Journal of Wasit for Science and Medicine 2025: 18, (3), 13-20

Assessment of Magnesium and Zinc Levels in Borage Plant Under the Effect of Irradiation and Spraying with Nanoparticles

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Abstract

The study investigated effects of irradiation and nanoparticles spraying on the chemical content of borage leaves in 20 experimental groups. Each with ten replicates, categorized based on treatment type to gamma radiation, and nanoparticle spraying which were sprayed uniformly on the aerial parts of each plant at 21 days after germination. Using a fine-nozzle hand sprayer to ensure full coverage without excess. Results showed that the spraying of MgO nanoparticles at a concentration of 20 mg/L significantly increased magnesium levels ($p \leq 0.05$). Reaching a peak value of 1.50 ± 0.14 mg/L compared to the control group. In the case of zinc, treatment with ZnO nanoparticles at 40 mg/L led to a modest improvement, with the highest observed concentration being 1.73 ± 0.14 mg/L. The radiation-only groups (CR1–CR3) failed to show any significant improvement in mineral levels; instead, there were notable decreases in some groups, especially at higher doses (180 Gy in CR3). Combined treatments (N1R1–N4R3) showed no significant improvement over nanoparticle spraying alone. Nanoparticle spraying alone was more effective than radiation in improving both magnesium and zinc levels. The combination of radiation and nanoparticle spraying did not yield better results than nanoparticle treatment alone, suggesting that radiation might weaken the benefits of nanoparticles in mineral uptake.

Keywords: Irradiation, Borage Leaves, Nanoparticles.

1. Introduction

Borage (Borago officinalis L.) is an herbaceous plant native to Europe, North Africa and Asia Minor and widely cultivated in North Africa and Asia Minor [1]. It is an important vegetable crop grown in some countries [2] including Iran. It is also a medicinally important plant that contains more than 20 % gamma-linolenic acid (GLA) in its seed oil [3]. Borage is rich in many chemical compounds such as amino acids, carbohydrates and proteins are the primary metabolic products. Other compounds such as alkaloids, phenolics, steroids, terpenoids are the secondary metabolic products which have pharmacological importance [4].

Research indicates that the major biologically active compounds in the plant include flavonoids, terpenes, alkaloids, saponins, coumarins [5], and flavonoids [6]. Exposure of borage seeds to different levels of gamma irradiation has varying effects. Higher doses of gamma radiation have an inhibitory effect, while lower doses may have a stimulatory effect. Low doses have been shown to enhance cell reproduction, germination, cell division, enzyme activation, stress resistance, and crop yield [7].

Due to the physical and chemical properties of nanoparticles, they can be considered as bio-stimulants. The ability of these materials applied in small quantities in general and by foliar spray or in nutrient solutions has been described to modify the general health of the plant and the nutritional quality of crops as well as their tolerance to various stresses [8]. Current studies show that nanotechnology can be widely used to address agricultural problems such as the inefficient use of fertilizers and pesticides [9]. Because of recent advances of nanotechnology applications in plants, the focus of research was and still is based on the potential provided by this technology in improving plant growth and the production of secondary compounds.

However, some researchers have addressed the disadvantages that can result from the use of such nanomaterials [10]. Concluded that soaking black seed seeds in a solution of nano-copper and nano-cadmium, each separately and at concentrations of (0.25, 0.50) mg/L for 3-6 hours caused genetic changes at the DNA level. The results concluded that both nano-copper and nano-cadmium achieved effects like mutagenic factors such as exposure to gamma rays [8].

Also found that treating onion plants with nano-titanium oxide caused DNA distortions. Therefore, these researchers recommended intensifying the study of genetic changes resulting from the accumulation of nanomaterials, as well as determining the concentration and duration of exposure that cause these changes or defects in the genetic material. Finally, different materials may act through different pathways and, it remains difficult to determine the threshold between toxicity and beneficial effects [11]. The study aims to investigate the effect of gamma irradiation and ZnO or MgO nanoparticles spraying on the magnesium and zinc content of borage plants.

2. Materials and Methods

2.1 Design and Implementation of Experiments

Borago officinalis seeds from Wasit University were used in this field experiment in 2024. Season in the experimental nursery of the Al-Ahrar Agriculture Directorate, Wasit. Soil was collected from a 0-30 cm depth near the river, air-dried, and sieved (4 mm) for analysis. Pots (21×18 cm) were filled with 15 cm of soil mixed with 1 kg Dutch peat moss (POTGROND). Plants were grown under open field conditions and fertilized monthly with 5 g/L foliar N-P-K (20-20-20).

Experiments in the current study involved gamma radiation treatment using a (Cobalt-60 Gamma Chamber 900) at the University of Baghdad. Seeds were subjected to (100, 140, and 180) Gy while a control group was not exposed to radiation. Seeds were prepped, exposed to 12 Gy of radiation per hour, and then stored. Zn NPs (20, 40 mg/L) and Mg NPs (10, 20 mg/L) were dissolved in one liter of distilled water, mixed to ensure even dispersion, and then sprayed on aerial parts 21 days post-germination with a fine-nozzle sprayer to ensure even coverage.

2.2 Experimental Design

The study included 20 experimental groups, each with ten replicates, categorized based on treatment type that included gamma radiation, nanoparticle spraying, or their combination. The control (C) untreated reference group, gamma radiation (CR1-CR3). Seeds irradiated at 100, 140, and 180 Gy before cultivation. Moreover, nanoparticles spraying after cultivation (N1–N4). Plants treated with ZnO NPs (20, 40 mg/L) or MgO NPs (10, 20 mg/L). Combined treatments (N1R1-N4R3), seeds exposed to 100, 140, or 180 Gy followed by ZnO or MgO NPs application.

2.3 Estimation of Magnesium Content in Leaves

The estimation of magnesium content of the leaves in the digested sample was determined using a flame photometer (ELICO, Model CL 361, India) [12].

2.4 Estimation of Zinc Content in Leaves

Zinc analysis from each sample was done using zinc spectrophotometric method [13]. Samples of leaf were first dried in an oven at 70 °C for 8 hours. Then, samples were crushed, and 1 gram of the crushed powder was added to a vial containing 8 ml of HNO_3 and $HClO_4$ (1:1 ratio) for acid digestion. Samples were kept in the dark until a clear solution was obtained. The solution was filtered, and the volume was made up to 100 mL, and atomic absorption spectrophotometer (GBCSAVAAT AA: Australia) was then used to determine zinc.

2.5 Statistical Analysis

Data of current study was statistically analysed and represented as mean ± standard error (SEM). Analysis of variance (ANOVA) was performed, and the means of the recorded data were compared using the Least Significant Difference (LSD) test at a 5 % significance level.

3. Results and Discussion

3.1 Estimation of Magnesium Content in Leaves

The research indicates several important results related to magnesium levels, the N4 group has a significant increase ($p \leq 0.05$) in magnesium concentration by (1.50 ± 0.14 mg/L) when compared to control group, and the increased level may indicate a positive effect of the nanoparticles on magnesium retention or bioavailability.

This result is consistent with a study by Salas-Leiva et al. that found that some types of nanoparticles can enhance magnesium absorption and bioavailability [14]. This effect may be due to the ability of nanoparticles to improve cell membrane permeability or modulate cellular transport processes. Lower concentrations of nanoparticle spraying (N2 and N3) did not show significant improvements (0.87 ± 0.12, and 0.91 ± 0.11 mg/L). Suggesting that higher doses of nanoparticles are more effective in enhancing magnesium absorption in different physical and chemical properties of nanomaterials lead to diverse biological effects [15].

The combination of nanoparticles with radiation (N1R1) showed a significant increase ($p \leq 0.05$) in magnesium levels (1.23 ± 0.24 mg/L) when compared to the radiation alone in CR1 group (0.88 ± 0.22 mg/L).

The result is consistent with a study by Singh and co-workers [16] which showed that radiation can affect mineral balance in the plant, including magnesium. While the same concentration of nanoparticles but with radiation in high dose in N1R3 the magnesium level shows a significant decrease ($p \leq 0.05$) to (0.86 ± 0.23 mg/L), indicating a potential harmful effect of radiation. This contrasting effect is consistent with a study by Lei et al. [17] who found that some nanoparticles can modulate the cellular response to radiation, including effects on mineral homeostasis.

Table 1: Effect of nanomaterial and irradiation on magnesium levels.

Magnesium levels (mg/L)	
Group	Mean ± SEM
C	1.09 ± 0.25
N1	1.17 ± 0.22
N2	0.87 ± 0.12
N3	0.91 ± 0.11
N4	1.50 ± 0.14
N1R1	1.23 ± 0.24
N2R1	0.94 ± 0.22
N3R1	0.92 ± 0.21
N4R1	0.90 ± 0.11
CR1	0.88 ± 0.22
N1R2	0.90 ± 0.2
N2R2	0.90 ± 0.12
N3R2	1.00 ± 0.15
N4R2	0.97 ± 0.13
CR2	0.87 ± 0.33
N1R3	0.86 ± 0.23
N2R3	0.94 ± 0.26
N3R3	0.91 ± 0.22
N4R3	0.97 ± 0.21
CR3	0.95 ± 0.11
LSD	0.014

Where, CR1-CR3 = Gamma irradiation at (100, 140, and 180) Gy. N1-N4 = ZnO NPs (20, 40 mg/L) and MgO NPs (10, 20 mg/L). N1R1-N4R3 = Combined treatments of gamma irradiation and nanoparticle application.

3.2 Estimation of Zinc Content in Leaves

The control group showed stable zinc levels under varying radiation conditions, with values ranging from (1.51 ± 0.12 to 1.73 ± 0.14 mg/L). This stability suggests a fundamental interaction with the experimental conditions, indicating that zinc levels are maintained despite radiation exposure. The ratio of zinc concentration in the N1 and N4 groups are (1.72 ± 0.21, 1.73 ± 0.08 mg/L), exceeding that of the control group.

The increase suggests that the nanoparticles may improve zinc retention or bioavailability, especially under non-radiation conditions, and these results are consistent with previous studies that have confirmed that nanotechnology can improve the availability of nutrients [18,19]. This can suggest a protective effect of the nanoparticle spraying against radiation-induced zinc depletion in other groups. Zinc levels were good in the groups of radiation control, maintaining a scale of (1.73 ± 0.08 and 1.67 ± 0.21 mg/L) in R1 and R2 respectively but in R3 group it shows a significant decrease ($p \leq 0.05$), (1.51 ± 0.12 mg/L).

This can indicate that zinc didn't affect with radiation at low doses, but its high doses have a negative effect. These results are consistent with research indicating that radiation can deplete essential minerals such as zinc [20]. This effect may come from the exposure of seeds to gamma rays in high dose which may lead to genetic changes that affect the genes responsible for nutrient uptake or the regulation of their levels within cells [21]. The N3R2 and N4R3 groups showed the low zinc content at (1.63 ± 0.15 mg/L), suggesting potential vulnerabilities of specific nanoparticles under radiation exposure. Excessive oxidative stress may lead to increased free radical production and may lead to damage of the enzymes responsible for mineral uptake and transport, preventing the utilization of the added nanoparticles.

Table 2: Effect of nanomaterial and irradiation on zinc levels.

Zinc levels mg/L	
Group	Mean ± SEM
C	1.65 ± 0.23
N1	1.72 ± 0.21
N2	1.65 ± 0.22
N3	1.69 ± 0.11
N4	1.73 ± 0.14
N1R1	1.70 ± 0.13
N2R1	1.65 ± 0.1
N3R1	1.68 ± 0.09
N4R1	1.73 ± 0.08
CR1	1.67 ± 0.21
N1R2	1.68 ± 0.12
N2R2	1.64 ± 0.14
N3R2	1.63 ± 0.15
N4R2	1.66 ± 0.11
CR2	1.71 ± 0.13
N1R3	1.71 ± 0.14
N2R3	1.64 ± 0.12
N3R3	1.67 ± 0.11
N4R3	1.63 ± 0.11
CR3	1.51 ± 0.12
LSD	0.0245

Where, CR1-CR3 = Gamma irradiation at (100, 140, and 180) Gy. N1-N4 = ZnO NPs (20, 40 mg/L) and MgO NPs (10, 20 mg/L). N1R1–N4R3 = Combined treatments of gamma irradiation and nanoparticle application.

4. Conclusion

This study demonstrated that nanoparticle spray was a more effective means of supplementing magnesium and zinc consumption in Borago officinalis compared to utilizing gamma radiation. Magnesium content increased significantly, particularly when utilizing MgO NPs at increased dosages, whereas zinc consumption improved with ZnO NPs.

On the other hand, gamma radiation alone did not enhance mineral uptake and, at higher concentrations (180 Gy), impaired the absorption of magnesium and zinc. Moreover, the combination of radiation with nanoparticle spraying provided no extra benefits compared to nanoparticle treatment alone, suggesting that radiation might suppress the ability of the plant to effectively utilize nanoparticles.

However, to achieve the best improvement in magnesium and zinc content in Borago officinalis, nanoparticle spraying (especially at higher concentrations) must utilized without pre-exposure to gamma radiation since radiation may debilitate the plant's ability to absorb these essential minerals.

5. References

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