THE PRODUCTIVITY FORMATION OF THE SPRING BARLEY VARIETIES UNDER THE EFFECT OF ABIOTIC STRESS AGAINST DIFFERENT MINERAL NUTRITION BACKGROUNDS AND THE SEEDS PRETREATMENT WITH BIOGENIC ELEMENTS

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Abstract

Obtaining stable yields of spring barley grain in conditions of global climate change is possible only with the use of highly resistant varieties that are responsive to the use of mineral fertilizers. Physiological and biochemical studies are necessary for an objective assessment of the varieties resistance to stresses, developing during the critical period of the generative organs forming, which leads to the yield shortage. These studies are also necessary for developing ways to increase productivity. The purpose of this work was to study the physiological and biochemical reactions of varieties to the effects of stress, changes in the background of mineral nutrition and the use of biogenic elements of selenium and silicon. Studies were performed during laboratory and vegetative experiments. The objects of the study were two varieties of spring barley: NurandMoskovsky2, which were different in initial resistance. Abiotic stress was modeled in laboratory experiments using an osmotic active solution of sucrose, as well as in vegetative experiments by stopping watering at the sixth stage of organogenesis (watering was resumed after reaching permanent wilting point). Different levels of mineral nutrition were created by adding salt when establishing vegetative experiment. There were two mineral nutrition backgrounds: background I – NPK(100mg/kg of soil) and background II – NPK(300 mg/kg of soil). These edspre treatment was carried out in the control with water, in experimental variants with solutions of sodium silicate (0.15%) and sodium selenite (0.01%), taken in equal proportions in the amount of 5% of the treated seeds weight. The complex of physiological and biochemical parameters was determined, including the level of
free-radical oxidation by the content of malondialdehyde, the content of photosynthetic pigments, the exosmos of leaf electrolytes, the absorbing activity of the roots by the ability to absorb thetagged nitrogen, the linear dimensions of the apex and its water content, water-holding capacity of the leaves. Studies revealed differences in the reaction of seedlings to stress. The growth function of the Moskovsky 2 variety was osmotically inhibited to a greater extent and the content of malondialdehyde increased, indicating a lower adaptability of the Moskovsky2 variety, compared to the Nur variety. It was revealed that the effectiveness of mineral fertilizers depends on the varietal specificity of barley, due to the genetic characteristics of plants, as well as on the level of mineral nutrition. Thus, a high level of mineral nutrition contributed to the rapid recovery of the physiological functions of the Nur variety after stress and did not affect the recovery of the Moskovsky 2 variety. It was also established that the seeds pretreatment with selenium and silicon increased the productivity of the varieties, both under optimal growing conditions and under the action of stress for both varieties. The obtained results also show that the physiological and biochemical parameters allow us to quickly and accurately determine the effect of stress on the plant. The obtained data can be used to optimize nutrition in the cultivation of the above-mentioned varieties without loss of yield under stress conditions.

**Keywords**: Spring barley, stress, productivity, nutrients

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**I. Introduction**

Global climate change and its impact on the environment is a major problem related to the country's food security. Since the 1990s, governments of different countries and scientists around the world have begun to pay great attention to climate change, sustainable development of ecosystems, their functioning and productivity. In modern climate scenarios, a high probability of negative consequences for grain production is forecasted [I-VIII]. Under these conditions, the variety acts as an independent factor in increasing productivity, which is of great importance along with the cultivation technology [IX-XI]. According to Zhuchenko [XII], in the XXI century, agricultural production should be based on new paradigms, one of which is the use of highly adaptable varieties with high potential that can be maximally realized in a wide range of soil and climatic conditions.

Modern agriculture is based on the effective use of soil-climatic and economic opportunities, choosing low-cost or innovative technologies. Accordingly, for each opportunity, it is necessary to select resistant varieties that are responsive to the appropriate conditions of mineral nutrition. One example of increasing the resistance of varieties can be the optimization of mineral nutrition with biogenic elements of selenium and silicon.

According to the classification of nutrients, selenium and silicon belong to useful elements. However, with the development of analytical and molecular methods of analysis, information about their active participation in metabolism is expanding.
The physiological need of plants in silicon has now been established. It was shown that it is not only a structural element of conductive and epithelial tissues, but it is also included in metabolic pathways, changing the expression of genes responsible for the synthesis of enzymes and silicon is a factor limiting mitotic processes [XIV-XVI]. The biochemical basis of silicon stress resistance is shown by Epstein E. [XVII]. A significant effect of silicon on yield growth and the development of plant resistance is reflected in the studies of many authors [XVII-XXVII].

Selenium is a useful element for plants, it is one of the vital elements for humans and animals. Today, selenium causes an increasing interest, due to the existence of vast territories with a lack of this element and a shortage of it among the population. Selenium is involved in enhancing the adaptive potential of plants, reducing oxidative stress and helping to reduce lipid peroxidation processes, it also has a stimulating effect on the growth and metabolism of plants [XXVIII-XXXIII].

In our earlier studies we discovered the positive role of the seeds pre-treatment with selenium and silicon for highly productive spring barley varieties, which are recommended for cultivation with intensive and innovative technologies [XXXIV, XXXV].

The aim of this work was to study the effect of abiotic stress, induced by drought, on the physiological and biochemical reactions of spring barley varieties that differ in productivity, and to determine the integrity of the use of selenium and silicon to improve drought resistance. In addition, the basic stability of the varieties seedlings was determined according to the content of the membrane oxidation products (meaning the prospective assessment of the varieties resistance according to this indicator).

II. Material and methods

Experiments were carried out with varieties of spring barley (*Hordeum vulgare* L.) Nur and Moskovsky 2.

In laboratory experiments, plants were grown in roll culture on an osmotic solution of sucrose (3.8 atm) in a heat chamber, maintaining a constant temperature and humidity.

Seed germination was determined according to GOST 12-38-84 in Petri dishes, by the method of Buchinger (modified by all-Russian research Institute of Agrochemistry) and by the ability of seeds to germinate on osmotic solutions.

Vegetative experiments were carried out in soil culture on sod-podzolic medium-loamy soil (Table 1).

Nutrients were introduced during the establishment of the experiments, creating two nutrition backgrounds: background I – 100 mg/kg of soil and background II – 300 mg/kg of soil. During the vegetation, an optimal level of water supply was maintained – 70% of the nutrients.
Before sowing, the seeds were treated with solutions of sodium silicate (0.15%) and sodium selenite (0.01%) in an equal ratio, in an amount of 5% of the treated seeds weight.

The soil was chalked according to the norm of \( \text{Н}_\text{г} \). The experiments were laid by the method of Zhurbitsky [XIII]. Abiotic stress was created at the sixth critical stage of organogenesis, determining the potential productivity of grain crops. The soil drought was modeled by stopping the irrigation, which was resumed when the moisture started to stabilize.

Table 1. Agrochemical characteristics of sod-podzolic medium-loamy soil

| humus, % (according to TyurinGOST 2621391) | \( \text{pH}_{\text{KCl}} \) (GOST 2648385) | \( \text{H}_\text{e} \) (GOST 2621291) | \( \text{S} \) (GOST 2782188) | \( \text{T} \) | \( \text{P}_2\text{O}_5 \) | \( \text{K}_2\text{O} \) | \( \text{Al}, \text{ mg/kg of arid soil} \) (according to Kirsanov), GOST 26207-91) | meq/100g of soil | \( \text{V}, \% \) |
|---|---|---|---|---|---|---|---|---|---|
| 2.1 | 4.5 | 4.2 | 12.0 | 13.2 | 74 | 93 | 82 | 10.0 |

In the experiments, the complex of physiological and biochemical parameters characterizing the nonspecific resistance of plants was determined, which consisted of the level of free-radical oxidation, the content of photosynthetic pigments and the intake of tagged nitrogen \((^{15}\text{N})\).

The absorptive capacity of the root system and the assimilation of incoming nitrogen \((^{15}\text{N})\) was determined by the isotopic indication method. To determine the activity of the plant root system before the end of stress, a small amount (15 mg/vessel) of nitrate nitrogen, which was highly enriched with stable isotope \(^{15}\text{N}\) (95AT%), in the form of Ca\((^{15}\text{NO}_3)_2\), was introduced with the irrigation. Then, after 8 hours, or a day, or 5 days, or 7 days, plant samples were taken and recorded. Samples were analyzed on a Delta V Advantage isotope mass spectrometer coupled with a Flash EA element analyzer with a two-reactor oxidation and deoxidation scheme. The method is based on the burning of the plant material according to Dumas in an oxygen stream of the oxidation reactor \((\text{Cr}_2\text{O}_3+\text{Co}_3\text{O}_4+\text{AgO})\) at a temperature of 1030°C, then deoxidizing nitrogen compounds to \(\text{N}_2\) in a reactor with pure granulated
deoxidated copper at 680°C, followed by atomization and fractionation of $^{14}N$ and $^{15}N$ atoms under the action of magnetic field. The formula for calculating the received nitrogen:

$$N = \frac{N_C (15N_{pi} - 0.365)}{15N_{c} - 0.365},$$  \hspace{1cm} (1)

where $N$ is the amount of nitrogen supplied during the short exposure period, mg/vessel; $N_C$ is the total amount of nitrogen at the end of exposure, mg/vessel; $^{15}N_{pi}$ - enrichment by $^{15}N$ atoms in a plant sample,%; $^{15}N_{c}$ - enrichment with $^{15}N$ atoms in the salt when added,%; 0.365 - natural enrichment with $^{15}N$ atoms,%.

Water status indicators were determined according to [XIV-XVII]. To calculate the photopotential, the assimilation surface of the plants was measured on the phytoplanimeter FPL-74.

The intensity of free-radical processes was determined by the content of the products from membranes lipid peroxidation, which react and give persistent staining with thiobarbituric acid (ТБК пр.). The main product of the lipid peroxidation is malondialdehyde. The thiobarbituric acid content was determined on the spectrophotometer Helios Omega UV-VIS.

The content of photosynthetic pigments, chlorophylls $a$, $b$ was determined in a 100% acetone extract by a spectrometric method. To assess the effect of stress, the level of mineral nutrition and biogenic elements of selenium and silicon, morphophysiological monitoring of the organogenesis stages onset was carried out, the linear dimensions of the cone growth of the main shoot in the V-VI stages of organogenesis were estimated, as well as the number of laid flowers, their reduction, productivity and structure.

The repetition of the experiment was fivefold. 20 plants were grown in the vessels. The data were processed mathematically.

### III. Results

Studies shown that the varieties differed in the content of malondialdehyde in the roots and the underground part of the seedlings, both under optimal growing conditions and when cultivated on an osmotic solution of sucrose. With minor differences in the linear sizes of the roots and seedlings grown on water, the malondialdehyde content in the roots of the Nur variety was 45% less than that of the Moskovsky 2 variety. The effect of osmotic stress led to an increase in the malondialdehyde content, indicating the development of oxidative stress, which was more pronounced for Moskovsky 2 variety. The differences between varieties in the degree of stress are more clearly manifested in the analysis of seedlings. Osmotic stress led to a threefold increase in the malondialdehyde content of Moskovsky 2 variety and to only 30% increase for the Nur variety (Figure 1).

In vegetative experiments, the varieties of barley differed in response to an increase in the background of mineral nutrition. In optimal growing conditions, in the
phase of shooting, the photosynthetic potential of the Nur variety increased by 20%, and of Moskovsky 2 by 14%. Under the action of drought, the duration of the assimilation surface functioning decreased in the Nur variety against the background II, and in Moskovsky 2 variety, on the contrary, it decreased against the background I (low nutrition availability). The exoosmos of electrolytes in the leaves, which characterizes the stability of the cell membranes in Moskovsky 2 variety, did not depend on the level of mineral nutrition, and was lower against the background II for Nur variety.

![Figure 1. The content of malondialdehyde in the seedlings of different barley varieties](image)

Varieties under optimal growing conditions differed in apex growth rate. Prior to the onset of drought, the apex length (Figure 2) of the Nur variety was 5.2 cm against the background I and 1.1 cm against the background II, as for the Moskovsky 2 variety, the differences in apex sizes were less, and amounted to 1.5 cm against the background I and 1.0 cm against the background II.
Figure 2. Linear dimensions of apex in barley varieties in optimal conditions and understress (drought).

The soil drought in the background I reduced the size of the apex in both varieties, due to a decrease in its water content. With a high nutrition supply, the development of apex was more intense in the Nur variety, the growth rate of apex during the drought was 0.082 relative units, but for Moskovsky 2 variety it was two times less (0.045 relative units). After earing, the length of the ear in the Nur variety was 7.3 cm against the background I and 8.4 cm against the background II, and the Moskovsky 2 variety’s ear was 5.5 cm against the background I and 4.0 cm against the background II (Figure 2).

In the vegetative experiment, the reaction of varieties to changes in the level of mineral nutrition was evaluated. The changes features in physiological parameters during the period of stress exposure and after its termination (during the recovery period) (Table 2) were established.

The magnitude of the photosynthetic potential, which characterizes the magnitude and duration of the assimilation surface activity, helped us to determine the reaction of varieties to stress in various mineral nutrition conditions. Under optimal water supply conditions, an increase in the level of mineral nutrition led to an increase in the photosynthetic potential of both varieties. Increasing soil drought negatively influenced the formation of the assimilation surface against both backgrounds. A significant decrease in the photosynthetic potential was observed in the Moskovsky 2 variety against a high NPK background. The Nur variety, on the contrary, showed the indicators depression against a low NPK background (Table 2).
Table 2. Indicators of the physiological state of barley varieties under the action of stress, depending on the availability of NPK

| Growing conditions | Nutrition level | Moskovsky 2 | Nur |
|--------------------|-----------------|-------------|-----|
|                    | photosynthetic potential, cm²/plant | exoosmos of the electrolytes, % of full exit | photosynthetic potential, cm²/plant | exoosmos of the electrolytes, % of the full exit |
| watering           | Backround I     | 765         | -   | 1194 | -   |
|                    | Backround II    | 825         | -   | 1440 | -   |
| stress             | Backround I     | 573         | 54.3| 622  | 50.5|
|                    | Backround II    | 187         | 55.0| 1320 | 39.9|

After stopping the watering, the water content of the second leaf, which was fully formed and was the nearest to the embryo stem on the sixth stage of organogenesis, gradually decreased in both varieties. Despite the decrease in the available moisture in the soil, the water content in the embryo stem decreased less than the moisture content of the leaf (Figure 3).

Restoration of water content after 6 days of the Nur variety recovery was more actively observed against the background II, while the basic mineral elements were very well supplied. The leaf and apex hydration of the Moskovsky 2 variety against the same background continued to decline.
Figure 3. The hydration of leaves and growth cone under the action of soil drought and during the period of recovery

The use of selenium and silicon contributed to an increase in the content of photosynthetic pigments in the leaves of the both studied varieties against the nutrition backgrounds I and II.

Table 3. Chlorophyll content in barley leaves before the end of stress, mg/g of wet weight

| Variety | Nutrition background | Seeds pretreatment with $\text{H}_2\text{O}$ | Seeds pretreatment with $\Sigma \text{Se} + \text{Si}$ |
|---------|----------------------|---------------------------------------------|--------------------------------------------------|
| Nur     | Background I         | $a$  $b$  $\Sigma a+b$  $a/b$              | $a$  $b$  $\Sigma a+b$  $a/b$                      |
|         |                      | 6.9  5.3  12.2  1.36                      | 10.4  7.5  17.9  1.15                           |

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With a higher content of photosynthetic pigments in the Nur variety against the background I, their number increased to a greater degree with increasing nutritional background, comparing to Moskovsky 2. The ratio of chlorophylls a to b depended on the varietal specificity. In variants without pretreatment, the chlorophylls ratio of the Nur variety was 1.3–1.36, and of Moskovsky 2, 1.43–1.46. When using selenium and silicon in a high nutritional background (background II), both varieties showed a decrease of this ratio value – 1.15 and 1.16.

Under optimal cultivation conditions, the Nur variety was distinguished by a more active uptake of tagged nitrogen and greater responsiveness to the raising nutritional background. The use of selenium and silicon increased the intake of tagged nitrogen and its inclusion in the proteins of the aerial mass. The amount of $^{15}\text{N}$ absorbed by the 7th day of exposure increased from 6.8 mg/vessel to 8.2 mg/vessel with the increase in the background of nutrition and pretreatment by selenium and silicon. The Moskovsky 2 variety absorbed 5 mg/day of $^{15}\text{N}$ by the same period and did not change this indicator with an increase in the nutrition background.

The use of selenium and silicon in the background II did not affect the absorptive capacity of the Moskovsky 2 variety. A similar pattern was also noted when evaluating the inclusion of $^{15}\text{N}$ in the proteins of the aboveground mass (Figures 4, 5).

The intensity determination of the tagged nitrogen entry into plants of both varieties after the end of stress exposure (drought) showed that the restoration of the absorptive capacity of the root system was more active against the background of mineral nutrition I in both varieties; seed treatment with selenium and silicon increased the intake of $^{15}\text{N}$ and its inclusion in aboveground proteins masses. However, in the Moskovsky 2 variety, the total amount of $^{15}\text{N}$, assimilated by proteins, was 2.5 mg/vessel in the control group and 3 mg/vessel in experimental group (using pretreatment by selenium and silicon) versus 2.2 mg/vessel and 3.9 mg/vessel in the Nur variety, respectively.
Figure 4. Assimilation and inclusion of $^{15}$N in proteins at the optimum and in the period of recovery of the Nur variety.

Figure 5. Assimilation and inclusion of $^{15}$N in proteins at the optimum and in the period of recovery of the Moskovsky 2 variety.

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Table 4. Productivity of barley varieties under the action of stress, depending on the seeds pretreatment $\Sigma$Se + Si, g/vessel

| Variant                | Seeds pretreatment | Moskovsky 2 | Nur  |
|-----------------------|-------------------|-------------|------|
|                       |                   | Optimum     | Stress | Optimum | Stress |
| Background I          | $H_2O$            | 6.3         | 4.3    | 10.2     | 6.1    |
|                       | $\Sigma$Se+Si     | 6.5         | 5.0    | 10.8     | 7.9    |
| Background II         | $H_2O$            | 6.8         | 4.3    | 17.5     | 11.6   |
|                       | $\Sigma$Se+Si     | 7.0         | 4.7    | 18.4     | 14.5   |

IV. Discussion

Estimation of the seedlings stability by the content of malondialdehyde is based on the information on the free-radical oxidation of polyunsaturated fatty acids in biological systems [37]. Ershova A.N. (2018) showed that the free active form of oxygen is always present in the plant body and performs important physiological functions. Metabolism and phytohormone synthesis depend on the production of free active oxygen, they induce the activity of genes involved in plant defense reactions. In normal conditions, the formation of free active oxygen is balanced by the irritation and does not lead to irreversible damage of the membranes. Malondialdehyde is the main product of lipid peroxidation, therefore the determination of its content in seedlings in the absence of stress may indicate the level of metabolism. An aqueous solution of sucrose induced oxidative stress in seedlings, due to a sharp accumulation of free active oxygen, which can prove the increase of malondialdehyde content (Figure 1).

Differences between the content of malondialdehyde in optimal conditions and under stress indicate a greater initial drought tolerance of the Nur variety. In the experiments, there was a different responsiveness of varieties to an increase in the level of mineral nutrition. In the Nur variety with optimal water supply conditions and under the action of drought, the photosynthetic potential increased, which indicates a greater resistance of its assimilation surface to dehydration. As for the Moskovsky 2 variety against the mineral nutrition background II, the drought led to a restriction of the growth activity of the leaf apparatus and a decrease in the time of its functioning. Consequently, in areas with unstable water supply with unfavorable forecasts, this variety is better cultivated with a moderate supply of mineral nutrition.

Under the action of increasing soil drought, there was an increase in water deficiency in the leaves, their water content decreased and the membrane permeability to electrolytes changed. The exoosmosis of electrolytes, or ion leakage and, as it has been established recently, the sum of inorganic ions, as well as organic matter is one of the earliest non-specific cell responses to adverse effects. It is often considered as the result of irreversible damage to the membranes, and accordingly, as
an indicator, which helps to assess the degree of the cell damage. However, when stress is weak, this effect is reversible and is not associated with cell death, but is aimed at reducing the intensity of physiological and biochemical processes, preserving the viability of the plant organism [XXXIX].

The result of the research shown that, when the permanent wilting point establishes, the membranes of the Nur variety are less damaged against the high background of mineral nutrition, which ensures the stability of cell membranes. In Moskovsky 2 variety, membrane damage was almost the same at both levels of mineral nutrition.

To assess the effect of stress at different levels of mineral nutrition, we evaluated the growth pattern of cones and their water content.

The ability of plants to grow constantly is associated with the functioning of the apical meristem of the root and stem, where the processes that determine the growth and morphogenesis of organs take place [XLI]. In addition, the apical meristems are the main sites for the synthesis of phytohormones such as cytokinin (root apical meristem) and auxin (shoot apical meristem) [XLII]. Meristematic cells are very sensitive to various types of stress, in particular, to high and low temperatures, drought, salinity, increased levels of radiation, and the effects of heavy metals: cadmium, lead and zinc [XLIII-XLVI].

Apex is a link in the system of donor-acceptor relations between the vegetative and generative zones of stem, and the constant change of attracting activity of various organs reflects the stages of the morphogenetic program of plant development. Assessment of varietal features of the cone growth development contributes to the establishment of the norm of the reaction of each variety, and hence to the strategy for implementing its genetic program in various environmental conditions.

It is assumed that the embryostem is an indicator of the adaptation reaction [XLVIII]. Under optimal water supply conditions, a high mineral background inhibits the growth of a cone in both varieties, however, due to drought, as a result of adaptive reactions in both varieties, the development of embryo stem continued against the background I of mineral nutrition in both varieties and the resistance of apexes to drought of the main shoot was lower.

The progressing soil drought reduced the water content of the leaves to a greater extent than the water content of the embryostem, which is a manifestation of the adaptive strategy of plants aimed at maintaining the viability of their generative organs. The availability of mineral nutrition determined the resistance of varieties to dehydration. The high nutritional background II was optimal for the Nur variety, so the stem hydration after 6 days of recovery was restored to the control level, while Moskovsky 2 variety had a similar pattern against the background I. Thus, it can be noted that the realization of the adaptive potential of the varieties depends on the conditions of mineral nutrition.
The seeds pretreatment with selenium and silicon increased the content of photosynthetic pigments (Table 3). The pigment system of plants is one of the first to respond to stress and determine the efficiency of photoassimilation [XLVII]. Changes in the content of photosynthetic pigments affect the activity of photosynthesis, the rate of the carbon dioxide absorption, the accumulation of assimilates and, ultimately, the productivity.

Barley varieties differed in response to changes in nutritional background and the seeds pretreatment. With a higher content of photosynthetic pigments in the Nur variety, their number with increasing availability of basic mineral elements grew to a greater extent in Moskovsky 2 variety. The use of selenium and silicon was effective in both varieties and contributed to an increase in the content of chlorophyll pigments compared to the untreated control group. A change in the ratio of chlorophylls $a/b$ on a high nutritional background under the action of drought indicates the development of an adaptive response, which is caused by an increase in the content of chlorophyll $b$, providing ontogenetic adaptation of plants [XLIX].

An assessment of the absorptive capacity of the root system of plants revealed both general and specific features of the intake of the tagged nitrogen into the ground organs of barley varieties and its inclusion in proteins. Under optimal cultivation conditions, the Nur variety is distinguished by a more active absorption and assimilative capacity of the root system, and greater responsiveness to increasing of the nutritional background.

The use of selenium and silicon increased not only the absorption of introduced tagged nitrogen, but also contributed to a more active inclusion of $^{15}$N in the proteins of the aerial part of plants (Figures 4, 5). In Moskovsky 2 variety, under optimal growing conditions, the absorption rate and further assimilation were less pronounced. The effectiveness of the seeds pretreatment was also less pronounced.

Progressive soil drought led to inhibition of $^{15}$N intake in plants of both varieties on the first day after tagging. Increased nutritional background also slowed down the activity of the absorptive capacity of the root system.

The seeds pretreatment with biogenic elements led to a more rapid recovery of the absorptive capacity of the root system after stress and contributed to accelerating the use of the supplied nitrogen for protein synthesis.

In addition, the seeds pretreatment selenium and silicon increased the productivity of varieties, both under optimal growing conditions and under stress (Table 4).

V. Conclusion

The carried-out research shown that the formation of productivity and the realization of the adaptive potential of spring barley varieties under conditions of progressive soil drought is determined by the provision of the basic mineral nutrition elements. In the Nur variety, against a high nutritional background, an increased resistance of the assimilation surface to dehydration was noted, the stability of cell...
membranes and the hydration of the embryostem under stress, as well as the rapid recovery of water stress during the recovery period were preserved to a greater degree. In Moskovsky2 variety, on the contrary, the average supply of NPK (background I) provided sustainable implementation of ontogenesis. Along with this, it is possible to note the same change of individual indicators in the studied varieties. On a high nutritional background, during the drought, the embryo stem continued to develop, and against a reduced background I, the apex growth stopped in both varieties.

Despite the noted features in the strategy of the productivity formation, the use of selenium and silicon in the form of the seeds pretreatment optimized adaptive reactions, increased the content of pigments, in particular chlorophyll $b$, which, along with the light-harvesting function, is a protector from photo-destruction. The seeds pretreatment with selenium and silicon contributed to reducing the negative impact of the water supply deficit on the absorption of nitrate nitrogen ($^{15}\text{N}$) and its inclusion in proteins, which reduced the productivity depression in both barley varieties.

References

I. 2009. Kyoto Protocol to the United Nations Framework Convention on Climate Change (Kioto, December 11, 1997). *Environmental Consulting*, 4: 29-41.

II. Kattsov V.M., Govorkova V.A. 2013. Expected changes in surface air temperature, precipitation and annual runoff on the territory of Russia in the 21st century: results of calculations using an ensemble of global climate models (CMIP5). Proceedings of the MGO, vol. 569, pp. 75-97.

III. 2014. The second assessment report on climate change in the territory of the Russian Federation. Moscow: Roshydromet, p.1008.

IV. Shi S.B., Ben G.Y, Zhao X.Q., Han F. 2001. Effects of supplementary UV-B radiation on net photosynthetic rate in the alpine plant. *ActaPhytoecol.*, 25: 520-524.

V. DiffenbaughN.S., Field C.B. 2013. Changes in ecologically critical terrestrial climate conditions. *Science*, 341: 486-492.

VI. Pavlova V.N., Varcheva S.E. 2017. Assessment of climatic risks of yield losses in regional farming systems. *Fundamental and applied climatology*, 3: 122-132.

VII. Pavlova V.N. 2010. Analysis and assessment of the impact of climatic conditions of the last decades on the yield of grain crops in the agricultural zone of Russia. The collection: Problems of ecological monitoring and modeling of ecosystems, vol. XXIII, pp. 215-230, Moscow.
VIII. Gordeev A.V., Kleschenko A.D., Chernyakov B.A., Sirotenko O.D. 2006. Bioclimatic potential of Russia: theory and practice. Moscow: Limited Liability Company Scientific Publications Association KMK, p. 512.

IX. Glukhovtsev V.V., Tsarevsky S.Y. 2012. The value of spring barley varieties with energy-efficient cultivation technologies (crop testing in the cultivation of the minimum tillage and application of mineral fertilizers on the planned yield). Reports of the RAAS, 4: 3-6.

X. Goncharenko A. A. 2016. Ecological stability of the grain crops varieties and the task of selection. Grain economy of Russia, 3: 31-36.

XI. Sapega V.A., Tursumbekova G.S. 2016. The yield of mid-ripening varieties of spring wheat and the parameters of their adaptability in different natural and climatic zones of the northern Trans-Urals. Successes of modern natural science, 11-1: 65-69.

XII. Zhuchenko A. A. 2005. Adaptive potential of cultivated plants (ecological and genetic basis). Anniversary Session of the RAAS dedicated to the 75th anniversary of its formation "The role and place of agricultural science in the agro-industrial complex of Russia", Moscow, June 23, 2004 and scientific session of the RAAS “Genetic resources and biotechnology”. Moscow and St. Petersburg, June 24-25. Moscow, pp. 134-140.

XIII. Bityutsky N.P. 2014. Mineral nutrition of plants. St. Petersburg State University, p. 548.

XIV. Law C., Exley C. 2011. New insight into silica deposition in horsetail (Equisetum arvense). Plant Biol., 11, p. 112.

XV. Ma J. F., Yamaji N., Mitani-Ueno N. 2011. Transport of silicon from roots to panicles in plants. Jpn Acad, Ser B, Vol. 87: 377-385.

XVI. Ma J.F., Yamaji N, Tamai K, Mitani N. 2007. Genotypic difference in Si uptake and expression of Si transporter genes in rice. Plant Physiol., Vol. 145: 919-924.

XVII. Epstein E. 1994. The anomaly of silicon in plant biology. Proc. Natl. Acad. Sci. USA, Vol. 91: 11-17.

XVIII. Gong H.J., Chen K.M., Zhao Z.G., Chen G.C., Zhou W.J. 2008. Effects of silicon on defense of wheat against oxidative stress under drought at different developmental stages. Biologia Plantarum, 52(3): 592-596.

XIX. Tale Ahmad S., Haddad R. 2011. Study of silicon effects on antioxidant enzyme activities and osmotic adjustment of wheat under drought stress. Czech. J. Genet. Plant Breed, 47(1): 17-27.

XX. Kolesnikov M.P. 2001. Silicon forms in plants. Advances in biological chemistry, 41: 301-322.
XXI. Kulikova A.K., Yashin E.A., Smyvalov V.S. 2013. The effectiveness of silicon-containing drugs in the protection of barley crops and obtaining environmentally safe products. *Vestnik of Ulyanovsk state agricultural academy, 4*(24): 17-24.

XXII. Matychenkov V.V. 2008. The role of mobile silicon compounds in plants and in the soil-growing system. Author. Dissertation for Dr. of Biol. Sciences: 03.00.12, 03.00.27. Pushchino, p. 34.

XXIII. Nikiforova S.A. 2009. The effectiveness of pretreatment of barley seeds with biologics and diatomaceous powder in the conditions of the Middle Volga region. Dissertation for the Candidate of Agro. Sciences: 06.01.04. Saransk, p. 18.

XXIV. Pashkevich E.B., Kiryushin E.P. 2008. The role of silicon in plant nutrition and in protecting crops from phytopathogens. *Problems of agrochemistry and ecology, 2*: 52-57.

XXV. Samsonov N.E. 2005. The role of silicon in the formation of phosphate regime of sod-podzolic soils. *Agrochemistry, 8*: 11-18.

XXVI. Slastya I.V. 1997. Agri-environmental aspects of the use of silicon compounds in the protection of barley and fodder beet. Dissertation for the Candidate of Agro. Sciences: 06.01.15. Moscow, p. 60.

XXVII. Shmakova N.V. 2003. The effectiveness of silicon compounds and their mixtures with fungicides on spring wheat in the Middle Urals. Dissertation for the Candidate of Agro. Sciences: 06.01.11, Moscow, p. 18.

XXVIII. Vikhreva A.A., Blinoforov A.A., Kleimenova T.V. 2012. Selenium in plant life: monograph. Penza: RIO PGSHA, p. 222.

XXIX. Nikonov I.N., Ivanov L.I., Kovalenko L.V., Folmanis G.E. 2009. The influence of nanoscale selenium on the growth of agriculturally significant crops. *Prospective materials, 4*: 54–57.

XXX. Davydova O.E., Velitsky V.A., Yarovskiy P.P. Physiological, biochemical and stress-protective functions of selenium in plants. *Physiology and biochemistry of cultural plants, 41*(2): 109-123.

XXXI. Baraboy V.A., Shostakova E.N. 2004. Selenium: biological role and antioxidant activity. *Ukrainian Journal of Biochemistry, 76*(1): 1-4.

XXXII. Golubkina N.A., Papazyan T.T. 2006. Selenium in nutrition: plants, animals, people. Moscow: Pechatniygorod, p. 254.

XXXIII. Kong L.G., Wang M., Bi D. 2005. Selenium modulates the activities of antioxidant enzymes, osmotic homeostasis and promotes the growth of sorrel seedlings under salt stress. *Plant Growth Regulation, 45*(2): 155-163.
XXXIV. Osipova L.V., Kurnosova T.L., Bykovskaya I.A. 2016. Increasing the adaptive potential of spring barley (*hordeum vulgare l.*) under the action of abiotic stress. *Problems of agrochemistry and ecology*, 3: 48-51.

XXXV. Osipova L.V., Nilovskaya N.T., Kurnosova T.L., Bykovskaya I.A. 2015. Influence of abiotic stresses on spring barley plants during pretreatment of seeds with selenium and silicon. *Agrochemistry*, 9: 54-60.

XXXVI. Zurbitsky Z.I. 1968. Theory and practice of the vegetative method. Moscow: Nauka, p.266.

XXXVII. Merzlyak N.M. 1999. Activated oxygen and plant vital activity. *Sorovskiy educational journal*, 9: 21-25.

XXXVIII. Ershova A.N., Berdnikova O.S., Chebotova L.V. 2018. Succinate dehydrogenase and free radical processes in the mitochondria of maize plants under the action of hypoxia and CO2 environment. Bulletin of Voronezh State University, Series: Chemistry. Biology. Pharmacy, 3: 186-192. Tarchevskiy I.A. 2001. Metabolism of plants under stress. Kazan. Fan., p. 447.

XXXIX. Melekhov E.I. 1985. The regulation principle of the cell damage process rate and the reaction of protective inhibition of metabolism (RZTM). *Journal of general biology*, 46(2): 174-189.

XL. Pahomova V.M. 1995. The main provisions of the modern theory of stress and nonspecific adaptation syndrome in plants. *Tsitologiya*, 37(1/2): 66-91.

XLI. Zubov D.A. 2016. Stem cells of plants and animals: two sides of the same coin. Part I. *Genes & Cells*, XI(3): 14-22.

XLII. Polevoy V.V., Salamatova T.S. 1991. Physiology of plant growth and development: study guide. Leningrad: LSU publishing, p. 239.

XLIII. Dovgalyuk A.I., Kalinyak T.B., Blume Y.B. 2001. Cytogenetic effects of salts of toxic metals in the cells of the apical meristem of the roots of *Allium cepa* L. seedlings. *Cytology and Genetics*, 35(2): 3-10.

XLIV. Kravets E.A., Mikhheev A.N., Ovsyannikova L.G., Grodzinsky D.M. 2011. Critical level of radiation damage to the apical meristem of the root and the mechanisms of its recovery in *Pisum sativum*. *Cytology and Genetics*, 1: 24-34.

XLV. Feller U., Anders I., Wei S. 2015. Effects of PEG-induced water deficit in *Solanum nigrum* on Zn and Ni uptake and translocation in split root systems. *Plants*, 4: 284-297. doi:10.3390/plants4020284

XLVI. Kaznina N.M., Laidinen G.F., Titov A.F. 2006. Influence of cadmium on the apical meristems of the stem of barley plants. *Ontogenesis*, 37(6): 444-448.

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XLVII. Popova I.A., Maslova T.G., PopovaO.F. 1989. Features of the pigment apparatus of plants of different botanical and geographical zones. Ecological and physiological studies of photosynthesis and respiration of plants. Leningrad: Nauka, pp.115-130.

XLVIII. Udovenko G.V., Goncharova E.A. 1993. Physiological and genetic mechanisms of plant adaptation to abiotic stresses. The collection: The species and their productivity in the area. UNESCO program "Man and the Biosphere", p. 339-340.

XLIX. Tyutereva E.V., Ivanova A.N., Voitsekhovskaya O.V. 2014. The role of chlorophyll b in plant ontogenetic adaptations. Advances in modern biology, 134(3): 249-256.