The effect of nanoparticles of iron, copper and molybdenum on the morphometric parameters of plants Solanum tuberosum L.

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Abstract. Over the past decade, nanotechnology has led to the need for rigorous research on ultrafine nanomaterials, which increase productivity and quality of agricultural products. However, most studies are extremely controversial regarding the effect of nanomaterials on the seed germination rate, the growth of the roots and the aerial parts of plants, or it is difficult to compare both in doses and dimensions of nanoparticles, and in types of plants. In the experiment, nanoparticles of Fe (90-110 nm), Cu (50-110 nm) and Mo (100-120 nm) in 4 concentrations with a geometric progression were used. Germination energy and germination were determined according to GOST 12038-84, the content of photosynthetic pigments according to the method of N. D. Smashevsky (2011), phytotoxicity according to the method of Kazeev K. (2003). Thus, the data obtained indicate that the treatment of Solánum tubérosum L. tubers with iron nanoparticles stimulated the growth of sprout length (55.1% and 21.4%), roots (34.4% and 12.5%) and the content of chlorophyll a (57 - 98%) relative to the control at a concentration of 0.0125 ... 0.025 M. At the same time, the nanoparticles of copper and molybdenum by the significance of their effects on plants turned out to be ineffective.

1. Introduction

Nowadays, the development and implementation of nanotechnology in such industries as industry, medicine, and agriculture, have been particularly influenced by technogenic nanoparticles [1]. Due to their unique properties and characteristics, nanoparticles are widely used in many aspects of daily life, including catalysts, cosmetics, medicines, and the environment [2]. The widespread and unrestricted use of nanoparticles has led researchers to consider the issues of their application and the impact on the environment [3]. The potential impact of nanoparticles on the environment should be carefully analyzed, since, falling into the soil during atmospheric deposition, rainfall and in other cases, nanomaterials accumulate over time in the soil, because of their poor migration ability [4]. Plant organisms, as primary sources, are diverse and accessible objects, the use of which in screening studies makes it possible to evaluate both the specificity of the effect of nanoparticles and their dose-dependent effects; those. plant sensitivity can be considered as an indicator of the ecotoxicity of nanomaterials [5]. In addition, plant organisms serve as a bioaccumulatant for transporting nanoparticles, as a result of which plant agrocenoses can suffer from oxidative stress caused by nanoparticles [6].
2. Formulation of the problem
At the present time, experimental materials are rapidly accumulating, which show how unique and diverse nanoparticles are in their manifestations. Their properties depend not only on the physical nature, method of preparation, size, structure of nanoparticles, but also on the biological model on which the tests are carried out. It is also important to note that the main physiological indicators of the plant toxic effects of NPs are the germination energy, the elongation of the roots, the biomass of the leaves. Several researchers in their works [7, 8] indicate that some NPs can have significant negative consequences, such as reduction in seed germination and inhibition of the length of sprouts and plant roots.

There are practically no experimental data related to the study of the effect of nanoparticles on the biochemical and physiological processes in the sprouts of Solanum tuberosum L. plants. As is known, the concentration of photosynthetic pigments determines the activity of the photosynthetic apparatus, the rate of accumulation of assimilants, which as a result affects the productivity and growth of plants.

Thus, the necessity and importance of such studies are relevant in modern science and environmental management, since the pros and cons of nanoparticles require a comprehensive assessment.

3. Materials and methods
The studies were carried out in the Center for Collective Use of the FSBI FSC BST RAS. Testing of the biological activity of Fe nanoparticles (90-110 Nm), Cu (50-110 Nm) and Mo (100-120 Nm) was carried out in 4 concentrations with a geometric progression (0.0125; 0.025; 0.05 and 0.1 M) and in 3 replications. Before the start of the experiment, the potato tubers were disinfected in 0.01% KMnO4 for 5 minutes, then washed with distilled water and dried for 15-20 minutes. Then the tuber was laid out in plastic containers (5-7 cm) in 10 pcs. Separately prepared suspensions of nanoparticles according to TU 931800-4270760-96, for which purpose the exact weights of the drug were dissolved in distilled water and processed in an ultrasonic disperser (USN, f-35 kHz, N-300 W, Russia) for 30 minutes. Then the tuber samples were poured with 100 ml of freshly prepared suspensions of NPs of Fe, Cu, and Mo, shaken the container for 5 minutes, and, subsequently, poured the suspension. Untreated NP tubers (0 g / kg) were used as controls. After that, the containers with tubers were germinated in a climatic chamber (“POL-EKO-APARATURA SP.J.”, Typ: KK 1200 TOP + FIT) for the first week without illumination at a temperature of 23 ± 1°C and humidity of 83 ± 2%, and subsequent three weeks at 16-hour illumination at a temperature of 25 ± 2°C and 8 hours at a temperature of 18 ± 2°C and humidity of 83 ± 2% (GOST 20290-74). Germination and germination were determined in accordance with GOST 12038-84. The content of photosynthetic pigments was determined in ethanol extract spectrophotometric by the method of N.D. Smashevsyk, (2011) [9]. The content of chlorophyll and carotenoids was determined by the weight of the raw green mass, the calculations were carried out according to the Smith and Benitez formulas (Wintermans, de Mots, 1965). To assess the toxicity, the phytoeffect (inhibition effect) was determined by the formula:

\[ Et = \left( \frac{Lk - Lon}{Lk} \right) \times 100\% \]

where Et is the effect of inhibition, %; Lop - the average length of the roots in the experience, cm; Lk - the average length of roots in the control, mm.

4. The discussion of the results
Analysis of publications devoted to the effect of metal NPs on plant organisms shows that the most common indicators, based on which they assess the impact of pollutants, are germination, length of sprouts and roots. The calculation of the germination energy of tubers showed that during the processing of tubers of Fe nanoparticles with a concentration of 0.0125 and 0.25 M, there was a significant increase in the length of sprouts by 55.1% and 21.4% (P≤0.05) and roots 34.4% and 12.5% relative to the control. At a concentration of 0.1 M, the metal had a negative effect on the germination of tubers and the length of sprouts in comparison with the control by 55-70%. In the place where, in the presence of Cu and Mo NPs in doses from 0.0125 to 0.1 M, the germination energy value was lower than the control by 1.7 and 1.2 times, respectively (P <0.05). At the same time, the length of sprouts at the same concentrations was lower than the control by 22.0% and 36% (Fig.1, 2).
As shown by the results of the research, the treatment of tubers with iron nanoparticles improves the growth parameters of potatoes, at a concentration of 0.0125 and 0.025 M, which cannot be said about copper and molybdenum nanoparticles (Fig. 1, 2). This corresponds to the literature data, since potatoes can filter out nanoparticles, avoiding their effects, unlike other crops (wheat, cucumber, soybean) that accumulate them [10].

As shown by the measurement results, on day 21, when exposed to suspensions of copper and molybdenum nanoparticles at concentrations of 0.05 and 0.1 M, a slowdown in the growth of roots and sprouts was observed in comparison with the control up to 65.0%. Thus, in the experiment, the “growth inhibition effect” of the length of roots and sprouts was manifested both on day 14 and on day 21 after the treatment of tubers of copper and molybdenum tubers (Table 1).

The physiological capabilities of plants are determined by both the structural and biochemical organization of the pigment apparatus. It is known that chlorophylls a, b and carotenoids play a key role in photosynthetic processes, and a change in their concentration and ratio in the pigment complex is an indicator of environmental distress. Therefore, studies have been conducted related to the study of the effect of iron, copper, and molybdenum nanoparticles on the pigment content in plant leaves.
Analysis of chlorophyll content in the leaves of Solanum tuberosum sprouts showed some differences in the presence of nanoform metals. The positive effect of Fe nanoparticles in doses from 0.0125 to 0.1 M on the level of chlorophyll a and b in sprouts was established; its content significantly increased by more than 57% - 98% in comparison with the control (Fig. 3). Perhaps the effect of increasing chlorophyll caused by iron ions, isolated from their composition.

![Photosynthetic pigments](image)

**Figure 3.** The content of photosynthetic pigments in plant sprouts of Solánium tuberósum L. after treatment with suspensions of iron nanoparticles.

However, the absence of changes in the content of chlorophyll a under the influence of copper nanoparticles was reliable, although insignificant (by 4.7%), and chlorophyll b increased at all concentrations, but the maximum increase was observed at a concentration of 0.05 M, almost 2.5 times (Fig. 4). A similar pattern was observed in germs when exposed to molybdenum NPs. So, with the appearance of dark color of sprouts, a decrease in the content of chlorophyll a was noted, at a concentration above 0.025 M, an average of 6.9%. At the same time, the level of chlorophyll b changed significantly by 2.5-3 times (Fig. 5). According to the literature there are conflicting data regarding the effect of NPs on the chlorophyll content: some speak about an increase in the content of pigments [11], others - on the contrary, about a decrease in chlorophylls [12].

Parallel to chlorophylls a and b, carotenoids are a part of the pigment-protein complex. Analysis of the carotenoid content in Solanum tuberosum sprouts showed that this group of photosynthetic pigments was not sensitive to metal NP. Consequently, after treatment with Cu and Mo, an increase in carotenoids was detected in comparison with the control up to 45% (P > 0.05), which indicates an increase in oxidative processes or a primary nonspecific reaction of plants to stress.

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**Table 1.** Evaluation of the growth inhibition effect of Solanum tuberosum after exposure to Fe, Cu and Mo NPs

| Options   | The effect of inhibition, % |                |                |
|-----------|----------------------------|----------------|----------------|
|           | Sprout length | Root length | Sprout length | Root length |
| Fe 0.0125 | 14 days   | 21 days     | 14 days   | 21 days     |
| Fe 0,025  |            |             |            |             |
| Fe 0,05   |            |             |            |             |
| Fe 0,1    |            |             |            |             |
| Cu 0,025  |            |             |            |             |
| Cu 0,05   |            |             |            |             |
| Cu 0,1    |            |             |            |             |
| Mo 0,0125 |            |             |            |             |
| Mo 0,025  |            |             |            |             |
| Mo 0,05   |            |             |            |             |
| Mo 0,1    |            |             |            |             |

Options: Fe, Cu, Mo; NPs: nanoparticles; Sprout length: length of sprouts; Root length: length of roots; Chlorophyll: chlorophyll content; Carotenoids: carotenoid content; Photosynthetic pigments: photosynthetic pigments content; Iron: iron content; Copper: copper content; Molybdenum: molybdenum content.

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4
Figure 4. The content of photosynthetic pigments in plant sprouts of Solánum tuberósum L. after treatment with suspensions of copper nanoparticles.

Figure 5. The content of photosynthetic pigments in plant sprouts of Solánum tuberósum L. after treatment with suspensions of molybdenum nanoparticles.

It is also important to note that when treating Fe NPs above 0.05 M, a significant deviation of the level of carotenoids from the control was observed (from 4.2% to 20.3%). As noted above, a sharp increase in the concentration of green pigments is a factor limiting photosynthesis, in other words, the synthesis of chlorophylls is very sensitive to all sorts of influences that disrupt metabolic processes in the cell. An increase in the concentration of Fe nanoparticles causes an increase in the content of carotenoids in the sprouts; this is probably due to the mobilization of the compensatory mechanisms of the plant in order to preserve its inherent level of assimilation process.

5. Conclusion
Summarizing the results obtained on the biological activity of Fe, Cu, and Mo NPs with respect to the Solánum tuberósum model plant, we can conclude that nanometals contributed to both inhibition and increase in plant growth, depending on their sensitivity, as well as the physicochemical features of the nanomaterials under study. If we compare copper and molybdenum nanoparticles by the significance of their effects on Solánum tuberósum L. plants, they are equally ineffective on plants, and iron nanoparticles have a stimulating effect on increasing the length of sprouts, roots and chlorophyll a content at a concentration of 0.025...0.025 M.
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