ON THE POSSIBILITY TO GROW HIGH-SELENIUM WHEAT IN THE KUZNETSK BASIN

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(Received March 17, 2014; Accepted in revised form March 24, 2014)

Abstract: Selenium is an indispensable biologically active trace element; being part of the most important enzymes and hormones, it participates in most metabolic processes and has antioxidant properties. The Kuznetsk Basin (Kemerovo oblast) is a region where selenium deficiency is associated with adverse environmental conditions in addition to natural factors; as a result, the population experiences a severe shortage of this trace element. Fortified foods of mass consumption can be a major source of selenium, especially for socially disadvantaged strata. This paper shows the possibility of obtaining wheat with high selenium content in grain in the regional context. It is proved that the most significant factors that ensure wheat with good technological properties are the method, the phase, the amount and multiplicity of selenium application, and the simultaneous introduction of enriching supplements and complex mineral additives. The threshold quantities of selenium supplements are established.

Keywords: selenium, enrichment, wheat, climatic conditions, soils, Kemerovo oblast, technology, grain quality

UDC 664:631
DOI 10.12737/4089

INTRODUCTION

The Kuznetsk Basin is a region with well-developed chemical, metallurgical, and coal industries. Despite the environmental improvements observed in the past years, the situation remains unfavorable. As is known, an unfavorable environment increases the need for various micro- and macroelements to support body functions in aggressive conditions, including the need for selenium, an indispensible biologically active microelement, which is part of major enzymes and hormones; it participates in the majority of metabolic processes and has antioxidant properties [1, 2, 3, 4, 5, 6, 7]. Another important role of selenium is antagonism to heavy metals: mercury, arsenic, and cadmium and, to a lesser extent, to lead and thallium. [8, 9]. Thus, the population of Kemerovo oblast needs adequate selenium consumption; in addition, enriched staple foods can become a major source of selenium, especially for disadvantaged strata.

The adequate consumption of selenium by the human organism, according to various sources, is considered 50–200 mcg/day [9, 10]. Selenium deficiency develops if the human body receives 5 mcg/day of selenium or fewer, the toxicity threshold being 5 mg/day. Russia, according to the methodological recommendations 2.3.1.2432-08 "Norms of Physiological Requirements in Energy and Food Substances for Various Groups of the Population of the Russian Federation," has established requirement levels of 30–75 mcg/day. The physiological requirements are 55 mcg/day for adult women, 70 mcg/day for adult men, and 10–50 mcg/day for children. The upper permissible requirement level is 300 mcg/day.

At present, the main ways of selenium metabolism in the human organism have been decoded: in natural conditions, selenium enters the human organism mainly as selenium-containing amino acids, selenomethionine (Se–Met) and selenocysteine (Se–Cys); the artificial introduction of selenium into a selenium-deficient organism is possible in the form of sodium selenite or sodium selenate [11].

The main cause of selenium deficiency is its shortfall in humans who live in a biogeochemical province with a low level of this element in foods, soils, and drinking water [9]. The Kuznetsk Basin is among such territories.

The selenium content in phytogenic foods depends on the plant type, the development stage, the geochemical characteristics of a vegetation period, the amount of the element available in soil, microorganism activity, and precipitation. The selenium content in zoogenic foods depends on the amount of the bioaccesible element in feeds [12].

Among foods most rich in selenium are cereal grains and products of their processing (brown bread, wheat, oats), mushrooms, nuts, garlic, horse radish, spinach, onions, pumpkins, strawberries, black currants, and cranberries; as well as meat and fish products [8, 12, 13, 14].

There are the following ways of solving the problem of selenium deficiency in humans.

The use of products with initially (naturally) high selenium contents, including foods imported from selenium-rich regions and countries.

The United States with its both selenium-rich and selenium-poor territories solves this problem by food haulage. There is an efficient practice of importing wheat from selenium-rich regions of Australia, Canada, and the United States, which leads to its increased level in the blood of New Zealanders, Lithuanians, and Finns, whose soils are poor in this trace element [9, 15, 16].

It is possible to increase the selenium level in plants by enriching fertilizers with various selenium compounds. There is a practice of using fertilizers with various selenium forms [11, 17, 18, 19, 20]. However, this method may lead to intoxication during soil liming; therefore, the level of selenium in soils should be strictly controlled [11, 12, 21].

Finland's experience is illustrative. The optimization of the population's selenium status was accomplished at the national level in various ways: by introducing long-term fertilizer programs, by using biologically active and selenium-containing additives (primarily, baker's yeast enriched with selenium), and by purchasing grain from selenium-endemic countries (the United States, Canada, and Australia) [16, 22]. Slovenia enriches plant products with selenium by spraying plants with sodium selenate solutions; however, the share of selenium adsorbed by plants is low, only about 2–3% of the amount applied. There is a positive practice of enriching grain varieties in Australia [23]. The advisability of enriching corn with selenium was shown in the Republic of Malawi (East Africa) [24].

Taking into account the low selenium status of the region and relying on the available best practices of solving this problem, we set the goal of this work as to probe into the possibility of obtaining high-selenium wheat grain in the natural and climatic conditions of the Kuznetsk Basin.

OBJECTS AND METHODS OF RESEARCH

During the development of a high-selenium wheat technology, we chose as the object of enrichment the In Memory of Aphrodite wheat variety, which was bred by the Kemerovo Research Institute of Agriculture and which is now undergoing variety testing.

Sodium selenite and sodium selenate were tested as enriching additives (EAs).

Grain quality was assessed by the following indicators: color and smell, vitreousness, gluten quantity and quality, acidity, moisture contents, the general and fractional contents of trash and grain impurities, the content of small grains and grain sizes, the content of wheat grains damaged by chinch bugs, the content of foreign metal matters, infestation with pests, and ash contents.

The grain was analyzed by safety indicators at the test laboratory of the Kemerovo Interregional Veterinary Laboratory.

The quantitative content of selenium was determined by the inversion voltammetry method at the STA1 analytical voltammetric complex (OOO YuMKh, Tomsk, Russia) using a mercury–graphite electrode, formed in situ (relative to a chlorine–silver electrode). The experiments were conducted with a 5-tuple replication, and the results were processed statistically.

RESULTS AND DISCUSSION

The field experiment was carried out at the Kemerovo Research Institute of Agriculture in 2009–2012 jointly with A.V. Myakashkina [25]. A diagram of the experiment to obtain high-selenium wheat is given in Fig. 1.

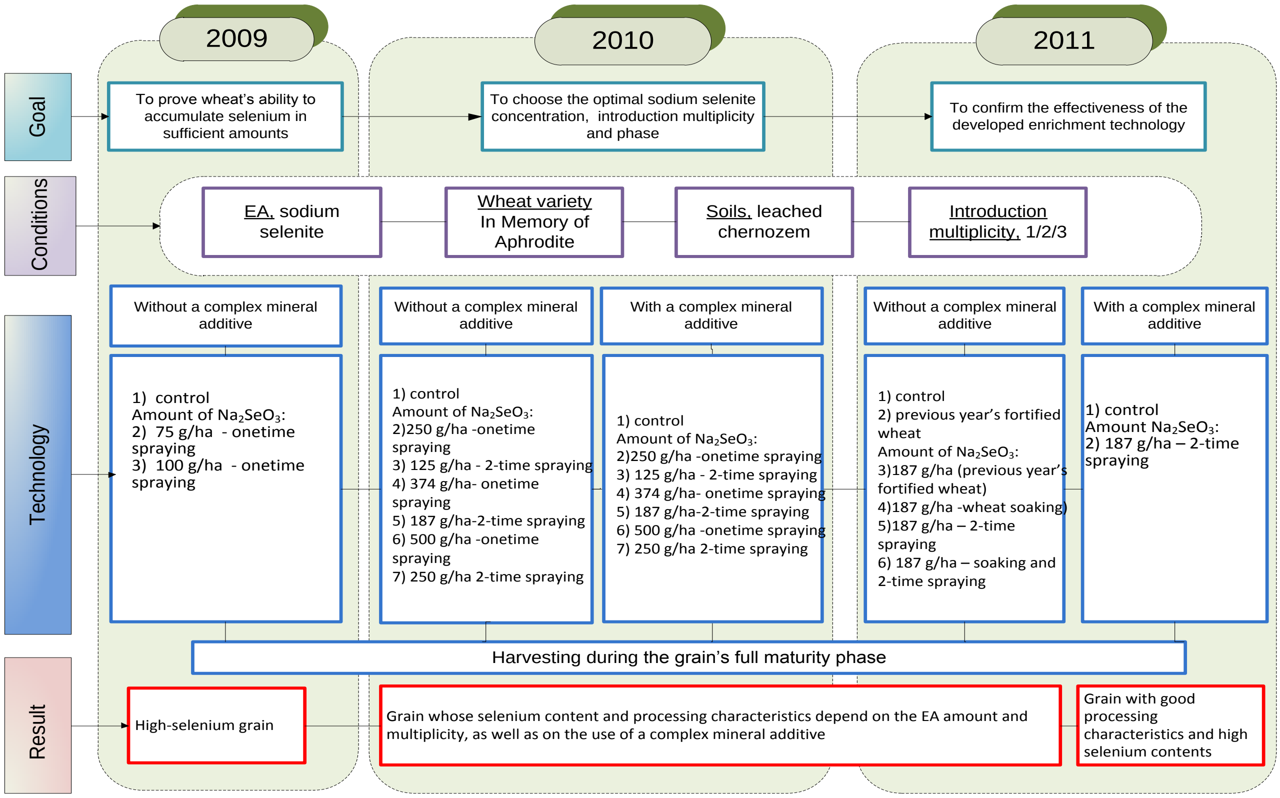

Fig. 1. Diagram of the experiment to grow high-selenium wheat.

The choice of wheat as the object of selenium enrichment was affected by the fact that this is a valuable grain crop capable of accumulating selenium and transforming it into an organic form, selenomethionine; there is a positive foreign experience in this sphere.

The following factors affecting selenium accumulation in plants were identified:

Raw material

1. The choice of wheat variety. As is known, the amount of selenium accumulated in grain depends on the quality and quantity of gluten protein. We chose the In Memory of Aphrodite wheat variety as the object of enrichment, which was bred at the Kemerovo Research Institute of Agriculture and which is characterized by high gluten qualities, as well as by a good resistance to diseases and pests in the conditions of the Kuznetsk Basin.

Variety characteristics: Lutescens; the mass of 1000 grains is 34–39 g; the number of kernels in an ear is 24.7–26.7. It is a middle-early variety. Against the infection background, it is poorly infected by dust-brand, powdery mildew, and middle leaf rust, having a high standability. The wet gluten content is 28%. Productivity is 3.26–4.02 t/ha.

2. The choice of the enriching selenium-containing additive. Sodium selenite was chosen as the selenium additive due to the following advantages:
– good water solubility;
– the ability to embed into organic compounds;
– favorable influence on biochemical processes in plants: all methods of treatment with sodium selenite (preplanting, extraroot, and binary) stimulate the extension of the leaf surface and footstalk; as a result, selenium increases the content of chlorophyll, the main photosynthetic pigment, and accelerates plant development, increasing plant biomass; and
– cost effectiveness (currently the cheapest selenium form).

3. The choice of the complex mineral additive was predetermined by the fact that selenium embeds into gluten protein; consequently, the higher the gluten content in grain, the more selenium the wheat can accumulate (up to 50% on average). We assumed that the application of a fertilizer that increased gluten would increase the cumulative properties of wheat in relation to selenium. In this context, we investigated the influence of a complex mineral additive, Master Osobyi (a fully soluble microcrystalline fertilizer (Na-18:P-18:K-18+micro), which contains microelements in the EDTA chelate form (Zn, Cu, Mn, Fe) and which is stable in a wide pH range. It can be used in the most sophisticated irrigation systems and for foliar application; it does not contain sodium, chlorine, and carbonates and has a very high degree of chemical purity, which is a decisive factor of efficient nutrition and foliar dressings, increasing NPK fixation by plants from soil and fertilizer).

Technology

It represents a totality of enrichment parameters: the method, the phase, and the multiplicity of application of the selenium-enriching additive. Several ways of enriching plants with selenium are known:
– applying selenium salts to soil (root irrigation),
– applying selenium-containing fertilizers,
– surface sprinkling with selenium salts, and
– applying selenium salts during seed sprouting.

Analysis of the existing methods of EA application allowed us to identify the following advantages of surface sprinkling:
– enriching plants with selenium through leaves at certain stages of development produces a larger effect than the use of fertilizer, because a plant during vegetation accumulates the largest dose of microelements, which allows us to obtain very high selenium contents in the ready product;
– the soil is not contaminated with selenium salts;
– surface sprinkling is the most economically advantageous way;
– the possibility to use this method does not depend on the properties of the soil where a plant grows; and
– extraroot enrichment makes it possible to deliver the necessary amount of a microelement directly into the plant, where it joins the metabolism several hours after the treatment.

The selenium additive was applied at two phases: the booting stage and the milk-ripe stage on the basis of biochemical processes during plant growth.

Soil and climatic conditions

Soil type influence on selenium contents in plants

The selenium content, as well as that of many other microelements in plants, depends on soil type. For normal selenium accumulation, plants need a fertile soil, the environment's neutral reaction, and the absence (small amounts) of heavy metals.

In the Kuznetsk Basin, three soil-evaluation zones were identified: low-, medium-, and high-bonitet soils (soil bonitation (from Latin *Bonitas*, goodness) is a relative evaluation of soils by their productivity).

By the degree of soil erosiveness, the Kuznetsk Basin falls into zones IV, V, VI, and VII, which are characterized by medium-to-small deflation, weak-to-strong washout, and, starting from zone VI, the soils are susceptible to the development of erosion processes. Table 1 shows data about the possibility of enriching plants with selenium depending on soil type, erosion zone, and soil bonitet, all other conditions being equal.

The analysis of soil characteristics has shown that the following six districts of the oblast are the most favorable for growing high-selenium wheat: Leninsk-Kuznetskii, Promyshlennovskii, Topki, Yurga, and Kemerovo. Chernozem and gray forest soils with their good fertility, high extent (7) of agricultural development, large plow land area, and bonitet prevail in these districts. The other districts are suitable for growing fortified stock, but, taking into account soil erosion and washout, there is the probability of a reduced efficiency of fortification.

Influence of climatic conditions on selenium accumulation

Since the gluten content in grain is 30% dependent on favorable climatic conditions, the growing of high-quality grain needs a sufficient amount of moisture, a relatively high air temperature, and intensive insolation. In addition, each plant-development phase requires its own temperature regime and rainfall. Table 2 gives aggregate data about climatic conditions in the Kuznetsk Basin in the 2009–2011 summer periods.

Table 1. Characteristics of the Kuznetsk Basin' soils by district

Soil type	Soil erosion zones	Soil bonitet zones	District	suitable/unsuitable for enrichment
Chernozem and gray forest soils	IV zone	High	Belovo	++
Chernozem and gray forest soils	IV zone	High	Leninsk-Kuznetskii	++
Chernozem and gray forest soils	IV zone	High	Promyshlennovslii	++
Chernozem and gray forest soils	VI zone	High	Prokopyevsk	+
Chernozem and gray forest soils	IV zone	High	Topki	++
Chernozem and gray forest soils	IV zone	High	Yurga	++
Podzolized chernozem	IV zone	Medium	Kemerovo	++
Sod-podzol and podzolized gray forest soils	V zone	Medium	Yaya	+
Sod-podzol and podzolized gray forest soils	V zone	Medium	Mariinsk	+
Sod-podzol and podzolized gray forest soils	V zone	Medium	Tyazhinskii	+
Sod-podzol and podzolized gray forest soils	VII zone	Medium	Tisul'	+
Sod-podzol and podzolized gray forest soils	VII zone	Medium	Novokuznetsk	+
Podzolized gray forest soils	IV zone	High	Krapivinskii	+
Podzolized gray forest soils	V zone	Medium	Izhmorskii	+
Sod-podzol and podzolized gray forest soils	VII zone	Medium	Chebula	+
Sod-podzol, light-gray and gray soils.	V zone	Low	Yashkino	+

+ + well-suited for enrichment, + poorly suited for enrichment

Table 2. Meteorological conditions in the Kuznetsk Basin, 2009–2011

Indicators	May				June				July				August			
	Ten-day periods			Per month	Ten-day periods			Per month	Ten-day periods			Per month	Ten-day periods			Per month
	1	2	3		1	2	3		1	2	3		1	2	3	
Average annual air temperature, ^{0}C	7.1	9.3	12.7	9.7	15.0	16.1	17.8	16.3	18.9	18.9	18.7	18.8	17.5	15.7	13.1	15.4
Average annual precipitation, mm	13	15	17	43	16	22	25	63	16	24	24	64	21	17	21	59
Air temperature, ^{0}C																
2009	9.3	14.3	11.4	11.7	16.2	12.2	13.4	13.9	18.6	20.8	18.2	19.1	17.4	14.7	16.1	16.1
2010	6.2	6.4	12.7	8.6	15.9	18.5	15.6	16.7	16.9	18.9	15.3	17.0	15.3	13.8	16.9	15.4
2011	6.2	6.4	12.7	8.6	15.9	18.5	15.6	16.7	16.9	18.9	15.3	17.0	15.3	13.8	16.9	15.4
Precipitation, mm																
2009	22	9	24	55	54	12	36	102	24	12	36	72	38	7	17	62
2010	7	9	13	29	5	1	17	23	53	39	44	136	48	20	5	73
2011	7	9	13	29	5	1	17	23	53	39	44	136	48	20	5	73
Hydrothermal index 2009			1	1.3				2.4				1.3				1.3
Hydrothermal index 2010				1.00				0.46				2.60				1.53
Hydrothermal index 2011				1.00				0.46				2.60				1.53

The 2009 vegetation period was characterized by good moisture provision until the heading phase of the grain crops. Precipitation in June and May was 55 and 102 mm, respectively, which was above the norm by 28–63%. The temperature was slightly below the norm but sufficient for forming good quantitative indicators of wheat quality. The second half of vegetation was more arid compared to the first half: 72 mm of rainfall in July (the norm being 64 mm) and 62 mm of rainfall in August (the norm being 59 mm). The average daily temperatures in July exceeded the norm, creating, in combination with reduced humidity, an "uncomfortable" atmosphere for plant development and increasing the probability of obtaining dry feeble grain. The ripening of spring wheat by calendar days went until September 15. The hydrothermal index (HTC), the ratio of precipitation to evaporated moisture, during the period of grain formation and filling was 1.3.

The 2010 vegetation period was characterized by insufficient moisture provision until the heading phase of grain crops. The rainfall in June and May was 23 and 29 mm, respectively, which was 63–67% of the norm, in consequence of which the quantitative characteristics of the grain suffered. In the second half of vegetation, an abundant rainfall was observed: 136 mm in July (the norm being 64 mm) and 124 mm in August (the norm being 59 mm). The low average daily temperatures in July, limited sunshine, and excessive moisture increased the length of the vegetation period of grain crops. The ripening of spring wheat by calendar days went until September 15 and longer. Ripening unevenness was observed; 50% and more of stalks were behind in development phases the main haulm stand. The HTC during grain formation and filling was 1.53– 2.60.

The 2011 vegetation period was characterized by insufficient moisture provision during the planting–tillering period of grain crops, which largely affected the formation of the reproductive organs. During the tillering period of spring wheat, HTC = 0.2–0.6, which affected negatively the formation of wheat productivity. Moisture shortages in May and June were accompanied by high temperatures, by 2–3^{0}C higher than the norm.

The flowering period (the beginning of milk ripeness) was characterized by high average daily temperatures, 19.5^{0}C, and nonproductive rainfall, 2.0 mm; HTC = 1.1. This did not provide the kernels with the necessary amount of moisture, which, in turn, affected gluten quality. During the grain filling period, a sufficient moisture provision was observed; HTC = 1.3; and the number of sunshine hours was 20 below the norm. The harvest time was accompanied by periodic rains.

Thus, the most favorable period for growth, grain development, and gluten accumulation was the summer of 2009.

Analysis of sensitivity of grain quality to fortification methods

Test results of 2009

The goal of the experiments in 2009 was to prove the hypothesis of the possibility of wheat fortification by the example of the In Memory of Aphrodite variety in the conditions of Kemerovo oblast. Moreover, of special interest was to establish the effect of EAs on productivity.

The results of field tests (Table 3) confirmed this hypothesis: the findings showed that the In Memory of Aphrodite wheat variety was suitable for enrichment with selenium by the surface sprinkling method in the conditions of Kemerovo oblast.

Table 3. Enriching additive's effect on wheat yields and selenium contents in grain, 2009

Indicator	Sample no.		
	No. 1 (Control)	No. 2	No. 3
Introduction method	=	Surface spraying	Surface spraying
Concentration of Na_2SeO_3 solution, %	0	0.025	0.05
Amount of sodium selenite applied, g/ha	0	75	125
Total amount of sodium selenite introduced per 1 ha	0	60 g/250 L	125 g/250 L
Planting date	May 20, 2009		
Harvesting date	15.09.2009 г.		
Yield, t/ha	2.72 ± 0.024	2.75 ± 0.024	2.80 ± 0.024
Amount of selenium in grain, mg/kg	0.010 ± 0.002	0.015 ± 0.0037	0.027 ± 0.0037

In their quality, the samples are competitive with the control group and correspond to the requirements for commercial grain. It was established that wheat samples treated with sodium selenite exceeded the control group by their linear dimensions: by up to 25% in length and by up to 50% in width. The difference compared to the control group of an indicator such as the mass of 1000 grains was about 3%; the acidity decreased with the increased concentration of the salt applied.

The application of sodium selenite affected the productivity insignificantly; the samples treated with sodium selenite showed a positive tendency to increase productivity.

The mathematical treatment of the data obtained by the correlation analysis method (after Pearson) show the reciprocal influence of various qualitative characteristics on one another: indicators such as gluten and selenium contents in grain are interdependent and directly proportional; i.e., the more the gluten in grain, the larger the selenium content is.

Test results of 2010

At this stage, we studied the effect of irrigation multiplicity and the presence of fertilizer, as well as determined the optimal amount of sodium selenite to apply. To this end, we simulated 14 wheat samples that differed in all the above characters.

The evaluation of the grain quality of these wheat samples showed that, by organoleptic indicators, all the experimental samples were as good as the control group. The data about the quantity and quality of gluten in the samples are given in Table 4.

In the table results, we can trace a dependence of gluten quantity on the multiplicity of sodium selenite application and on the use of the Master Osobyi complex mineral additive. All other conditions being equal, the application of this additive contributes to an increase in the gluten amount by 10–17% on average.

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Table 4. Grain yields and selenium contents, 2010

Sample no.	Amount of Na_2SeO_3, applied, g/ha	Irrigation multiplicity, times	Amount of fertilizer applied, kg/ha	Amount of selenium in grain, mg/kg	Yields, t/ha
Sample no. 1	0	1	0	0.01 ± 0.015	2.69 ± 0.74
Sample no. 2	0	1	4	0.01 ± 0.015	2.74 ± 0.248
Sample no. 3	224	1	0	0.017 ± 0.021	2.76 ± 0.248
Sample no. 4	224	1	4	0.023 ± 0.009	2.83 ± 0.496
Sample no. 5	112	2	0	0.020 ± 0.004	2.76 ± 0.248
Sample no. 6	112	2	4	0.023 ± 0.009	2.90 ± 0.248
Sample no. 7	374	1	0	0.033 ± 0.009	2.6 ± 0.496
Sample no. 8	374	1	4	0.040 ± 0.007	2.7 ± 0.496
Sample no. 9	187	2	0	0.030 ± 0.002	3.0 ± 2.484
Sample no. 10	187	2	4	0.049 ± 0.004	3.32 ± 2.484
Sample no. 11	500	1	0	0.047 ± 0.002	1.5 ± 0.248
Sample no. 12	500	1	4	0.050 ± 0.007	1.5 ± 0.248
Sample no. 13	250	2	0	0.042 ± 0.012	2.78 ± 2.484
Sample no. 14	250	2	4	0.051 ± 0.004	2.85 ± 2.484

In the table results, we can trace a dependence of gluten quantity on the multiplicity of sodium selenite application and on the use of the Master Osobyi complex mineral additive. All other conditions being equal, the application of this additive contributes to an increase in the gluten amount by 10–17% on average.

After a onetime application of sodium selenite at a high concentration (500 g/ha), a grain class reduction was observed, probably, due to the negative influence of high concentrations of sodium selenite on plant development; after a two-time application of sodium selenite, the concentration of selenium in the solution was significantly lower, which positively affected plant growth and development, and samples treated with sodium selenite at stage 2 contained by 5–11% more gluten, the difference with the control group reaching 17%.

In 2010 the use of sodium selenite also affected the linear dimensions of wheat grains: as the salt concentration increased to 374 g/ha, the grain dimensions increased (the length, up to 7%, the width, up to 30%); in addition, three factors influenced this indicator: the amount of sodium selenite applied, the multiplicity of its application, and the use of fertilizer. After a onetime application of sodium selenite at a concentration of 500 g/ha, the biometric characteristics of grain deteriorated, and the grain became hollow. After the application of the same amount of salt at stage 2, the indicators did not decrease but rather increased compared to the control group by 16–25 %. The application of the complex mineral additive also affects this indicator: the linear dimensions of the grain exceeded those of the samples not treated by fertilizer.

The largest amount of selenium accumulated by wheat, 0.051 mg/kg (sample 14), was obtained during surface sprinkling of plants with sodium selenite in the amount of 250 g/ha. The second largest in selenium content was sample 12; however, a onetime EA application led to the inhibition of plant growth and reduced productivity. Sample 10 also showed good results although the amount of selenite used was much lower, which was economically more profitable. Moreover, this sample had the highest productivity.

Since the selenium content in the grain of samples 14, 12, and 10 was approximately the same (within the experimental error), we may assume that the two-time application of sodium selenite in the amount of 187 g/ha together with the use of the complex mineral additive is optimal (sample 10).

Test results of 2011

The main goal of research in 2011 was to confirm the data obtained in 2010. In addition, it was interesting to study plant growth and development from wheat grains with the high selenium content of the 2010 harvest, as well as to evaluate the effect of seed soaking in a sodium selenite solution before planting.

All the samples showed sufficiently good qualitative results, but the samples treated only with surface sprinkling had better indicators than the samples with seeds soaked before planting. The results of determining selenium contents in the wheat of 2011 and wheat productivity are given in Table 5.

Table 5. Grain yields and selenium contents, 2011

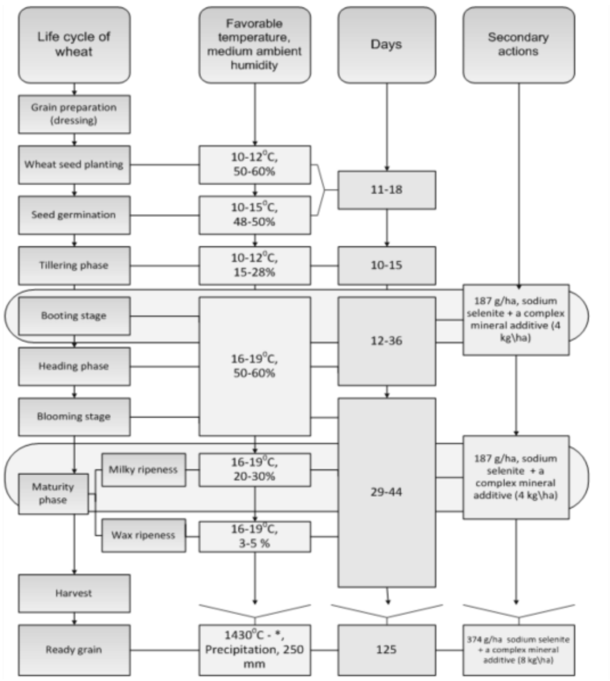
Sample no.	Amount of Na_2SeO_3, applied, g/ha	Application multiplicity, times	Amount of fertilizer applied, kg/ha	Amount of selenium in grain, mg/kg	Yields, t/ha
Sample no. 1	0	0	0	0.01 ± 0.015	2.69 ± 0.74
Sample no. 2*	0	0	0	0.015 ± 0.015	2.74 ± 0.248
Sample no. 3**	187	1	0	0.020 ± 0.024	2.76 ± 0.248
Sample no. 4*	187	1	0	0.037 ± 0.024	2.83 ± 0.496
Sample no. 5**	187	2	0	0.052 ± 0.049	2.76 ± 0.248
Sample no. 6	187	2	4	0.087 ± 0.024	2.90 ± 0.248
Sample no. 7	187	3	0	0.085 ± 0.024	2.6 ± 0.83

* seed from the 2010 crop grain, ** seed soaked in a sodium selenite solution before planting

It follows from the table data that the 2011 results on the whole confirm the data obtained in 2009–2010: the two-time treatment of wheat with sodium selenite in the amount of 187 g/ha leads to an in increase in productivity by 7–30%; moreover, the application of the Master Osobyi mineral additive helps increase the ability to accumulate selenium by more than 60%. Sample 7 decreased its productivity by 13%; we may assume that EA application in amounts of more than 500 g/ha even in series leads to the inhibition of plant development and the reduction of productivity.

The 2011 results also showed the inadvisability of using high-selenium seed for planting: the selenium content in grain grown from it was higher than in the control group but fairly low, 0.015 mg/kg (before planting, 0.030 mg/kg); we may assume that selenium was used during plant growth and development. Seed soaking in a sodium selenite solution before planting led to an insignificant increase of selenium in the finished grain.

Our research has shown that it is possible to grow high-selenium wheat in the conditions of the Kuznetsk Basin. The result of the 2009–2011 research was a technology of fortifying wheat with selenium, which is given in Fig. 2 and the main elements of which are the life cycle of plant growth and development, the most favorable meteorological conditions, and the phases of EA and fertilizer application. The novelty of the proposed high-selenium wheat method was confirmed by a Russian patent.



Note: * 1430°C is the sum of positive temperatures (above 5°C) during the vegetation period (75–110 days)

Fig. 2. Technology of enriching wheat with selenium.

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