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Zinc-oxide and nano ZnO oxide effects on growth, some biochemical aspects, yield quantity, and quality of flax (*Linum uitatissimum* L.) in absence and presence of compost under sandy soil

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Abstract

Background: Nanofertilizers have been provided a new efficient alternative to normal regular fertilizers. Nano-particles can help in increasing reactive points of these nanoparticles, which increases the absorption of these fertilizers in plants.

Materials and methods: Thus, a field experiment was conducted in sandy soil during two winter seasons of 2016/2017 and 2017/2018 at experimental station of National conditions, El-Behira Governorate-Egypt. The objective of this study was the effect of ZnO as normal chelated micronutrient and ZnO as nanoparticle foliar application at rates of 0, 20, 40, and 60 mg/L, with two rates of compost (0.0 and 3.00 ton/fed) on growth parameters, photosynthetic pigments, yield, and chemical analysis of flax (*Linum usitatissimum* L cv., Sakha-2) plants.

Results: The obtained results showed that adding of compost to the sandy soil by 3.0 ton/fed, increased markedly growth parameters (shoot and root length (cm), fresh and dry weights (g), photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids, and total pigments (μg/g fresh wt)), free amino acids and proline (mg/100 g dry wt), total carbohydrate percentage, yield quantity and quality (technical shoot, fruiting zone lengths and plant height (cm), No. of fruiting branches/plant and No. of capsules/plant, weight of straw (g), weight of 1000 seeds (g), biological yield (kg/fed), seed yield (kg/fed), and straw yield (kg/fed)), oil percentage, and oil yield (kg/fed) compared to control treatments (without compost). Also, the obtained data clarified that applied foliar treatment with normal ZnO with rates 40 mg/L significantly increased the yield and all parameters of flax plant during studied growing seasons. The interaction between compost addition and different concentrations of either ZnO or nano ZnO revealed that different concentrations increased different studied parameters without or with the addition of compost to sandy soil as compared with untreated plants.

Conclusion: Treatment of flax plant with ZnO and nano ZnO improved the studied growth parameters, biochemical aspects, and consequent yield in the absence and presence of compost.

Keywords: Compost, Flax, Nanoparticles, Osmoprotectants, Sandy soil, Yield, Zinc oxide

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Introduction

Flax (*Linum usitatissimum* L.) is an essential crop as it is known as the producer of two substances: linen products from fiber and edible oil from flaxseed. Flax plant is an ancient cultivated economic crop in Egypt (Bakry et al. 2012 and 2015). Flax seeds contain 30–48% of oil abundant in unsaturated fatty acids, chemical industry in drying oil (for the production of printing and other inks, varnishes, paints, and linoleum) (Sadak Mervat and Dawood 2014).

Nowadays, sustainable agriculture is an important requirement for reducing environmental pollution increased via extensive using of chemical fertilizers. In developing countries, including Egypt, the challenge faced in sustainable agriculture is more serious. Using mineral fertilizers is very essential for plant nutrition because they are easy to use and have vast absorption and utilization by plant (Lampkin 1990). These fertilizers contribute to human and animal food toxicity and environmental pollution and adversely affect chemical and physical properties of soil, ground water, fauna, and ecosystem (Camargo and Alonso 2006). Thus, it is important to use an alternative soil fertility amendment technique to get high plant growth and yield and at the same time ensure ecological sustainability.

Compost is a natural mean for enhancing fertility of agricultural land as well as increasing crop production (Ouédraogo et al. 2001). Addition of compost to soil is considered as a basis for soil microbe nutrition thus increased their activities. The increased activities of soil microbes caused release of different nutrients of compost such as nitrogen, sulfur, and phosphorus into the soil and make them available for plant use (Gliessman 2015). Compost incorporation helps in stabilization of soil aggregation thus enhance soil structure density and porosity which lead to decrease of erosion and soil run off and improved plant root environment (Saison et al. 2006). In addition, using compost improves water holding capacity (WHC) of soil as well as water availability for plant, reduce nutrient leaching, and decrease evaporation. Finally, it acts as a long-term slow release fertilizer (Hepperly et al. 2009).

Zinc (Zn) is an essential micronutrient and absorbed in the form of divalent cations, and it is important for plant growth and production. It is important in different vital physiological processes as synthesis of protein, maintenance of membrane integrity, and production of energy (Hansch and Mendel 2009). Zinc plays an essential role in biosynthesis of different plant growth hormones as auxins (Mansour 2014). In addition, zinc is important for leaf cells for chlorophyll formation (leaf green pigment) and in regulation of starch biosynthesis and root development (Wassel et al. 2007), as well as it activates some enzymes as dehydrogenases, phosphor hydrolases, peptidases, and proteases.

Nanofertilzers or nano-encapsulated nutrients might have properties that are effective to crops, released the nutrients on-demand, and controlled release of chemical fertilizers that regulate plant growth and enhanced target activity (DeRosa et al. 2010; Nair et al. 2010, and Naderi and Abedi 2012). Nanoparticles (nanoscale NSPs) are molecular accumulations ranging from 1 to 100 nm in at least one dimension (Ball 2002). Nanofertilizers were designed and offered a new effective alternative to ordinary fertilizers. Nano-particle characteristics (increased surface area) enable these nanoparticles in increasing their reactive points, which induces changes in absorption of these fertilizers in plants (Anonymous 2009).

Therefore, the objectives of this study were to compare between Zn as a normal micronutrient and ZnO as nanoparticle on growth, quantity, and quality of flax plant productivity as well as compost addition under sandy soil.

Materials and methods

Two field experiments were carried out at the experimental station of National Research Centre, Al Nubaria district El-Behira Governorate-Egypt, during two successive winter seasons of 2016/2017 and 2017/2018. Seeds of flax plant were obtained from Agricultural Research Centre, Ministry of Agriculture, Giza, Egypt. Zinc oxide or Zinc oxide nanoparticle used in the present study was supplied from Sigma-Aldrich Co.

The soil was classified as sandy soil. Mechanical, chemical, and nutritional analysis of the experimental soil is reported in Table 1 according to Chapman and Pratt (1978).

Flax seeds (*Linum usitatissimum* L. Sakha-2) were planted in sandy soil at rate of 2000 seeds/m^2 on the 25th of November in both seasons and were pulled when signs of full maturity appeared, then left on ground for suitable complete drying. Capsules were removed carefully. The experimental plot area was 3.0 m in width and 3.5 m in length including rows 3.5 m long, and the distance between rows was 20 cm apart (plot area was 10.5 m^2). The agronomic practices followed recommended flax production in Al Nubaria region. Irrigation was carried out using the new sprinkler irrigation system where water was added every 5 days. The layout of the experiment was a split plot design with three replications, to study the effect of two rates (0.0 and 3.0 ton/fed) of compost incorporated to the soil on all parameters of flax production as well as Zn as affected by four ZnO as normal chelated micronutrient and the same treatments of ZnO as nano-particle foliar application rates. The two field experiment at the growing season was consisted of 48 plots including eight

Table 1 Mechanical, chemical, and nutritional analysis of the experimental soil

Mechanical analysis												
Mechanical analysis	Sand						Silt 20-0 µ %		Clay < 2 µ %		Soil texture	
	Course 2000–200 µ%			Fine 200–20 µ %								
	47.46			36.19			12.86		4.28		Sandy	
Chemical analysis												
Chemical analysis	pH 1:2.5	EC dSm^{-1}	$CaCO_{3}$ %	OM%	Soluble cations (meq/l)				Soluble anions (meq/l)			
					Na^{+}	K^{+}	Mg^{+}	Ca^{++}	CO_{3}^{-}	HCO_{3}^{-}	Cl^{-}	SO_{4}^{-}
	8.25	0.11	0.9	0.9	0.7	0.02	0.1	0.3	0.0	0.2	0.8	0.12
Nutritional analysis												
Nutritional analysis		Available nutrients										
		Macro element (ppm)				Micro element (ppm)						
		N	P	K		Zn	Fe			Mn		Cu
		12.9	3.6	52.9		0.12	1.98			0.46		0.06

ZnO foliar application rates and two compost application rates as organic fertilizer with three replications. The compost rates were assigned to the main plots, and the ZnO as normal chelated micronutrient or ZnO as nanoparticle foliar application rates assigned to the subplots. The ZnO foliar application rates were of 20, 40, and 60 mg/L, as well as control treatment (without ZnO). Control treatments were applied using foliar application at the same volume of water without ZnO which were applied twice after 30 and 45 days from sowing in the two growing seasons. Pre-sowing, 150 kg/fed of calcium super-phosphate (15.5% P_2O_5) was used. Nitrogen was applied after emergence in the form of ammonium nitrate 33.5% at rate of 75 kg/fed in five equal doses. Potassium sulfate (48% K_2O) was added at two equal doses of 50 kg/fed. Plant samples were taken after 60 days from sowing to determine all growth characters and some biochemical parameters, including shoot length (cm), shoot fresh and dry weights (g/plant), root length (cm), root fresh and dry weights (g/plant). At harvest, randomized ten flax plants were selected from each plot including plant height (cm), fruiting zone length (cm), number of fruiting branches/plant, number of capsules/plant, seed yield/plant (g/plant), biological yield/plant (by weight of plant in g/plant), and 1000 seeds weight (g). Also, seed yield (kg/fed), straw yield (ton/fed), and biological yield (by weight of plants in m^2), and multiplying in area of fed in m^2 (kg/fed) were studied.

Chemical analysis measured photosynthetic pigments, total phenol contents, and some antioxidant enzymes such as polyphenol oxidase (PPO), peroxidase (POX), catalase (CAT), and superoxide dismutase (SOD). Plant samples were dried in an electric oven with drift fan at 70 °C for 48 h, till constant dry weight for determination of total soluble sugars (TSS), free amino acids, and proline contents.

Chemical analysis

Photosynthetic pigment contents of fresh leaves (chlorophyll a and b and carotenoids) in fresh leaves were estimated using the method of Lichtenthaler and Buschmann (2001). Plant samples were dried in an electric oven with drift fan at 70 °C for 48 h till constant dry weight for determination of total soluble sugars (TSS), free amino acids, and proline contents. Total phenol content was measured as described by Danil and George (1972). Total soluble sugars (TSS) were extracted by the method of Homme et al. 1992 and analyzed using Spekol Spectrocolorimeter VEB Carl Zeiss (Yemm and Willis 1954). Free amino acids were extracted according to Vartainan et al. (1992) and estimated according to Yemm and Cocking (1955). Proline was extracted as free amino acid and assayed according to Bates et al. (1973). Seed oil content was determined using a Soxhlet apparatus and petroleum ether (40–60 °C) according to A.O.A.C. (1990).

The obtained data were statistically analyzed on randomized complete block design, RCBD, under split plot system according to Snedecor and Cochran (1990). Means were compared by using least significant differences (LSD) at 5% level of probability.

Results

Changes on growth criteria

Effect of compost application

Data in Table 2 show that adding compost at rate 3.0 ton/fed markedly increased all growth criteria of flax plants of the growing seasons. Results demonstrated that addition of compost to sandy soil increased markedly

Table 2 Effect of compost application (0.0 and 3.0 ton/fed) on growth criteria of flax plant under sandy soil (data are means of two seasons)

Growth characters	Compost rate (ton/fed)		
	0.0	3.0	LSD at 0.05
Shoot length (cm)	62.13	63.88	NS
Shoot fresh weight (g)	3.99	4.21	NS
Shoot dry weight (g)	0.34	0.47	NS
Root length (cm)	12.79	13.50	NS
Root fresh weight (g)	0.90	0.92	0.01
Root dry weight (g)	0.11	0.12	NS

shoot and root length, fresh and dry weights of shoot, and dry weight of root compared with those plants without compost addition. Meanwhile, addition of compost caused significant and marked increases in fresh weight of root.

Effect of ZnO or nano ZnO foliar application rates

Growth parameters of flax plants as influenced by the either ZnO or nano ZnO foliar application rates are shown in Table 3. Different concentrations of ZnO or nano ZnO (20, 40, and 60 mg/l) increased markedly shoot and root length, and shoot and root fresh and dry weight of flax plant as compared with untreated plants. Data clearly show that 60 mg/L was the most effective concentration of ZnO on most of growth parameters. Meanwhile, 40 mg/L was the most effective treatment on plants treated with nano ZnO compared with the other used concentrations.

Effect of interaction between compost and different concentrations of ZnO and nano ZnO

The effect of different concentrations of ZnO or nano ZnO on growth parameters of flax plant grown with or without compost amended to soil are presented in Table 4. Different concentrations of ZnO or nano ZnO (0, 20, 40, and 60 mg/L) increased markedly shoot and root length, shoot and root fresh and dry weight of flax plant as compared with untreated plants either of plants grown in soil without or with compost amended to soil. Data clearly show that 60 mg/L was the most effective concentration of ZnO or nano ZnO on most of growth parameters of plant grown without compost addition to soil. Meanwhile, 40 mg/L was the most effective treatment on plants grown in soil with compost addition in most studied parameters.

Changes in yield and yield components

Effect of compost

Data presented in Table 5 show the effect of addition of compost with the rate of 3.0 ton/fed on yield and yield components of flax plants grown under sandy soil. Data show that plants grown in soil without the addition of compost show marked increases in technical shoot and fruiting zone length, plant height. Meanwhile, addition of compost increased significantly fruiting branches and number of capsules/plant, biological yield/plant, straw yield/plant, 1000 seeds weight, seeds yield ton/fed, oil yield ton/fed, biological yield ton/fed, and straw yield/fed.

Effect of ZnO or nano ZnO foliar application rates

The effect of foliar treatment of either ZnO with different concentrations (0.0, 20, 40, and 60 mg/L) or nano ZnO (0.0, 20, 40, and 60 mg/L) on flax plant is presented in Table 6. Increasing concentrations of ZnO or nano ZnO caused gradual increases in different yield parameters as compared with control plants (Table 6). Foliar treatment of 60 mg/L was the most effective concentration as it increased 1000 seeds wt; oil percentage; and seed, oil, biological, and straw yield/fed either in plants treated with ZnO or nano ZnO.

Table 3 Effect of ZnO or nano ZnO (0, 20, 40, and 60 mg/l) on growth criteria of flax plant under sandy soil (data are means of two seasons)

Growth criteria	Treatments (mg/l)	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)
ZnO	Control	57.67	5.31	0.39	11.00	0.30	0.05
	20	60.33	4.36	0.48	12.17	0.84	0.08
	40	65.00	3.6	0.28	13.17	1.20	0.17
	60	65.50	2.68	0.2	14.83	1.28	0.13
Nano ZnO	Control	54.67	3.34	0.21	11.00	0.47	0.03
	20	58.33	5.99	0.87	11.67	0.69	0.09
	40	70.17	2.61	0.24	12.83	1.72	0.25
	60	64.33	2.1	0.56	10.5	0.82	0.12
LSD at 0.05		3.03	0.94	0.22	1.31	0.26	0.05

Table 4 Effect of compost (0.0 or 3.0 ton/fed) and/or ZnO or nano ZnO (0, 20, 40, and 60 mg/l) on growth criteria of flax plant under sandy soil

Compost	Treatment (mg/L)	Conc (mg/l)	Shoot length (cm)	Fresh wt (g)	Dry wt (g)	Root length (cm)	Root fresh wt (g)	Dry wt (g)
0.00	**ZnO**	0.0	54.67	1.22	0.21	11.00	0.30	0.05
		20	59.67	1.90	0.34	11.67	0.70	0.06
		40	59.67	2.32	0.38	12.33	1.04	0.17
		60	66.67	2.98	0.51	16.00	1.19	0.13
	Nano ZnO	20	57.00	3.18	0.44	12.67	0.97	0.12
		40	61.33	3.76	0.57	14.00	1.35	0.17
		60	62.00	5.31	0.56	16.67	1.36	0.12
3.00	**ZnO**	0.0	57.67	1.31	0.39	11.00	0.47	0.13
		20	61.00	3.34	0.51	13.00	0.85	0.29
		40	78.67	4.33	0.58	13.33	1.61	0.40
		60	67.00	3.67	0.65	14.33	1.77	0.44
	Nano ZnO	20	59.67	3.66	0.53	11.33	0.53	0.14
		40	70.67	9.31	1.30	11.33	0.82	0.26
		60	64.00	5.31	0.86	11.67	0.86	0.29
LSD at 0.05			4.28	1.32	0.31	1.85	0.36	0.17

Effect of interaction between compost and foliar treatment of normal ZnO or nano ZnO different concentrations

The effect of foliar treatment of normal ZnO or nano ZnO with different concentrations (0.0, 20, 40, and 60 mg/l) to flax plant grown in sandy soil without or with compost addition is presented in Table 7. Addition of compost increased different yield attributes (Table 7) as compared with those plants grown without compost addition. Increasing concentrations of either normal ZnO or nano ZnO caused marked increases in different yield parameters as compared with control plants either without or with compost addition (Table 7). Forty milligrams per liter normal ZnO was the most effective treatment in increasing different yield parameters of flax plant without compost addition. Meanwhile, 60 mg/L nano-ZnO is the most effective concentration on flax plant without compost addition. With the addition of compost to sandy soil, 60 mg/L is the most effective concentration on most yield parameters.

Table 5 Effect of compost with the rate of (3.0 ton/fed) on yield and yield components of flax plant under sandy soil (data are means of two seasons)

Yield characters	Compost rate (ton/fed)		
	0.0	3.0	LSD at 0.05
Technical shoot length (cm)	49.96	47.75	NS
Fruiting zone length (cm)	17.25	16.58	NS
Plant height (cm)	67.21	64.33	NS
No of Fruiting branches/plant	8.79	9.29	NS
No of capsules/plant	26.08	38.54	1.47
Biological yield/plant (g)	1.89	3.42	0.21
Seed yield/plant (g)	0.97	1.92	0.23
Straw yield/plant (g)	0.92	1.50	0.36
1000 seeds wt. (g)	7.48	9.84	0.31
Seed yield (kg/fed)	439.67	492.92	9.43
Oil yield (kg/fed)	148.67	171.52	0.77
Biological yield (kg/fed)	2327.99	2720.05	7.86
Straw yield (kg/fed)	1888.32	2227.14	1.57
Oil %	33.53	34.53	0.43

Table 7 shows that increasing concentrations of both normal ZnO or nano ZnO caused marked increases in straw yield/plant; 1000 seeds wt; oil percentage; and seeds, oil, biological, and straw yield/fed of flax plant as compared with control plants either without or with compost addition (Table 7). Sixty milligrams per liter normal ZnO or nano ZnO was the most effective treatment in increasing different yield parameters of flax plant without or with compost addition. Except straw wt/plant, 40 mg/l is the most effective concentration on flax plant without or with compost addition.

Changes in photosynthetic pigments

Effect of compost

The effect of addition of compost to sandy soil with the rate of 3 tons/fed on photosynthetic pigments are presented in Table 8. Data clearly show that compost treatment caused significant increases in different photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids, and consequently total pigment) as compared with plants grown in soil without compost. The percentage of increase in compost-treated plants in

Table 6 Effect of ZnO or nano ZnO different concentrations (0, 20, 40, and 60 mg/l) on yield and yield components of flax plant under sandy soil (data are means of two seasons)

Yield characters	Conc (mg/L)							
	ZnO				Nano ZnO			LSD at 0.05
	Control	20	40	60	20	40	60	
Technical shoot length (cm)	43.00	49.67	52.67	54.50	46.17	51.67	45.50	3.02
Fruiting zone length (cm)	16.67	17.67	18.00	16.67	15.50	21.67	19.83	2.33
Plant height (cm)	59.67	67.33	70.67	71.17	61.67	73.33	65.33	3.67
No of Fruiting branches/plant	6.67	10.17	10.33	8.00	10.67	8.67	11.50	1.43
No of capsules/plant	21.33	28.00	28.83	26.17	36.00	41.67	50.17	3.55
Biological yield/plant (g)	1.24	2.03	2.64	1.65	2.37	2.92	2.72	0.34
Seed yield/plant (g)	0.51	1.02	1.19	1.16	0.82	1.11	1.10	0.12
Straw yield/plant (g)	0.73	1.01	1.45	0.50	1.55	1.81	1.62	0.32
1000 seeds wt. (g)	6.56	7.21	7.83	8.32	7.52	8.12	8.87	0.20
Oil %	31.20	33.12	34.68	35.13	33.94	35.28	36.14	0.34
Seed yield (kg/fed)	314.06	430.20	487.20	527.20	421.20	571.40	634.34	5.25
Oil yield (kg/fed)	97.99	142.63	168.84	185.25	142.88	201.26	229.04	2.28
Biological yield (kg/fed)	1284.20	2118.25	2592.10	3317.40	2309.95	3488.70	3681.55	7.54
Straw yield (kg/fed)	970.14	1688.05	2104.90	2790.20	1888.75	2917.30	3047.21	7.65

chlorophyll a, chlorophyll b, carotenoids, and total pigments were 11.76%, 4.61%, 4.44%, and 8.30% respectively as compared with those plants grown without compost addition.

Effect of ZnO or nano ZnO foliar application rates

With regard to the effect of foliar treatment of ZnO with different concentrations (0, 20, 40, and 60 mg/L), data presented in Table 9 show the stimulatory effect of either ZnO or nano ZnO on increasing different photosynthetic pigments as compared with untreated controls. Data clearly show that 40 mg/L was the most effective concentration on increasing different photosynthetic pigment content either ZnO or nano ZnO treatment as it caused highest increases in all photosynthetic pigments (Chl a, Chlo b, carotenoids, and total pigments).

Effect of interaction of compost and/or different concentrations of ZnO or nano ZnO

With regard to the effect of foliar treatment of ZnO or nano ZnO with different concentrations (0.0, 20, 40, and 60 mg/l), data presented in Table 10 show the stimulatory effect of either ZnO or nano ZnO different concentrations (20, 40, and 60 mg/L) on increasing different chlorophyll a, chlorophyll b, carotenoids, and consequently total pigments as compared with untreated controls either without or with the addition of compost to sandy soil. Data clearly show that nano ZnO is more effective than ZnO foliar treatment as it caused the highest increases in all photosynthetic pigments (Chl a, Chlo b, carotenoids, and total pigments).

Changes in free amino acids, proline, and total carbohydrates

Effect of compost

Addition of compost to sandy soil increased significantly free amino acids, proline, and total carbohydrates of flax shoot as compared with those plants grown without addition of compost (Table 11). The percentage of increases reached to 32.84% in free amino acids, 22.32% in proline, and 11.84% in total carbohydrates of flax plant.

Effect of ZnO or nano ZnO foliar application rates

Foliar treatment of ZnO or nano ZnO with different concentrations (0.0, 20, 40, and 60 mg/L) to flax plant increased significantly and gradually free amino acids, proline, and total carbohydrates of flax plants either with the addition of compost or without compost as compared with the corresponding controls (Table 12).

Effect of interaction between compost and foliar treatment of ZnO or nano ZnO different concentrations

Foliar treatment of ZnO or nano ZnO with different concentrations (20, 40, and 60 mg/L) to flax plant increased significantly and gradually free amino acids, proline, and total carbohydrates of flax plants either with the addition of compost or without compost as compared with their corresponding controls (Table 13). Sixty milligrams per liter of both ZnO and nano ZnO was the most effective treatment as it gave the highest contents of free amino acid, proline, and total carbohydrates of flax plant.

Table 7 Effect of interaction of compost and/or ZnO and nano ZnO different concentrations (0, 20, 40, and 60 mg/l) on yield and yield components of flax plant under sandy soil (data are means of two seasons)

Compost	Treatment	Conc	Technical shoot length (cm)	Fruiting zone length (cm)	Plant height (cm)	No. of Fruiting branches/plant	No. of capsules/ plant	Biological yield/plant (g)	Seed yield/ plant (g)
0.00	Zn O	0.0	43.00	16.67	59.67	6.67	21.33	1.24	0.51
		20	54.00	17.33	71.33	8.33	23.33	1.87	0.99
		40	53.67	19.67	73.33	14.00	29.33	2.51	1.12
		60	48.67	16.67	65.33	7.00	27.33	1.75	1.09
	Nano ZnO	20	45.33	18.00	63.33	9.00	25.67	2.56	1.05
		40	51.67	16.33	68.00	9.67	28.33	2.02	1.22
		60	60.33	16.67	77.00	12.00	32.00	2.56	1.27
3.0	ZnO	0.0	43.67	16.33	60.00	6.33	26.33	1.65	0.64
		20	52.00	18.00	70.00	7.67	35.33	2.19	0.80
		40	58.67	18.67	74.33	11.00	35.33	2.64	1.04
		60	47.67	25.33	73.00	11.33	55.33	2.66	1.18
	Nano Zn	20	53.33	18.00	71.33	8.33	36.67	2.56	0.85
		40	56.67	24.67	81.33	9.67	48.00	3.21	1.18
		60	55.33	18.33	73.66	11.67	45.00	2.77	1.02
LSD at 0.05			4.28	3.30	5.18	2.02	5.02	0.48	0.17

Compost	ZnO	Conc (mg/l)	Straw yield/plant (g)	1000 seeds wt. (g)	Oil %	Seed yield (kg/fed)	Oil yield (kg/ fed)	Biological yield (kg/fed)	Straw yield (kg/fed)
0.00	ZnO	Control	0.73	6.56	31.20	303.40	94.66	1288.40	985.00
		20	0.87	7.50	33.74	456.32	153.95	2167.80	1711.48
		40	1.39	7.98	35.55	475.00	168.86	2519.80	2044.80
		60	0.66	8.37	35.88	531.40	190.66	3269.30	2737.90
	Nano ZnO	20	1.15	6.92	32.50	404.08	131.31	2068.70	1664.62
		40	1.51	7.67	33.81	499.40	168.82	2664.40	2165.00
		60	1.31	8.27	34.39	523.00	179.83	3365.50	2842.50
3.00	ZnO	Control	1.01	6.85	32.75	344.72	112.89	1400.00	1055.28
		20	1.39	7.49	33.62	443.00	148.91	2538.10	2095.10
		40	1.60	7.98	34.74	635.40	220.71	4184.10	3548.70
		60	1.49	8.59	35.37	664.60	235.09	4025.10	3360.50
	Nano ZnO	20	1.71	7.55	34.27	399.40	136.85	2081.80	1682.40
		40	2.03	8.25	35.83	507.40	181.80	2793.30	2285.90
		60	1.75	9.15	36.92	604.08	223.00	3338.00	2733.92
LSD at 0.05			0.45	0.28	0.47	7.42	3.22	10.66	10.82

Table 8 Effect of compost addition to soil (0.00 and 3.0 tons/ fed) on photosynthetic pigments (μg/g fresh wt) of flax leaves under sandy soil

Compost	0.00	3.00	LSD at 0.05
Chlorophyll a	1.19	1.33	0.02
Chlorophyll b	0.716	0.749	0.003
Carotenoids	0.383	0.400	0.001
Total pigments	2.29	2.48	0.02

Table 9 Effect of ZnO or nano ZnO different concentrations on photosynthetic pigments (μg/g fresh wt) of flax leaves under sandy soil

Treatments	ZnO				Nano ZnO			LSD at 0.05
	Control	20	40	60	20	40	60	
Chlorophyll a	1.06	1.19	1.29	1.22	1.35	1.38	1.30	0.02
Chlorophyll b	0.69	0.72	0.75	0.71	0.76	0.76	0.73	0.02
Carotenoids	0.37	0.39	0.40	0.38	0.41	0.41	0.39	0.01
Total pigments	2.12	2.30	2.44	2.31	2.51	2.55	2.42	0.03

Table 10 Effect of compost and/or ZnO or nano ZnO different concentrations on photosynthetic pigments (μg/g fresh wt) of flax leaves under sandy soil

Compost (ton/fed)	Treatment	Conc (mg/L)	Chl a	Chlo b	Carotenoids	Total pigments
0.00	ZnO	0.0	1.06	0.69	0.37	2.12
		20	1.16	0.70	0.37	2.23
		40	1.29	0.73	0.39	2.41
		60	1.16	0.70	0.37	2.23
	Nano ZnO	20	1.22	0.74	0.40	2.36
		40	1.29	0.77	0.41	2.47
		60	1.29	0.72	0.38	2.39
3.00	Zn SO	0.0	1.29	0.71	0.38	2.38
		20	1.35	0.74	0.42	2.51
		40	1.35	0.72	0.40	2.47
		60	1.31	0.72	0.40	2.43
	Nano ZnO	20	1.34	0.73	0.39	2.46
		40	1.41	0.81	0.43	2.65
		60	1.30	0.75	0.40	2.45
LSD at 0.05			0.02	0.03	0.01	0.04

Discussion

Sandy soil tends to have large particles and has a gritty texture and low water and nutrient availability that affect adversely on plant growth. Compost amended to sandy soil improves water retention thus dissolve nutrients to enhance sandy soil structure (Rosen and Bierman 2005). Compost addition to sandy soil increased growth criteria and yield attributes of flax plant (Tables 2 and 3). These obtained data are in accordance with those obtained earlier by Oworu et al. (2010) on amaranths, Masarirambi et al. (2010) on red lettuce, Abou-El-Hassan and Desoky (2013) and Kortei and Quansah (2016) on lettuce, Afriyie and Amoabeng (2017) on radish, Babaeia et al. (2017) on wheat plant, and Coelho et al. (2018) on maize plant. These increases in different growth parameters and yield attributes in response to compost addition to soil might be due to the direct effect of compost in supplying different required nutrients to plant thus improving fertility of soil as well as acting as conditioning for soil in addition to the indirect effect resulted from the high quantity of microorganisms that increase availability of nutrient to plant such as nitrogen, sulfur, phosphorus, manganese, and micronutrient. Moreover, those microorganisms secrete a lot of exudates and metabolites that act as plant growth regulators (Marschner et al. 2012). In addition, using of compost can be an excellent opportunity to increase crop yield. The term "plant-growth promoting-fungi" was established to designate some rhizosphere fungi able to promote a direct effect on plant growth upon root colonization or by the treatment with their metabolites (Hossain et al. 2014; Gomaa et al. 2015). Gomaa et al. (2015) found that soil impact with compost significantly increased the yield component of maize plant under water stress.

Table 11 Effect of compost addition to soil (0.00 and 3.0 tons/fed) on free amino acids, proline (mg/100 g dry wt), and total carbohydrate percentage of flax shoots under sandy soil

Compost	0.00	3.00	LSD 0.05
Free amino acids	250.36	332.57	0.95
Proline	63.63	77.83	0.39
Total carbohydrates	40.38	45.16	0.20

Compost inoculation enhanced photosynthetic pigments of flax plant over those plants grown without compost addition (Table 8). In agreement with this result, Rady et al. 2016 and Kortei and Quansah (2016) found that compost addition to soil increased photosynthetic pigment on common bean and lettuce plants, respectively. This stimulating effect of compost is consistent with compost effects on stomatal opening. As well as, the processes involved of compost lead to increased rates of photosynthesis and of carbon compounds to the plants (Finlay and Söderström 1992) and increase the contents of chlorophyll which increase the rate of photosynthesis and carbohydrate synthesis (Swaefy et al. 2007). Moreover, the increases in chlorophyll contents might be attributed to the content of mutant *penicillium* in compost which improve photosynthetic pigment content (Nguyen et al. 2012). Moreover, addition of compost induced an increase in the rate of the uptake of elemental K and other nutrient elements and thus increases in chlorophyll content (Marschner 1995).

Table 12 Effect of ZnO and nano ZnO levels (0, 20, 40, and 60 mg/l) on free amino acids, proline (mg/100 g dry wt), and total carbohydrate percentage of flax leaves under sandy soil

Compost	ZnO				Nano ZnO			LSD at 0.05
Treatments	0.0	20	40	60	20	40	60	0.05
Free amino acids	215.65	243.75	263.41	278.65	320.75	348.67	364.70	0.60
Proline	48.72	60.76	70.84	74.21	76.94	82.19	90.70	0.26
Total carbohydrates	35.82	37.97	40.47	47.24	41.30	48.09	54.60	0.30

With respect to the effect of compost on the content of free amino acids, proline, and total carbohydrates of flax plants, the obtained data reveal that compost addition to sandy soil improved the abovementioned parameters of flax plant (Table 11). Those results are in good agreement with those obtained on Iris (Ali 2005), flax (Bakry et al. 2013), and mustard (Mondal et al. 2017). The increased levels of the abovementioned parameters might be attributed with the increased levels of photosynthetic pigments thus leading to production of increased amount of photosynthate in the leaves. The results also reveal that biofertilizers have pronounced influence on biosynthesis of carbohydrates in leaves (Rao et al. 2007). As well as for regulating the osmotic balance of crop plants synthesis and accumulate of secondary metabolites as proline in leaves, our finding supports the earlier finding of Sheteawi and Tawfik (2007)

The effect of foliar treatment of ZnO or nano ZnO on growth criteria and yield attributes of flax plant grown under sandy soil are presented in Tables 3 and 6. Foliar treatment with ZnO increased shoot and root length, root fresh and dry weight; this increases were non-significant in fresh and dry weight of flax plant compared with nano ZnO. Meanwhile, nano ZnO foliar treatment increased non-significantly fresh wt of shoot and significantly shoot dry wt of flax plant compared with ZnO. In agreement with our obtained results, Atteya et al. (2018) and Gheith et al. (2018) stated that zinc treatment increased growth and yield parameters of jojoba and maize plants. Prasad et al. (2012) suggested that ZnO NPs are absorbed by plants to a larger extent as compared to $ZnSO_4$. They also observed the beneficial effects of nanoparticles in enhancing plant growth, development, and yield in peanut at lower doses, but at higher concentrations, ZnO nanoparticles were detrimental just as the bulk nutrients. Mahajan et al. (2011) stated that ZnO NPs promoted the root and shoot length and root and shoot biomass. In this concern, Prasad et al. (2012) stated that zinc oxide have potential to promote yield and growth of some crops. They added that zinc oxide nanoscale treatment (25 nm mean particle size) at 1000 ppm concentration promoted seed germination and plant growth in peanuts. In this concern, Tawfik et al. (2017) stated that nano Zn increased growth parameters of *Atriplex halimus*. Naderi and Abedi (2012) stated that the increase in vegetative

Table 13 Effect of interaction between compost and ZnO or nano ZnO different concentrations (0, 20, 40, and 60 mg/l) on free amino acids, proline (mg/100 g dry wt.), and total carbohydrate percentage of flax leaves under sandy soil

Compost	Treatment	Conc (mg/l)	Free amino acids	Proline	Total carbohydrates
0.00	ZnO	0.0	215.65	48.72	35.82
		20	248.15	62.83	37.40
		40	265.19	74.19	38.33
		60	279.90	75.40	42.15
	Nano ZnO	20	239.35	58.70	38.55
		40	261.64	67.49	42.62
		60	277.40	73.02	52.34
3.00	ZnO	0.0	296.18	61.49	36.65
		20	312.35	75.30	39.90
		40	335.59	82.14	43.09
		60	352.15	89.70	46.75
	Nano ZnO	20	329.15	78.59	42.70
		40	361.75	82.25	53.09
		60	377.25	91.70	62.45
LSD 0.05			0.85	0.36	0.43

growth in plant can be due to fundamental role of Zn in protecting and maintaining structural stability of cell membranes. Cakmak (2000) added that Zn could be used in protein synthesis, membrane function, cell elongation as well as tolerance to environmental stresses. With respect to the effect of Zn on yield and yield components, these results are consistent with those stated by Asadazade et al. (2015) on sunflower plant. The increases in yield parameters of flax plant might be attributed to the increase in growth parameters and photosynthetic pigment contents, thus increase in all substances and bio constituent synthesis and their translocation from leaf and different organs of plants up to seed production. The stimulated effect of nano Zn on increasing yield of flax plant is inconsistent earlier by many authors as Feizi et al. (2010) and Asadazade et al. (2015).

With respect of Zn effect on photosynthetic pigments, similar results were obtained by Franklin et al. 2007, Mady 2009, Saad 2015, and Sofy 2016. Moreover, Fletcher et al. (2000) showed that the cytokine level increase was concurrent with enhanced biosynthesis of chlorophyll. Such increase in photosynthetic pigment content in the leaves of plants may be attributed to the enhancing effect of ZnO on chlorophyll accumulation through the useful role of Zn on plant growth. Raliya and Tarafdar (2013) reported that ZnO NPs induced a significant improvement in chlorophyll synthesis. With regard to Zn nanoparticles treatment, these obtained results are in harmony with those obtained by Weisany et al. 2011, Soliman et al. 2015, Babaeia et al. 2017, and Tawfik et al. 2017. Moreover, Abdel Latef et al. (2016) showed that exogenous application of ZnO NPs improves photosynthetic pigments of lupine plant; they reflected these increases to the role of Zn element in keeping chlorophyll synthesis via protection of sulfhydryl group. According to Govorov and Carmeli (2007), metal nanoparticles can induce the efficiency of chemical energy production in photosynthetic systems. However, higher content of photosynthetic pigments, i.e., chlorophyll a, chlorophyll b, and carotenoids, would increase the rate of photosynthesis; due to which, there was more production of photosynthesis process, which in turn increased the weight and growth of plant as it was observed in our study (Tawfik et al. 2017).

Regarding the effect of Zn foliar treatment either ZnO or nano ZnO on free amino acids, proline, and total carbohydrates contents of flax plant. Data show that either ZnO or nano with different concentrations increase free amino acids, proline, and total carbohydrates of flax plant. These obtained results are in harmony with those obtained by Weisany et al. (2012) and Babaeia et al. (2017). In this concern, Helaly et al. (2014) stated that ZnO NPs induced proline synthesis and improved tolerance to abiotic stress. Proline, free amino acids, and total soluble sugar contents of plant cells play an important role in osmotic adjustment under stress thus protecting macromolecule structure and membranes of cell. With respect with total carbohydrates, these increases in response to different treatments were reported earlier by Alloway (2008); he stated that zinc is an important micronutrient for metabolism of different macromolecules of cell as protein, carbohydrate, auxin biosynthesis, and integrity of membrane. As well as, Zn plays an important role in carbohydrate biosynthesis and structure of enzymes involved in amino acid formation (Soliman et al. 2015).

Conclusion

From the present study, it could be concluded that addition of compost to sandy soil increased growth, some biochemical aspects, and yield attributes of flax plant. In comparison, between foliar treatment of either normal ZnO or nano ZnO effect on enhancing growth and yield of flax plant, data clearly show that both of normal ZnO or nano ZnO have stimulating effects on growth and yield of flax plant via enhancement of photosynthetic pigments, free amino acids, and carbohydrates of flax plant. The interaction between compost addition to sandy soil and foliar treatment of either normal ZnO or nano ZnO has a synergistic effect on growth and yield of flax plant.

Abbreviations

ZnO: Zinc oxide; ZnO nano: Zinc oxide nanoparticles; WHC: Water holding capacity; TSS: Total soluble sugars; PPO: Polyphenol oxidase; POX: Peroxidase; CAT: Catalase; SOD: Superoxide dismutase

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Authors' contributions

Mervat Sh Sadak designed and performed the experiment, responsible for all the physiological and biochemical analysis, and also wrote and reviewed the manuscript. Bakry A Bakry contributed to the design and farming plants and responsible for statistical analysis. All authors shared in every step of this work, and all of them contributed in writing the manuscript. All authors wrote, read, reviewed, and approved the final manuscript.

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