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Effect of Zinc Oxide Nanoparticles on Growth, Chemical Composition and Yield of Potato (*Solanum tuberosum* L.).

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ABSTRACT

In this study ZnO NPs powder was used hence various analytical techniques, such as UV–Visible spectroscopy, such as Fourier transform infrared spectroscopy and UV-Visible spectroscopy. (FTIR), Transmission Electron Microscopy (TEM). TEM revealed both ZnO NPs small round nanoparticles and big rod nanoparticles. Zinc oxide nanoparticles' UV-vis absorbance spectrum, which ranges from 190 nm to 1100 nm. Field experiment was done in the Tag El-Ezz Experimental Research Station of the Agricultural Research Center in the Egyptian governorate of Dakahlia, during two successive seasons; 2019 and 2020 to assay the effect of foliar spraying with nanoparticles (NPs) of Zinc (0, 20, 40, 60, 80,100 and 200 mgL^{-1}) and non-nanoparticles Zn in the form of Zn- EDTA at 200 mgL^{-1} with a randomized complete block design on the growth, chemical composition and yield of potato (*Solanum tuberosum* L.). In general Spraying Zn0-NPs onto leaves greatly improved the vegetative growth characteristics, yield and improved nutritional contents of potato tubers. It is worthy to mention that, 80 mgL^{-1} of ZnO-NPs have the highest effect on most characters and increase the yield of potato tubers (ha) by (69.89 and 41.69%) compared to control during the two seasons.

Keywords: Nano zinc oxide; *Zn- EDTA; Tubers from Solanum tuberosum L. produce.*

INTRODUCTION

After rice, wheat, and maize, the potato (*Solanum tuberosum* L.), one of the most significant solanaceous vegetable crops for domestic consumption and exportation, came in at number four of the production (Abdeldaym *et al.*, 2018 and Abuarab *et al.*, 2019). The cultivated area of potatoes in Egypt was 175,161 ha in 2019, which produced 5.08 million tonnes of tubers, with an average output per hectare of roughly 30.38 tonnes (FAO, 2019). To cultivate and sell roughly 678.000 tonnes of potatoes, Egypt imports 135.000 tonnes of potatoes from the European Union. A cheap food full of antioxidants, carbohydrates, vitamin C and B, minerals, and vital amino acids is the potato (khalid *et al.*, 2020).

Zinc (Zn) is an important micronutrient for plants, animals and human, in many plants, the lack of which is a prevalent problem (OjedaBarrios *et al.*, 2014). Such enzymes as dehydrogenase, aldolase, isomerase, trans phosphorylase, RNA, and DNA polymerase all require it to function. Additionally, it aids in the production of tryptophan, cell division, preservation of cell structure, and photosynthesis. It is also regarded as a cofactor in the synthesis of numerous proteins (Marschner, 2012). Also, it is responsible in protecting and keeping structural stability of cell membranes (Welch *et al.*, 1982 and Cakmak, 2000) and required for chlorophyll production (Al-Toki and Halloul, 2021). Due to their large yield in a short amount of time and shallow root system, potatoes are a crop that heavily depletes soil nutrients. Hence, application of micronutrients especially zinc becomes essential that, Potato producers utilize a lot of phosphorous fertilizer when planting their crops, which interferes with the plant's ability to use zinc, making potatoes particularly susceptible to zinc. When soil temperatures are low, phosphorus and zinc are particularly crucial for potato early growth. (Hafeez *et al.*, 2013).

Synthetic fertilisers used extensively and in large quantities could harm the environment by accelerating soil deterioration, eutrophication, air pollution, and groundwater contamination (Seleiman *et al.*, 2020). So, the world tries utilizing new technologies fertilization as environment is one of the reasons potatoes are extremely susceptible to zinc, because they are smaller than stomata openings in leaves, nano fertilizers are easily absorbed by plants when applied foliar. This reduces fertilizer usage by boosting NUE, reduces environmental pollution, and ultimately increases yield (Tarafdar *et al.*, 2012 and Al-Toki and Halloul, 2021). Nano fertilizers consider promise for attaining sustainable agriculture (El-Nasharty *et al.*, 2021).

The effectiveness of nano zinc (ZnO NPs) in boosting seed germination and plant growth has led to the perception that it is a material that is safe for biological species, chemical constituents and yield.The formulation of nanofertilizer allows for the controlled release of nutrients in accordance with crop needs and prevents nutrient interactions with soil, water, and microorganisms that result in the immobilisation of nutrients (Derosa *et al.*, 2010 and Singh *et al.*, 2017). Anticipated that using nano zinc as a foliar spray will give plants the dual benefits of an easily absorbed plant micronutrient and a bio-stimulant. (El-Saied and Maha, 2022).

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The goal of this study is assessment the impact of foliar fertilizers containing varied concentrations of either zinc oxide nanoparticles (ZnO-NPs) or zinc EDTA on potato growth, yield, and nutritional content (*Solanum tuberosum* L.)

MATERIALS AND METHODS

Characterization of ZnO NPs

Zinc oxide nanoparticles powder was obtained commercially from Sigma Aldrich Company in Cairo (https://www. sigmaaldrich.com/).

The ZnO NPs powder was evaluated using a variety of analytical techniques, including UV-Visible spectroscopy and Fourier Transform Infrared spectroscopy. (FTIR), Transmission Electron Microscopy (TEM).

UV–Visible spectroscopy

Nanopowder from each reaction was suspended in an equivalent volume of sterile de-ionized water for UV-Visible spectroscopy, a UV-Vis Spectrophotometer UV-3092 from Lab India Analytical Instruments Pvt. Ltd., in the wavelength range of 200-700 nm, was used to conduct the spectrum scans (Jamdagni *et al*., 2018).

Using FT-IR spectroscopy

Fourier transform infrared (FT-IR) spectroscopy can be used to identify different phytochemical elements involved in the reduction and stability of the nanoparticles. KBr was applied to a little amount of sample powder before it was placed on the sample holder and compressed. The Attenuated Total Reflectance (ATR) approach was used to acquire the FT-IR spectra for dried powdered ZnO NPs using a Perkin Elmer FT-IR Spectrophotometer Frontier, keeping a total of 50 scans for each sample analysed (Themo Fisher Scientific model, FT-IR is10, USA).

Microscopy with an electron microscope (TEM)

The material was examined using a TEM, or transmission electron microscope. To determine the shape and size of the nanoparticles, the ZnO NPs dispersion was dropped and dried on a Gilder G200 TEM grid with a standard 200 square mesh and a 3.05 mm diameter. The size and form of the particles in the obtained micrographs were then determined. (Arora *et al*., 2014).

The experiment's location:

To investigate the effects of Zn foliar spraying in the form of nano and chelate on potato growth, yield, and quality, two field experiments were conducted in the winters of 2019 and 2020 at the Experimental Station of the Agriculture Research Center in Tag El- Ezz, Dakahlia Governorate, Egypt (31°31' 47.64'' N latitude and 30°56' 12.88'' E longitude).

The soil analysis of the experimental site was described in Table (1)

Table 1. Average physical-chemical properties of the experimental soil during two seasons.

Properties	Values	properties	Values
Clay (%)	29.50	accessible macro- and micronutrients (mg kg^{-1} soil)	
Sand (%)	33.50	N	35.15
Silt (%)	37.00	P	5.23
Texture	Sand clay loam	K	178
Organic matter (%)	1.17	Zn	0.41
E.C. soil suspension (1:5) dsm^{-1}	2.33	Fe	1.21
pH soil suspension (1:2.5)	7.93	Mn	1.10

Experiment layout and Treatments:

The potato (*Solanum tubersum* L.) tubers used in this study were imported from Holland and were purchased from the Ministry of Agriculture and Land Reclamation's Agricultural Research Center (ARC). Sliced potato tubers (approximately 35 g pieces). Eight treatments were used in the study's studies, which were set up in a complete randomized block design with three duplicates; thus, 24 experimental units made up the entire experiment. The plot measured 10.5 m2, and it had three rows that were each 5 m long and 0.7 m broad. On one side of ridges, tuber fragments were planted at a depth of 10 to 15 cm, 25 cm apart from one another.

Farmyard manure (FYM) was added at a rate of 49.4 m3 ha-1 to the soil prior to cultivation. FYM's chemical composition was demonstrated in Table (2). The following chemical fertilizers were used: 296.4 kg N, 185.25 kg P_2O_5, and 237.12 kg K_2O_5 hectare^{-1} in a form of respectively calcium super phosphate (15.5% P2 O5), potassium sulphate (48% K2 O), and ammonium sulphate (20.5% N). Cultivation process were performed in the 2nd January for the two seasons. The Ministry of Agriculture and Land Reclamation advised the use of additional field procedures for cultivating potatoes.

Table 2. FYM's chemical composition as an average over two seasons

Properties	Value
pH (1:10)	5.91
EC (1:10)(dSm^{-1})	3.14
Organic matter (%)	35.89
Nitrogen (%)	1.49
Phosphorous (%)	1.01
Potassium (%)	0.84
Fe (mg kg^{-1})	21.73
Zn (mg kg^{-1})	8.56

Treatments:

1) Control (spraying with distilled water)
2) 200 mgL^{-1} of zinc-EDTA.
3) 20 mgL^{-1} of nanozinc.
4) 40 mgL^{-1} of nano zinc.
5) 60 mgL^{-1} of nano zinc.
6) 80 mgL^{-1} of nano zinc.
7) 100 mgL^{-1} of nanozinc
8) 200 mgL^{-1} of nano zinc.

Zinc was applied through Zn- EDTA (12 % Zn) and used nano zinc (ZnO-NPs) was provided by Agriculture Research Center (ARC), three instances of foliar spraying were applied to potato plants, the first time being 40 days after seeding. Twice more spraying was done (20 days among them).

Data Recorded:

Vegetative growth parameters.

To measure the vegetative development parameters (plant height (cm), number of branches and leaves plant^{-1}, fresh and dry weight of shoot (g) plant^{-1}), samples were taken at random at 70 days after planting.

Tuber yield and its components.

The tubers in plant^{-1} were counted and weighed. Calculations were made for weight yield ha^{-1} (tons).

Chemical analysis

Fresh leaves were randomly selected from three plant samples to be tested for the presence of photosynthetic pigments such as chlorophyll a, chlorophyll b, and carotene according to Metzner *et al.* (1965).To assess the quality of the tubers, N, P, K, Zn, protein, and total carbohydrates were assessed in the fresh weight of the tubers at harvest. According to what was described by, the modified Micro-kjeldahl apparatus was used for total N-determination Jones *et al*. (1991). Protein content was calculated by multiplying N content by 5.25 (Ranganna, 1977). Model number UV2100 S/N: BH 1604160303 used spectrophotometry to assess the total phosphorus concentration. Energy supply: AC220V/50Hz. 250V/ 3.15A FASTACTING FUSE according to Peters *et al.* (2003). The JENWAY PFP7 model was used to photometrically determine the total potassium content according to Peters *et al.* (2003). Zn (mg kg^{-1}) were calculated using the aforementioned procedures by Khazaei *et al.* (2017). Anthrone technique was used to estimate total carbohydrates (Sadasivam and Manickam, 1996).

Analytical Statistics

The presented data were statistically evaluated using LSD at 5% in accordance with (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Results

ZnO nanoparticles physical and chemical characteristics

Transmission electron microscope (TEM) analysis of ZnO nanoparticles described that, ZnO nanoparticles sample is made of round and spherical small particles and rod big particles that had different sizes ((Figures 1 and 2).

ZnO nanoparticles were exposed to Fourier Transform Infrared Spectroscopy (FT-IR) (Figure 3), to detect several characteristic functional groups. Samples had absorption peaks in the range of 3750 cm^{-1}, 3650 cm^{-1}, 3450 cm^{-1}, 1630 cm^{-1}, 1540 cm^{-1}, 1510 cm^{-1}, 1382 cm^{-1}, 901 cm^{-1} and 445 cm^{-1}. Peaks at 3450 cm^{-1} and 3650 cm^{-1} were ascribed to hydroxyl groups stretching vibration. Peaks at ~ 2922 cm^{-1} were assigned to –CH stretching indicating CH2 and CH3 groups' presence. Asymmetric and symmetric C-O stretching were attributed to peaks at around 1400–1586 cm 1. Peaks near 1000 cm1 were attributed to -CH deformation, indicating bending of -CH2 and -CH3, metal oxides generally exhibit absorption bands in the fingerprint region as a result of interatomic vibrations (1000 cm1).

Peaks between 415–480 cm1 were ZnO and they represent the stretching vibration of Zn–O.

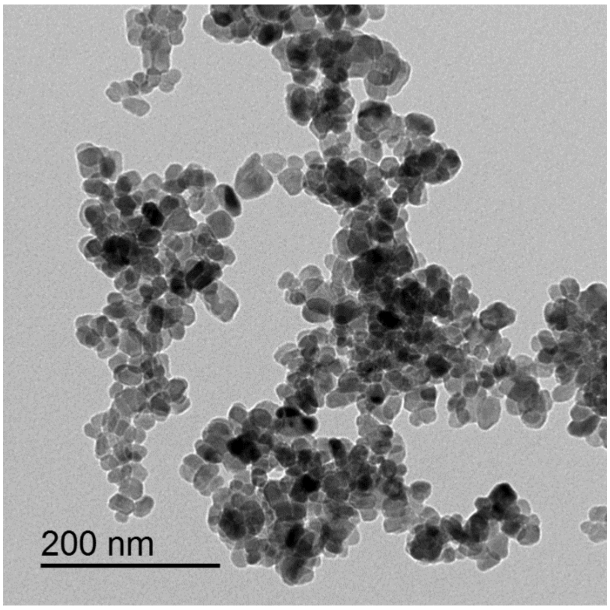

Figure 1. Physical characterization of ZnO nanoparticles using TEM.

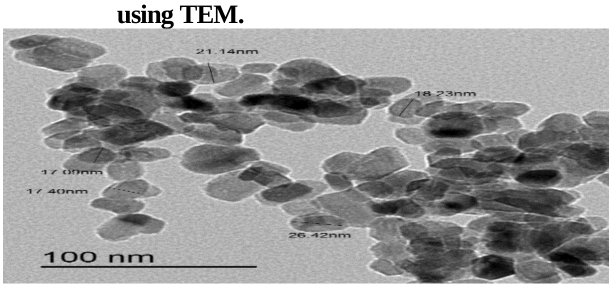

Figure 2. TEM revealed both ZnO NPs small round nanoparticles and big rod nanoparticles.

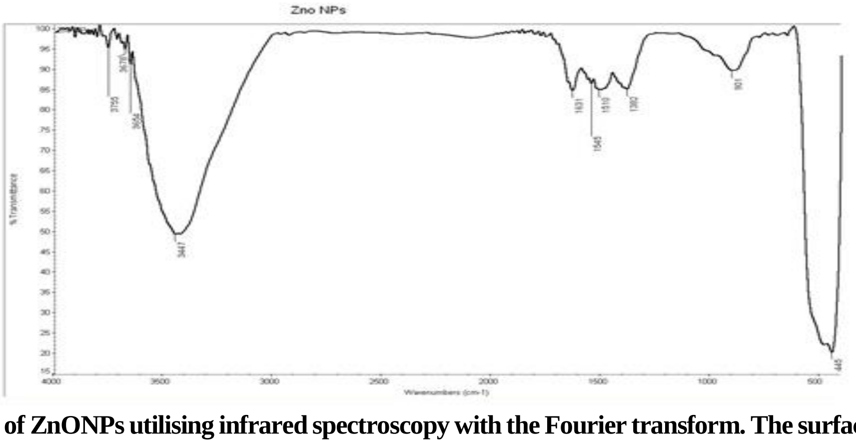

Figure 3. Analysis of ZnONPs utilising infrared spectroscopy with the Fourier transform. The surface functional group and structure of the ZnO NPs were revealed by the FTIR spectra.

Additionally, UV-Vis spectroscopy was carried out to support the creation of ZnO NPs.

Figure (4) described the generated absorption spectra by ZnO NPs, the ZnO NPs were distributed in ultrapure water before the UV-Vis measurement was carried out. The intrinsic band-gap of Zn-O absorption is responsible for the absorption peak that was observed at 300 nm.

Vegetative growth parameters

According to the data in Table 3, plants sprayed with zinc-EDTA or nano zinc at different doses responded differently from controls. The growth traits of the potato plant were greatly improved over the course of two seasons by spraying with ZnO-NPs at a rate of 80 mgL-1. When compared to control plants during the two seasons of 2019 and 2020, the plant height, number of branches, number of leaves, and fresh and dry weight of the shoot all increased by (14.37, 27.74%), (52.78, 64.71%), (48.98, 48.11%), and (41.14, 31.56%), respectively. This was done after spraying ZnO-NPs at a concentration of 60 mgL-1.

The improvement in development traits may be attributable to ZnO-NPs' structural contributions to vital organic molecules that support growth, like IAA and GA3 (Cakmak 2000), the effectiveness of nanoparticles on enhanced expression of some protein-coding genes (Salama *et al*., 2019).

Additionally, nanoparticles have a significant impact affect cell development and division, particularly in meristematic regions, and they raise tryptophan and auxin production, which increases internode length and plant height (Kaya and Higgs, 2002). The same results were also reported by Keerthana *et al.* (2021) on potato, Kolenˇcík *et al.* (2022) on lentil and El-Saied and Maha (2022) on pea.

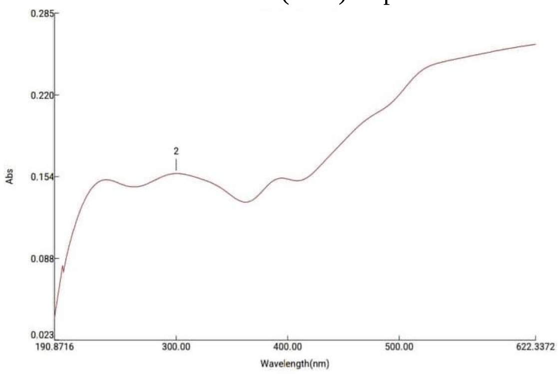

Figure 4. ZnO nanoparticles analysis via spectrophotometer. The UV-vis absorbance spectrum of zinc oxide nanoparticles from 190 nm to 1100 nm.

Table 3. Effect of ZnO-NPs concentrations on potato plant vegetative development traits throughout two seasons (2019 and 2020).

Treatments	Plant height (Cm)		Branch (No.)		Leaves (No)		Shoot fresh weight (g plant^{-1})		Shoot dry weight (g plant^{-1})	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control	87.00	92.77	9.00	8.50	49.00	53.00	64.44	69.50	29.00	31.50
Zn-EDTA 200 mgL-1	93.00	100.50	11.75	11.00	64.50	63.50	71.00	73.00	33.66	34.45
ZnONPs 20 mgL^{-1}	89.00	103.75	11.00	11.00	52.00	58.00	68.80	71.78	30.07	32.18
ZnONPs 40 mgL^{-1}	94.50	114.00	12.25	12.50	62.50	69.00	73.50	79.50	34.19	37.42
ZnONPs 60 mgL^{-1}	96.00	116.20	13.00	12.50	67.00	76.00	78.00	84.50	35.43	40.17
ZnONPs 80 mgL^{-1}	99.50	118.50	13.75	14.00	73.00	78.50	82.50	87.07	40.93	41.11
ZnONPs 100 mgL^{-1}	94.77	109.35	12.65	11.75	67.50	65.00	76.50	80.77	35.73	37.66
ZnONPs 200 mgL^{-1}	92.50	107.50	12.00	10.50	63.00	59.00	74.75	75.43	35.30	34.91
LSD at 5%	4.16	4.38	2.39	1.89	2.73	3.91	3.41	3.00	4.15	3.69

Yield attributes

The data in Table (4) described that, ZnO-NPs concentrations applied topically considerably increased yield and yield components.According to the results, there is insignificant difference among the treatments for number of tubers plant^{-1}. While foliar application of ZnO-NPs influenced higher yield in potato. Foliar spray ZnO-NPs at 80 mgL-1 per plant increased the weight of tubers per plant by (69.89 and 41.72%) and tubers weight per ha by (73.65 and 41.69%) during two seasons respectively. Several studies have reported that the application of ZnO-NPs had a positive effect on the yields of plants as Lenka and Das (2019) and Neogi and Das (2022) on potato and Adil *et al.* (2022) on wheat. For several metabolic processes, Zn serves as an important element that activates enzymes. Many metabolic activities are considered to be activated by Zn, one of the necessary metals. Zinc is absorbed more quickly by the leaves because it exists in nanoparticle form, and it regulates the metabolism of plant hormones by altering auxin levels through tryptophan synthesis. As a result, it accelerates cell division, which causes tubers to grow to a bigger size (Kolenˇcík, *et al*., 2020).

Table 4. Effect of ZnO-NPs concentrations on potato plant yield characteristics throughout two seasons (2019 and 2020).

Treatments	Number of tubers plant^{-1}		Weight tubers (g) plant^{-1}		Weight yield (ton) ha^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control	4.00	3.50	465.00	582.50	26.57	33.29
Zn-EDTA 200 mgL^{-1}	4.50	4.00	679.00	703.75	38.80	40.21
ZnONPs 20 mgL^{-1}	4.00	4.00	615.00	690.00	35.14	39.43
ZnONPs 40 mgL^{-1}	4.50	4.50	725.50	744.00	41.46	42.51
ZnONPs 60 mgL^{-1}	5.00	4.00	772.00	795.50	44.11	45.46
ZnONPs 80 mgL^{-1}	5.00	4.50	790.00	825.50	46.28	47.17
ZnONPs 100 mgL^{-1}	4.50	4.00	704.75	784.00	40.27	44.80
ZnONPs 200 mgL^{-1}	5.00	3.50	690.00	712.00	39.43	40.69
LSD at 5%	n.s.	n.s.	7.48	6.49	1.80	1.35

Chemical analysis

Photosynthetic pigments

Application of 80 mgL-1 ZnO-NPs greatly boosted the pigments in leaves. where the levels of carotenoid, chlorophyll a, and b dramatically increased by (51.15, 41.86%), (107.94, 104.98%) and (45.38, 56.47%) when compared to control plants in the first and second growing seasons, respectively (Table 5). This effect may be attributable to the zinc foliar spray, as plants need zinc to produce protochlorophyllides, grow chloroplasts, and repair photosystem II. Additionally, ZnO-NPs foliar spray increased the glutamic to glycin ratio (Salama *et al*., 2019), They produce chlorophyll and are in charge of developing plant tissues. Additionally, the nanoparticles play a role in the efficiency of photosynthetic processes by causing chlorophyll to absorb light and transfer energy to the nanoparticles (Mingyu, et al., 2007 and Mohsenzadeh and Moosavian, 2017). Additionally, the stimulating impact of ZnO's on carbonic anhydrase made it easier for CO_2 to be transported to carboxylation sites in the chloroplast (Salama *et al.*, 2019). Carbonic anhydrase is involved in the control of stomata (Hu *et al.*, 2010). Our results are in harmony with Adil *et al.* (2022) on wheat & Mogazy and Hanafy (2022) on faba bean.

Table 5. Effect of ZnO-NPs concentrations on potato plants' photosynthetic pigments throughout the course of two seasons (2019 and 2020).

Treatments	Chl a (mg g^{-1} f. wt)		Chl b (mg g^{-1} f. wt)		Total chlorophyll (mg g^{-1} f. wt)		Carotenoid (mg g^{-1} f. wt)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control	0.391	0.430	0.189	0.201	0.580	0.631	0.238	0.255
Zn-EDTA 200 mgL^{-1}	0.448	0.503	0.290	0.341	0.738	0.844	0.293	0.317
ZnONPs 20 mgL^{-1}	0.490	0.512	0.314	0.330	0.804	0.842	0.305	0.319
ZnONPs 40 mgL^{-1}	0.499	0.522	0.321	0.361	0.820	0.883	0.319	0.330
ZnONPs 60 mgL^{-1}	0.543	0.596	0.344	0.392	0.887	0.988	0.327	0.361
ZnONPs 80 mgL^{-1}	0.591	0.610	0.393	0.412	0.984	1.022	0.346	0.399
ZnONPs 100 mgL^{-1}	0.482	0.507	0.337	0.371	0.819	0.878	0.320	0.333
ZnONPs 200 mgL^{-1}	0.415	0.478	0.242	0.311	0.657	0.789	0.302	0.311
LSD at 5%	0.0071	0.0075	0.0076	0.0103	0.0077	0.0083	0.01067	0.0090

Nutritional quality of potato tubers

The nutritional value of potato tubers can be assessed using a variety of factors. The results in Table (6) showed that, spray with Significant differences in the effects of ZnO-NP concentration were observed on nutrient contents in potato tubers during two seasons 2019 and 2020. It is worth mentioning that 80 mg l^{-1} ZnO-NPs increment N, P, K and Zn, by (22.96, 51.58, 28.08, 7.13, 22.94 and 9.02 %), respectively for 1st season. The 2nd season has the same trend. ZnO-NPs enhanced phosphatase and phytase enzyme activity, which promoted phosphorus mobilisation and uptake in plants (Adhikari and Pandey, 2020). Zn engaged in preserving the shape of the plasma membrane and play a role in the action of the enzymes that allow plants to absorb NPK, encourage enzyme activity, and aid in the synthesis of secondary metabolites. These results are in agreement with these findings Neogi and Das (2022) on potato.

Regarding to Zn content in potato tubers, it was noticed that foliar spray ZnO-NPs concentrations significantly affect Zn content (Table 6). It appears that foliar spray of ZnO-NPs influnces potato tubers Zn content; it may have affected other physiological parameters such as photosynthetic processes (Faizan *et al*., 2021) because zinc can be essential component in photosynthesis (Sturikova *et al.*, 2018).

For the first season, foliar spray of ZnO-NPs up to 80 mgL^{-1} enhanced total protein and total carbs by 22.93 and 9.01%, respectively, in comparison to control (Table 7). These results are in harmony with Marzouk *et al.* (2019) on potato. Our findings are a result of zinc's ability to speed up photosynthesis, which in turn increases the metabolism of carbohydrates (Elizabath *et al.,* 2017). Also, it involved in the structure as activated component of protein and enzymes.

Table 6. Mineral contents of potato tubers throughout two successive seasons as a result of ZnO-NPs concentrations (2019 and 2020).

Treatments	N (%)		P (%)		K (%)		Zn ($mgkg^{-1}$)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control	1.96	2.02	0.570	0.498	1.96	2.02	19.50	19.44
Zn-EDTA 200 mgL^{-1}	2.21	2.32	0.700	0.680	2.23	2.36	20.50	20.65
ZnONPs 20 mgL^{-1}	2.02	2.11	0.640	0.637	2.17	2.27	19.88	19.90
ZnONPs 40 mgL^{-1}	2.27	2.41	0.716	0.702	2.39	2.46	20.61	20.88
ZnONPs 60 mgL^{-1}	2.38	2.52	0.812	0.789	2.44	2.53	20.73	20.81
ZnONPs 80 mgL^{-1}	2.42	2.55	0.864	0.841	2.51	2.55	20.89	21.00
ZnONPs 100 mgL^{-1}	2.27	2.32	0.719	0.780	2.31	2.41	20.93	20.87
ZnONPs 200 mgL^{-1}	2.20	2.27	0.707	0.735	2.14	2.36	20.84	20.77
LSD at 5%	0.072	0.069	0.022	0.017	0.133	0.094	0.265	0.117

Table 7. Effect of ZnO-NPs concentrations on total protein and total carbohydrates of potato tubers during two successive seasons (2019 and 2020).

Treatments	Total protein (%)		Total carbohydrate (%)	
	1st season	2nd season	1st season	2nd season
Control	12.25	12.62	26.50	25.33
Zn-EDTA 200 mgL^{-1}	13.81	14.5	28.00	28.14
ZnONPs 20 mgL^{-1}	12.62	13.18	27.22	26.34
ZnONPs 40 mgL^{-1}	14.19	15.06	28.61	28.23
ZnONPs 60 mgL^{-1}	14.87	15.75	28.77	29.23
ZnONPs 80 mgL^{-1}	15.06	15.93	28.89	29.45
ZnONPs 100 mgL^{-1}	14.19	14.5	28.56	29.08
ZnONPs 200 mgL^{-1}	13.75	14.18	28.28	28.19
LSD at 5%	0.147	0.148	0.164	0.197

CONCLUSION

The present study aimed at evaluating Zn foliar spray using (Zn-EDTA) and Zn nanoparticles. It can be concluded that foliar spraying with Zn -NPs have beneficial effects on the development and output of potato plants. ZnO-NPs at 80mgL-1 gave the highest plant growth and yield. The findings of this study lend credence to the idea that fertilizing crops with nanoparticles through foliar application may be a potential way to increase potato yield, nutritional value, and quality.

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تأثير جزيئات أكسيد الزنك النانوي على النمو والمحتوي الكيميائي و إنتاجية محصول البطاطس

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الملخص

يحاول العالم استخدام تقنيات التسميد الجديدة كأسمدة نانوية لزيادة المحاصيل الزراعية. تعتبر الأسمدة النانوية الامل لتحقيق الزراعة المستدامة . فتم توصيف مادة الزنك النانونية باستخدام بعض التقنيات مثل UV–Visible spectroscopy, Fourier Transform Infrared spectroscopy (FTIR), Transmission Electron Microscopy (TEM). ووأضحت نتائج التحليل (TEM) ان جزئيات الزنك النانونية دائرية صغيرة وعصوية كبيرة وتتراوح مابين (190 nm -1100nm). وتم تنفيذ تجربة حقلية بمحطة البحوث التجريبية بتاج العز ، مركز البحوث الزراعية ، محافظة الدقهلية ، مصر خلال موسمين متتاليين 2019 و 2020 لدراسة تأثير الرش الورقي لجزيئات أكسيد الزنك النانوي بتركيز (صفر و 20 و 40 و 60 و 80 و 100 و 200 ملجم زنك لتر $^{-1}$) و بتركيز 200 ملجم زنك لكل لتر في صورة EDTA على النمو والتركيب الكيميائي وإنتاج البطاطس و نفذت التجربة بتصميم القطاعات الكاملة العشوائية أظهرت النتائج المتحصل عليها أن للإضافة الورقية لجزيئات أكسيد الزنك النانوي تأثيرات معنوية على جميع الصفات محل الدراسة مثل النمو الخضري ، المحصول و المحتوي الغذائي لدرنات البطاطس. يمكن أن تختتم هذه الدراسة لمحصول البطاطس النامي في الأراضي الطينية الطمية بإضافة الرش الورقي لجزيئات أكسيد الزنك النانوي بتركيز 80 مجم / لتر لها أعلى تأثير على معظم الصفات وزيادة محصول الهيكتار لدرنات البطاطس بنسبة (69.89 و 41.69٪) مقارنة بالكنترول (بدون رش زنك) خلال موسمين.