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Growth and Productivity of Garden Pea (*Pisumsativum* L.) as Affected by Foliar Application of Carbon Nanotubes (CNT) and Zinc Oxide Nanoparticles (ZnO NPs)

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Abstract

A field experiment was conducted to evaluation the garden pea (*Pisumsativum* L.) cvMaster Bresponse to the foliar application of carbon nanotube (CNT) or zinc oxide nanoparticles (ZnO NPs) during two consecutive winter seasons (2016/2017 and 2017/2018). CNT and ZnO NPs were sprayed three times at a week-intervals starting at thethree true-leaf stage. Three different doses were used (100, 150 and 200 ppm), in addition to, untreatedplants (control). Generally, the datarevealed that treated plants were superior to the control (untreated) onesin both seasons concerning total pod yield, total chlorophyll ($\mu g/cm^2$), 50% flowering (days), weight of 100-seed (g), average green-pod weight (g) and total number of green-pods per plant. The highest total pod yield/feddan was produced by the pea plants sprayed with ZnO NPs at concentration of 100 ppm. The second highest total pod yield/ feddanexhibited by plants sprayed with 150 ppm CNT. Stem length (cm), number of branches per plant, days to the first flower, green pod length (cm) and weight of dry seeds for the treated versus untreated plants exhibited inconsistent significance considering the two years. However, average number of seeds per pod was not significant in both years. It is concluded that CNT and ZnO NPs seem to hold a promise for enhancing pea crop productivity. Here, the total pod yield was elevated by as high as 190% relative to the untreated control.

Keywords: *Carbon nanotube, crop productivity, pea, Pisumsativum, nanotechnology, zinc oxide nanoparticles.*

Introduction

Pea (*Pisumsativum* L.) is one of the most important leguminous vegetable crops grown during winter season in Egypt for local consumption and exportation. The pods of pea contain a great amount of protein and carbohydrates and, therefore pea is considered as one of the most important sources of human nutrition (Zaghloul *et al*., 2015). Nanotechnology has the potential to improve global food production and food quality through increased plant protection against diseases and pests, monitoring plant growth and strengthening agriculture sustainability (Frewer *et al*., 2011; Gruère *et al*. 2011; Biswal *et al*., 2012; Ditta, 2012; Prasad *et al*., 2012; Sonkaria *et al*., 2012; Pérez-de-Luque and Hermosín, 2013).

Nanotechnology offers a prominent position in transforming agriculture by improving existing crop management techniques and food production practices (Elkady and Shokry., 2015). Carbon nanotubes (CNT) in many cases can penetrate the seed coat and plant cell wall which depends on their size, concentration and solubility. The penetration of carbon nanotubes into the plant system can bring changes in metabolic functions leading to an increase in biomass and yield) Husen and Siddiqi, 2014). It has been reported (Raliya, 2013) that that ZnO NPs induce a significant improvement in guar or lond bean (*Cyamopsistetragonoloba*) plant biomass, shoot and root growth, root area, chlorophyll and protein synthesis, rhizospheric microbial population, acid phosphatase, alkaline phosphatase and phytase activity in cluster bean rhizosphere.

It is evident from the correlative light and scanning microscope, and inductive coupled plasma/atomic emission spectroscopy that seedling roots of mung bean *(Vignaradiate)* and chickpea or chick peas (*Cicer-arietinum*) absorbed ZnO NPs and promoted the root and shoot length, and root and shoot biomass (Mahajan *et al*., 2011). Furthermore, Prasad *et al*. (2012) recorded that Nano ZnO have positive impact on germination, growth, and yield of peanut *(Arachishypogaea)*. The present investigation was implemented to assess effects of CNT and ZnO NPs foliar applications on pea pod yield and some of its major components.

Materials and Methods

The current study was carried out at private farm in Halafee, Ballina City, Sohag, Egypt (26° 3′ 0″ N and 32° 15′ 0″ E), during two successive seasons (2016/2017 and 2017/2018). The soil in the experiment site was sand clay loam and its main physical and chemical characteristics are shown in Table (1). The commercial pea (*Pisumsativum* L.) cv. master B. is described as being high yielding cv. Responses of podyield and some main related traits to the application of carbon nanotube (CNT) and zinc oxide nanoparticles (ZnO NPs) were assessed for pea plants grown on November 21, in both 2016 and 2017). The CNT and ZnO NPs were provided by Dr. N. A. Youness, Al-Azhar Univ., Assiut branch.

Table 1. Some main physical and chemical properties of the samples taken from soil during the two study seasons.

Characteristic	Value	Characteristic	Value
O.M.%	0.0062	Mg^{+2}	0.036%
$CaCO_3$%	1.62	Na^{+}	6.5
Sand%	55.2%	K^{+}	0.035
Silt %	20.8%	Available (ppm)	
Clay%	24%	NH_4	48.0
Texture class	Sand Clay loam	N	0.032%
pH	7.4	P	0.0054%
EC (dS/m)	2.4	Zn	2.5
Cl	0.355	Ca^{+2}	0.03%

Treatment and Experiment Design

CNT and ZnO NPs were applied as foliage spray with doses 100, 150, and 200 ppm of CNT or ZnO NPs. The spray was done three times weekly starting at threetrue-leaf stage. The control plants were untreated. The seven treatments (untreated control plus 6 foliage spray concentrations) were studied in a randomized complete-block experiment with three replicates. Seeds of master B cv were planted 15 cm apart on the northern side of 3.5 m long and 50 cm wide ridges. Characterization of CNT and ZnO nanoparticles are presented in Figures (1 to 4).

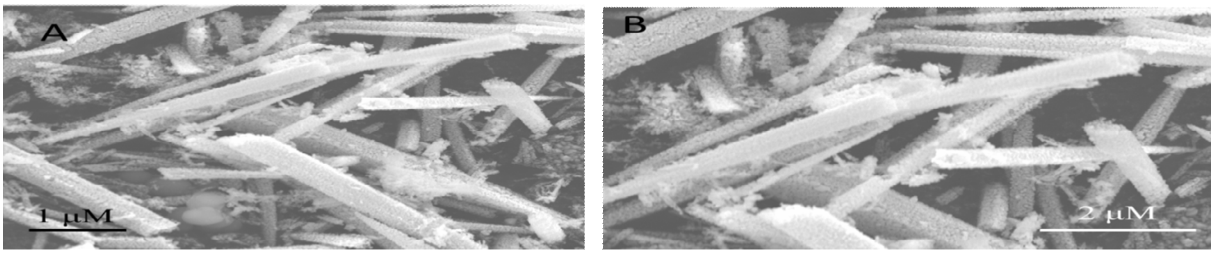

Figure 1. The FE-SEM (field emission scanning electron microscopes) images for the MWCNTs (multi- walled carbon nanotubes), (A and B) High resolution and focusing FE-SEM image of CNT.

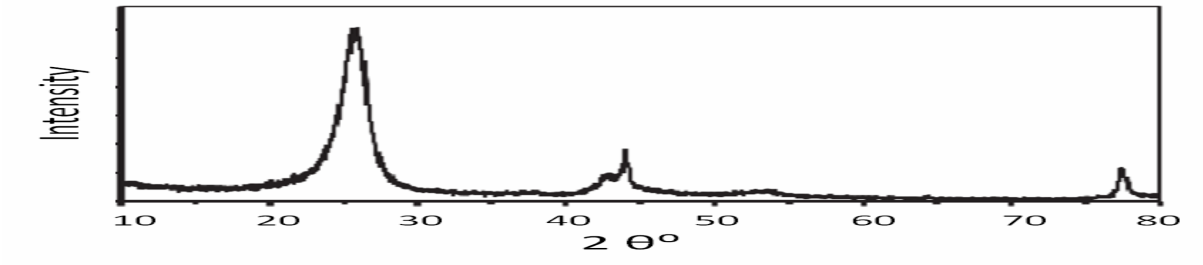

Figure 2. The XRD (X-ray diffraction)-pattern of the MWCNTs (multi- walled carbon nanotubes).

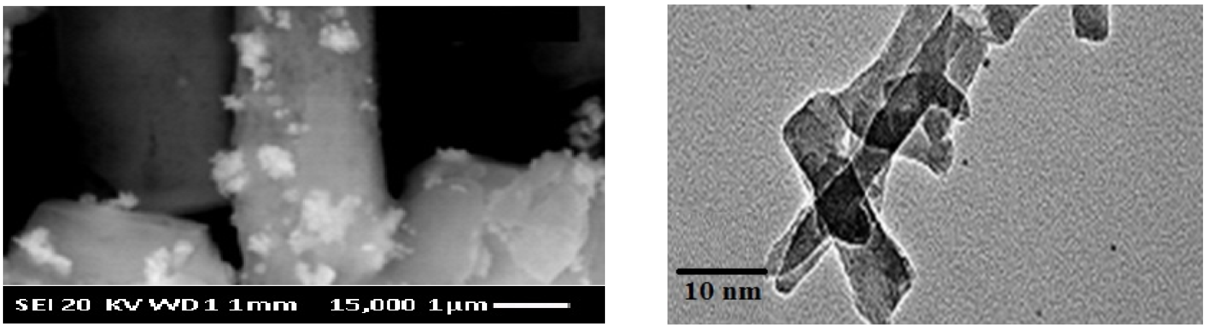

Figure 3. SEM (scanning electron microscopes) and TEM (transmission electron microscopy) micrographs of Zinc Oxide Nanoparticles (ZnO NPs).

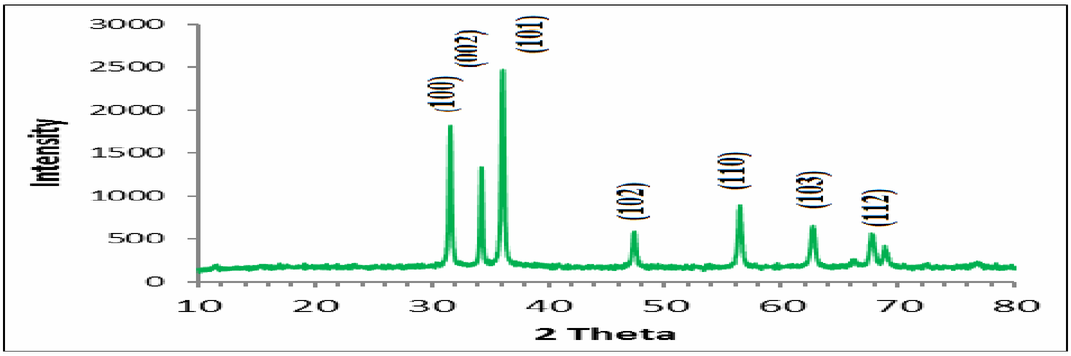

Figure 4. XRD (X-ray diffraction) patterns of prepared Zinc Oxide Nanoparticles (ZnO NPs).

Cultural practices and recorded parameters

Pea (*Pisumsativum* L.) plants were fertilized with 100 kg/fed ammonium nitrate (33.5% N), 150 kg/fed calcium superphosphate (15.5% P_2O_5) and 100 kg/fed potassium sulfate (48% K_2O) according (Hasan1991). The following growth, development and pod yield traits were recorded:1) plant growth and development including plant length (cm), number of branches per plant, days to the first flower, 50% flowers (days) and total chlorophyll (µg/cm^2) using a hand-held SPAD chlorophyll meter and2) pod crop comprising total green pods yield per fed, green pod length (cm), average green pod weight (g), average number of seeds per pod, weight of green100-seed (g), seed dry weight (g) and total number of green pods per plant.

Statistical process

Separate year and combined over the two study years analysis of variance (ANOVA) were conducted as described by Gomez and Gomez (1984). Polynomial contrasts were determined for concentrations within each of CNT and ZnO NPs, separately. Further, selected orthogonal contrasts were studied. Additionally, however, the Least Significant Values for mean comparisons within each of CNT and ZnO NPs and for overall mean comparisons were calculated.

Results and Discussion

The foliar application of CNT and ZnO NPs showed a substantial consistent impact on pea chlorophyll content in the leaf tissues, days to 50% flowering, weight of 100-seeds, pod weight, number of pods per plant and total pod yield comparing with the untreated control in both years of the study (Table 2A to 5B). Considering the two seasons, foliar application of CNT and ZnO NPs did not consistently affect number of branches/plant, stem length, days to the first flower, pod length and weight of dry seed. However, number of seeds per pod displayed insignificant changes in both seasons as compared with the untreated control.

Total pod yield harvested from pea plants sprayed with CNT showed a quadratic response such that the highest value was obtained when used 150 ppm in the first season (Table 2A and 2B). However, a linear response was observed in the second season and the highest total pod yield was produced by pea plants received 150 ppm CNT. On the other hand, the total pod yield of plants treated with foliar application exhibited linear response in both seasons. The highest total pod yield was obtained from plants sprayed with 100 ppm ZnO NPs (Table 2A and 2B). Clearly, the highest overall total pod yield resulted from plants spray with 100 ppm ZnO NPs. The treatment with 150 ppm CNT produced the immediate second high pod yield.

Total chlorophyll linearly responded to the foliar application of CNT and ZnO NPs in both seasons (Table 3A and B). Use of CNT, apparently, resulted in the highest-chlorophyll content in the leaf tissues of the pea received the foliar application of 100 ppm in the first season and 100 – 150 ppm in the second season. For ZnO NPs, the highestchlorophyll content was for the application of 100 ppm in the first season but 150 – 200 ppm in the second season.

Flowering of 50% of the pea plants was not affected by differential concentrations of CNT application in both seasons (Table 3A and B).This result indicate that same level of earliness in flowering can be achieved using any of the tested concentrations. Nevertheless, ZnO NPs application prompted early flowering response as quadratic function in the first season and linear function in the second season. Accordingly, the earliest plants to flower were those received 100 ppm ZnO NPs in the first season and 100 ppm to 150 ppmZnO NPs in the second season.

Weight of 100-seeds of the pea plants was not affected by differential concentrations of CNT and ZnO NPs applications in both seasons (Table 4 A and B). Accordingly, same weight of 100-seeds existed regardless the concentrations utilized from CNT and ZnO NPs. Concerning pod weight (Table 4 A and B), CNT treatment exhibited a quadratic response to the different concentrations in both seasons of the study. The highest average weight of the pod was produced by the plants sprayed with 150 ppm CNT in both seasons. ZnO NPs foliar application showed a quadratic response to the different concentrations in the first season and linearresponse to the different concentrations in the second season. The greatest pod weight was obtained from plants sprayed with 100 ppm in both seasons. Overall results revealed that pod weight was similar whether used 150 ppm 0f CNT or 100 ppm ZnO NPs. The number of pods/plant displayed a linear response to CNT concentrations in both seasons. The largest number of pods was obtained from plants received foliar application of 100 ppm CNT (Table 5 A and B). Dissimilarly, ZnO NPs showed a quadratic response to the different concentrations in the first season and the largest number of pods was obtained from plants received foliar application of 200 ppm ZnO NPs. No significant differences among the various concentrations were detected in the second seasons.

Moderate positive correlation coefficients (r) were found for total pod yield with total chlorophyll content and most of the main yield components traits. These included weight of 100-seeds, number of pods/plant and dry seed weight. Moderate negative r value was estimated between total pod yield and days for 50% flowering. Unique high r value was detected between total pod yield and average pod weight. Thus the foliar application with CNT or ZnO NPs seemed to enhance pod formation, growth and filling. This situation is assumed to arise as a result of activating the photosynthetic assimilation and translocation.

In general, the increase in pea pod yield ranged from 125% to 190% relative to the untreated control. The plants received CNT had pod yield that was estimated by 125% and 153%, in the first and second season, respectively. Those pea plants treated with ZnO NPs foliar spray yielded, on average, 138% and 190% of the untreated plants yield in the first and second season, respectively. The current results are in agreement with Khodakovskaya *et al.*(2013) who indicated that the delivery of CNT activated the reproductive system of the plants and increased the production of fruits**.**CNT application to tomato plants during watering produced two-times more fruits per plant compared to the control plants. Nano-carbon can adsorb nitrogen from ammonia and release hydrogen ions which enhances water and nutrient absorption by plants, thus, it would enhance the N, P and K uptake into the plant. It was suggested that the combined application of N and nano-carbon could increase the yield and quality of crops (Wu *et al*., 2010). Moreover, the addition of nano-carbon with urea increased the dry matter accumulation of soybean, enhanced the relative growth rate at seedling stage and significantly increased soybean yield (Li et *al*., 2015).

The effect of ZnO NPs has been observed on the seed germination and root growth of C. arietinumseeds (Pandey *et al*., 2010). The effect of these ZnO NPs on the reactivity of phytohormones, especially indoleacetic acid (IAA) involved in the phyto-stimulatory actions, is also carried out. Due to oxygen vacancies, the oxygen deficient, i.e. zinc-rich ZnO NPs increased the level of IAA in roots (sprouts), which in turn indicate the increase in the growth rate of plants as zinc is an essential nutrient for plants. The onion plants treated with ZnO NPs at the concentration of 20 and 30 μg ml $^{-1}$ showed better growth and flowered 12–14 days earlier in comparison with control. Treated plants showed significantly higher values for seeded fruits per umbel, seed weight per umbel, and 1000-seed weight over control plants. It was indicated that high-quality seedsalong with all other inputs (size, number, etc.) was responsible for the enhancement in final yield. ZnONPs can reduce flowering period in onion by 12–14 days and produce high-quality healthy seeds (Laware and Raskar, 2014).

Zinc-containing nano materials are needed for chlorophyll production, fertilization, pollen function, and synthesis of auxins. Also, Zn protects the plants from drought stress (Sharma *et al.* 2009). Studies on the effects of Nano scaleZnO on the germination, seedling vigor, plant growth, flowering, chlorophyll content, pod yield, and root growth of the peanut plants showed positive effects on all the studied parameters at a concentration of 1000 ppm ZnO and inhibitory effects at higher concentrations of 2000 ppm which revealed the judicious usage of these particles on plants (Prasad *et al*. 2012). From this study, it is concluded that CNT and ZnO NPs seemed to hold a promise for enhancing plant crop productivity. Here, the total pod yield was elevated by as high as 190% relative to the untreated control.

Table 2A. The average total pod yield per feddan (ton), number of branches/plant and stem length (cm)for garden pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2016/2017.

Treatment	**Total pod yield ton/feddan**	**No. of branches /plant**	**Stem Length(cm)**
	2016/2017		
Untreated	1.0226	11.900	59.600
CNT (ppm) spray			
100	1.850	12.333	61.667
150	2.301	12.600	63.100
200	1.269	12.500	62.900
$\bar{x}$	**1.807**	**12.477**	**62.555**
LSD[1]$_{0.05}$	0.119	0.477	2.212
Polynomial contrasts	**Q[4]**	**NS[7]**	**NS**
ZnO NPs (ppm) spray			
100	2.430	11.900	67.900
150	1.152	12.450	62.300
200	1.457	13.300	66.400
$\bar{x}$	**1.679**	**12.550**	**65.533**
LSD[2]$_{0.05}$	0.153	0.899	5.889
Polynomial contrasts	**L[5]**	**L**	**NS**
Significanceof selected contrasts			
Control vs. others	**[6]	**NS**	**NS**
CNT vs. ZnO NPs	**	**NS**	**NS**
LSD [3]$_{general}$	0.127	0.690	3.573
CV	**4.361**	**3.125**	**3.167**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01 level of probability; [7] insignificant.

Table 2B. The average total pod yield per feddan (ton), number of branches/plant and stem length(cm)for garden pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2017/2018.

Treatment	Total yield ton/feddan	No. of branches /plant	Stem Length (cm)
		2017/2018	
Untreated	0.978	10.800	56.100
CNT (ppm) spray			
100	2.229	10.400	67.900
150	2.484	11.600	63.700
200	1.280	10.700	67.200
$\bar{x}$	**1.998**	**10.900**	66.266
LSD[1] 0.05	0.326	0.226	4.177
Polynomial contrasts	**L[5]**	**Q[4]**	**Q**
ZnO NPs(ppm) spray			
100	2.843	11.000	62.300
150	1.456	11.700	67.300
200	1.748	10.100	66.900
$\bar{x}$	**2.016**	**10.933**	**65.500**
LSD[2] 0.05	0.204	0.858	5.293
Polynomial contrasts	**L**	**Q**	**NS**
Significanceof selected contrasts			
Control vs. others	**[6]	**	*[7]
CNT vs. ZnO NPs	**	**NS[8]**	**NS**
LSD[3] general	0.183	0.470	3.960
CV	**5.545**	**2.427**	**3.452**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponses; [6] significant at 0.01;[7] significant at 0.05 level of probability; [8] insignificant.

Table 3A. Days to the first flower, 50% flowering and total chlorophyll (µg/cm^2) for garden pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2016/2017.

Treatment	**Days to the first flower**	**50% Flower (days)**	**Total chlorophyll**
	2016/2017		
Untreated	55.000	61.666	14.330
CNT (ppm) spray			
100	52.000	56.000	26.765
150	52.667	56.500	23.590
200	54.667	57.500	23.285
$\bar{x}$	**53.111**	**56.666**	**24.546**
LSD[1]$_{0.05}$	**2.724**	1.731	1.572
Polynomial contrasts	**NS**	**NS**	**L[5]**
ZnO NPs(ppm) spray			
100	53.500	54.666	27.170
150	54.000	62.500	23.175
200	53.000	56.500	22.875
$\bar{x}$	**53.500**	**57.888**	**24.406**
LSD[2]$_{0.05}$	3.980	2.251	1.309
Polynomial contrasts	**NS**	**Q[4]**	**L**
Significance of selected contrasts			
Control vs. others	*[7]	**[6]	**
CNT vs. ZnO NPs	**NS[8]**	**	**
LSD[3]$_{general}$	2.445	1.671	1.178
CV	**2.566**	**1.622**	**2.876**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01; [7] significant at 0.05 level of probability; [8] insignificant.

Table 3B. Days to the first flower, 50% flowering and total chlorophyll (µg/cm^2) for garden pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2017/2018.

Treatment	**Days to the first flower**	**50% Flower (days)**	**Total chlorophyll**
		2017/2018	
Untreated	50.666	56.000	18.835
CNT (ppm) spray			
100	52.000	55.000	27.265
150	53.500	54.000	27.503
200	**53.330**	56.666	23.810
$\bar{x}$	**52.944**	**55.222**	**26.192**
LSD[1]$_{0.05}$	1.889	2.562	1.679
Polynomial contrasts	**NS**	**NS**	**L[4]**
ZnO NPs(ppm) spray			
100	51.000	56.666	**18.470**
150	51.500	57.000	23.675
200	53.500	58.500	24.130
$\bar{x}$	**52.000**	**57.388**	**22.091**
LSD[2]$_{0.05}$	3.643	1.646	2.594
Polynomial contrasts	**NS**	**L**	**L**
Significance of selected contrasts			
Control vs. others	**NS[7]**	*[6]	**[5]
CNT vs. ZnO NPs	**NS**	**	*
LSD[3]$_{general}$	1.953	1.422	1.465
CV	**2.103**	**1.420**	**3.522**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated. [4] linearresponse; [5] significant at 0.01; [6] significant at 0.05 level of probability; [7]insignificant..

Table 4A. The average weight of 100-seeds, average pod weight and pod length /cm for pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2016/2017.

Treatment	**Weight of 100-seeds (g)**	**Average pod weight (g)**	**Pod length (cm)**
	2016/2017		
Untreated	30.390	3.550	8.650
CNT (ppm) spray			
100	42.717	5.720	9.250
150	43.750	7.633	9.050
200	46.590	4.875	8.350
$\bar{x}$	**44.352**	**6.076**	**8.883**
$LSD^1_{0.05}$	4.494	0.414	0.843
Polynomial contrasts	**NS**	**Q[4]**	**L[5]**
ZnO NPs(ppm) spray			
100	46.060	7.653	8.225
150	46.780	3.975	8.616
200	44.170	5.386	9.275
$\bar{x}$	**45.670**	**5.671**	**8.705**
$LSD^2_{0.05}$	4.580	0.918	1.532
Polynomial contrasts	**NS**	**Q**	**NS**
Significance of selected contrasts			
Control vs. others	**[6]	*[7]	**NS[8]**
CNT vs. ZnO NPs	*	**	**NS**
$LSD^3_{general}$	3.508	0.469	0.888
CV	**4.594**	**4.758**	**5.691**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01; [7] significant at 0.05 level of probability; [8] insignificant..

Table 4B. The average weight of 100-seeds, average pod weight and pod length /cm for pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2017/2018.

Treatment	**Weight of 100-seeds (g)**	**Average pod weight(g)**	**Pod length (cm)**
	2017/2018		
Untreated	32.150	4.350	7.700
CNT (ppm) spray			
100	46.800	6.165	9.200
150	45.160	8.000	9.150
200	43.417	6.225	8.400
$\bar{x}$	**45.125**	**6.796**	**8.916**
LSD[1]$_{0.05}$	6.319	0.572	0.424
Polynomial contrasts	**NS**	**Q[4]**	**L[5]**
ZnO NPs(ppm) spray			
100	47.480	7.925	8.600
150	47.290	4.875	9.550
200	44.870	4.875	9.350
$\bar{x}$	**46.546**	**5.891**	**9.166**
LSD[2]$_{0.05}$	4.255	0.096	0.429
Polynomial contrasts	**NS**	**L**	**L**
Significance of selected contrasts			
Control vs. others	*[7]	*	**[6]
CNT vs. ZnO NPs	**	**	**NS[8]**
LSD[3]$_{general}$	3.731	0.295	0.345
CV	**4.780**	**2.736**	**2.195**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01; [7] significant at 0.05 level of probability; [8] insignificant..

Table 5A. The average number of pods/plant, number of seeds/pod and dry seed weight for pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2016/2017.

Treatment	**No. of pods/plant**	**No. of seeds/pod**	**Dry seed weight (g)**
	2016/2017		
Untreated	6.025	5.730	8.720
CNT (ppm) spray			
100	9.275	4.713	12.590
150	7.950	4.425	11.443
200	4.000	4.230	10.886
$\bar{x}$	**7.075**	**4.456**	**11.640**
LSD[1]$_{0.05}$	2.048	0.505	2.674
Polynomial contrasts	**L[5]**	**NS**	**NS**
ZnO NPs(ppm) spray			
100	9.900	4.666	12.510
150	7.475	4.685	11.000
200	10.175	5.545	10.920
$\bar{x}$	**9.183**	**4.965**	**11.476**
LSD[2]$_{0.05}$	0.834	2.122	1.800
Polynomial contrasts	**Q[4]**	**NS**	**NS**
Significance of selected contrasts			
Control vs. others	**[6]	**NS[7]**	**
CNT vs. ZnO NPs	**NS**	**	**
LSD[3]$_{general}$	1.140	1.014	1.694
CV	**8.190**	**11.746**	**8.540**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01 level of probability; [7] insignificant.

Table 5B. The average number of pods/plant, number of seeds/pod and dry seed weight for pea plants received foliar application with different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs) in addition to the untreated control in 2017/2018

Treatment	No. of pods/plant	No. of seeds/pod	Dry seed weight (g)
		2017/2018	
Untreated	9.640	6.030	8.990
CNT (ppm) spray			
100	9.675	5.591	10.573
150	9.350	5.160	11.416
200	5.400	5.180	11.120
$\bar{x}$	**8.141**	**5.310**	**11.036**
LSD[1] 0.05	0.587	0.507	1.059
Polynomial contrasts	**L[5]**	**NS**	**NS**
ZnO NPs(ppm) spray			
100	8.000	5.466	10.870
150	8.375	6.630	11.600
200	8.850	6.345	9.570
$\bar{x}$	**8.408**	**6.147**	**10.680**
LSD[2] 0.05	1.626	0.650	0.768
Polynomial contrasts	**NS**	**L**	**Q[4]**
Significance of selected contrasts			
Control vs. others	**[6]	**NS[7]**	**NS**
CNT vs. ZnO NPs	**	**	**
LSD[3] general	0.890	0.570	0.645
CV	**5.911**	**5.555**	**3.427**

[1] The least significant (LSD) to separate means of the different concentrations of CNT.
[2] The least significant (LSD) to separate means of the different concentrations of ZnO NPs.
[3] The least significant (LSD) to separate any two means across the different concentrations of CNT, ZnO NPs and the untreated.
[4] Quadraticresponses; [5] linearresponse; [6] significant at 0.01 level of probability; [7] insignificant..

Table 6. Correlation coefficients of the studied traits with the total pod yield of garden pea received foliar application of different concentrations of carbon nanotubes (CNT) or zinc oxide nanoparticles (ZnO NPs)

Traits	Correlation coefficient (r)[(1)]
Number of branches /plant	-0.143 ns
Stem length(cm)	0.287 ns
Days to first flower	-0.197 ns
Days for 50% flowering	-0.553 ns
Total Chlorophyll	0.406 ns
Weight of 100-seeds (g)	0.498 ns
Average pod weight (g)	0.889 **
Pod length (cm)	0.211 ns
No.of pods/plant	0.388 ns
Number of seeds/pod	-0.188 ns
Dry seed weight (g).	0.440 ns

[(1)] n = 7

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نمو وإنتاجية البسلة تحت تأثير الرش بأنابيب الكربون النانومترية وأكسيد الزنك النانومتري

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الملخص

لقد أجريت تجربة حقلية لتقييم صنف البسلة (ماستر بي) من حيث استجابته للرش بأنابيب الكربون النانو مترية واكسيد الزنك النانو متري. فلقد اجري الرش بهذه المركبات ثلاث مـــرات بفاصل أسبوع بين الرشة والآخرى بداية من طور الثلاث ورقات الحقيقيـــة. وقـــد اســـتخدمت التركيزات الآتية ١٠٠، ١٥٠ و٢٠٠ جزء في المليون بالإضافة الى معاملة الكنتـــرول (الغيـــر معامل). وقد أوضحت النتائج على وجه العموم تفوق النباتات المعاملة على نباتـــات الكنتـــرول (الغير معاملة) وذلك في كل من موسمي الدراسة وذلك من حيث المحصول الكلي و الكلوروفيل الكلي و عدد أيام الازهار لـــ ٥٠ % من النباتات ووزن الـــ ١٠٠ بذرة ومتوســـط وزن القـــرن الأخضر وعدد القرون للنبات وقد وجد أن أعلى محصول قرون كان من النباتات التي تم رشـــها بـــ أكسيد الزنك النانومتري عند تركيز ١٠٠ جزء في المليون. تلي هـــذه المعاملـــة اســـتخدام النباتات التي تم رشها بـــ ١٠٠ جزء في المليون بأنابيب الكربون النـــانو متـــري. أمـــا بـــاقي الصفات وهي طول الساق، عدد الافرع على النبات، وعدد الأيام لظهور اول زهرة على النبات، وطول القرن الأخضرو وزن البذور الجافة لم يكن تأثيرها مستقر حيث شهدت معنوية لهـــا فـــي عام واحد من عامي الدراسة، اما متوسط عدد البذور في القرن لم تكـــن معنويـــة فـــي عـــامي الدراسة. وقد أستنتج أن أنابيب الكربون النانو مترية وأكسيد الزنك النانو متري تعتبر معـــاملات واعدة في تحسين إنتاجية البسلة وفي الدراسة الحالية قد تم الحصول على محصول وصل الـــى ١٩٠ % مقارنة بمحصول النباتات الغير معاملة.