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Biological Effect and Selenium Accumulation in Wheat under Conditions of Selenium Deficient Biogeochemical Province

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Abstract

Effect of presowing seed treatment and leaf-treatment of plants with different doses of sodium selenite on growth processes, photosynthesis characteristics, spring wheat yield and selenium accumulation in wheat under the conditions of selenium-deficient biogeochemical province in Transbaikalia were studied.

Key words: selenium, wheat, growth, photosynthesis characteristics, crop yield, accumulation, selenium deficient province

INTRODUCTION

In the last two-three decades the interest to selenium, vital micronutrient for a human body and animals at the normal contents and a dangerous toxicant in case of its elevated concentration sharply increased. The main function of selenium as micronutrient is, first of all, its participation in antioxidant processes. In the form of selenocysteine it is a part of four active centers of glutathione peroxidase enzyme, protecting the cells from damaging effect of free radicals [1, 2]. More than 30 diseases of the human being and agricultural animals are owed to deficiency of selenium: endemic cardiomyopathy (Keshan disease), white muscle disease, exudative diathesis, atrophy of liver, *etc.*

Many regions of Russia and neighbouring countries are characterized by the low content of selenium in environmental medium. The population of Se-deficient territories is in conditions of the increased risk of development of cardiovascular and oncological diseases. Some biogeochemical provinces with deep deficiency of selenium in the environment are known: some provinces of China, New Zealand, and Transbaikalia.

The selenium content in soils of the various areas of Transbaikalia varies from 12 to 197 μg/kg [3], while the average (clarke) content taken as an ecological norm is 400 μg. In 1986–1987 Keshan disease – a selenium deficient cardiomyopathy [4] of the population in the Chita region was revealed [4]. The content of selenium in blood of the patients was 0.53–0.83 μmol/L (latent form) and 0.18–0.42 μmol/L (chronic form), *i. e.* was 10 times less than the norm (1.77–2.79 μmol/L). The wide extension of diseases related with selenium insufficiency in this region is observed at live stock animals and poultry that results in significant economic damage to the live stock breeding of the region [5]. For the first time the white muscle disease was registered in the Western Transbaikalia (Buryatia) among lambs in 1936. Lamb mortality from this disease reached 30–50 % of the total number of newborns in some years [6]. Application of sodium selenite in live stock breeding of Transbaikalia considerably reduced mortality and increased live stock yield and reproductive ability of the farm livestock.

The necessity of selenium for plants isn't established today [7]. Its investigation in plants is of interest, first of all, because of selenium content and possibilities of enrichment the people and animals by this element for treatment and prevention of diseases caused the selenium deficiency. This is due to the presence of the elements in organically bound, *i. e.* the most assimilable form in plants. Grain crops, notably wheat, are the most important source of selenium for human body [8].

The purpose of the work is studying the effect of pre-seeding treatment of the seeds and foliar treatment of plants by sodium selenite on the growth processes, photosynthetic characteristics, a yield of spring wheat and selenium accumulation in it in the conditions of large deficiency of this element in East Transbaikalia.

EXPERIMENTAL

Spring wheat (the released variety Buryatskaya 79) and high grade ("kh. ch.") sodium selenite (Na_2SeO_3) were taken as the objects for investigation.

Field experiment was carried out at the test plot of Transbaikalian Scientific Research Institute of Agriculture, Siberian Branch of the RAAS, in 2003–2005 at the fallow ground fertilized by $N_{60}P_{60}K_{60}$. The soil was light loamy noncalcareous black earth with humus content 2.7 % (according to Tyurin). Nitrate concentration was 7–10 mg/kg, mobile phosphorus – 116, exchange potassium 110 mg/kg (according to Kirsanov), gross selenium – 185 μg/kg; pH_{aqua} 6.8. The square of the test plot was 25 m^2 (record plot – 20 m^2), four replications, consecutive arrangement. The seeding was carried out with the use of seeder SN-16 by line planting (the distance between the drills was 15 cm) with the subsequent rolling down.

Three series of trials were conducted. In the first series the seeds were pre-treated by 100 m of Na_2SeO_3 solution in amounts of 25, 50, 100 mg/kg; in the second one the plants were treated by Na_2SeO_3 solution in amounts of 25, 50, 100 g per hectare; in the third series the pretreatment of the seeds was carried out by Na_2SeO_3 solution – 25, 50, 100 of mg/kg and the subsequent treatment of plants by Na_2SeO_3 solution in amounts of 25, 50, 100 g per hectare. The plants were sprayed by Na_2SeO_3 solutions in a heading phase. Water discharge was 200 L per hectare of crops. Control plants were treated by water. Dynamics of growth was defined by measurement of plants height. The harvesting from the record plot was carried out at wax ripeness phase by the Sampo combine harvester by total weight method. The elements of crop structure were counted by taking 10 plants from stationary plots [9]. The assimilating surface of leaves, photosynthetic efficiency and photosynthetic potential were determined by Nichiporovich [10], and the chemical composition of grain and straw – according to Pleshkov [11]. The content of selenium in various organs of wheat was determined by fluorometry in the Laboratory of Biochemistry of Research Institute of Medical Ecology at the Chita State Medical Academy. Mathematical processing of data on productivity was carried out with use of methods of the dispersive and correlation analysis [12, 13].

RESULTS AND DISCUSSION

Plant growth is integrated physiological process providing realization of the ontogenesis hereditary program and all the changes in biochemical processes under the effect of various endogenic and exogenic factors. The data of Table 1 demonstrate stimulation of height growth of wheat plants as result of seeds treatment by selenium in amounts of 25 and 50 mg/kg. The most height difference compared with control plants was noted in at the boot stage and was 14 % in comparison with control.

One of the most important indicators of the growth processes intimately related with final productivity of plants is the size of assimilating surface. It is caused by the fact that the most part of crop organic matter is produced by leaves. According to our data, the increase in a leaf surface of wheat under the influence of selenium ranged up to 27 % in comparison with control sample. The largest increase in a leaf surface of tested plants was noted at the heading phase. At the milk phase decrease in the leaf surface of wheat at the expense of decline of the bottom leaves was observed. In-

TABLE 1

Effect of selenium on growth process and assimilating surface of wheat

Experiments	Phase			
	Tillering	Boot stage	Heading	Milky ripe stage
	Plant height, cm			
Control	28±1.4	49±2.3	73±3.4	74±3.3
Seed treatment by Na_2SeO_3 solution, 25 mg/kg	26±1.2	54±2.5	78±4.1	78±4.1
The same, 50 mg/kg	27±1.6	56±2.8	81±3.7	80±3.8
The same, 100 mg/kg	25±1.1	47±2.2	69±3.3	70±3.5
	Leaf surface, thousands of m^2/ha			
Control	2.1±0.11	12±0.5	22±1.1	19±0.9
Seed treatment by Na_2SeO_3 solution, 25 mg/kg	2.0±0.09	14±0.7	24±1.3	21±1.2
The same, 50 mg/kg	2.1±0.12	14±0.8	28±1.5	23±1.1
The same, 100 mg/kg	1.9±0.10	13±0.7	20±0.9	17±0.8

crease in dry matter yield of wheat plants in a milk stage under the influence of selenium was 607–669 g/m^2 (546 g/m^2 in control). That allows to reveal correlation dependence between mass of plants and leaf surface in a heading phase is revealed (r = 0.9).

The important parameter of productive activity characterizing the ability of plants to synthesize and accumulate organic matter in crops is net productivity of photosynthesis. In the course of vegetation this parameter is exposed to essential fluctuations (Table 2) connected with changes of activity of physiological processes which are caused both by internal and external factors. Some decrease in photosynthetic efficiency in initial phases of development and significant increase in boot–milky ripe stages under the effect of selenium was noted. The increase in the size of leaf surface under the effect of selenium resulted in increase of photosynthetic potential of wheat crops – the total indicator defining efficiency of plants. For tested plants the photosynthetic potential was 1.262–1.451, and for control – 1.118 million $m^2 \cdot$ day/ha. Close correlation between photosynthetic potential and wheat productivity (r = 0.8) is revealed.

Productivity and qualitative structure are the final integrated criteria of estimation of diverse effects on plants. Positive effect of selenium on growth processes and photosynthetic characteristics provided the best conditions for realization of potential productivity of wheat. The data in Table 3 show that treatment itself of seeds by sodium selenite in ratio of 25 and 50 mg/kg, as well as together with treatment of wheat crops in ratio of 25 and 50 g/ha reliably caused a rise in grain yield – 8.7–12.0 % in comparison with control. The increase in a grain yield of tested plants is mainly depends on quantity of productive stalks, and to a lesser extent – on amount of grains and mass of grains from a spike.

In vegetative tests on the soddy podzolic soil pre-seeding treatment of spring wheat seeds

TABLE 2

Effect of selenium on the photosynthetic efficiency and photosynthetic potential (PP) of wheat

Experiments	Photosynthetic potential, g/($m^2 \cdot$ day)			PP, 10^6 $m^2 \cdot$ day/ha
	Tillering – boot stage	Boot stage – heading	Heading – milky ripe stage	
Control	4.4±0.21	1.7±0.08	7.7±0.41	1.118
Seed treatment by Na_2SeO_3 solution, 25 mg/kg	4.1±0.19	1.9±0.09	8.9±0.46	1.273
The same, 50 mg/kg	4.2±0.22	2.1±0.11	9.3±0.43	1.451
The same, 100 mg/kg	3.9±0.18	1.5±0.07	7.1±0.34	1.110

TABLE 3

Effect of selenium on wheat yield and its structure (averages for the period 2003–2005)

Experiments	Yield, t/ha	Number of productive stems, sp./m^2	Number of grains in a spike	Grain weight from 1 spike, g
Control	2.30	251	27	1.10
Seed treatment by Na_2SeO_3 solution, 25 mg/kg	2.50	265	28	1.12
The same, 50 mg/kg	2.58	275	29	1.13
The same, 100 mg/kg	2.21	250	28	1.08
Control – water treatment of plants	2.32	255	27	1.13
Spray treatment of plants by Na_2SeO_3 solution, 25 g/ha	2.34	254	28	1.14
The same, 50 g/ha	2.43	257	28	1.14
The same, 100 g/ha	2.27	256	27	1.11
Seed treatment and spray treatment of plants by Na_2SeO_3 solution, 25 mg/kg (seed) + 25 g/ha (plants)	2.51	272	28	1.15
The same, 50 mg/kg + 50 g/ha	2.60	287	29	1.16
The same, 100 mg/kg + 100 g/ha	2.11	251	27	1.10
$HCP_{0.5}$	0.22	20	1.0	

by sodium selenite at the rate of 5 g of selenium per 1 centner of seeds in the conditions of water deficiency gave an increase of a grain yield of Ivolga variety for 17 %, and thousand grain weight – for 13 % in comparison with control. At the same time Moskovskaya-35 wheat variety showed negative reaction to the seed treatment by selenium [14].

The main characteristics of quality of food and fodder plants – the content of protein in grain and vegetative mass. Application of sodium selenite resulted in increase in the protein content in grain of 1.1 to 1.6 %, in straw – of 0.37 to 0.67 % in comparison with control (Table 4). Besides, the content of phosphorus in grain under the influence of selenium raised, and the content of potassium was practically stable.

Selenium application for plants enrichment is of particular interest because of wide spread of endemic diseases of the population and the animals in Transbaikalia caused by considerable deficiency of selenium in environment medium. According to the data of Table 4, application of sodium selenite raised the content of selenium in wheat grain to 249–360 μg/kg, or in 8, 10 and 12 times in comparison with control (31 μg/kg). The content of selenium in straw under the effect of treatment the seeds and plants by sodium selenite also increased. As result of pre-seeding treatment of wheat seeds

TABLE 4

Effect of selenium on the chemical composition of wheat grain and straw

Experiments	Crude protein, %	Selenium, μg/kg*	P_2O_5, %	K_2O, %
Control	14.2/4.64	31/38	1.14/0.33	0.40/0.52
Seed treatment and spray treatment of plants by Na_2SeO_3 solution, 25 mg/kg (seed) + 25 g/ha (plants)	15.3/5.11	249/181	1.31/0.30	0.41/0.70
The same, 50 mg/kg + 50 g/ha	15.8/5.31	295/383	1.37/0.28	0.43/0.73
The same, 100 mg/kg + 100 g/ha	15.1/5.01	360/922	1.30/0.26	0.39/0.65

Note. The first number is the content in wheat grain, the second – in wheat straw.

* Dry basis.

by sodium selenite concentration of selenium in grain raised in 3–6 times, and at foliar treatment of plants – in 4–8 times in comparison with control options.

The daily physiological selenium requirement for the adult is 70 μg, the top admissible level – 150–200 μg. The bottom level of selenium entry necessary for prevention of pathology and clinical implications of function weakening is 21 μg/day [2, 15]. Daily average norm of consumption of white bread being 250 g, 63–90 μg of selenium can arrive in a human body in case of treatment wheat seeds by sodium selenite; that amount practically satisfies daily requirement for this element. At the same time consumption of wheat bread made from control wheat plants results in as less as about 10 μg of selenium delivery to the organism. It is especially important because as it was already noted above, wheat is one of the main sources of intake of selenium in a human body.

The advantage of selenium assimilation from vegetable food is an organic, the most assimilable form of selenium. The optimum form of selenium assimilation is selenomethionine; its availability is 5–10 times higher than that from inorganic compounds. Selenium arriving to cereals is there converted mainly to selenomethionine. The higher animals and the human beings can't synthesize selenomethionine – the only active form of selenium which, unlike other forms of selenium, can be incorporated into tissue proteins and thereby can give positive physiological effect. Foliar treatment of plants enriches wheat grain by selenium five times as much as the control plants as was observed in Slovenia [16], and a fodder plant yellow lupine (*Lupinus luleus*) – in 4–9 time (Bryansk Region, Russia) [17].

Enrichment of vegetable products by selenium to the level which is optimum for assimilation by human being has positive effect because it favours decrease of cancer risk, cardiovascular pathology, inflammatory processes, cataract; increase in immunological activity, regulation of a normal gestation course and prevention of risk of premature birth, mortality of newborns, and decrease of toxic effect of heavy metals. Selenium is also a part of the enzymes involved in synthesis and metabolism of iodine-containing hormones [18].

Thus, selenium proves to be physiologically active trace element in wheat plants in the conditions of the selenium-deficient biogeochemical province. Selenium in plant bodies is assumed to carry out the same protective role, as in animal organism (especially under stress) [7]. Transbaikalia is characterized by adverse climatic conditions concerning supply of water. The amount of precipitation during the vegetative period may reach 250 mm, and usually – 200–100 mm or less. That is why the yield of wheat for example in 2004 in control group was only 11 centner/ha.

The experiments imitating drought at the wheat booting stage – getting into ear demonstrates that selenium promotes increase of water content in leaves tissues and thereby increases of drought resistance of plants [19]. So, the positive effect of selenium on growth processes, photosynthetic activity and wheat crop in our experiments could be explained by it its effect to water conditions of plants.

It is established as well that selenium in plants is present in protein compounds as a part of amino acids – selenomethionine, selenocysteine, methylselenocysteine, and also in the free amino acids which are not connected with proteins [7]. Therefore, selenium takes part in one of the most important processes in plants – nitrogen metabolism, and this promotes increase in protein content in reproductive and vegetative parts of wheat in our tests. Increase of the content of the nitrogenous compounds with hydrophilic characteristics and higher water-retention capacity, apparently is the major factor determining positive effect of selenium to water conditions of wheat plants, and consequently, and to its productivity.

CONCLUSIONS

1. Application of sodium selenite for pretreatment of seeds of spring wheat under conditions of the extreme selenium-deficient biogeochemical province provided positive effect on growth processes, photosynthetic activity and productivity. It demonstrates that selenium in optimum doses is physiologically active trace element in plants. Optimum doses for treatment of seeds are 25 and 50 mg/kg.

2. Selenium improved the quality of wheat grain and straw because of increase of crude protein and phosphorus content. Besides, sele-

nium accumulation in grain was 8–12 times as much as benchmarks. So, it is possible to satisfy daily need of a person for organically bound the most assimilable form of selenium. Foliar treatment of plants providing selenium accumulation by barrier-free type more effectively increases selenium content in a crop.

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