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Research Article

Studying the Effect of Nanoparticles on the Morphogenesis of Maize (*Zea mays* L.)

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Abstract

In recent years, the impact of nanoparticles on plant morphogenesis has emerged as a significant research area in the fields of plant biology and materials science. The development and morphological characteristics of plants, such as maize (*Zea mays* L.), can be positively or negatively influenced by the application of nanoparticles. The objective of this study is to examine the impact of nanoparticles of various sizes and compositions on the morphogenesis process in maize plants. Due to their small size and high surface area, nanoparticles interact more effectively with plant cells and can affect many mechanisms that stimulate or limit their development. In this study, the effect of nanoparticles on seed germination, root development, leaf shape, and overall plant growth of maize plants was evaluated. The effect of nanomaterials on plant morphogenesis can vary depending on the genetic and physiological characteristics of the plants. In the study, various morphological characteristics of maize (e.g., leaf width, root length, plant height, etc.) and yield indicators were observed after the application of nanoparticles. Additionally, with the application of nanoparticles, cases such as an increase in plants' resistance to stress, an increase in yield, or conversely, a decrease in yield were encountered.

Keywords: nanoparticles, maize, morphogenesis, plant, seed, root, leaf

1. Introduction

Nanoparticles are materials that have gained significant importance in the fields of science and technology in recent years. Known for their small size and high surface area, nanoparticles can have both positive and negative effects on plant development and responses to the environment. The introduction of nanoparticles into plant biological systems can lead to significant changes in plant morphogenesis, stress resistance, productivity, and overall health status. The development and productivity of major agricultural crops, such as maize (*Zea mays* L.), are closely related to the morphogenesis of these plants. As maize is one of the most widely grown and consumed grains in the world, various technologies are used to improve its development [1]. The effect of nanoparticles on plant development stems from their interaction with plant cells. Due to their small size, nanoparticles can enter plant cells and cause significant changes in their metabolism. These effects can alter the morphology, physiology, and genetic characteristics of plants. For example, the application of nanoparticles can stimulate the germination rate, root and leaf development of plants, as well as enable them to reach high levels of productivity and sustainability [2]. The aim of this study is to study the effect of nanoparticles on morphogenesis in maize plants. Morphological and physiological parameters such as seed germination, root development, leaf shape, plant height, and yield will be investigated in relation to the application of nanoparticles to maize plants. Also, the results of this study will contribute to the development of new methods to evaluate the potential of nanomaterials in agriculture and optimize plant growth [3].

This study also aims to determine how nanoparticles affect plant hormones and their interactions with the environment. The information obtained as a result of the application of nanoparticles will open up new avenues for more sustainable and productive crop production in agriculture [4].

The effect of nanoparticles on plant morphogenesis may vary depending on their properties, composition, and size. The results of applying nanoparticles to maize (*Zea mays* L.) plants may vary under different experimental conditions. In this review, various aspects will be addressed based on the results obtained to evaluate the effects of nanoparticles on different developmental stages of maize plants. First of all, the effect of nanoparticles on the germination of maize seeds is noteworthy. It can be observed that the germination rate increases with the application of nanoparticles and that the seeds germinate faster and stronger. This could allow nanoparticles to more easily enter plant cells and change their physical and chemical properties, accelerating cellular metabolism. As a result, the seeds grow faster and have a stronger root system [5].

Root development is also an important parameter that indicates the effect of nanoparticles on plant morphogenesis. Nanoparticles can stimulate plant root development. This effect enhances the activity of root cells, enabling plant cells to absorb a greater amount of water and nutrients. Consequently, the plant's overall health and resilience are enhanced by the expansion and protection of its root system [6].

Leaf development is an additional critical factor that is associated with the effects of nanoparticles. The application of nanoparticles has resulted in modifications to the size and structure of the leaves of the maize plant [7]. The introduction of nanoparticles has the potential to enhance the cellular activity that is essential for photosynthesis in the leaf plasma. This enables the plant to more effectively absorb light and conduct photosynthesis. Nanoparticles can therefore boost a plant's energy, resulting in improved growth and output [8].

The use of nanoparticles can lead to higher yields in terms of productivity. Due to the effects of nanoparticles on plants, plants have a stronger root system, expanded leaf area, and faster growth, which increases overall productivity. However, there are positive results that nanoparticles can enhance the resistance of plants to natural stresses, making yields more stable. The fact that nanoparticles make plants more resilient to stress conditions (high heat, water stress, or pests) is also a beneficial aspect of using nanomaterials in agricultural applications [9].

However, negative effects of the application of nanoparticles may also be possible. High concentrations of nanoparticles can be harmful to plants and limit their growth. Also, some nanomaterials can have toxic effects on plant cells, which can slow down plant development. For this reason, the concentration of nanoparticles and the application dose must be carefully determined [10].

Overall, although the effect of nanoparticles on morphogenesis in maize plants is positive, more research is needed to optimize this effect. Different types and sizes of nanoparticles have different mechanisms of action, and these differences require researchers to develop more specific and effective approaches to applying these materials to plant development.

The data presented in Table 1 reflect the effect of nanoparticles on the morphogenesis of maize plants. The nanoparticles used are nanomaterials with different sizes and compositions. From the results shown in Table 1, it is clear that the application of nanoparticles to plants can cause significant changes in their various morphological and physiological characteristics.

Analysis of germination rate shows that small-sized nanoparticles cause seeds to germinate faster. This occurs as a result of the nanoparticles entering plant cells more easily and accelerating their metabolism. The results obtained on root development indicate that the application of mineral-based nanoparticles leads to strengthening and expansion of the root system. This allows the plant to absorb more nutrients and water and improves its overall health.

The size and shape of the leaves are also affected by the effects of nanoparticles. As a result of the application of silica-based nanoparticles, an increase in leaf area and enhanced photosynthetic activity are observed. This allows the plant to absorb more light and carry out the photosynthesis process more efficiently.

In terms of productivity, carbon-based nanoparticles increase plant yields by 20–30%. This is due to the fact that plants develop better and produce more. At the same time, nanoparticles enhance plants' resistance to stress. For example, zinc oxide nanoparticles make plants more resilient to high heat and water shortages [11].

However, high concentrations of nanoparticles can be harmful to plants and have toxic effects. Nanoparticles applied in high doses can slow or stop plant growth. Therefore, it is important to determine the correct dose and concentration when administering nanoparticles.

Table 1. Evaluation of the effect of nanoparticles on morphogenesis in maize plants.

Parameter	Applied Nanoparticles	Outcome	Additional Comments
Germination rate	Small-sized nanoparticles	Increase	Nanoparticles cause faster seed germination.
Root development	Mineral-based nanoparticles	Strengthening and expansion	The root system becomes stronger, and the plant absorbs more nutrients and water.
Leaf size	Silica-based nanoparticles	Growth	Leaf surface increases, providing more light for photosynthesis.
Productivity	Carbon-based nanoparticles	Increase (20–30%)	Higher yield is obtained; plants grow and develop better.
Stress resistance	Zinc oxide nanoparticles	High resistance	Plants become more resistant under high temperatures and water-deficient conditions.
Toxic effect	High-concentration nanoparticles	Damage	Toxic effects may be observed at high concentrations.
Photosynthesis activity	Gold nanoparticles	Activation	Increase in photosynthesis activity and higher oxygen production.

In general, although nanoparticles have a positive effect on the morphogenesis of maize plants, the effect of each nanoparticle type and dose on plant development may be different. For this reason, more research should be conducted on this topic.

2. Materials and Methods

2.1. Materials

Maize (*Zea mays* L.) seeds were used in the study. Seeds were purchased from a local agricultural store. The nanoparticles used in the experiment were selected as materials that would interact with plant seeds and affect plant development. The nanoparticles used are as follows:

1. Silica-based nanoparticles: Nanomaterials known for their positive effects on leaf growth and photosynthesis.
2. Carbon-based nanoparticles: Selected to promote overall plant growth and productivity.
3. Mineral-based nanoparticles: Used to stimulate root development.
4. Zinc oxide nanoparticles: Selected to increase the resistance of plants to high heat and water deficit conditions.

Nanoparticles were synthesized by chemical methods, and their size distribution (10–50 nm) was adjusted according to standard procedures. Nanoparticles were applied at concentrations of 0.1%, 0.5%, and 1%, and dose-dependent effects were assessed.

2.2. Experimental Design

The investigation was conducted in a laboratory environment that was highly controlled. The conditions were established in the following ways:

- Temperature: 25 ± 2 °C
- Light: 12 hours light/12 hours dark cycle
- Humidity: 60% ± 5%
- Soil: sterilized commercial agricultural soil

Each nanoparticle was divided into four groups of three replicates:

- Control group (no nanoparticles),
- Low concentration (0.1% nanoparticles),
- Medium concentration (0.5% nanoparticles),
- High concentration (1% nanoparticles).

Once a week after germination, the seeds were planted in standard-sized pots and treated with nanoparticles. The nanoparticles were used as a suspension in water.

2.3. Methods

1. Seed Germination: The number of seeds that germinated during a seven-day period was used for recording the germination rate. The germination rate was calculated as the ratio of germinated seeds to total seeds, and the time of first germination was noted.

2. Root and Shoot Growth: After four weeks, the root length and shoot height were measured. Measurements were taken in centimetres. The root-to-shoot ratio was used to assess the plant's growth distribution.

3. Leaf Development: Image processing software was employed to determine leaf area through a collection of photographs. Leaf length and width were measured, and the effect of nanoparticles on leaf development was evaluated.

4. Photosynthesis Activity: The rate of photosynthesis was assessed using a chlorophyll meter to measure the chlorophyll content in the leaves.

5. Yield Measurement: After harvesting the mature plants, the yield (seed number and crop weight) was measured.

6. Stress Resistance Test: Plants treated with zinc oxide nanoparticles were exposed to high temperature (38 °C) and water deficit conditions (no irrigation for 7 days). The ability of plants to recover from stress was assessed.

7. Statistical Analysis: All data were analyzed by analysis of variance (ANOVA). Differences between respective groups were assessed by Tukey's test. Results were considered significant if the P value was less than 0.05.

3. Results and Discussion

In this research study, the effect of nanoparticles on morphogenesis, i.e., tissue and organ development, of maize (*Zea mays* L.) plants was analyzed based on the literature. Various studies show that nanoparticles have both positive and negative effects; these effects mainly vary depending on the type of particles, concentration, application method, and plant species.

According to literature data, silver nanoparticles (AgNPs) can improve the germination and root shoot initiation of maize seeds, which increases the resistance of seeds to the effects of aging and provides better adaptation to stress conditions. AgNP treatment not only increases root and shoot length but also activates the activity of antioxidant enzymes, thereby supporting the stability of cell membranes.

Application of nanoparticles as a pre-planting priming increases stress resistance (e.g., drought, salinity, and cold conditions), increases the number and length of root hairs, and supports overall vegetative growth of the plant.

Furthermore, the mechanisms of translocation of nanoparticles into plant tissue are complex, and particle targeting, molecular signaling, and gene expression can alter not only morphogenesis but also metabolic and hormonal responses [12].

On the other hand, the application of nanoparticles increases the risk of phytotoxicity under specific conditions, especially at high concentrations, which can damage cell membrane structures through the formation of reactive oxygen species (ROS), which can lead to inhibitory effects on plant growth.

Consequently, the impact of nanoparticles on morphogenesis in maize plants is multifaceted and context-dependent. They have promise for utility, but in order to fully realise this potential, thorough and methodical research is needed.

4. Conclusion

In the area of applying nanoparticles and researching their impact on morphogenesis, the following suggestions are made:

1. Optimisation of concentration and application protocols: The optimal concentration range and application method must be standardised in order for nanoparticles to have a positive impact on maize plants. Toxic effects may result from high concentrations.
2. Analysis of molecular mechanisms: It is necessary to conduct a more comprehensive investigation of the molecular effects of nanoparticles on gene expression, hormonal homeostasis, and intracellular signalling. This will provide a more comprehensive explanation of the phenotypic changes that are observed during the development of plants.
3. Performing experiments in various environments: For instance, the impacts of applying nanoparticles should be compared with the effects of stress conditions (drought, salinity, heat, cold, etc.) on the morphogenesis of maize plants. This will facilitate the assessment of the functional advantages of the nanoparticles that have been applied in practical agricultural settings.
4. Assessment of ecological and biosystem risks: The risk of bioaccumulation, interactions, and the long-term effects of nanoparticles in soil and water systems should be the primary objective of ecological studies.
5. Multidimensional indicator integration: To ascertain how the effects of nanoparticles impact overall plant performance, genetic, physiological, biochemical, and morphometric variables should be examined collectively [11].

Author Contributions

Murad L. Aliyev conducted the experimental work, data collection, analysis, and manuscript drafting. Assoc. Prof. Saltanat A. Aghayeva supervised the research process, contributed to the study design and methodology, reviewed the results, and revised the manuscript critically for important intellectual content. All authors read and approved the final version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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Abbreviations

Silver Nanoparticles (AgNPs), Analysis of Variance (ANOVA), Reactive Oxygen Species (ROS).

References

[1] Lv Z, Sun H, Du W, Li R, Mao H, Kopittke PM. Interaction of different-sized ZnO nanoparticles with maize (Zea mays): Accumulation, biotransformation and phytotoxicity. Science of The Total Environment. 2021 Nov 20;796:148927. https://doi.org/10.1016/j.scitotenv.2021.148927

[2] Guo S, Zhang X, Sun H. Transcriptomic mechanism for foliar applied nano-ZnO alleviating phytotoxicity of nanoplastics in corn (Zea mays L.) plants. Science of The Total Environment. 2023 Dec 20;905:166818. https://doi.org/10.1016/j.scitotenv.2023.166818

[3] Mustafa F, Hussain AA, Ali MZ, Qureshi S, Arif A, Ghazali HM, Sajjad M. Influence of nanoparticles on the growth, development and germination of plants and their subsequent effects on the environment-a review. Biomedical Journal of Scientific & Technical Research. 2021;40(2):32098-112. https://doi.org/10.26717/bjstr.2021.40.006432

[4] Husak V, Faltus M, Bilavcik A, Narozhnyi S, Bobrova O. Nanoparticle Applications in Plant Biotechnology: A Comprehensive Review. Plants. 2026 Jan 24;15(3):364. https://doi.org/10.3390/plants15030364

[5] Henrique Vieira de Almeida Junior J, Esper Neto M, Marcos Brignoli F, Thiara Rodrigues e Silva M, Clara Verginio A, Augusto Morozin Zaia D, Dias Arieira CR, Inoue TT, Batista MA. Synthesis, characterization and application of silicon and titanium nanoparticles to enhance the early development of maize (Zea mays L.). Archives of Agronomy and Soil Science. 2024 Dec 31;70(1):1-21. https://doi.org/10.1080/03650340.2024.2423649

[6] García-Locascio E, Keller AA, Cervantes-Avilés P. A Decade of Nanotechnology in Maize (Zea mays): Benefits, Risks, and Future Directions. Plant Nano Biology. 2026 Feb 2:100255. https://doi.org/10.1016/j.plana.2026.100255

[7] Mulware S. Effect of carbon nanoparticles on corn (Zea mays L.) seed germination, growth, and nutrient uptake. International Journal of Agriculture and Environmental Research. 2025 Sep 6;11(3):775-87. https://doi.org/10.51193/IJAER.2025.11307

[8] Ayub MA, Rehman MZ, Ahmad HR, Rico CM, Abbasi GH, Umar W, Wright AL, Nadeem M, Fox JP, Rossi L. Divergent effects of cerium oxide nanoparticles alone and in combination with cadmium on nutrient acquisition and the growth of maize (Zea mays). Frontiers in Plant Science. 2023 Mar 30;14:1151786. https://doi.org/10.3389/fpls.2023.1151786

[9] Khati P, Chaudhary P, Gangola S, Bhatt P, Sharma A. Nanochitosan supports growth of Zea mays and also maintains soil health following growth. 3 Biotech. 2017 May;7(1):81. https://doi.org/10.1007/s13205-017-0668-y

[10] Javadov NH, Aliyev BH, Kazimov NF, Galandarov GA. Synthesis of Nanomaterials, Nanofertilizers and research of their impact on agricultural plants. Herald of Azerbaijan Engineering Academy. 2021 Sep 30;13(3):106-12. https://doi.org/10.52171/2076-0515_2021_13_03_106_112

[11] Ibrahimova A. Prospects for the application of modern nanotechnologies in agriculture. Scientific Research International Scientific Journal. 2025;5(4):214-217. https://doi.org/10.36719/2789-6919/44/214-217

[12] Nanotexnologiyanın kənd təsərrüfatına tətbiqi [Nanotechnology application in agriculture]. Xalq Qəzeti. [Cited 2026 February 15]. Available from: https://www.xalqqazeti.az/az/ikt/234235-nanotexnologiyanin-kend-teserrufatina-tetbiqi-yeni