

# Effect of Foliar Application of Zinc Oxide Nanoparticles on Selected Vegetative Growth Traits of Two Garlic (*Allium sativum* L.) Cultivars

Mazin H. Hasan<sup>1</sup>, Obaida A. AbdulHussein<sup>2</sup>, Mustafa M. Mohammed<sup>3</sup>

<sup>1</sup> Nanomaterials Research Center, University of Anbar, Anbar, IRAQ

<sup>2</sup> Department of Physics College of Education, Al-Iraqia University, Baghdad, IRAQ

<sup>3</sup> Department of Biology, College of Education for Pure Science, University of Anbar, Anbar, IRAQ

\* Corresponding author email: [dr.obaida.amer@gmail.com](mailto:dr.obaida.amer@gmail.com)

## Abstract

The purpose of the experiment was to find out how the vegetative growth characteristics of two garlic cultivars were affected by ZnO nanoparticles. Using a randomized complete block design (RCBD), the research examined two primary components and their interactions, with three replicates for each factor. The compatibility of two garlic cultivars with four concentrations of ZnO nanoparticles (0, 50, 100, and 150 mg/L) led to the inclusion of 24 experimental units in the study. The Iraqi Local Garlic variety (49.225cm, 5.475 branch number, 376 555 cm<sup>2</sup>) was superior in height, number of branches, and leaf area, respectively, compared to the Persian (Iranian) variety (47.25cm, 4.107 branch number, 347.667 cm<sup>2</sup>). The 150 ZnO nanoparticles concentration (50.275 cm, 5.175 number of branches, 998.18 cm<sup>2</sup>) was superior in height, number of branches, and leaf area, respectively, compared to the control treatment. As for the bilateral interaction between the variety and the concentration of ZnO nanoparticles, the treatment of the local variety and the concentration of ZnO nanoparticles was superior to 150, concentration (51.25 cm, 5.75 number of branches, 545.70 cm<sup>2</sup>) was superior in height, number of branches, and leaf area respectively compared to the control treatment.

**Keywords:** Zinc oxide; Co-precipitation method; *Allium sativum*; Foliar application

**Received:** May 2026; **Revised:** June 2026; **Accepted:** June 2026; **Published:** July 2026

## 1. Introduction

Garlic (*Allium sativum* L.) is an important vegetable crop belonging to the family Alliaceae. It is rich in carbohydrates, proteins, calcium, phosphorus, iron, riboflavin, niacin, and ascorbic acid, making it a valuable source of nutrients. Garlic (*Allium sativum* L.) is one of the most widely consumed spices worldwide and is rich in bioactive sulfur-containing compounds such as allicin, alliin, diallyl sulfides, ajoene, and S-allyl-cysteine. These compounds possess various biological activities, including antioxidant, antimicrobial, anti-inflammatory, anticancer, antidiabetic, and cardiovascular protective effects [1-3]. Foliar fertilization is a good approach to optimize nutrient uptake, raise crop production, and promote plant development [4]. When a soil lacks nutrients or is under environmental stress, this method is especially helpful as root uptake is restricted [5]. One of the fastest developing technologies is nanotechnology. By means of their controlled and slow release of nutrients, nano fertilizers enhance nutrient usage efficiency and lower environmental pollution [6]. In plants, zinc

(Zn) deficiency could cause delayed maturity, slowed development, and lower crop yield [7]. According to research, applying Zn (Zn) fertilizers to soil and leaves greatly increases enzyme activity, plant metabolism, and tolerance [8]. Compared to traditional Zn fertilizers, Zn nanoparticles enhance absorption efficiency and help in stress resistance, enzyme activation, and seed germination [9]. Using Zn nano fertilizers helps photosynthesis, root development, and chlorophyll synthesis, so raising the general crop output [10]. In addition, Zn is of high importance in protein metabolism and regulation of oxidative stress, improving the plant's capability for withstanding abiotic stresses such as drought and salinity [11].

## 2. Materials and Methods

A field experiment has been conducted according to the Completely Random Block Design (CRBD) and three replications as a factorial experiment (2×4×3), experimental unit experiment 1 (m<sup>2</sup>) the distance between each unit and the other is 35 cm at the experimental unit contains four lines, the distance

between the lines is 20 cm, each line contains four holes, and the distance between one hole and the next is 20 cm, at a rate of 16 holes for each experimental unit, so the total number of experimental units is (24) units. The University of Anbar, College of Education for Pure Sciences was selected as experiment field during the growth season 2022-2023. The following factors included ZnO nano fertilizer with four concentrations (0, 50, 100, and 150 mg/L) with a control treatment (without any addition) and two cultivars of (*Allium sativum*) plants (Persian (Iranian) and local).

**Table (1) Some physical, chemical, and qualities of field soil before cultured**

Characteristics		Value
Soil texture		Sandy Clay
Soil interaction (pH)		8
Electrical conductivity (decisions/m)		8.05
Soil separators (%)	Silt	93.25
	Mud	12.25
	Sand	48.5
Available nitrogen (mg.kg <sup>-1</sup> soil)		21.08
Available potassium (mg.kg <sup>-1</sup> soil)		144.12
Available phosphorus (mg.kg <sup>-1</sup> soil)		11.15
Dissolved ions in soil (mg.kg <sup>-1</sup> soil)	Ca <sup>++</sup>	1.20
	Mg <sup>++</sup>	0.91
	Na <sup>+</sup>	1.25
	K <sup>+</sup>	0.05
	SO <sub>4</sub> <sup>-2</sup>	1.61
	Cl <sup>-</sup>	2.01
	HCO <sub>3</sub>	0.08

In the early morning, the specified concentrations of the nano-fertilizer were foliar-applied to the experimental units according to the designated treatments. The first application was carried out when the plants had reached the 4–6 leaf stage, approximately 26 days after planting. A 2-L plastic hand sprayer was used for spraying. Two drops of a surfactant solution were added to the spray solution and thoroughly mixed with the nano fertilizer suspension to reduce surface tension, enhance adhesion, and ensure complete wetting and uniform coverage of the leaf surface.

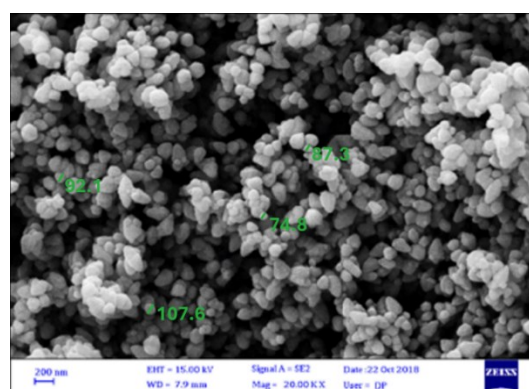
The plants were sprayed until runoff, while the control treatment was sprayed with distilled water only. Appropriate precautions were taken during application to prevent spray drift and contamination of adjacent experimental plots.

A second foliar application of the same nano fertilizer concentrations was performed 59 days after the first application, following the same procedure and under similar early-morning conditions.

ZnO nanoparticles (NPs) was prepared by using , the co-precipitation method employing an aqueous solution of zinc salts (zinc acetate dihydrate). The ZnO NPs were precipitated by adding ammonium hydroxide base. The precipitate was then washed, dried, and calcined to obtain nanoparticles. Field-

emission scanning electron microscopy (FE-SEM) was used to confirm the size of the zinc oxide nanoparticles, as shown in Fig. (1).

ZnO NPs spray solution was prepared by dissolving 1 g of ZnO NPs in a small amount of acetic acid, then bringing the volume to 1 liter of distilled water. The concentrations used in the study were then prepared at 0, 50, 100, and 150 mg/L, according to the dilution law. As for the ZnO NPs spraying, the process was carried out in the early morning using a pressurized hand sprayer, and only once. The plants were sprayed until they were completely wet. As for the control treatments, they were sprayed with distilled water.



**Fig. (1) FE-SEM image of ZnO NPs**

The height of the plant has been measured from the end of the growing tip to the point of contact with the soil. Three replicates and three randomly selected plants from each experimental unit's two median lines underwent the measurement procedure. Next, the average was determined using the previously described methodology [12].

The number of plant branches was calculated for three random plants taken from the two medians of each experimental unit and for three replicates, and then the average was calculated.

Leaf area was estimated non-destructively using mathematical models based on leaf length and width measurements, as described by [13].

The SPSS (2019) program was utilized to determine how various factors affected the study parameters. In this investigation, the LSD, or least significant difference (0.05), was used to meaningfully compare means [14].

### 3. Results and Discussion

The plants treated with the variety outperformed the Iraqi Local Garlic variety with the highest average height of 49.225 cm compared to the Iranian variety, which gave the lowest average height of 47.25 cm. The plants treated with 150 mg/L ZnO NPs also outperformed with the highest average height of 50.275 cm compared to the plants not treated with nano fertilizer. As for the binary interaction, the Iraqi

Local Garlic variety at a concentration of 150 mg/L gave the highest average height of 51.25 cm compared to the lowest height of 48 cm for the Iraqi variety and a concentration of 0 mg/L.

**Table (2) Effect of varieties and ZnO NPs on plant height**

Varieties	Concentrations of nano fertilizer (mg/L)				Mean of Varieties
	0	50	100	150	
Iraqi Local Garlic	48	48.2	49.45	51.25	<b>49.225</b>
Persian (Iranian)	45	46.2	48.5	49.3	<b>47.25</b>
ZnO NPs Mean	<b>46.5</b>	<b>47.2</b>	<b>48.97</b>	<b>50.275</b>	-
L.S.D.: 0.05	Varieties: 2.478 NS, Conc.: 3.811 NS, Var. Conc.: 5.01*				

\* (P<0.05), NS: Non-Significant.

The plants treated with the variety had the highest average number of branches per plant for the local garlic plant, which amounted to 5.475 (branches per plant), compared to the Persian (Iranian) variety, which gave the lowest average number of branches per plant, 4.107 (branches per plant). The plants treated with 150 mg/L ZnO NPs also had the highest average number of branches per plant, 5.1075 (branches per plant), compared to the plants not treated with nano fertilizer. As for the binary interaction, the Iraqi variety, at a concentration of 150 mg/L, had the highest average number of branches, reaching 5.75, compared to the lowest average number of branches, reaching 3.00 cm, for the Iranian variety and ZnO NPs concentration 0.

The plants treated with the variety had the highest average leaf area of the local garlic plant, which amounted to 376.555 cm<sup>2</sup> leaf area compared to the Iranian variety, which gave the lowest average leaf area of 347.667 cm<sup>2</sup>. The plants treated with 150 mg/L ZnO NPs also had the highest average leaf area of 998.18 cm<sup>2</sup> compared to the plants not treated with nano fertilizer. As for the binary interaction, the Iraqi variety at a concentration of 150 mg/L had the highest average leaf area of 545.70 cm<sup>2</sup> compared to the lowest average leaf area of 190.06 cm<sup>2</sup> for the Iranian variety and a concentration of nano zinc of 0 mg/L.

In recent years, the use of ZnO NPs fertilizers has gained significant attention for their potential to enhance the growth and productivity of various crops. Although studies on garlic (*Allium sativum*) are limited, research on related plant species provides valuable insights into the effects of ZnO NPs on plant growth. It is noted from Tables (2, 3, and 4) that the following studied plant traits (plant height, number of branches, and leaf area) were superior with the use of ZnO NPs. These traits increased directly with the increase in ZnO NPs concentration. The ability of ZnO to activate and form the internal growth

regulator indole acetic acid (IAA) and inhibit its oxidation is thought to be the cause of the superiority regarding plants treated with ZnO. This helps to promote the elongation and growth of plant cells [7]. ZnO has an important role in photosynthesis, the conversion of carbohydrates to starch, and the production of proteins, all of which promote plant growth, along with being a co factor for numerous fundamental enzymes in critical processes. Additionally, ZnO affects the synthesis of chlorophyll, which has a direct effect on the nutrient supply that plants require [15]. Although ZnO supplements could enhance several growth parameters, *Allium sativum*. has demonstrated that their influence on plant height might not often be statistically significant [16]. Moreover, studies on habanero pepper showed that foliar spraying with ZnO NPs at a concentration of 1000 mg/L favorably affected stem diameter, plant height, and chlorophyll content, so generating higher fruit yield as well as biomass accumulation than in control and zinc sulfate treatments. This implies that ZnO NPs could raise pepper plant growth conditions [17]. The results showed that foliar spraying of such nanoparticles improved number of branches, plant height, and leaf area, thereby suggesting that ZnO NPs is absolutely essential in promoting vegetative growth in pepper plants [18].

**Table (3) Effect of varieties and ZnO NPs on branch number**

Varieties	Concentrations of nano fertilizer (mg/L)				Mean of Varieties
	0	50	100	150	
Iraqi Local Garlic	5.2	5.3	5.65	5.75	<b>5.475</b>
Persian (Iranian)	3.00	4.31	4.52	4.60	<b>4.1075</b>
ZnO NPs Mean	<b>4.1</b>	<b>4.805</b>	<b>5.085</b>	<b>5.175</b>	-
L.S.D.: 0.05	Varieties: 1.167 *, Conc.: 1.294 NS, Var. Conc.: 1.685 *				

\* (P<0.05), NS: Non-Significant

**Table (4) Effect of varieties and ZnO NPs on leaf area**

Varieties	Concentrations of nano fertilizer (mg/L)				Mean of Varieties
	0	50	100	150	
Iraqi Local Garlic	192.02	307.55	460.95	545.70	376.555
Persian (Iranian)	190.1	300.03	449.88	450.66	347.667
ZnO NPs Mean	191.06	303.79	455.415	998.18	---
L.S.D.: 0.05	Varieties: 26.57 *, Conc.: 38.01 *, Var. Conc.: 59.44 *				

\* (P<0.05)

These findings line up with [31] and [32], who demonstrated how giving nutrients boosts plant leaf count. This rise is a result of nutrients' indirect and

direct influence on improved vegetative development by means of activating carbon metabolism systems. Also, vital are respiration, higher growth hormones, compounds necessary for cell elongation, division, as well as development include amino acids and enzyme cofactors. Nutrients also stimulate the plant to produce cytokines, which are important for encouraging the growth of lateral buds, stimulating various enzymes, and increasing chlorophyll formation.

### 5. Conclusion

The results showed that the application of ZnO NPs positively affected garlic growth, with the highest concentration (150 ppm) significantly improving plant height, leaf number, and leaf area. These results suggest that foliar application of nanozinc may be a useful strategy for supporting garlic crop growth.

### References

- [1] V. Lanzotti, "The analysis of onion and garlic", *J. Chromatogr. A*, 1112(1-2) (2006) 3-22.
- [2] A. Shang et al., "Bioactive compounds and biological functions of garlic (*Allium sativum L.*)", *Foods*, 8(7) (2019) 246.
- [3] M. Iciek, I. Kwiecień, and L. Włodek, "Biological properties of garlic and garlic-derived organosulfur compounds", *Environ. Mol. Mutagen.*, 50(3) (2009) 247-265.
- [4] H. Marschner, "**Marschner's mineral nutrition of higher plants**", Academic Press (NY, 2011).
- [5] P. Wojcik, "Uptake of mineral nutrients from foliar fertilization", (2004).
- [6] M. Kah et al., "A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues", *Nat. Nanotechnol.*, 13(8) (2018) 677-684.
- [7] I. Cakmak, "Enrichment of cereal grains with zinc: agronomic or genetic biofortification?", *Plant Soil*, 302 (2008) 1-17.
- [8] P.N. Bhattacharyya, "Soil factors associated with zinc deficiency in crops and humans," *Environ. Geochem. Health*, 31(5) (2009) 537-548.
- [9] R.K. Rattan et al., "Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study", *Agric. Ecosyst. Environ.*, 109(3-4) (2005) 310-322.
- [10] P. Wang et al., "Nanotechnology: a new opportunity in plant sciences", *Trends Plant Sci.*, 21(8) (2016) 699-712.
- [11] H. Marschner, "**Marschner's Mineral nutrition of higher plants**", 2<sup>nd</sup> ed., Academic Press (NY, 1995).
- [12] D.W. Wiersma, E.S. Oplinger and S.O. Guy, "Environment and Cultivar Effects on Winter Wheat Response to Ethepon Plant Growth Regulator 1", *Agron. J.*, 78(5) (1986) 761-764.
- [13] F.A.R. Gonçalves et al., "Non-destructive evaluation of the leaf area of garlic crop using mathematical models", *Biosci. J.*, 36(5) (2020) 1600-1606.
- [14] D. George and P. Mallery, *IBM SPSS statistics 29 step by step: A simple guide and reference*. Routledge (2024).
- [15] L. Taiz and E. Zeiger, "Plant Physiology. Sinauer Assoc", Sunderland Publishing, Inc. (MS, 2002), pp. 1-690.
- [16] S. Nasreen et al., "Response of garlic to zinc, boron and poultry manure application", *Bangladesh J. Agric. Res.*, 34(2) (2009) 239-245.
- [17] J.I. García-López et al., "Foliar application of zinc oxide nanoparticles and zinc sulfate boosts the content of bioactive compounds in habanero peppers", *Plants*, 8(8) (2019) 254.
- [18] G.S. Nechitailo et al., "Influence of Iron, Zinc, and Copper Nanoparticles on Some Growth Indices of Pepper Plants", *Nanotech. Russ.*, 13(3-4) (2018) 161-167.