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The effect of nanoparticles of biogenic ferrihydrite on the development of *Lepidium sativum* L.

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Abstract. The basis of the study was the assumption that the nanoparticles of biogenic ferrihydrite exhibit biological activity in relation to plant organisms, which can be used in the cultivation of agricultural crops. The research studied the effect of nanoparticles of biogenic ferrihydrite on the development of seeds and seedlings of *Lepidium sativum*. Structural indicators were studied: masses of the aerial and root parts, linear dimensions of the above ground and root parts of seedlings. The activity of the photosynthetic apparatus was assessed by the relative index of the delayed fluorescence of chlorophyll seedlings of watercress. The germination energy and germination of seeds were investigated. The most pronounced effect of nanoparticles is registered in the increase in the total phytomass of seedlings and the length of the above ground part. A slight decrease in the photosynthetic activity of watercress sprouts was noted. The effect of nanoparticles of biogenic ferrihydrite on seed germination was not manifested.

1. Introduction

In recent years, the effect of nanoparticles on organisms of various levels of organization has been actively studied [1-4]. At low concentrations (1-100 mg/l), a stimulating effect is observed, and at high concentrations (> 100 mg/l), the inhibitory effect of nanoparticles on the growth and development of plants [5].

Nanoparticles of man-made and natural metals are widely used in soil cover and water bodies. It determines the interest of researchers in studying the value of nanoparticles in the development and functioning of organisms. Since the 2000s, much work has been carried out to identify the effect of metal-containing nanoparticles (Zn, Cu, Hg, etc.) on germination, growth, and other indicators of plants. It has been established that iron nanoparticles and iron oxides, depending on their concentration, can have an inhibitory effect on tomato plants [6].

Recently, much attention has been paid to the study of the effect of metal oxides on organisms living in soil and aquatic environments [5-6]. The inhibitory effect of biogenic nanocomposites on phytopathogenic bacteria [8], technogenic nanoparticles of metals on phytopathogenic fungi [9] has been established.

2. Methods

Watercress is an early ripe cold-resistant plant of the Cabbage family, which is a spicy-flavoured and medicinal crop. The degree and nature of the influence of biogenic ferrihydrite nanoparticles on watercress was established under experimental conditions when growing seedlings (table 1). Nanoparticles of biogenic ferrihydrite, isolated from the culture of aerobic bacteria, were used [10-11].

Laboratory studies were carried out using a climatic chamber with regulation of external factors (temperature 24 °C, illumination 3000 lux, humidity 80%).

Watercress seeds were placed in Petri dishes with water and suspension of biogenic ferrihydrite nanoparticles was added for a number of concentrations (1.5 mg/l, 3.0 mg/l, 4.5 mg/l, 6.0 mg/l, 7.5 mg/l, 9.0 mg/l, 10.5 mg/l, 12.0 mg/l, 13.5 mg/l, 15.0 mg/l). On the 3rd day of the exposure, the germination energy was recorded and on the 5th day seed germination. On the 8th day, the length and mass of the above ground and root parts were measured.

As an indicator of the state of the plant's photosynthetic apparatus, a relative index of delayed fluorescence (RIDF) is used – the ratio of levels of delayed fluorescence (DF) of chlorophyll in their induction maxima when excited by high (DF_H) and low (DF_L) intensity ($RIDF = DF_H / DF_L$). Due to its relativity, RIDF does not depend on the size of the plant object, and it changes only when it is affected by its photosynthetic apparatus [12].

The use of fluorescent methods makes it possible to quantify the state of plants. The source of information is the process of delayed chlorophyll fluorescence. The intensity of the millisecond delayed fluorescence was recorded on "Photon 10" fluorometer. Delayed fluorescence was recorded from the upper side of the leaves. Before measuring the delayed fluorescence, the plants were kept in the dark for 15 minutes.

Statistical processing of the data was performed using the STATISTICA 10 (StatSoft) application package. In this paper, the data of linear and weight parameters of seedlings, RIDF are shown as arithmetic mean with standard error.

Table 1. The experiment scheme.

Indicators	Nanoparticle concentration, mg/l	Exposure time		
		3 days	5 days	8 days
Energy of seed germination, %	0	+	–	–
	1.5-15.0	+	–	–
Seed germination, %	0	–	+	–
	1.5-15.0	–	+	–
Seedlings length, cm	0	–	–	+
	1.5-15.0	–	–	+
Mass of seedlings, mg	0	–	–	+
	1.5-15.0	–	–	+
RIDF, rel. un.	0	–	–	+
	1.5-15.0	–	–	+

3. Results and discussion

Data on seed development are presented in figure 1. Germination energy was 92-97%, with 93% in control. The germination of cress seeds was 93-98%, in control – 98%. No significant influence of nanoparticles of biogenic ferrihydrite was found.

The results of measuring the length and mass of watercress seedlings in the experiment are presented in table 2. The length of the aerial part of the seedlings in the presence of biogenic ferrihydrite nanoparticles exceeded that in the control variant at almost all the studied nanoparticle concentrations. At the same time, the length of the root part in the presence of biogenic ferrihydrite nanoparticles was mainly reduced compared with the control, with the exception of the variants with nanoparticle concentrations of 1.5 and 4.5 mg/l. The study of information on the mass of seedlings showed an excess of the control value at all concentrations of nanoparticles of both the above ground part and the root.

Obviously, the stimulating effect of the nanoparticles of biogenic ferrihydrite on the biomass of watercress and the length of the above ground part of seedlings was manifested. The linear dimensions of the root part were reduced in the presence of biogenic ferrihydrite nanoparticles.

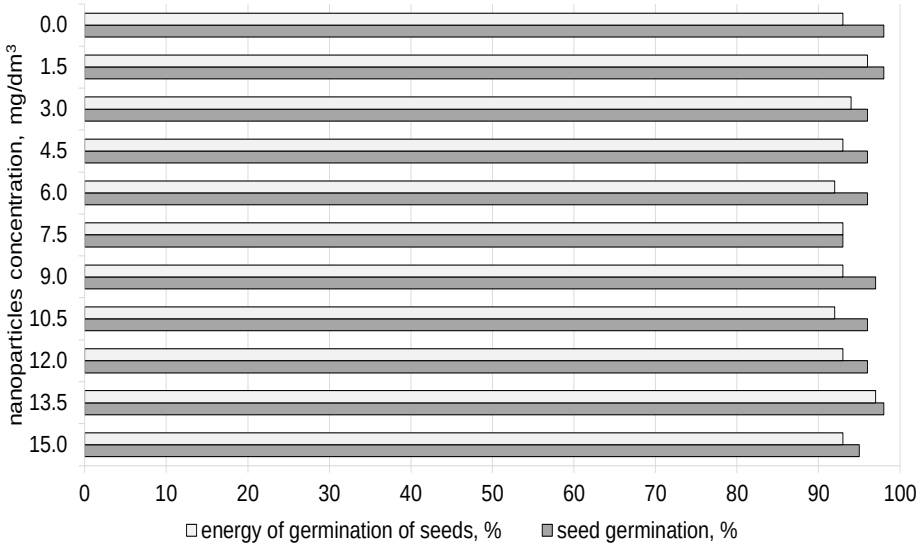

Figure 1. Germination energy and germination of *L. sativum* seeds in the presence of biogenic ferrihydrite nanoparticles.

Table 2. Linear and weight parameters of *L. sativum* seedlings in the presence of biogenic ferrihydrite nanoparticles on the 8th day of exposure.

Concentration of nanoparticles, mg/l	Length, cm		Weight, mg	
	Root part	Above ground part	Root part	Above ground part
1.5	6.4±1.1	2.4±0.6	0.9±0.1	8.9±0.8
3.0	4.5±1.5	2.1±0.5	1.0±0.1	8.5±0.2
4.5	6.5±1.7	2.6±0.8	1.2±0.1	9.7±0.4
6.0	5.4±2.3	2.4±0.9	0.9±0.1	10.1±1.3
7.5	5.9±1.1	2.4±0.6	1.7±0.3	12.9±1.3
9.0	4.8±1.3	2.5±0.7	1.0±0.1	12.9±1.0
10.5	6.3±1.8	3.0±0.7	1.8±0.1	13.4±0.1
12.0	4.0±1.4	2.6±0.6	1.4±0.2	12.8±1.0
13.5	3.4±1.2	2.7±0.6	1.8±0.2	12.8±0.6
15.0	3.7±1.3	3.0±0.8	1.2±0.3	12.7±1.4
0 (control)	6.4±2.0	2.1±0.5	0.7±0.1	6.5±0.4

Estimation of the level of photosynthetic activity by the relative index of delayed fluorescence of chlorophyll showed its decrease in watercress seedlings in an environment with nanoparticles, except for a concentration of 9.0 mg/l (figure 2, control – 100%).

The study of the development of seeds and seedlings of watercress in an environment with ferrihydrite nanoparticles for a number of plant indicators revealed an ambiguous effect of exposure (table 3). At a reliable level, the stimulation of the length of the aerial, mass of the above ground and root parts of seedlings was manifested. A decrease in the length of the roots is fixed for the majority of the concentrations of nanoparticles. Suppression of photosynthetic activity was observed at low concentrations of nanoparticles in the medium.

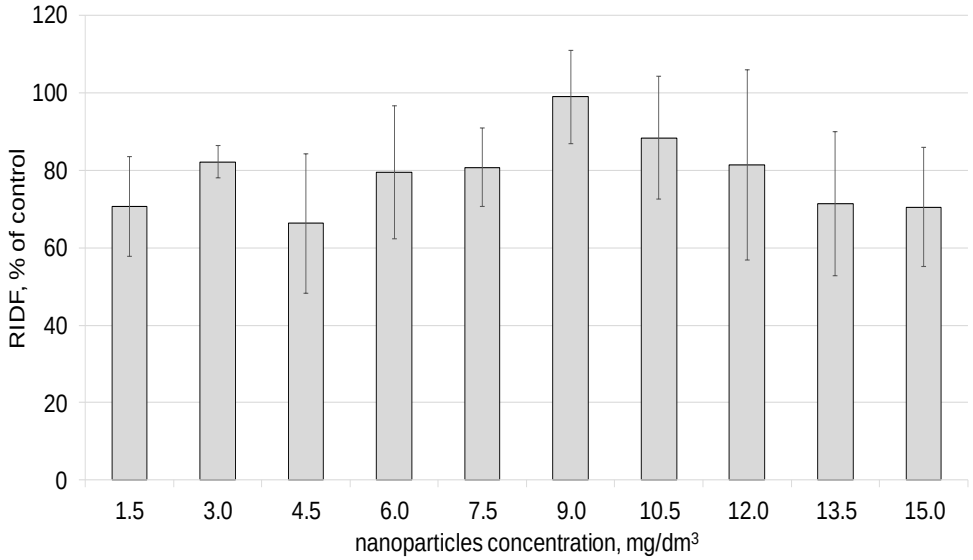

Figure 2. Relative index of delayed fluorescence (RIDF) of chlorophyll *L. sativum* seedlings in the presence of biogenic ferrihydrite nanoparticles.

Table 3. The effect of nanoparticles of biogenic ferrihydrite on the development of *L. sativum*.

Development stage	Indicator	Concentration of nanoparticles, mg/l	Significance level	Effect
Seeds	Germination energy	1.5-15.0	no	absent
Seeds	Germination	1.5-15.0	no	absent
Seedlings	Above ground part length	1.5; 4.5-15.0	<0.01	stimulation
		3.0	no	absent
Seedlings	Root part length	1.5-4.5; 10.5	no	absent
		6.0-9.0; 12.0-15.0	<0.001	suppression
Seedlings	Above ground part weight	1.5-15.0	<0.001	stimulation
Seedlings	Root part weight	1.5-15.0	<0.001	stimulation
Seedlings	Relative index of delayed fluorescence of chlorophyll	1.5-4.5	<0.05	suppression
		6.0-15.0	no	absent

4. Conclusion

Based on the obtained results, it can be concluded that the nanoparticles of biogenic ferrihydrite have a pronounced biological activity in relation to the early stages of ontogenesis of *L. sativum*. This is manifested in the action of both morphometric parameters and functional characteristics in the seedling stage, but does not affect seed germination. The use of nanoparticles of biogenic ferrihydrite can be recommended to increase the phytomass of this spicy culture grown in greenhouse conditions.

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