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Effect of nanoparticles on the Almond (*Prunus amygdalus*) tree flower fertilization

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Abstract: This article presents the results of the effects of SiO_2 and Fe_3O_4 nanoparticles on flowering, flower fertilization and nanoparticle accumulation in flower petals and almond fruit. The results showed that under normal conditions, 80% and 30% of the total number of flower buds in the almond varieties Leyla and Nuray form flowers. However, the fertilization of flowers in both varieties is only about 21.1%. The application of Fe_3O_4 nanoparticles increases flower formation by 86% in Leyla and 53.4% in Nuray, and the fertilization of the formed flowers by 44.5% in Leyla and 27.4% in Nuray compared to the control. The application of SiO_2 nanoparticles increases flower formation by 78% in Leyla and 31.3% in Nuray, and the fertilization by 22.2% in Leyla and 46.8% in Nuray compared to the control. TEM analysis revealed that these particles bioaccumulated in all three layers (seed, endocarp and mesocarp) and that more pathologies occurred in the endocarp and mesocarp layers. Experimental results showed that nanoparticles did not affect fruit morphology. While Fe_3O_4 nanoparticles increased net seed yield by 3% in the Leyla variety, SiO_2 nanoparticles reduced it by 2%, but no difference was observed in the Nuray variety.

Keywords: Iron oxide, Nanotecnology, Silicon dioxide, nanoparticles, Nanoparticle accumulation.

Introduction

The flowering process in fruit trees and the normal fertilization of flowers are the main physiological processes determining their productivity. Flower fertilization is a complex process, and environmental factors such as temperature, humidity, wind and pollinators have a significant impact on this process. Recently, the application of nanotechnology in agriculture, including plant breeding, has become relevant. Although important results have been obtained in this field, the application of nanomaterials is still under scrutiny in solving many issues. Research in scientific literature shows that the effect of nanoparticles on flowering and fertilization in fruit trees is poorly studied, despite some conducted experiments. For example experiments with onion plants (*Allium cepa* L.) investigated the effect of ZnO nanoparticles on the flowering process. It was discovered that applying ZnO nanoparticles at concentations of 20 – 30 mkg/L resulted in plants flowering 12-14 days earlier compared to the control group (Laware & Shilpa Raskar, 2014). Additionally, Ag were found to nanoparticles stimulate flowering in Lilium cv, increasing the number of flowers, chlorophyll and carotenoids (Piotr Salachna *et al*., 2019). The results showed that both SiNPs and AgNPs had potential usefulness in pest management programs (Salah *et al*., 2023). Iron oxide (IONPs) and silver nanoparticles have been used as a solution to combat antibi otic-resistant pathogens (AlKhafaji *et al*., 2024; Shareef *et al*., 2023; Almudhafar *et al*., 2022). The application of Ag nanoparticles to *Passiflora edulis Sims* also stimulated budding, flowering and fruit formation processes, resulting in a 51.67%, increase in floweing rate and a 2.33 times increase in the number of flowers compared to the control group. Fertilization rate also increased by 56.67%. (Truong Hoai Phong *et al*., 2022). Similarily, when Eustoma grandiflorum cultivar Mariachi Blue plants were sprayed with solutions containing of varying concentrations of ZnO and $CaCO_3$ nanoparticles every 20 days, the number of flowers increased by 56.3% compared to the control (Zeynab Seydmohammadi *et al*., 2020). The application of TiO_2 nanoparticles to tropical and subtropical Litchi (Litchi chinensis Sonn.) fruit trees improved pollination power, yield and fruit quality (Huang *et al*., 2022). Moreover, the effects of Ag and Zn nanoparticles on vegetative development, pollen viability, yield and fruit quality were tested on 8-year-old peach trees (*Prunus persica* L. Batsch). Spraying peach trees with a dispersion of these nanoparticles at flowering resulted in increased shoot diameter, leaf area, chlorophyll content, number of flowers, and fruit quality (Mosa *et al*., 2021).

Our studies on apple trees have demonsrated that spraying flowers and leaves with a dispersion solution of SiO_2 and Fe_3O_4 nanoparticles significantly enhancens the fertilization efficiency of their flowers. The application of SiO_2 and Fe_3O_4 nanoparticles also enhancens the size and composition of the fruits. TEM analysis revealed that nanoparticles can accumulate in the peel, mesocarp and seeds during fruit formation, as shown in the results by Lamiyya Ismayilova *et al*.(2022).

Based on the analysis of literature data from experiments in this field, it can be concluded that nanoparticles have a positive impact on tree flowering, flower fertilization, flowering duration and effective pollination. Du to the the limited research in this area, we decided to continue our experiments specifically on almond trees. Almond trees are extensively cultivated in Azerbaijan with their productivity being influenced by the local climatic conditions. One approach to potentially increase almond productivity is by enhancing the flowring and prosesses. Our experiments were carried out on two 8-year-old almond trees, focusing on the Leyla and Nuray varieties, which are commonly grown. The impact of nanoparticles was also assessed across various almond varieties.

Plant material

Two 8-year-old varieties of sweet almond trees, Leyla and Nuray, cultivated at the Saray support station of the Institute of Genetic Resources of the Ministry of Science and Education of Azerbaijan, were used in the experiments. Almond is a perennial tree that sheds its leaves in winter and grows up to 12 meters in height. Almond trees can live up to 50 years and begin to bear fruit at the age of 4-5 years, ones they have a well-developed root system. Generative shoots in almond trees are easily distinguished from vegetative shoots. Flower buds are formed on short fruiting branches and are called bouquets. Almond flowers are bisexual and consist of five petals, which are white or light pink. The number of stamens in the flowers is 20-30 and, since they are shorter than the female column, they are located at a lower level. Each flower usually has one stamen. Almond flowers are located singly or in whorls on biennial stems. Each whorl has 2-3, and sometimes 4-7 flowers. Almond fruits are in the shape of a flattened egg. The outer layer of the fruit, the exocarp, consists of a skin covered with hairs. The middle layer, the mesocarp, forms a green shell surrounding the core. This layer resembles a peel and splits into two parts when the fruit ripens. The inner layer of the fruit is its core, which is called the endocarp. Inside the fruit are seeds covered with a chestnut-colored shell. The Nuray Leyla almond variety is the most common variety in Azerbaijan. The Nuray variety is highly resistant to drought, heat and diseases. The “Nuray” variety is cultivated in dry subtropical regions of Azerbaijan, while the Leyla variety is cultivated in dry subtropical areas.

Nanoparticles

The SiO_2 and Fe_3O_4 used in the experiments were physically obtained from powdered nanoparticles from Skyspring Nanomaterials.Inc. (Houston TX, USA). The sizes of the powdered SiO_2 and Fe_3O_4 nanoparticles were in the range of 20-30 nm. A dispersed solution of nanoparticles was obtained by dissolving them in deionized water at a concentration of 0.5 g/l. Before application, the dispersed solution was processed in an ultrasonic sonicator (QSONICA sonicator) for 15 minutes to separate the agglomerated nanoparticles from each other. The trees were sprayed with this dispersed solution for a short time.

EPR method

The localization of Fe_3O_4 nanoparticles in almond fruits was detected also by the EPR method. First, the EPR spectrum of the solution of Fe_3O_4 nanoparticles was recorded on a Bruker ESP300E (Bruker, Germany) device, and the accumulation of these nanoparticles in plant fruits was determined based on the change in the EPR signal.

Design of experiments

For the experiments, three trees of each Leyala and Nuray varieties were selected in the experimental area where almond trees were cultivated. The distance between the trees was 3 meters. One of these trees was allocated as a control variant, one for applying Fe_3O_4, and the other for applying SiO_2 nanoparticles. Three branches of each tree were selected for the experiment. The branches were sprayed with a dispersion solution of nanoparticles at two stages of tree development. The first spraying was carried out at the budding stage of the generative organs on 03.05.2024 and the second time at the full flowering stage on 28.03.2024. The applied concentration of nanoparticles was 0.5 g/l Before spraying, the dispersion solution of nanoparticles was processed in an ultrasonic device for 10 minutes.

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TEM analysis

For TEM analysis, samples were fixed in a solution containing picric acid, 2% paraformaldehyde, 2% glutaraldehyde, 1% caffeine, 0.1% Li, and 0.1M phosphate buffer (pH 7.4). After incubation in a vacuum apparatus for at least one day, they were fixed in a 1% osmium tetroxide solution prepared in phosphate buffer (pH 7.4). Thin (1-2 µm) sections for imaging were prepared from the blocks using a Leica EM UC7 ultramicrotome (Leica, Germany), stained with methylene blue, azure II, and basic fixin, following the general protocols for electron microscopy (Kuo, 2014). Images were captured using a Primo Star microscope (Zeiss, Germany) and viewed with an EOS D650 digital camera (Canon, Japan) (Morikawa *et al*., 2018), withe necessary adjustments made to the images. Morphometric analysis of the images was conducted on electrograms captured in TIF format using a computer program (The TEM imaging platform) developed by the German company Olympus Soft Imaging Solutions Gmbh.

Determination of nanoparticles

For the precise determination of the location and size of nanoparticles in living samples, an analysis of electrograms of ultrathin (50-70 nm) sections, is being conducted. Unstained sections are used with the "Intensity profile" computer program to generated histograms for both control and experimental groups. These histograms show the length of structures along the horizontal axis (in nm) and the corresponding grey values along the vertical axis. It is imported to note that the grey value parameters can be accurately distinguished from each other. These indicators have been utilized within living organisms (Hajiyeva *et al*., 2024; Hajiyeva *et al*., 2023; Nasirov *et al*., 2024; Rzayev *et al*., 2022)

Results & Discussion

Morphophonological analysis.

The experiments focused on studying the formation of flower buds in almond trees, the timing of flowering, the transformation of flowers into fruits, the accumulation of nanoparticles in fruits and the morphology of fruits. Flower buds begin to form on almond trees on March 5th. The first blooms are seen about a week later, with flowering ending on March 28th, and fertilized fruits appearing in early May. Prior to nanoparticle treatment, the number of flower buds on branches was counted. The control group was sprayed with distilled water, while the experimental groups were sprayed with a nanoparticle dispersion solution at a concentration of 0.25 g/l. A second spraying was done during full flowering. In a normal state, 297 fruit buds were counted in 2 branches of the Leila variety, with 80% of them devoloping into flowers. Only 21.1% of these flowers were fertilized and produced fruit. For the Leila almond tree, branches treated with Fe_3O_4 nanoparticles, 86% the flowers were fertilized resulting in 53 fruits. For the branches treated with SiO_2 nanoparticles 78% of the buds developed into flowers with 22.2% of them producing fruit the results of these phenological observations are shown in Figure 2.

In the normal state, 195 fruit buds were counted in 2 branches of the Nurai variety, out of which 58 (30%) were flowers. Only 12 of these flowers were fertilized (20.7%) and turned into fruits. Two branches of the Nurai almond tree selected for the application of nanoparticles had 191 fruit buds. After spraying these branches with Fe_3O_4 nanoparticles, the number of flowers formed was 102 (53.4%). 28 of these flowers were fertilized and turned into fruits (27.4%). The number of fruit buds on the two branches of the tree chosen for the application of SiO_2 nanoparticles was 150, and after spraying, 47 of these buds turned into flowers (31.3%). 22 of these flowers were fertilized and turned into fruits (46.8%). The results of these phenological observations are shown in Figure 3. Based on the results of phenological observations, the following conclusion was drawn the total fertilization of flowers in the control variant of the Leila almond was 21.1%, while in the Nurai tree (20.7%) the percentage of fertilization increased after the introduction of nanoparticles. When introducing Fe_3O_4 nanoparticles, the fertilization rate was 44.5% for the Leila variety and 27.4% for the Nurai variety. The use of SiO_2 nanoparticles, resulted in insignificant fertilization for the Leila almond, but a more than twofold increase in fertilization for the Nurai almond flowers. These results indicate that the effect of nanoparticles on flower pollination is dependent on both the type of trees and their composition.

Accumulation of Nanoparticles in Fruits.

Figure 4 presents images of the normal anatomical structure of all three layers (marked with 1- mesocarp, 2- endocarp, 3- seed) of the embryo of the fertilized ovary of the Leyla variety during the flowering period obtained by light microscopy. Figure 4A shows the structure of the embryo at low magnification and Figure 4B at high magnification, with the boundaries between all three layers highlighted. The cells that make up the mesocarp part (marked with the number 3 in Figure 4A and 4B are round or oval, and closely spaced together. Additionally, the mesocarp is finished with "hairs" that have a cellular structure on the outside. In the endocarp layer (marked with number 2 in Figure 4A and 4B, which forms the skin of the almond fruit, the cells are elongated in shape. The last seed (marked with the number 1 in Fig. 4A and 4B has a single-layered dense cell layer on the outside, but the cells inside forming the structure of the seed are large and relatively few compared to other layers. In the control group, no pathologies were observed during the examination of the anatomical structure of all three layers of the embryo using a light microscope. Additionally, the ultrastructure of the fruit embryo was studied using the electron microscopic method (Fig.5). Fig. 5A and 5B show the ultrastructure of seed cells of the Leyla cultivar at low magnification, while figure 5C shows a magnification of over 100 000. The cell envelope and cytoplasmic structures are visible in this image. A higher magnification (Fig. 5C) shows the cell envelope. Analysis of the envelope and cytoplasm using the "Intensity profile" program revealead that in the studied area (indicated by the red line in Fig. 5C) the grey value ranged from 6000 to 6500 (Fig. 5D). Figure 5E displays the ultrastructure of the endocarp layer of a plant embryo highlighting relatively small and elongated cells, sheath, cytoplasm, and various structures. Figure 5F provides a high magnification (100,000 times) image of these cells. Analysis of the image, in Figure 5G indicates that the grey value varies from approximately 6000 to 6500. Figures 5H and 2I present TEM images of the third layer (mesocarp). The cells in this layer have round or oval cytoplasmic structures. In the analysis of Fig. 5I, the grey value was found to be between more than 6000 and 6800 similar to other layers (Fig. 5J). No serious pathologies were observed in any of the three layers of the plant embryo (control group) whose ultrastructure was studied by TEM.

The embryo of the almond plant Leyla variety affected by Fe_3O_4 nanoparticles was studied using light and electron microscopic methods (Fig. 6 and 7). Figure 6A shows the seed (number 1) and shell (endocarp, number 2), and Figure 6B displys the outer layer of the embryo (mesocarp, number 3). In the light microscope images, the chaotic distribution of cytoplasmic elements within the cells in the mesocarp is noteceable (Fig. 6B). TEM images in Figure 7A and 7B show thinning of cell vacuoles damage to cytoplasmic membranes and movement of structural elements towards the cell center. Damage to the membranes of cytoplasmic organelles was also observed. In Figure 7C, a dark band is visible at the boundary between two sheaths in a high-magnification TEM image. The grey value in the area between the two shells decreased below 6000, wthis the size of nanoparticles determinate to be (Fig.9D) presents a TEM image of a nanoparticle – affected endocarp section, showing transparent vacuoles in thr cells, damaged membranes and scattered structural elements in the cytoplasm. Higher magnifications in Figure. 7F show nanoparticles in the sheath with a decrease in grey value from 6200 to 5600. The size of Fe_3O_4 nanoparticles detected was 20-25 nm (Fig. 7G). Figure 4H displays a TEM image of the last mesocarp of the plant embryo showing broken of cell structural elements and movement of orqanell fragments towards the center. In Figure 7I, nanoparticles are observed between the cell envelope and the cytoplasm with an increase in grey value from 6200 to 5500. The size of the particles was 20-25 nm (Fig.7J).

In another experiment, the researchers studied migration, and bioaccumulation of SiO_2 nanoparticles in the Leyla almond embryo using TEM and light microscopes. Figures 8A and 8B display a light microscopic image of the three embryo layers (1- seed, 2-endocarp, 3 - mesocarp). A space is visible between the mesocarp and endocarpthem to separate. Pathologies are evident in the cytoplasm of cells within in the mesocarp and endocarp. Figures 9A and 9B reveal TEM images of embryo seeds post exposure to SiO2 nanoparticles. In both images the cell envelope appears thinned and transparent, wthis organelle distrophy in the sytoplasm. Figure 9C highlights a thin dark layer forming between cell envelopes at high magnification in TEM. Software analysis of the TIF format image indicates a significant decrease in the grey value (shade degree) indicator below 6000, and the size of the mentioned nanoparticles is determined to be 30 nm (Figure 9D). An electron microscopic image of the plant embryo endocarp is shown in Figure 9E, where only cell sheaths in the bark layer (endocarp) are visible, wthis nanoparticles to appear in the cytoplasm at high magnification (indicated by the red arrow in Figure. 9F). Analysis of this image, shows a decrease in grey value from 6200 to 5600, with nanoparticle diameters ranging from 25-30 nm (Figure 9G). Ultrastructural characteristics of almond mesocarp post nanoparticle exposure are presented in Figure 9H, showing disrupted sheath homogeneity in cell walls, with some parts appearing dark and others light, and a lack of organells in the sytoplasm. Nanoparticles are visible at high maqnifications in the sytoplasm (Figure 9I), with a decrease in grey value from 6200 to 5700 upon analysis of the TIF format image, and a nanoparticle size of 20 nm determined (Figure 9J).

Structural analysis of almond fruit

Table 1 presents the structural analysis of Nuray and Leyla almond varieties. The height, width, and length of the fruits were measured. As shown in the table, nanoparticles did not significantly impact the size of the fruits of either variety unlike the control group where no drastic changes wre observed. Table 2 displays the sizes of the shell fruits of Nuray and Leyla almond varieties, along with the net seed yield (productivity) obtained from almond fruits as a percent age. The data indicates that nanoparticles do not have a significant effect on the size of the fruit. However, Fe_3O_4 nanoparticles increased the net seed yield from Leyla almond fruits by 3%, while SiO_2 nanoparticles decreased it by 2%. No differensis were observed in the Nuray variety. It is well understood that the productivity of almond trees is influenced by genetic characteristics, weather, soil conditions, fertilizer use and fruit ripening time. The impact of nanoparticles on the flowering process and fertilization of almond trees can be both direct and indirect.

EPR analysis

The accumulation of Fe_3O_4 nanoparticles in the petals of almond flowers and in the developing fruits can also be confirmed by recording EPR spectra. Therefore, samples were prepared from the flowers and fruits of both normal and Fe_3O_4 nanoparticles-treated almond trees and the EPR signals were recorded. Figure 10A shows the EPR signal of the petals of flowers taken from trees without Fe_3O_4 nanoparticles, while Figure 10B shows the EPR signal of the petals of almond flowers sprayed with Fe_3O_4 nanoparticles. It was evident that these signals belonged to the signals of Fe_3O_4 nanoparticles, but it was not possible to determine if these nanoparticles were on the surface of the flower petals or inside them. Figure 11A shows the EPR signals of almond fruits with the same characteristics

Table (1): Structural analysis of almond nuts

	Nuray variety			Leyla variety		
	Length (mm)	**Width (mm)**	**Height (mm)**	**Length (mm)**	**Width (mm)**	**Height (mm)**
Control	25.0±0.18	13.2±0.12	7.2±0.15	29.8±0.18	13.7±0.18	6.5±0.12
Fe_3O_4	25.6±0.06	13.5±0.06	7.4±0.12	30.4±0.06	13.9±0.12	6.8±0.09
SiO_2	24.0±0.12	13.1±0.06	6.8±0.15	29.0±0.12	13.3±0.18	6.4±0.06

Table (2): Structural analysis of young almond nuts

	Nuray variety				Leyla variety			
	Length (mm)	**Width (mm)**	**Height (mm)**	**Seed yield**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Seed yield**
Control	35.7±0.64	23.6±0.30	16.9±0.33	36%	49.3± 0.54	24.1±0.30	16.4±0.42	40%
Fe_3O_4	36.4±0.24	23.6±0.30	16.7±0.27	37 %	51.15±0.36	24.4±0.27	16.5±0.42	43%
SiO_2	34.4±0.79	23.5±0.24	15.8±0.24	37 %	48.0±0.48	24.0±0.30	16.2±0.36	38%

Fig. (1): Leyla almon tree (A), flowers (B), fruits (C) and seeds (D)

The effects of nanoparticles on plant development, nutrition, seed germination percentage, important physiological processes, as well as their accumulation and migration in plant organs have been studied in detail. However, the effects of nanoparticles on flowering, flower fertilization and fruit formation in plants, including fruit trees, have been less studied. Flowering and flower fertilization in fruit trees are known to be complex processes that are significantly influenced by environmental factors, such as temperature, air humidity, wind and pollinators. Effective flower fertilization is crucial for tree productivity making it a key concern in modern fruit growing. The impact of nanoparticles on flowering and flower fertilization remains a relevant topic in this field. Results from our experiments indicate that different nanoparticles have varying effects on different tree species. For instance, while the fertilization rate of flowers in both almond tree varieties was only 21.1%, the application of Fe_3O_4 nanoparticles increased effective fertilization to 44.5% in the Leyla almond tree and 27.4% in the Nuray tree. Similarily, th use application of SiO_2 nanoparticles resulted in a 22.2% increase in ferilization in Leyla and 46.8% increase a Nuray. Almond tree flowers rely on cross-pollination for fertilization. Despite having a large number of flowers under normal weather contitions, many go unfertilized and fall of. This failure is often du to a lack of polinators and the movement of pollen in the pollen tube. TEM analysis of nanoparticles revealed that when flowers were treated with nanoparticles, they easily entered into the pollen tube and accumulated in the fruits. It is possible nanoparticles adhere to pollen and act as carriers of sperm cells enhancing fertilization efficiancy by promoting sperm cell mobility though furtherexperimental evidence is needed to support these hypotheses. The molecular mechanisms underlying the impact of nanoparticles on the process of flower fertilization have not yet been clarified.

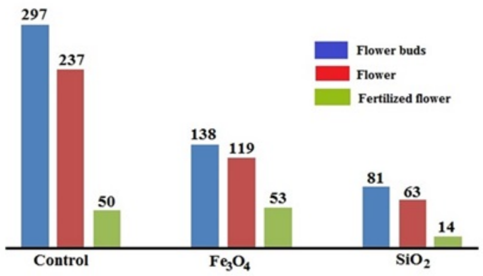

Fig. (2): Effects of nanoparticles on flower buds and flower fertilization in Leyla almond tree

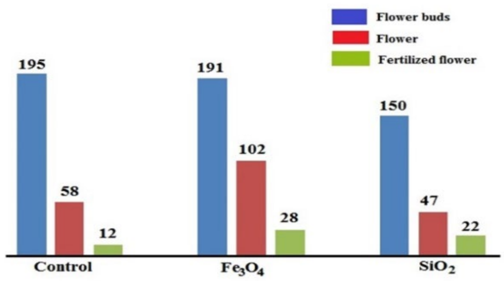

Fig.(3): Effects of nanoparticles on flower buds and flower fertilization in Nuray almond tree

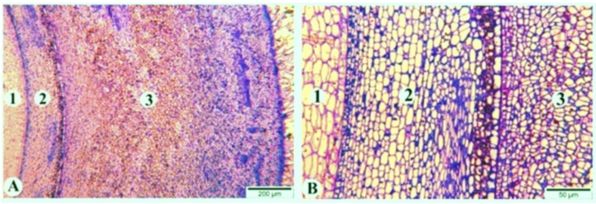

Fig. (4): Light microscopic images (A and B) of three layers of almond "Leyla" (embryo) in control group. Designations: 1- seed, 2- endocarp, 3 - mesocarp. Semithin section (1 µm), Morikawa et al. (2018) one-step staining (the explanation is given in the text).

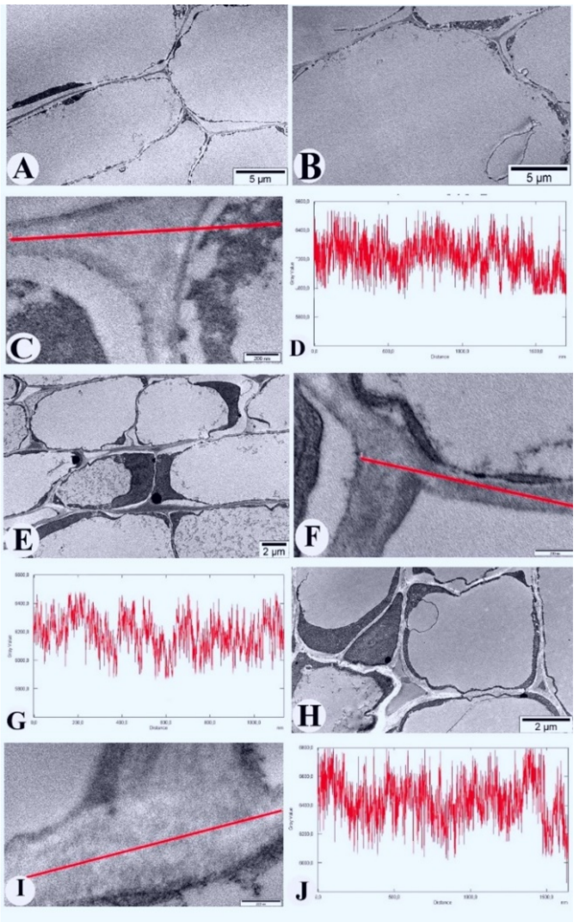

Fig. (5): Electron microscopic images (A, B, C, E, F, H and I) and diagrams (D, G, J) of three layers (A-D – seed, E-G – endocarp, H-J – mesocarp) of almond "Leyla" (embryo) in control group. Ultrathin sections (50-70 nm), stain: uranyl acetate and Pb citrate (the explanation is given in the text).

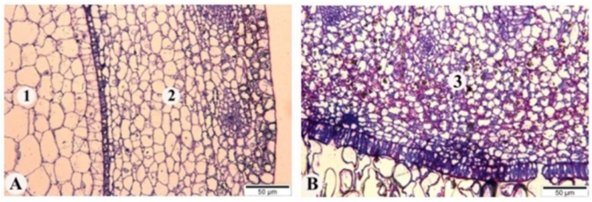

Fig. (6): Light microscopic images (A and B) of three layers of almond "Leyla" (embryo) after applying Fe_3O_4 nanoparticles. Designations: 1- seed, 2- endocarp, 3 - mesocarp. Semithin section (1 µm), Morikawa et al. (2018) one-step staining (the explanation is given in the text).

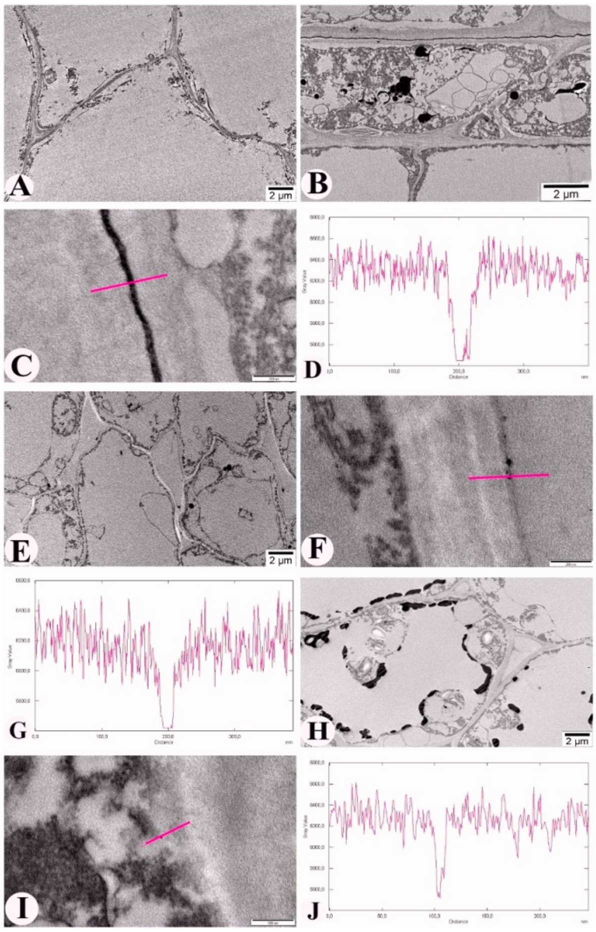

Fig. (7): Electron microscopic images (A, B, C, E, F, H and I) and diagrams (D, G, J) of three layers (A-D – seed, E-G – endocarp, H-J – mesocarp) of almond "Leyla" (embryo) after using Fe_3O_4 nanoparticles. Ultrathin sections (50-70 nm), stain: uranyl acetate and Pb citrate (the explanation is given in the text).

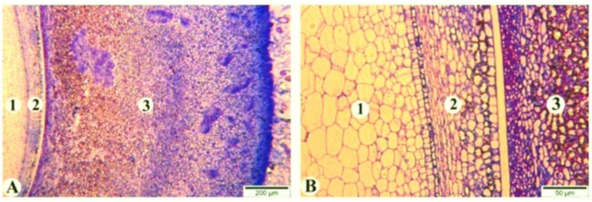

Fig. (8): Light microscopic images (A and B) of three layers of almond "Leyla" (embryo) after using SiO_2 nanoparticles. Designations: 1- seed, 2- endocarp, 3 – mesocarp. Semithin section (1 µm), Morikawa et al. (2018) one-step staining (the explanation is given in the text).

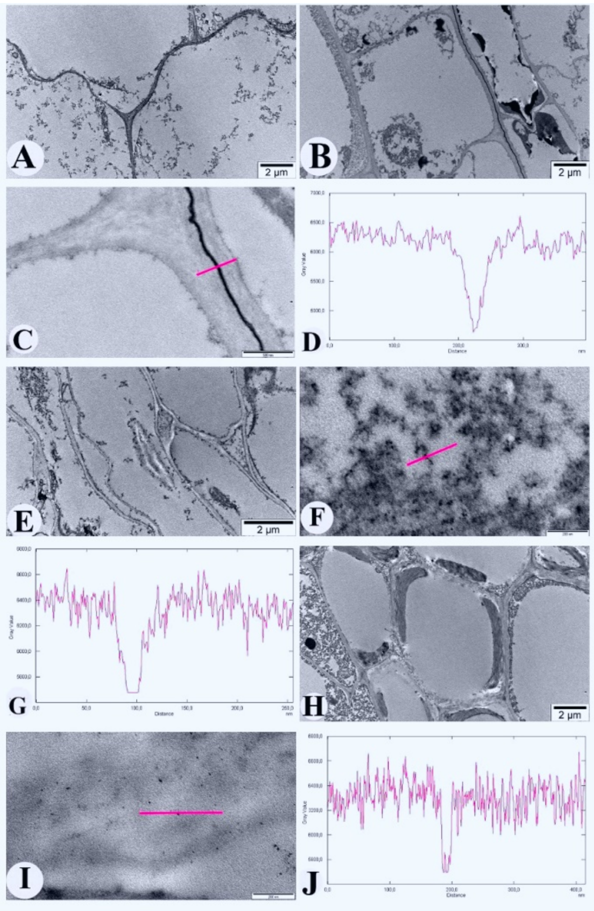

Fig. (9): Electron microscopic images (A, B, C, E, F, H and I) and diagrams (D, G, J) of three layers (A-D – seed, E-G – endocarp, H-J – mesocarp) of almond "Leyla" (embryo) after using SiO_2 nanoparticles. Ultrathin sections (50-70 nm), stain: uranyl acetate and Pb citrate (the explanation is given in the text).

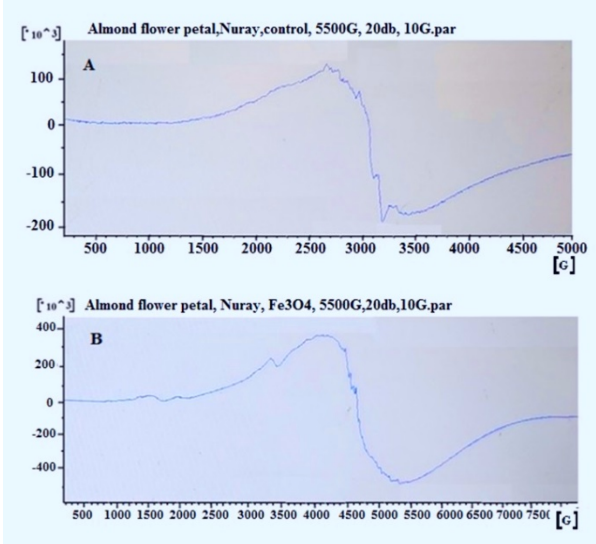

Fig. (10): The EPR signal of almond flower petal which were unsprayed (A) and sprayed with Fe_3O_4 (B).

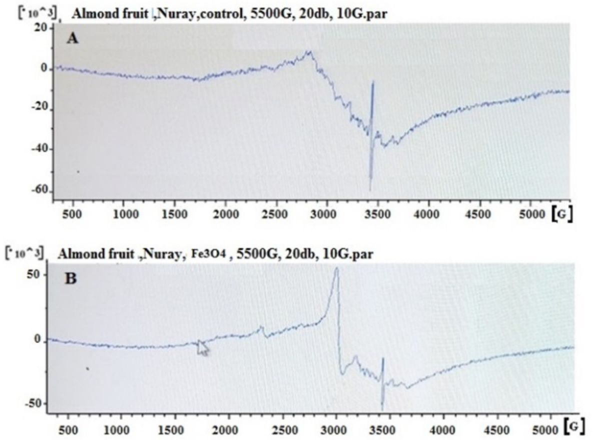

Fig. (11): The EPR signal of almond fertilized fruit which were unsprayed (A) and sprayed with Fe_3O_4 (B).

Conclusion

The results of our experiments show that the application of nanoparticles can enhance the formation of flower buds and fertilization of flowers in almond trees. Nanoparticles have the ability migrate from the pollen tube through flowers and accumulate in fruit structures. The impact of nanoparticles varies based on their type, application timing and size. Additionally, the effect of nanoparticles may differ depending on the tree variety. Confirmation of nanoparticles' accumulation in the fruits of almond trees to which they were applied was achieved through TEM analysis and recording EPR signals. It was discovered that nanoparticles bioaccumulate in the seeds, endocarp and mesocarp structures of almond fruits. SiO_2 nanoparticles were observed to induceto induse pathomorphological changes in the fruit structures.

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Contributions of authors

L.M.I. Performed experiments, prepared samples for analysis and analyzed the results
I.S.A. Writing – review & editing, Writing – original draft, Visualization, Supervision, Conceptualization.
E.K. G. Review & editing, Discussing – original draft.
F.H.R. Performing TEM analysis of samples, explaining and discussing the obtained results
V.B.A. Review & editing, Discussing – original draft.
M.A.B: Performing EPR analysis of samples, explaining and discussing the obtained results

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

No ethical approval was required for the present research.

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تأثير الجسيمات النانوية على تسميد أزهار شجرة اللوز(*Prunus amygdalus*)

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المستخلص: بينت نتائج الدراسة تأثير المعاملة بالجسيمات النانوية لاوكسيد السيليكون وأكسيد الحديد على الإزهار والاخصاب وتراكم الجسيمات النانوية في بتلات الأزهار وثمار اللوز. أظهرت النتائج أنه في ظل الظروف العادية، تتشكل أزهار بنسبة 80% و30% من إجمالي عدد براعم الزهور في صنفي اللوز Leyla وNuray. ومع ذلك، فإن إخصاب الأزهار في كلا الصنفين كان بحدود 21.1%. يؤدي تطبيق الجسيمات النانوية من أوكسيد الحديد إلى زيادة تكوين الأزهار بنسبة 86% في Leyla و53.4 % فيNuray، وإخصاب الأزهار المتكونة بنسبة 44.5% في Leyla و 27.4%في Nuray مقارنة بمعاملة المقارنة .يؤدي تطبيق الجسيمات النانوية من أوكسيد السيليكون إلى زيادة تكوين الأزهار بنسبة 78% في صنف Leyla وNuray 31.3%، والإخصاب بنسبة 22.2% في Leyla و 46.8%فيNuray مقارنة بمعاملة المقارنة، وقد كشف تحليل المجهر الإلكتروني النافذ أن هذه الجسيمات تراكمت حيوياً في جميع الطبقات الثلاث (البذرة، وطبقة الثمار الداخلية، وطبقة الثمار الوسطى) وأن المزيد من الأمراض حدثت في طبقات الثمار الداخلية وطبقة الثمار الوسطى. وأظهرت نتائج التجربة أن الجسيمات النانوية لم تؤثر على مورفولوجيا الثمار، بينما أدت الجسيمات النانوية Fe3O4 إلى زيادة صافي إنتاج البذور بنسبة 3% في صنفLeyla ، خفضت الجسيمات النانوية SiO2 ذلك بنسبة2% ، ولكن لم يلاحظ أي فرق في صنفNuray .

الكلمات المفتاحية: تكنولوجيا النانو، الجسيمات النانوية للحديد والسيليكون، تراكم الجسيمات النانوية.