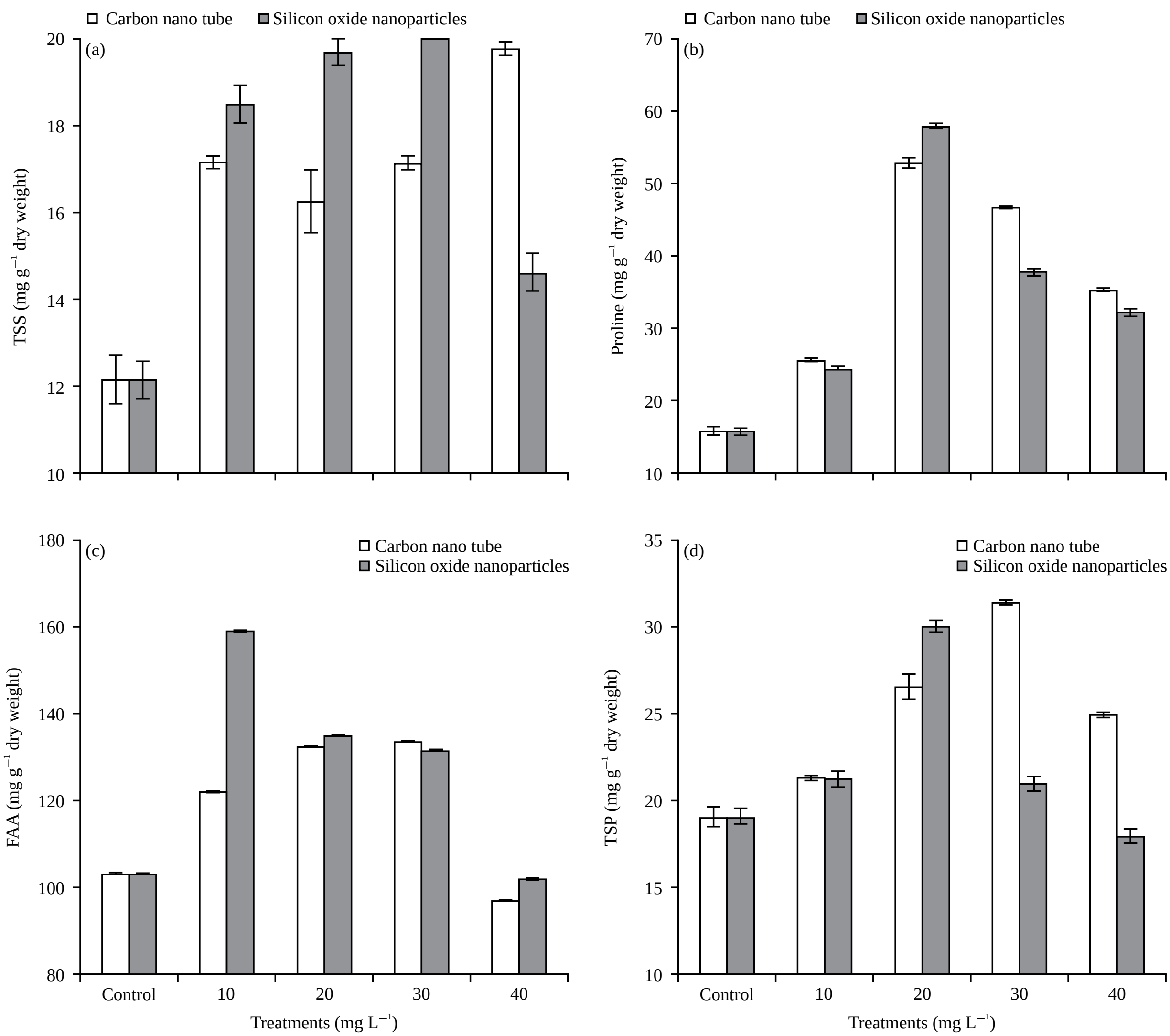


Fig. 2(a-d): Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels

(a) Total Soluble Sugars (TSS) (LSD at 5% 11.10), (b) Proline (LSD at 5% 2.88), (c) Free Amino Acids (FAA) (LSD at 5% 5.60) and (d) Total Soluble Protein (TSP) (mg g^{-1} dry wt.) (LSD at 5% 0.85) of soybean plants. Each value represents the Mean±standard error (n = 3)

(Pro), (c) Free Amino Acids (FAA) and d. Total Soluble Protein (TSP) as compared with the corresponding control. Exposure of soybean plants to SiO_2-NPs foliar spraying exhibited superiority in increasing TSS values compared to that recorded from CNTs and untreated control plants, except with 40 mg L^{-1} application. The maximum raise in proline and TSP were showed in plants treated with 20 mg L^{-1} SiO_2-NPs. In the meantime, the FAA recorded the maximum content at 10 mg/LSiO_2-NPs. Concerning the influence of CNTs (Fig. 2 a-d) the maximum raise in (c) FAA and (d) TSP were showed in plants treated with 30 mg L^{-1}, but (a) TSS recorded the highest value when 40 mg L^{-1} was applied.

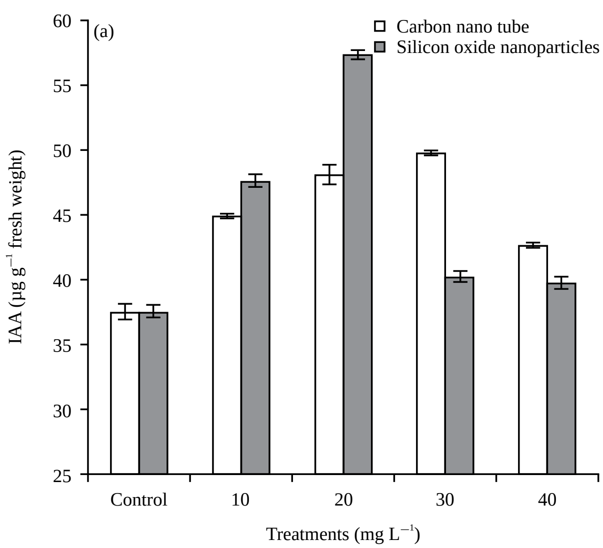
Changes in Indole acetic acid and Phenol contents: Data in Fig. 3a and b recorded the values of indole acetic acid and phenol contents on soybean plant affected by different concentrations ofCNTsandSiO_2-NPs. In general, either CNTs or SiO_2-NPs application increased significantly IAA content of soybean plants than that of the corresponding control. The concentration of 20 mg L^{-1} SiO_2-NPs induced the maximum increase in IAA content (57.41 μg g^{-1} fresh wt.), whereas CNTs treatment induced the maximum content at the rate of 30 mg L^{-1} (49.84 μg g^{-1} fresh wt.).

Figure 3b demonstrated that foliar spraying with CNTs or SiO_2-NPs on soybean plant grown in sandy soil generally increased significantly phenol contents in the treated plants than the control. It is observed that SiO_2-NPs revealed superiority than CNTs in improving the values of total phenol contents in soybean plants. The highest value(224.26 mg g^{-1} fresh wt.) was obtained with 30 mg L^{-1} SiO_2-NPs.

Changes in lipid peroxidation: Results illuminated, gradual reduction in malondialdehyde (MDA) contents observed with decreasing the concentrations of CNTs or SiO_2-NPs treated plants compared to control plant (Fig. 4a). Generally, the values of lipid peroxidation significantly ($p<0.05$) decreased with the treatment of CNTs than those obtained by SiO_2-NPs application.

Changes in antioxidant enzymes activity: Activities of various antioxidant enzymes of soybean plants grown under sandy soil conditions and foliar treated with CNTs or SiO_2-NPs illustrated in Fig. 4b-d.

Foliar spray of soybean plants with CNTs or SiO_2-NPs grown under sandy soil conditions significantly ($p<0.05$) increased the activities of both catalase (CAT; Fig. 4b) and superoxide dismutase (SOD; Fig. 4c) compared to the corresponding control. Data clearly show that SiO_2-NPs at rate of 40 mg L^{-1} was more efficient in CAT activity than other treatments as well as 30 mg L^{-1} was more efficient than other treatments for SOD. Whereas, POX recorded a gradual decrease with the CNTs or SiO_2-NPs compared to the corresponding control (Fig. 4d).



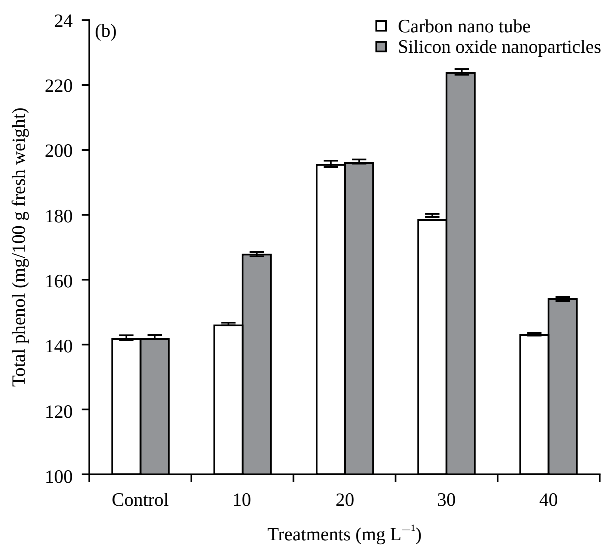


Fig. 3(a-d): Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels
(a) Indole Acetic Acid (IAA) (LSD at 5% 1.55) and (b)Total phenol contents of soybean plants (LSD at 5% 5.85), Each value represents the Mean ± standard error (n = 3)

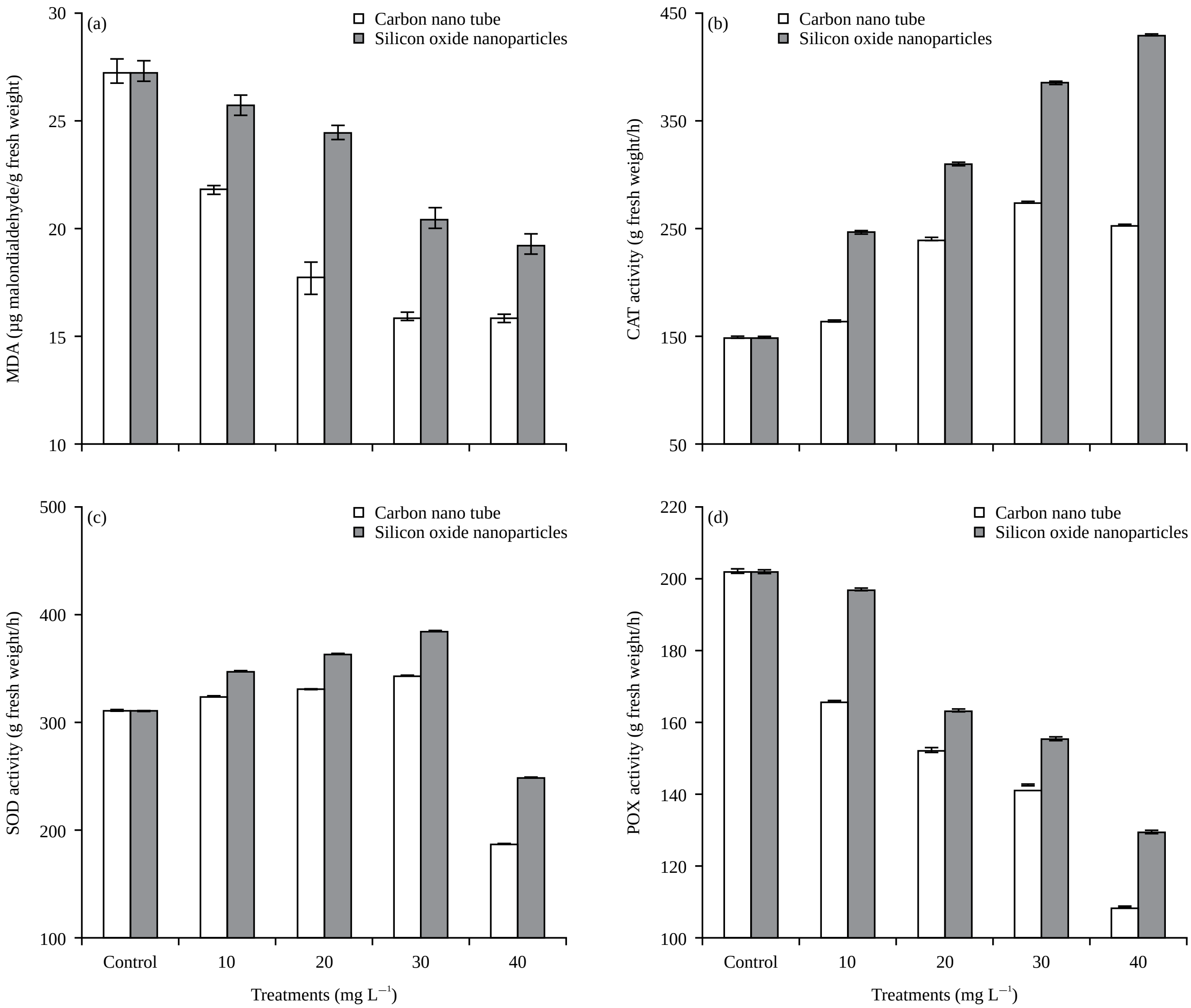


Fig. 4(a-d): Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels
(a) Lipid peroxidation and enzyme activities (LSD at 5% 0.37) (b) Catalase (CAT) (LSD at 5% 1.48), (c) Superoxide dismutase (SOD) (LSD at 5% 6.49) and (d) Peroxidase (POX) of soybean plants (LSD at 5% 8.34), Each value represents the Mean$\pm$standard error (n = 3)

Changes in seed yield and yield components: Table 3 illustrates the significant effect of various concentrations of CNTs and SiO_2-NPs on seed yield and its components of soybean under the sandy soil. The foliar application of CNTs or SiO_2-NPs induced a significant increase in all studied yield parameters (plant height, number of branches/plant, biological yield/plant, root length, root weight, number of pods/plant, the weight of 100-seeds (g) and seed yield (ton ha^{-1}) when compared to corresponding controls. SiO_2-NPs at (30 mg L^{-1}) proved to be the most effective treatment followed by CNTs at the rate of 20 mg L^{-1}.

Changes in the nutritional value of the seed yield: Table 4 shows the influence of CNTs or SiO_2-NPs on carbohydrates, protein, oil% and oil yield in seeds of the soybean. The foliar treatment of plants with various concentrations of CNTs or SiO_2-NPs raised the contents of carbohydrates, protein and oil % in seeds. The maximum increase in oil% and oil yield (kg ha^{-1}) by SiO_2-NPs at 30 mg L^{-1} and CNTs at 20 mg L^{-1} was observed in the produced seeds.

Changes in the fatty acid composition of oil samples: The results of the gas liquid chromatographic analysis of fatty acids

Table 3: Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels on yield and its components of soybean plants

Materials (mg L^{-1})	Plant height (cm)	Number of branches/plant	Biological yield/plant (g)	Root length (cm)	Root weight (g)	Number of pods/plant	Weight of 100-seeds (g)	Seed yield (ton ha^{-1})
Control	43.33±0.67	4.00±0.33	22.14±0.60	22.63±0.33	2.203±0.23	70.00±1.53	10.49±0.001	1.781±0.03
CNTs								
10	66.33±0.88	5.53±0.26	38.38±0.82	24.33±0.33	4.570±0.29	13.54±0.002	2.698±0.07	86.67±1.20
20	70.67±1.20	5.67±0.43	72.88±0.75	37.33±0.88	5.297±0.16	15.78±0.001	3.346±0.04	127.33±4.84
30	51.33±0.88	6.67±0.12	61.31±0.76	44.67±0.33	3.357±0.07	14.93±0.003	3.101±0.01	108.00±1.15
40	34.67±0.67	5.33±0.54	51.71±1.08	40.00±0.58	2.633±0.13	12.77±0.001	2.477±0.03	97.67±3.93
SiO_2-NPs								
10	48.67±0.33	5.67±0.67	34.75±0.78	23.33±0.88	2.230±0.23	13.60±0.001	3.161±0.02	81.67±0.67
20	56.33±0.67	6.67±0.26	74.65±1.03	23.00±0.58	2.723±0.13	15.14±0.001	3.967±0.04	93.00±1.53
30	75.33±0.33	7.00±0.30	85.79±1.11	46.33±0.33	5.563±0.02	17.94±0.002	4.046±0.07	130.67±1.67
40	45.33±0.67	5.33±0.37	32.99±1.44	22.33±0.33	2.087±0.05	12.50±0.001	2.717±0.03	85.33±0.88
LSD 5%	2.39	1.12	2.91	1.36	0.50	5.28	0.43	0.051

Each value represents the Mean±standard error (n = 3)

Table 4: Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels on the nutritive value of the soybean plants yielded seeds

Materials (mg L^{-1})	Carbohydrate (%)	Protein (%)	Oil (%)	Oil yield (kg ha^{-1})
Control	46.75±0.16	27.63±0.24	20.06±0.04	375.98±1.24
CNTs				
10	57.28±0.22	28.88±0.06	23.20±0.01	626.06±1.53
20	60.95±0.29	31.69±0.17	23.57±0.52	788.18±2.27
30	68.48±0.35	38.88±0.01	23.45±0.08	726.77±2.02
40	48.54±0.23	30.69±0.10	22.88±0.05	566.81±1.70
SiO_2-NPs				
10	57.23±0.46	37.75±0.35	24.06±0.11	653.23±1.23
20	64.35±0.17	34.03±0.46	22.12±0.38	762.60±0.92
30	69.69±0.17	33.75±0.52	24.41±0.24	888.94±1.45
40	54.02±0.55	26.34±0.06	23.47±0.02	563.50±1.04
LSD 5%	0.85	0.92	0.73	15.26

Each value represents the Mean±standard error (n = 3)

Table 5: Effect of Carbon Nanotubes (CNTs) and Silicon oxide Nanoparticles (SiO_2-NPs) at different levels on oil contents and its fatty acids constituents of soybean plants

		Carbon nanotubes(mg L^{-1})				Silicon oxide-NPs(mg L^{-1})			
Fatty acid	Control	10	20	30	40	10	20	30	40
Myristic C14:0	0.24	0.46	0.31	0.40	0.35	0.38	0.50	0.55	0.27
Palmitic acid C16:0	13.28	12.91	12.01	13.03	14.10	12.72	11.23	10.92	12.00
Stearic acid C18:0	6.66	6.48	5.88	5.71	5.66	5.47	5.30	5.35	5.05
Oleic acid C18:1c (MUFA)	19.76	22.85	23.80	21.14	21.48	23.76	24.13	24.92	23.27
Elaidic acid C18:1t (MUFA)	1.27	1.27	1.40	1.16	1.18	1.28	1.23	1.28	1.25
Linoleic acid C18:2 (PUFA)*	46.97	50.50	51.27	51.32	49.77	49.31	49.96	49.88	50.64
Linolenic acid C18:3 (PUFA)**	6.49	7.62	6.93	6.93	7.52	6.80	7.22	6.86	7.08
Arachidic acid C20.0	0.29	-----	0.40	0.43	---	0.41	0.43	0.67	0.44
Essential fatty acids	53.46	58.12	58.20	58.25	57.29	56.11	57.18	56.74	57.72
Unsaturated fatty acids	77.02	80.15	83.4	80.18	79.95	81.15	82.54	82.74	82.24
Saturated fatty acids	20.47	19.85	16.6	19.14	20.11	18.98	17.47	17.49	17.76
Ratio unsaturated/saturated	3.7	4.04	5.0	4.2	3.9	4.2	4.7	4.7	4.6

*Omega-6, **Omega-3, MUFA: Monounsaturated fatty acid, PUFA: Poly unsaturated fatty acid

methyl esters in oil of the soybean seeds represented in Table 5. Palmitic and stearic acids were the most predominant saturated fatty acid (13.28 and 6.66%) in control plants, while oleic, linoleic and linolenic acids were the main unsaturated fatty acids (19.76, 46.97 and 6.49%, respectively). It revealed that the different treatments with CNTs or SiO_2-NPs caused decreases in palmitic, stearic and total saturated fatty acids. The essential fatty acid omega-3 (Linolenic C18:3) and omega-6 (Linoleic C18:2) increased with all treatments used and accompanied by increases in total unsaturated fatty acids and decreased total saturated fatty acids as compared with control plants.

DISCUSSION

Certainly, the support of nanotechnology has exponentially increased in plant protection products, which may promise increased crop yield. Many morphological and physiological changes in plants are accompanied by the use of Nanoparticles (NPs) depending on its properties.

Soybean plants treated with various concentrations of CNTs or SiO_2-NPs significantly increased all morphological characters (Table 2). In this concern, in tomato plants, it was reported that the stimulated procedure of water uptake could be responsible for elevated biomass production under carbon nanotubes exposure[31]. Khodakovskaya *et al.*[6] suggested that the growth-promoting mechanism by CNT is probably linked to the capability of CNTs inactivation of genes/protein expression necessary for plant growth and its development, thus carbon nano-materials can be used as plant growth regulators. In addition, Patel *et al.*[32] mentioned that CNT work like motivators in plant growth regulation by stimulating the biosynthesis of IAA[33]. Regarding the effect of silica nanoparticles, Siddiqui and Al-Whaibi[34] and Siddiqui *et al.*[35] found that the Si-NPs increased in the growth characteristics of tomato seedlings and squash (*Cucurbita pepo* L.). Improving the uptake capability of water and fertilizers (several elements transport in the xylem)motivated the activity of some key enzymes like nitrate reductase and enhanced of IAA concentration and increased antioxidant enzyme activities[36].

The obtained results presented in (Fig. 1a-d) revealed that CNTs or SiO_2-NPs stimulated all photosynthetic pigments. In this connection, Verma *et al.*[37] found that water uptake, water transport and activated photosystem enhanced with lower concentrations of carbon nanomaterials (CNMs). Chichiriccò and Poma[38] stated that spinach plants treated with carbon nano-tubes raised electron flow and its photosynthetic activity because of the stimulating light absorption accompanied to the penetration of CNTs into the chloroplast membranes. Moreover, Giraldo *et al.*[39] found that *S. oleracea* treatment with carbon nanomaterials increased the number and size of chloroplasts and accordingly the chlorophylls and photosynthetic activities increased. Regarding the effect ofSiO_2-NPs, Suriyaprabha *et al.*[40] and Bao-shan *et al.*[41] recorded increased levels of chlorophyll content in *Zea mays* L. crop and Changbal larch seedling, respectively. Verma *et al.*[42] stated that Si fertilizer mitigated drought stress by minimizing loss of water throughout transpiration and improved light interception characteristics via keeping the leaf blade erect and improved photosynthetic parameters in sugarcane plants. Interestingly, CNTs or SiO_2-NPs treatment at a low concentration significantly increased the content of osmoprotectants (TSS, Proline, FAA and TSP)content in the leaves of soybean plants (Fig. 2a-d). In this concern, Siddiqui *et al.*[43] reported significant increases in proline, amino acid contents of carrot plants treated with 0.10 mg L^{-1} graphene oxide nanoparticles. Also, González-García *et al.*[44] found that the application of CNMs increased the content of tomato plant protein. As for Si NPs treatments, EL-Serafy[45] found significant increment in the accumulation of TSS of rose cut flowers. The increases in chlorophyll contents led to the increases of photosynthesis in plants, which result to the accumulation of soluble protein. Moreover, nano-SiO_2 found to be involved in the synthesis of proteins and amino acids[46]. Nano-SiO_2 application enhances the accumulation of proline and amino acids which finally ameliorate plant tolerance to abiotic stress[47,48].

The increase in IAA and phenol contents of soybean plants due to foliar spraying with CNTs or SiO_2-NPs (Fig. 3a and b) can be explained by the presence of CNTs which motivate the regulation of plant growth[32], since it acts as elicitors in the biosynthesis of indole acetic acid in *Brassica napus* L.[33]. In addition, silicon elements can improve plant tolerance to drought stress via regulating the levels of phytohormones[49]. The results obtained herein are in agreement with the findings of El-Bassiouny *et al.*[50] on wheat plants using ZnO-NPs.

Phenolic compounds are a chemically various set of secondary metabolites that maintains plants against different stress factors[51]. According to the obtained results, CNTs can adjust the antioxidant protection system of plants by increasing phenolic contents (Fig. 3b) and antioxidant enzyme activities (Fig. 4b-c). In this concern, Gonzalez-Garcia *et al.*[44] reported that the application of CNMs increased the content of phenols in tomato plants. Moreover, EL-Serafy[45] found that Si-NPs treatment significantly increased the accumulation of phenolic compounds in leaf epidermis compared to untreated rose cut flowers.

Application CNTs or SiO_2-NPs on soybean plants induced a significant ($p<0.05$) decrease in the accumulation of malondialdehyde (MDA) (Fig. 4a). These influences may be reflecting increased antioxidant enzyme activities (CAT and SOD; Fig. 4b and c). The MDA is an important lipid peroxidation product of oxidative damage to membrane lipids when the plant is in stress conditions of aging or injured[52]. The Si treatment showed to decrease the concentration of MDA in salt-stressed *Vitis vinifera L*[53]. In addition, Wang *et al.*[47] proved that application Si-NPs led to a decrease in the lipid peroxidation.

The activities of SOD and CAT content significantly ($p<0.05$) increased in response to all tested concentrations of both tested NPs materials (Fig. 4b and c). These results confirmed with Rong *et al.*[54] found that the activity of SOD and CAT in *Vicia faba* seedlings subjected to heavy metal stress enhanced when treated with multi-walled carbon nanotubes. Moreover, Li *et al.*[46] observed that SiO_2-NPs encourage antioxidant enzyme activities. Hashemi *et al.*[55] showed that Si decreased the inhibitory impact of stress on plant growth via enhancing CAT and peroxidase activities and preserving the membrane safety of root cells, as explained via decreased lipid peroxidation. Also, Kalteh *et al.*[48] reported that the exogenous nano-Si significantly enhances the activity of SOD, POX and CAT of faba bean.

The CNTs or SiO_2-NPs induced significant positive effect on most of the yield components of soybean plants grown under sandy soil conditions (Table 3). The increase in the seeds yield could be due to the enhancement in growth criteria and water content (Table 2), photosynthetic pigments (Fig. 1a-d), IAA content (Fig. 3a) and antioxidant enzyme activities(Fig. 4b and 4c) of treated soybean plants. The results were consistent with the research findings by Verma *et al.*[56]who reported that CNMs enhanced crop yield which dependent on the applied dose of CNMs.

In general, CNTs at low concentration enhanced water uptake transport, seed germination, photosystem and antioxidant enzyme activity; which activate water channels proteins and promote nutrition absorption. This indicates that the responses to nano-materials may be differed according to the type, dose and route of application of used CNMs[37]. Moreover, Ghorbanpour and Hadian[57] and Joshi *et al.*[58] indicated that carbon nanoparticles induced the better yield and productivity in *Satureja khuzestanica* and wheat plant, respectively. With regard to the increases in yield and its components of soybean in response to SiO_2-NPs might be because of it increases the nutrient contents, water uptake and antioxidant enzyme activities of which finally improved plant tolerance to abiotic stress[47]. Naz *et al.*[59] found that Si-NPs promoted growth and yield of *Brassica juncea* plants grown under environmental stresses. El-Naggar *et al.*[60] revealed that SiO_2-NPs can be applied as growth promoters which enhanced the growth, yield and yield components of maize plants.

Foliar spraying of CNTs or SiO_2-NPs significantly ($p<0.05$) augmented carbohydrate, protein and oil percentages in treated soybean plants yielded seeds (Table 4). In this concern, Ramadan *et al.*[61] demonstrated that spraying soybean plants either with ferric or magnesium oxides NPs induced marked increases in oil, carbohydrates and protein percentages in the seeds. Moreover, El-Bassiouny *et al.*[50] found that ZnO-NPs increased significantly the content of protein and carbohydrate percentages of yielded wheat grains. In addition, Liu *et al.*[62] found that iron nano-carbonate increased protein content in peanut. Sheykhbaglou *et al.*[12] showed that ferrous oxide nanoparticles significantly increased the nutritional compounds such as lipid and protein in soybean seeds.

From a health point of view, the present study proved that the use of CNTs or SiO_2-NPs was of positive impact on the profile of fatty acids in the oil of yielded soybean seeds (Table 4). This positive effect came clear since different treatments with both tested materials caused increases in the essential fatty acids (linolenic and linoleic). This increase is accompanied by increases in the total Unsaturated Fatty Acids (UFA) and a reduction in the total saturated fatty acids as compared with the control plants. In this domain and from the consumer health point of view, Ramadan *et al.*[63] stated that the increase in omega-3 PUFA of flax plants oil would benefit human health due to the intake of oleic, linoleic and linolenic acids which depresses the level of low-density lipoprotein in human blood. These results have conformity by Sheykhbaglou *et al.*[12] who showed that foliar spraying of soybean with 0.75 g L^{-1} of nano-Fe_2O_3 gave the most amount of linoleic acid and oleic acid in soybean seeds.

CONCLUSION

On the biochemical and physiological levels, the application of CNTs or SiO_2-NPs increased plant growth, water uptake, photosynthetic pigments, osmoprotectants, phenolic, endogenous indole acetic acid contents, antioxidant enzymes activities as well as the seed yield quantity and quality. Additionally, the decrease in the malondialdehyde level in soybean leaves confirmed a protective role of CNTs or SiO_2-NPs against cell membrane damage under sandy soil conditions. It was observed that SiO_2-NPs at 30 and CNTs at 20 mg L^{-1} were the most effective cases in seed yield as well as its nutritive value. The antioxidant defense system improved the growth and development of soybean plants which can potentially increase tolerance against various types of stress.

SIGNIFICANCE STATEMENT

The results of the article are perfect for performing on a large scale in the new lands. Since newly reclaimed sandy lands are known for their deficiency of water retention as the result of the evaporation speed due to high temperatures or quick filtration which suffers from obstruction agriculture problems, which will assist resolving the problem of human food gap.

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