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Selenium in nanosized form as an alternative to microfertilizers

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Annotation. Nowadays, it is an obvious fact that it is necessary to look for new approaches to agriculture, which would ensure the maximum reduction in the dependence of the volumes and quality of the crop on external factors. The use of nanopreparations in crop production is the most promising. The development of new technologies and techniques using nanomaterials, which would ensure high yields and quality of potato products, is relevant and has great practical importance. The research in recent years has established the important role of selenium in the regulation of plant activity.The purpose of this work was to research the effect of selenium nanoparticles and selenium in the form of micronutrient fertilizers on early-maturing varieties of potatoes for table use: adaptive capacity and nutritional value. Selenium nanopowder in the form of a solution contained the optimum nanoselenium concentration applied–0.13 g per hectare seeding rate. The potato tubers were soaked in distilled water 30 minutes before seeding. The treatment of potato tubers with selenium micronutrient, the dose of which amounted to 400 g per 1 hectare, was also carried out before planting. The soil preparation and agrotechnology cultivation generally accepted in the Ryazan region.The research results showed that presowing treatment of potato tubers with selenium nanopreparation had the most favorable effect on the adaptive capacity of plants (heat resistance, water-holding properties), as well as on yield increase, than treatment of tubers with selenium in the form of microfertilizer. The use of Se nanoparticles leads to an increase in the protein and vitamin C content. The Udacha potato variety showed great responsiveness to the entering of various forms of selenium in comparison with others. The use of selenium in the form of microfertilizer leads to an increase in the accumulation of starch and dry matter. These figures were the highest in potato tubers of the Zhukovskiy Ranniy variety.

Key words: selenium, nanoparticles, microfertilizer, potatoes, water-holding capacity, heat resistance, yield, starch, dry matter, protein, vitamin C.

INTRODUCTION

The volume of modern food production is constantly increasing, and therefore, the development of agriculture should be based on the achievements of modern science, that ensures the population's need for environmentally friendly and safe food, the main objectives of which are aimed at: protection of human life and health, preventing actions that mislead acquirers (consumers), environmental protection.

However, the quality of the products obtained depends not only on the feedstock, but also on the production conditions. For this, it is necessary to apply environmentally friendly methods, without using the hormones, antibiotics, genetically modified ingredients and other heterogenous agents (Pavlov, 2002).

A promising activity direction in crop production is the search and development of techniques that could increase the yield of cultivated plants without increasing the rates of fertilizer application, and also improve the quality of agricultural products. One of these directions is the transition to technologies that contribute to optimizing the plant nutrition with microelements and stimulants of their growth and development in accordance with the biological requirements of crops, to the strategy of integrated and differentiated use of genetic, soil, climatic and technological factors. Adaptive intensification of agriculture requires the widespread use of methods of biological correction, which includes the foliar nutrition with growth stimulants.

Microelements, which are part of a number of hormones, enzymes and vitamins, are directly involved in metabolic processes. An acute deficiency or excess of microelements leads to the appearance of many plant diseases (Mishin, 1991).

Recently, an interest has recently increased in the most important microelement - selenium, which, as vitamins A, C and E, is a part of the antioxidant-antiradical body defense system.

Most regions of Russia, as well as neighboring countries, are characterized by a low content of selenium in the environment.

Products of plant origin, in which selenium is contained in the most accessible form of selenmethionine, are the main ways of selenium entering the body.

It is established that selenium belongs to conditionally necessary microelements of nutrition of plants, however, it participates in their metabolic processes. Due to the proximity of ionic radii, selenium is capable of replacing sulfur in sulfides, and seleno-organic compounds are similar to sulfur. In case of excessive content in soil, selenium can have a toxic effect on plants (Gromova, 2004).

The use of inorganic forms of selenium (selenite- and selenite- ions) can cause negative phenomena associated with their high toxicity. That predetermines the search for other selenium derivatives.

The nanosized selenium in contrast to ionic forms is less toxic, and also has an increased bioavailability, it not only prevents, but also stops the development of malignant tumors. It is shown that selenium is involved in the chlorophyll production, the synthesis of tricarboxylic acids, as well as in the metabolism of high molecular weight fatty acids. It is a part of a number of redox enzymes alone or together with iron and molybdenum as a cofactor (Vapirov et al., 2000).

Thus, nanoparticles, in contrast to ionic forms, have a prolonged effect and are less toxic. These properties help to increase the absorption of mineral substance, carbohydrate metabolism, cell respiration and photosynthesis.

The production of environmentally friendly products and healthy food has recently become one of the priorities of the industry. The high-quality raw materials are the basis in this process.

One of the most important crops of versatile use is potatoes. The tubers of this plant contain on average 25% of dry matter, including 14–22% of starch and about 2% of protein. The particular importance in human nutrition is also due to the content of the most important components: vitamins and minerals. The potatoes, having also a fairly high potential of the content of ascorbic acid and especially valuable substances - antioxidants (carotenoids, anthocyanins), can have an important role in the prevention of a number of diseases. As a result, it is one of the most valuable products in the healthy human diet (Anisimov, 2006). All listed above, as well as high taste qualities, determine the high feed and nutritional value of potatoes.

The purpose of this work was to research the effect of various forms of selenium on early-maturing varieties of potatoes for table use: its adaptive capacity, yield and nutritional value.

MATERIALS AND METHODS

The following varieties of potatoes were chosen as objects of the research: Bryanskiy ranniy, Zhukovskiy ranniy, Udacha. This choice was due to the fact that all of the above listed varieties are early-maturing, for table use, with good taste, the tolerance region is Central, with a marketable average yield of 400 c ha^{-1}.

The Bryanskiy ranniy variety is a light-beige tuber, oval-rounded, the flesh is white. The eyeholes are small. The corolla is red-purple. The commodity yield is of 300–470 c ha^{-1}. The marketability is 90–93%. The weight of the grocery-ware tuber is 84–108 g.

The Zhukovskiy ranniy variety is a plant of medium height, semi-spreading. The leaf is small, green, glossy. The flowering is long, with medium intensity. The corolla is red-purple. The tubers are pink, the flesh is white. The eyeholes are small and red. The marketability is 90–92%. The commodity yield is of 400–450 c ha^{-1}. The weight of the grocery-ware tuber is 100–120 g.

The Udacha variety is a plant of medium height, semi-spreading. The leaves are dark green, with large lobes. The corolla is white. The tuber is light-beige. The eyeholes are small. The flesh is white. The commodity yield is of 300–500 c ha^{-1}. The marketability is 96%. The weight of the grocery-ware tuber is 120–250 g (Potato variety ..., 2013) (Fig. 1).

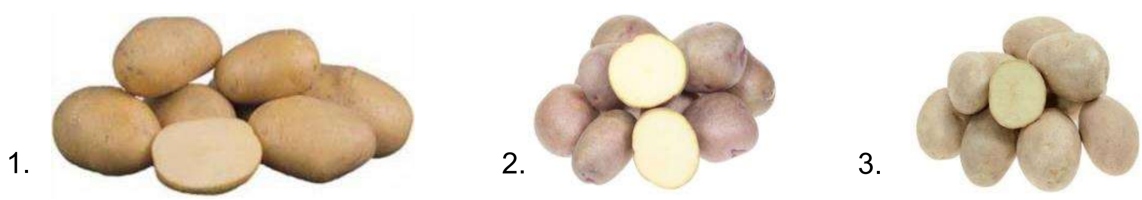

Figure 1. Potato varieties: 1. Bryanskiy ranniy; 2. Zhukovskiy ranniy; 3. Udacha.

The research was conducted in soil culture in 3–time replication in 2017. The parameters of agrochemical indicators of sod–podzolic soil are the following: humus – 1.47%; pH – 5.8; N_{total} – 0.100%; P_2O_5 – 18.7 mg per 100 g; K_2O – 9.8 mg per 100 g.

In the experiments, selenium was used in nanoform, as well as sodium selenite in the form of Voshchenko No. 3 microfertilizer (composition: zeolite 99%, sodium selenite 1%). Nanoparticles produced at the Moscow Institute of Steel and Alloys, the size of selenium nanoparticles was in the range of 4–8 nm. Selenium nanopowder (NP Se) in the form of a solution contained the optimal concentration of nanoselenium– 0.13 g per hectare seeding rate. The tubers of potatoes were soaked in distilled water 30 minutes before sowing (Ampleeva & Chernikova, 2018). The treatment with selenium microfertilizer, a dose of which was 400 g per 1 hectare, of potato tubers was also carried out before planting. (Table 1). The soil preparation and agrotechnology cultivation generally accepted in the Ryazan region (Dospekhov, 1985).

Table 1. The layout of the experiment

No.	Variant names, selenium doses	Abbreviations in tables
1	Control – without the use of selenium	Control
2	Voshchenko No.3 – selenium dose 400 g ha^{-1}	V No.3/400
3	Selenium nanopreparation – dose of 0.13 g ha^{-1}	NP–Se/0.13

The water–holding capacity, which characterizes the ability of colloids to retain water, was determined by the amount of water loss in the time interval of 20–40–60 minutes and expressed in % of the initial wet weight.

The heat resistance was estimated by the lethal temperature of the leaves kept in a water bath at different temperatures (Viktorov, 1983).

The protein content in potatoes was determined using biuret reagent and photoelectric colorimeter. The biuret method is based on the ability of protein solutions to give a violet color when interacting with a copper sulfate solution in an alkaline condition. The intensity of the color is proportional to the protein concentration in the solution.

The determination of starch content in potato tubers was carried out by the polarimetric method by its hydrolysis with a hydrochloric acid solution (Novokshanova, 2009).

The amount of ascorbic acid was determined by the 'Murri' method. The method is based on the transfer of ascorbic acid into a solution and on the ability to reduce it in an acidic environment 2.6–dichlorophenolindophenol sodium–to leucoform, while ascorbic acid is oxidized to dehydroascorbic acid. The reaction is due to the ascorbate oxidase enzyme. It should be noted that the higher the ascorbic acid content, the higher the activity of the ascorbate oxidase enzyme.

RESULTS AND DISCUSSION

The research conducted over past decades shows that biotic and abiotic factors causing excessive oxidative loads on plants limit the attainment of high stable yields of good quality.

One of the most important components of plant activity is water metabolism. The maintenance of a certain level of water balance in cells and tissues is a prerequisite not only for normal growth and development of plants, but also their resistance to environmental factors.

Under the conditions of increasing man-made load on the soil and periodically occurring droughts, it is of undoubted scientific and practical interest to study the effect of microelements on adaptive capacity and increasing the plant resistance.

The main function of selenium in plants is to participate in the construction of glutathione peroxidase–an enzyme of antioxidant protection of the plant organism from the action of free radicals produced from oxidative stress (Vikhreva et al., 2012).

The role of selenium in the implementation of the adaptation capacity of plants in case of insufficient water supply is associated with an increase in the resistance of the photosynthetic apparatus of agricultural plants. Selenium increases the leaf life, improving the efficiency of the leaf apparatus, and also contributes to better supply of maturing grains with nutrients. This reduces the specific surface density of the leaves, that indicates a more economical use of assimilates on the formation of the leaf surface and a decrease in the negative effect of drought (Seregina, 2011). In addition, a partial replacement of sulfur by selenium in ferrodoxils of chloroplasts was revealed, so that it can be assumed that selenium is involved in chlorophyll formation.

The results show that the use of various forms of selenium reduced water loss, that increased the water-holding capacity of plants (Table 2). In this case, the greatest effect was observed when using NP Se. Compared to the control, the water loss decreased by 6% in the Bryanskiy ranniy and Udacha potato varieties, and by 7% in Zhukovskiy ranniy.

As a rule, the water content of the leaves increases by 2–6% during using selenium, that leads to an increase in the plants resistance during a short–term soil drought through an increase in the water-absorbing function of the root.

Table 2. The effect of Se various forms on the water–holding capacity of potato leaves

Water loss, % of the initial weight	Control	V No. 3/400	NP-Se / 0.13
Bryanskiy ranniy	9	5	3
Zhukovskiy ranniy	9	4	2
Udacha	8	4	2

An important characteristic of the adaptation capacity of plants is heat resistance. The heat resistance is one of the indicators of drought resistance, reflecting the ability of plants to withstand high air and soil temperatures. The temperature above 40 °C is unfavorable for most plants in the temperate zone and cause the plant to die in case of prolonged exposure (Arestova, 2000). The higher plants do not tolerate positive temperatures above 51 °C for 10 minutes (Scherbakov, 1962).

The degree of heat resistance of leaves can be judged by the time at which pheophytin stains appear, and also by the degree of leaves turning brown, i.e. destruction of chlorophyll. If the leaf is exposed to high temperature and then immersed in a diluted solution of hydrochloric acid, so the damaged and dead cells turn brown due to the free penetration of acid, which will cause the conversion of chlorophyll to pheophytin, while the intact cells remain green, into cells.

The adaptive properties of selenium appeared when it was applied as a microfertilizer, and when it was used as a nanoform (Table 3).

Table 3. The heat resistance of potato leaves

Heat resistance, the number of pheophytin stains	Control	V No. 3/400	NP-Se / 0.13
Bryanskiy ranniy	12	10	5
Zhukovskiy ranniy	12	10	5
Udacha	11	9	4

However, NP Se had a much better impact on this indicator. Thus, the number of pheophytin stains on potato leaves decreased by 7 in comparison with the control. In the variant where Voshchenko No. 3 microfertilizer was used on the leaves of the Bryanskiy ranniy and Zhukovskiy ranniy varieties –by 5, on the leaves of the Udacha variety–by 2.

Puzina & Tsukanova (2008) have shown that the weight of potato tubers increased by 15–17% with using the selenium. The obtained data may be due to the antioxidant effect of selenium on plants, the mechanism of which is due to the functioning of proteins which active center contains 'selenium amino acids'.

The presowing treatment of potato tubers with selenium microfertilizer and NP Se had a different effect on the potatoes yield (Table 4). It should be noted that, in comparison with the control variant, the use of selenium made it possible to increase this indicator in two other variants.

Table 4. The effect of Se on the yield of potatoes

No.	Yield (t ha^{-1})	Control	V No. 3/400	NP-Se / 0.13
1	Bryanskiy ranniy	15.4	18.6	19.6
2	Zhukovskiy ranniy	15.4	18.4	19.4
3	Udacha	16.1	19.6	20.9

The analysis of the obtained data showed that the maximum yield increase was observed in variant with the use of NP Se (Fig. 2). Thus, the yield of Bryanskiy ranniy variety increased by 27%, Zhukovskiy ranniy variety–by 26%, Udacha–by 30%.

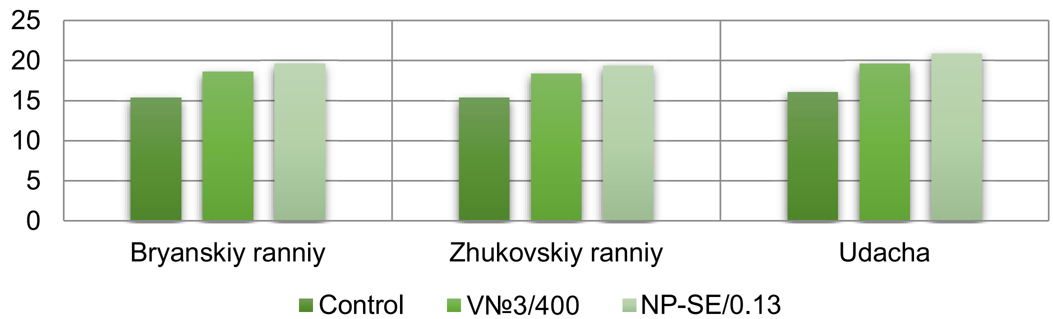

Figure 2. The effect of presowing treatment of potato seeds with various forms of selenium on the yield (t ha^{-1}).

Biochemical characteristics of tubers depend mainly on the genotype of the variety, however, the conditions of cultivation, the ratio and doses of fertilizers, the use of various preparations can significantly change their content, which affects not only the taste of tubers, but also the quality of the processed products.

The potato protein is highly nutritious and is superior to many other crops, contains almost all the essential amino acids and is equal to animal proteins, approximately to casein. It is contained more in the early varieties than in the late ones. The potato protein has genetic information and biological activity. The potato varieties that contain an increased amount of protein are the most viable, due to the fact that they are more resistant to pathogens (Shanina & Dubinin, 2015).

From the data in Table 5 it can be noted that the use of NP Se and selenium in the form of microfertilizer led to an increase in the protein content in all variants of the experiment. However, the largest increase in this component was due to the use of selenium in the form of nanoparticles. Thus, the protein content in potato tubers of the Bryanskiy ranniy variety increased by 35.2%, in Zhukovskiy ranniy by – 34.0%, and in Udacha by – 40.4%, compared with the control.

Table 5. The protein content in the wet weight of potato tubers

Protein, %	Control	VNo.3/400	NP-Se / 0.13
Bryanskiy ranniy	2.85	3.2	4.4
Zhukovskiy ranniy	2.77	2.95	4.2
Udacha	2.98	3.08	5

The starch is the main component of potatoes and widely used in the food industry as a thickener. At the same time, the structure and the taste of potatoes depends on its quantity. The starch consists of digestible and indigestible components. The last one, resistant starch is an important element for the intestinal microflora (Anisimov, 2006). The resistant starch inhibits carcinogenesis like other ballast substances, especially in the rectum.

Se nanoparticles and selenium in the form of microfertilizers had a positive effect on starch accumulation and dry matter content in all variants of the experiment (Table 6). It should be noted that the use of the Voshchenko No. 3 preparation increased these figures more than the use of NP Se. There is an inverse relationship between the protein and starch content in plants. The higher the protein content, the lower the starch content. Probably, when using selenium in nanoscale form and in the form of Voshchenko No. 3 microfertilizer, this tendency appeared.

Table 6. The content of starch and dry matter, %

Experiment variant	Bryanskiy ranniy		Zhukovskiy ranniy		Udacha	
	Starch	Dry matter	Starch	Dry matter	Starch	Dry matter
Control	14.5	23.1	14.1	22.5	16.0	23.4
VNo.3/400	20.1	24.3	22.0	26.2	21.7	25.6
NP-Se /0.13	18.3	24.1	17.9	24.8	16.6	23.8

Thus, in potato tubers of the Bryanskiy ranniy variety, the starch content increased by 27.86%, and the dry matter content–by 4.94%; of the Zhukovskiy ranniy variety–by 35.90% and 14.12%; of the Udacha variety–by 26.27% and 8.59%, respectively, compared with the control variant of the experiment.

The potatoes contain a whole range of vitamins that are good for humans, especially water-soluble ones, but their amount in tubers is a subject to large fluctuations. The relatively high content of vitamin C, as a natural source of ascorbic acid, has the particular importance.

Table 7. The content of vitamin C in the wet weight of potato tubers

Vitamin C mg, %	Control	VNo.3/400	NP–Se / 0.13
Bryanskiy ranniy	12.3	15.2	37.2
Zhukovskiy ranniy	12.8	15.9	39.4
Udacha	14.0	16.3	50.1

The use of selenium in the form of microfertilizers and in the form of nanoparticles led to an increase in the content of this substance in potato tubers of all varieties compared with the control variant of the experiment (Table 7). However, the greatest effect occurred during using NP Se.

Thus, the amount of vitamin C in the Bryanskiy ranniy variety increased by 66.9%, in the Zhukovskiy ranniy–by 67.5%, and in Udacha variety tubers–by 72.0%, in relation to the control.

If we compare the increase in this figure with selenium microfertilizer, then the increase occurred in the variety Bryanskiy ranniy by 59.1%, Zhukovskiy ranniy–by 59.6%, Udacha–by 67.5%, in comparison with the use of NP Se.

CONCLUSIONS

The obtained data allow concluding that the presowing treatment of potato tubers with selenium nanopreparation has the most favorable effect on the adaptation properties: heat resistance, water–holding capacity, and also yield increase, than the treatment of tubers with Voschenko No.3 microfertilizer. The Udacha potato variety showed great responsiveness to the application of various forms of selenium in comparison with the Bryanskiy ranniy and Zhukovskiy ranniy varieties.

A comparative analysis of various forms of selenium revealed that the use of Se nanoparticles led to an increase in protein and vitamin C, and in this case Udacha variety was the most responsive. The use of selenium in the form of micronutrients led to an increase in the accumulation of starch and dry matter. These figures were the highest in potato tubers of the Zhukovskiy ranniy variety.

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