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## Morphophysical reaction of *Hordeum vulgare* to the influence of microbial preparations

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Bacterial preparations contribute to the digestion of mineral nutrition, have antifungal activity, increase the grain productivity and biomass of cultivated crops. We studied the influence of microbiological preparations developed on the basis of microorganisms *Bacillus subtilis* and *Lactobacillus buchneri* on the growth processes, photosynthetic parameters and grain productivity of barley (*Hordeum vulgare* L.) of Sonet variety. The experiments were performed in 2019 in the North-West of the Russian Federation. The biological preparations were introduced by soaking seeds and treatment of the plants in the phase of third leaf with solutions of the preparations in the concentration of 1 mL/L. The laboratory surveys revealed the positive effect of the biological preparations on germination rate and energy of germination of seeds. Field trials were conducted on micro plots in six replications. During field experiments, we determined that introduction of biological preparations led to significant increase in the leaf area in the experimental plants (to 64.5%), increase in average daily growth gains (to 82.9%) and accumulation of biomass (to 73.1%). Somewhat higher efficiency was exerted by the biological preparation developed on the basis of a strain of *L. buchneri*. Perhaps, such effect takes place due to higher activity of pigment units of phytohormones of the auxin group. In our opinion, biological preparations accelerate the completion of the ontogenesis phases, thus the plants more rapidly achieve their genetically programmed sizes and transform to the stage of ear-formation. The studied biological preparations increased the coefficient of agricultural use of plants, and grain productivity of barley by up to 15.8%, and nutritional value remained. Microbial preparations on the basis of *B. subtilis* and *L. buchneri* exhibited efficiency, and their trials shall be continued on other crops on industrial scales.

**Keywords:** *Bacillus subtilis*; *Lactobacillus buchneri*; barley; morphological parameters; photosynthesis parameters; grain productivity.

### Introduction

Traditional agriculture, according to a number of authors (Lugtenberg & Kamilova, 2009; Porcel et al., 2014; Chebotar’ et al., 2016), has run its course; maximum parameters of productivity of particular varieties of plants and breeds of animals have been achieved, soils are exhausted, groundwater and surface waters are more and more saturated with various chemical agents, pests develop resistance to fungicides, pesticides, etc. (Tsavkelova et al., 2006; Pérez-Montaña et al., 2014; Moya et al., 2020). At the same time, lack of resources and pursuit of profits stimulate the scientific search for cheap and intense methods of agricultural production.

Currently, in the scientific community, talks about the necessity of transformation of agriculture along ecologically orientated lines can be heard more and more often (Montesinos et al., 2002; Vorobejkov et al., 2011; Novickij & Gniteckij, 2012). Particularly the studies on physiology and biochemistry of plants, genetics, microbiology and biotechnologies could be the main mechanisms of such transformation: there more appropriate varieties of plants, strains of primary producer microorganisms and pathogen-antagonist microorganisms are being selected, biological additives are synthesized, etc. (Höflich et al., 1995; Barber et al., 2017; Ge et al., 2017). At the same time, representatives of only one genus of bacteria are able to solve a broad range of tasks of modern science and production. For example, representatives of the *Bacillus* genus can stimulate the growth and development of plants and improve the immunity of plants due to synthesis of lipoproteins and substances of hormonal origin (Porcel et al., 2014; Maksimov et al., 2020). However, the microbiome is extremely diverse (Vasil’yeva et al., 2019), thus leading to a necessity for scien-

tists to continuously search for and study various strains most appropriate for particular goals of agriculture.

Unfortunately, the experience and achievements of the world’s leading scientists are way ahead of Russian science. Our country evidently has a notable deficiency in variety of biological preparations, and great differences in the natural and climatic conditions of the territories require a broad assortment of these preparations. Therefore, Ryabova (2016), in her analysis of the market, notes that in the Russian Federation as of 2015, there were officially registered around thirty microbiological fertilizers and twenty biological pesticides compared to hundreds of names of chemical fertilizers and preparations for the protection of plants (Ryabova, 2016). As of 2018, the situation had changed insignificantly, with 51 biopesticides and 25 growth regulators for plants officially registered and approved for use (Gosudarstvennyj catalog . . . , 2018). At the same time, in the USA as of 2010, the number of trademarks of biopesticides alone, not taking into account microbial fertilizers, amounted to over several hundred, and about 72 microorganisms were recorded as active agents of biological protection of plants (Ryabova, 2016). Biological preparations are broadly used in many countries of Europe, including Switzerland, Austria, Czech Republic and Finland, and also USA, China, Japan and others. Some farms in Western Europe have completely abandoned mineral nitrogenous fertilizers in favour of biological nitrogen (Montesinos et al., 2002; Novickij & Gniteckij, 2012).

It should be noted that most of the studies emphasize the effectiveness of the application of different microbiological preparations during growing agricultural crops (Jeon et al., 2003; Nuccio et al., 2013; Chebotar’ et al., 2016). Therefore, the studies by Bezgodova et al. (2018) revealed that the

tests of the Flavobacterin preparation (developed on the basis of strain *Flavobacterium* sp. 30) showed increase in the yield of barley by 9.8%, mass of 1,000 grains by 5.8%, and the content of protein by 15.8% (Bezgodova et al., 2018). Bondarenko & Zvolinskij (2012) showed the increase in the yield of barley by 6.1% from using *Flavobacterin*, by 9.2% from Mizorin (preparation is based on strain *Arthrobacter mysorens* 8) (Bondarenko & Zvolinskij, 2012). The studies by Novickij (2012), who studied the action of Baikal EM-1 preparation towards cultivated barley, showed increase the mass of 1,000 caryopses by 15.9% and the content of protein by 2.0% (Novickij & Gniteckij, 2012). Chebotar' et al. (2016) report positive influence of strains *Bacillus subtilis* TR6 and *B. subtilis* HC8 on the yield of barley (increase by 17.6% and 14.8% respectively) (Chebotar' et al., 2016). The study by Kunicyna & Stupina (2018) showed efficiency of using *Klebsiella mobilis*- and *Corynebacterium freneyi*-based biological preparations which increase the yield of barley by 18.5% and 27.0%, and the mass of 1,000 caryopses by 8.8% and 11.7% respectively (Kunicyna & Stupina, 2018).

Many researchers report that a significant contribution to efficient interaction of cultivated plants and microbiological strain is made by abiotic conditions of particular regions (temperature, moisture) and competition of soil microbiota (Vorobejkov et al., 2011; Ryabova, 2016; Chebotar' et al., 2016). Therefore, the search and composing of pairs of crop variety-strain of microorganism for particular territories are relevant. The objective of the study was the action of preparations of microbial composition on morphological and physiological characteristics of barley of Sonet variety.

## Materials and methods

The experiments were conducted in the experimental field of VolRC RAS Vologda Research Center of the Russian Academy of Sciences in the vegetation period of 2019.

As the object of study, we selected barley (*Hordeum vulgare* L.) of Sonet variety, a variety cultivated in the conditions of the North-West of Russia. As a microbiological preparation, we selected Naturost and Naturost-Aktiv which were developed on the basis of associative microflora of plants. The basis for Naturost preparation is cellular culture *B. subtilis*, and Naturost-Aktiv – *L. buchneri*. The manufacturer Biotrof claims that both biological preparations protect plants against pathogenic microorganisms, and contribute to the intensification of growth and the development of plants in the field and greenhouses. The seeds of the experimental groups were soaked in the working solutions of the preparations for 2 hours, and seeds of the control group in water. The concentration of the working solution was 1 mL of the preparation per 1 L of water. Apart from inoculation, we sprayed plants with working solutions of the same concentration according to the recommendations (into the phase of the third leaf).

The germination rate of seeds was assessed on light shelves at room temperature. In Petri dishes, 30 seeds were placed on each piece of filter paper. The experiment was replicated three times. The effect of the preparations on the germinated seeds was evaluated on the 4th and 7th day (GOAT 12038-84).

The micro plot field experiment was performed in the experimental field and included the following variants: processing with water (variant 1, control), processing with preparations Naturost (variant 2) and Naturost-Aktiv (variant 3). The experiment was replicated 6 times, the area of the record plot was 1 m<sup>2</sup>. The seeds were sown according to the approved norms for sowing barley – 5.0 M seeds per 1 ha. The crops were maintained according to the generally accepted agrotechnical techniques. No mineral fertilizers were applied.

Before the study of the action of the preparations, we performed the analysis of the plough soil horizon. Soil in the experimental field was dried, soddy-podzolic, medium loamy. The results of the chemical analysis of the soil (Table 1) reveal relatively low content of biogenic elements. Taking into account the objective of our study, low-fertile soils allow one to evaluate the effect of particularly microorganisms on the growth and the development of plants.

During the vegetation period, we monitored: humid and dry weight of one plant; height of plant; leaf area; general and productive tillering; average daily increments (30 plants); determining pure productivity of photosynthesis (according to Nichiporovich); the structure of the yield: produc-

tive tillering, sizes of the ear, mass and amount of caryopses, mass of grains from one plant (20 plants from each plot), mass of grains from m<sup>2</sup>.

**Table 1**

Chemical composition of soil of the experimental plots

Parameter	Value
Ammoniacal nitrogen, mg/kg	4.2 ± 0.6
Nitric nitrogen, mg/kg	38.9 ± 7.8
Mobile potassium, mg/kg	261.0 ± 39.2
Mobile phosphorus, mg/kg	260.0 ± 52.0
pH salt extract, U of pH	6.6 ± 0.1

Note: developed according to the results of chemical analysis of Vologodskiy Federal Budget Center of Agrochemical Service.

The distribution of the main parameters of the value of forage crops (sugar, protein, etc.) in the biomass of the studied plants was performed on SpectraStar 2200 IR-analyzer (UnityScientific, USA). The content of pigments was determined using SF-2000 spectrophotometer (LOMO, Russia), the pigments were extracted using three-fold extraction in 80% acetone, calculation – using Vernon equations. The substances were identified in five-fold biological replication.

The experimental data obtained during the surveys were analyzed, recorded in the field journal, and also electronic carriers. The data in the tables are presented as average values and their standard errors ( $\bar{x} \pm SD$ ). Statistical reliability of the obtained values was determined according to ANOVA data at the significance level of  $P < 0.05$ .

## Results

Data in Table 2 indicate that biological preparations stimulate the processes of germination of seeds, at the same time the length of both the underground and above-ground part of the shoot increases, and their ratio in general remains the same (0.65–0.73). Thus, under the influence of the *B. subtilis*-based biological preparation, the energy of germination of seeds increased by 8.3%, germination rate by 6.7%, length of the above-ground part of the shoot increased by 6.1%, while the same parameter for the roots decreased by 4.7% compared with the control. The effect of *L. buchneri*-based biological preparation was similar: energy of sprouting increased by 11.6% compared with the control, germination by 3.3%, the length of above-ground part of the shoot by 18.3%, and the length of roots by 7.5%. The obtained results of the laboratory experiment allow one to expect the manifestation of a stimulating effect from the preparations on the biological and economic productivity of barley in the field experiment.

Despite the fact that barley is considered an undemanding plant both in terms of temperature regime and soil moisture, the weather conditions of the vegetation period of 2019 were insufficiently favourable for its cultivation in the territory of the study. Average temperature of June in 2019 equaled 21.0 °C, July – 18.0 °C, August – 16.0 °C. But the strongest influence was caused by the drought after the sowing, significantly increasing the period before the sprouts appeared, and also decreasing the vitality of microorganisms of the biological preparations.

The results of the micro plot field experiment (Table 3) indicate that in the phase of the third leaf, the effect caused by the preparations was insignificant, with only a tendency towards increase in the growth parameters seen. Raw mass of the experimental plants increased by 5.6% and 10.0% compared with the control, and the leaf area – by 9.1% and 13.2%.

The data in Table 3 suggest that morphometric parameters of the experimental plants significantly differ from the control plants. Therefore, in the tillering phase, the raw mass of the experimental plants exceeded the control variant by 36.4–38.5%, dry mass – by 29.2–42.7%, and the leaf area – by 52.2–64.5%. The observed effect occurs due to increase in the quantity of leaves (by 27.5–37.3%), as well as increase in the area of one leaf (by 17.1–23.5%). In the phase of booting, the increase in the growth parameters of the experimental plants became even more notable. Therefore, the height of the experimental plants was greater than the control by 21.0–24.0%, the quantity of leaves – by 55.4–58.7%, raw mass – by 54.1–54.9%, dry weight – by 64.6–73.1%. Similar change in the morphometric parameters obviously reflects in the change in physiological and biochemical processes in the plants.

**Table 2**Energy of germination and germination rate of seeds of *Hordeum vulgare* L. during inoculation of the preparations of microbial composition ( $\bar{x} \pm SD$ ,  $n = 3$ )

Variant of experiment	Energy of germination, %	Germination rate, %	Length of coleoptiles, mm	Length of roots, mm	Ratio of the length of coleoptiles to roots
Control	26.7 ± 2.1	70.0 ± 3.7	36.7 ± 2.2	55.9 ± 1.6	0.657
Naturost ( <i>Bacillus subtilis</i> )	35.0 ± 1.4*	76.7 ± 2.7*	39.0 ± 0.9	53.3 ± 0.8	0.732
Naturost-Aktiv ( <i>Lactobacillus buchneri</i> )	38.3 ± 1.4*	73.3 ± 2.1	43.4 ± 0.5*	60.1 ± 0.3*	0.723

Note: \* – difference compared with the control is statistically significant at  $P < 0.05$ .**Table 3**Morphometric parameters of *Hordeum vulgare* L. over the process of ontogenesis ( $\bar{x} \pm SD$ ,  $n = 30$ )

Parameter	Phase of the development of plant	Control	Naturost ( <i>Bacillus subtilis</i> )	Naturost-Aktiv ( <i>Lactobacillus buchneri</i> )
Raw weight of one plant, g		0.249 ± 0.020	0.274 ± 0.022	0.263 ± 0.023
Dry weight of one plant, g		0.051 ± 0.003	0.056 ± 0.004	0.053 ± 0.005
Share of dry matter, %	Phase of the third leaf	20.50 ± 0.34	20.33 ± 0.69	20.05 ± 0.17
Leaf area of one plant, cm <sup>2</sup>		5.47 ± 0.75	5.97 ± 0.85	6.19 ± 0.38
Number of leaves		2.1 ± 0.3	2.1 ± 0.3	2.0 ± 0.1
Average leaf area, cm <sup>2</sup>		2.63 ± 0.26	2.88 ± 0.12	3.05 ± 0.11*
Raw weight of one plant, g		0.814 ± 0.100	1.110 ± 0.171*	1.127 ± 0.118*
Dry weight of one plant, g		0.178 ± 0.030	0.230 ± 0.030*	0.254 ± 0.044*
Share of dry matter, %	Phase of beginning of tillering	21.77 ± 0.99	20.80 ± 0.73	22.33 ± 1.02
Tillering		2.0 ± 0.2	2.4 ± 0.2	2.3 ± 0.1
Number of leaves		5.1 ± 0.1	6.5 ± 0.4*	7.0 ± 0.4*
Average leaf area, sq cm		2.60 ± 0.12	3.05 ± 0.12*	3.21 ± 0.27**
Leaf area of one plant, cm <sup>2</sup>		13.51 ± 1.86	20.56 ± 2.63*	22.23 ± 1.04**
Pure productivity of photosynthesis, g/m <sup>2</sup> of the leaf area per day		11.11	10.98	11.81
Raw weight of one plant, g		3.560 ± 0.855	5.513 ± 1.039**	5.486 ± 1.184**
Dry weight of one plant, g		0.964 ± 0.045	1.669 ± 0.072***	1.587 ± 0.081***
Share of dry matter, %	Phase of the beginning of booting	28.31 ± 2.24	29.52 ± 0.63	29.09 ± 1.12
Tillering		4.0 ± 0.5	5.8 ± 1.0	5.8 ± 1.1
Productive tillering		1.8 ± 0.3	2.3 ± 0.4	2.5 ± 0.4
Number of leaves		12.1 ± 2.7	19.2 ± 3.0*	18.8 ± 3.2*

Note: \* – difference compared with the control is statistically significant at  $P < 0.05$ , \*\* –  $P < 0.01$ , \*\*\* –  $P < 0.001$ .

The values of average daily increments (Table 4) confirm the stimulating action of the biopreparations. The most intensive increment over the tillering phase was caused by Naturost-Aktiv preparation, when the values of average daily increment exceeded the control by 60.0%, and in the booting phase – by Naturost, when the values of average daily increment were higher than the control by 82.9%.

**Table 4**Average daily increments of *Hordeum vulgare* L. ( $\bar{x} \pm SD$ ,  $n = 30$ )

Parameter	Time interval	Control	Naturost ( <i>Bacillus subtilis</i> )	Naturost-Aktiv ( <i>Lactobacillus buchneri</i> )
Average daily increment of raw mass, mg/day	phase of the third leaf – phase of beginning of tillering	47.1 ± 3.8	69.7 ± 6.0*	72.0 ± 5.4**
Average daily increment of dry mass, mg/day		10.5 ± 1.1	14.6 ± 1.6*	16.8 ± 1.6**
Average daily increment of raw mass, mg/day	Phase of tillering – phase of beginning of booting	97.2 ± 8.4	159.7 ± 12.1**	161.3 ± 10.2***
Average daily increment of dry mass, mg/day		28.1 ± 2.1	51.4 ± 4.0***	47.6 ± 3.2***

Note: \* – difference compared with the control is statistically significant at  $P < 0.05$ , \*\* –  $P < 0.01$ , \*\*\* –  $P < 0.001$ .

In view of the significant differences in the morphometric parameters and the values of average daily increments in the plants, pure productivity of photosynthesis (PPP) [the amount of dry matter expressed in grams accumulated in the 1 m<sup>2</sup> of the leaf surface per day] of the experimental variants insignificantly differed from the control (Table 3): pure productivity of photosynthesis of plants treated with *B. subtilis*-based biological preparation was lower than the control values by 0.126 g/m<sup>2</sup>; and under the effect of the *L. buchneri*-based biological preparation was higher by 0.700 g/m<sup>2</sup>. The values of PPP shows how many grams of the matter forms from 1 m<sup>2</sup> of the leaf surface per unit time, and therefore the obtained results of PPP indicate that in the experimental plants, the accumulation of dry matter proportionally increases with increase in the area of the leaf surface. An important indicator of photosynthetic activity is the content of pigments. The obtained data (Table 5) demonstrate absence of sig-

nificant differences in the content of chlorophyll between the experimental and control plants. Presumably: first, despite the increase in the growth parameters of the experimental plants, the “effect of dilution of chlorophyll” does not take place, i.e. the density of pigments remains on each unit of the area of plants, and, secondly, each pigmentary system works more intensively, leading to increase in the morphometric parameters.

**Table 5**Content of chlorophyll in the biomaterial of *Hordeum vulgare* L. ( $\bar{x} \pm D$ ,  $n = 5$ )

Parameter	Phase of the development of plant	Control	Naturost ( <i>Bacillus subtilis</i> )	Naturost-Aktiv ( <i>Lactobacillus buchneri</i> )
Chlorophyll <i>a</i> , mg/g of dry weight		3.68 ± 0.34	3.69 ± 0.31	3.70 ± 0.16
Chlorophyll <i>b</i> , mg/g of dry weight	Phase of the third leaf	5.75 ± 0.77	5.31 ± 0.50	5.48 ± 0.46
Total of chlorophylls <i>a</i> and <i>b</i> , mg/g of dry weight		8.00 ± 1.12	7.83 ± 0.82	7.83 ± 0.30
Chlorophyll <i>a</i> , mg/g of dry weight		1.96 ± 0.06	2.02 ± 0.03	1.93 ± 0.01
Chlorophyll <i>b</i> , mg/g of dry weight	Phase of tillering	4.43 ± 0.11	4.13 ± 0.30	4.76 ± 0.18*
Total of chlorophylls <i>a</i> and <i>b</i> , mg/g of dry weight		6.40 ± 0.05	6.16 ± 0.34	6.68 ± 0.19*

Note: \* – difference compared with the control is statistically significant at  $P < 0.05$ .

Analysis of the productivity of barley (Table 6) reveals the absence of reliable differences in the morphometric parameters of straw of the experimental and control plants. However, in general, the seed productivity of the barley plants after treatment with the biological preparations increased by 8.5–15.8%. This occurs as a result of increase in the mass of separate caryopsis and increase in the productivity of tillering. The content of nutrients in the biomaterial of the experimental and control plants significantly did not differ. Therefore, the content of digested protein in absolutely dry matter accounted for 103.7–105.5 g/kg, the content of total protein equaled 14.82–15.7%, content of cellulose – 6.67–7.32%, content of sugars – 5.41–6.31% of the dry weight.

**Table 6**  
Economic productivity of *Hordeum vulgare* L. ( $x \pm SD$ ,  $n = 20$ ,  $^{(a)} - n = 6$ )

Parameter	Control	Naturost ( <i>Bacillus subtilis</i> )	Naturost-Aktiv ( <i>Lactobacillus buchneri</i> )
Weight of one plant, g	4.84 ± 0.40	4.98 ± 0.49	5.17 ± 0.54
Weight of straw of one plant, g	2.79 ± 0.27	2.74 ± 0.35	2.79 ± 0.38
Weight of grains from one plant, g	2.051 ± 0.058	2.227 ± 0.100*	2.376 ± 0.178*
Productive tillering	3.9 ± 0.9	4.2 ± 0.6	4.3 ± 0.6
Height of one plant, cm	48.6 ± 4.5	49.0 ± 3.7	47.7 ± 4.2
Number of caryopses in the ear	14.0 ± 2.0	14.3 ± 1.9	13.8 ± 1.9
Weight of 1,000 caryopses, g <sup>(a)</sup>	40.74 ± 0.84	42.59 ± 1.90	41.45 ± 1.32
Weight of grain from m <sup>2</sup> , g <sup>(a)</sup>	278.14 ± 14.00	315.18 ± 18.26*	319.37 ± 20.65*
Coefficient of economic use	0.423	0.447	0.460

Note: \* – difference compared with the control is statistically significant at  $P < 0.05$ .

## Discussion

The morphologic parameters of the plants are due to the rates of their physiological processes. Many researchers report various mechanisms of action of microbiological preparations towards growth and the development of plants, including synthesis and complex interaction of phytohormones (Höflich et al., 1994; Vasil'yeva et al., 2019; Moya et al., 2020), mobilization of the substances (Shuliko et al., 2019), inhibition of pathogens as a result of synthesis of antibiotics, toxins and surfactants, and also the development of competition for the nutrients and place of colony of pathogenic bacteria (Veselova et al., 2019; Maksimov et al., 2020; Sabaté et al., 2020). The data obtained in the laboratory experiments show that the inoculation of biological preparations to the seeds has a stimulating effect on their germination. Perhaps, it is related to the synthesis of phytohormones of the auxin group by microorganisms or other biologically active substances.

During the micro plot experiment, at the early stages of ontogenesis (the phase of the third leaf), the differences between the experimental and the control plants were not as significant as at the subsequent stages and as could be expected after obtaining the results of the laboratory trial. This situation could be explained by the drought after the sowing which was unfavourable both for the plants and microorganisms. Significant morphometric differences between the experimental and control plants were seen in the phase of early tillering, i.e. after spraying biological preparations on the plants during the phase of the third leaf. During the treatment, the sizes of the plants were still insignificant, and during spraying the biological preparations, the microorganisms fall on both phyllosphere and soil (reach rhizosphere), where they cause their growth-stimulating action.

Increase in both dry and raw weight in the experimental plants may indicate influence of the biological preparations and processes of absorption of water and the processes of growth of plants.

Increase in the leaf area leads to increase in the average daily increments. First of all, such situation could be related to the enhancement of photosynthesis and activation of the work of pigmentary apparatus, which is indicated in a number of studies (Pigorev & Tarasov, 2014; Chernyad'ev, 2009). Interesting is the opinion of Seregina, who reports that positive effect of physiologically active substances on the process of photosynthesis could be considered in two aspects. On the one hand, increment in the leaf area occurs, and on the other hand – leaves are present on the plants for a longer time period and work longer for the reproductive organs (Seregina et al., 2018; Pavlovskaya et al., 2019). In our experiments, the microbiological preparations significantly induced the growth of leaf area of barley plants. Average daily increments, quantity of leaves, leaf area, intensity of photosynthesis and the content of chlorophyll, – all these indicators allow one to judge on the intensity of photosynthesis of plants in particular agroclimatic conditions (Yeryashev et al., 2017; Yevdokimova & Mar'ina-Chernmykh, 2018; Yasir et al., 2019). In our case, PPP of the experimental and control plants were characterized by similar accumulation of dry matter per unit of the leaf area after treatment with Naturost and somewhat more intensively for the plants processed with Naturost-Aktiv preparations. Thus, increase in the leaf area in the experimental plants is accompanied by remaining relative intensity of photosyn-

thesis, leading to significant increase in the average daily increments and, therefore, increase in the biomass. No doubt the main function of chlorophyll is its participation in photochemical synthesis of the organic compound from carbon dioxide and water, in our case the content of chlorophyll in the control and the experimental biomaterial significantly did not differ. Therefore, practically similar content of pigments in the biomaterial of the experimental and control plants against the background of increase in the rates of accumulation of the biomass indicate the intensification of the work of photosynthetic units in the experimental plants. At the same time, any changes in physiological processes in the plants, including at the early stages of ontogenesis (tillering, booting), affect the grain productivity (Yasir et al., 2019; Pavlovskaya et al., 2019). This correlates well with the results of our study.

By the end of the end of the experiment, the mass of the vegetative organs of the experimental and the control variants remained, but were insignificant. Therefore, the treatment with biological preparations presumably enhances the ontogenesis of plants to a large extent. Some authors report that the acceleration of the ontogenesis of plants contributes to faster organogenesis (new leaves form, the leaf area of the experimental plants becomes greater compared with the control), therefore contributing to the accumulation of dry matter and, as a result, grain productivity (Pigorev & Tarasov, 2014; Pavlovskaya et al., 2019). Such a picture is seen also in our case, increase in the rates of the growth processes and accumulation of the biomass at the early stages of ontogenesis leads to increase in the grain yield of one plant by 8.5–15.8%; during constant quantity of caryopses in the ear, there was observed the tendency towards increase in the tillering and the weight of caryopses. At the same time, greater increase in the grain productivity was seen in the plants treated with the *L. buchneri*-based preparation, as written earlier; the plants in that variant reached also higher parameters of pure productivity of photosynthesis.

Perhaps, one of the mechanisms of biological action of biological preparations was synthesis of phytohormones by microorganisms, particularly auxins, which at the early stages of ontogenesis contribute to the activation of cell division, better development of the root system and, therefore, faster growth of the plant. Synthesis of auxins by bacteria has been for many times confirmed in the works by Russian (Chernyad'ev, 2009; Kolmykova & Lukatkin, 2012; Pigorev & Tarasov, 2014) and foreign researchers (Glick, 1995; Tsavkelova et al., 2006; Pérez-Montañó et al., 2014), and their effect on the growth and development of plants is obvious. In our case, Naturost preparation is a bacterial culture of *B. subtilis*. A number of scientists report that the representatives of this genus of microorganisms are able to actively synthesize IAA, lipopeptides, ethylene, polyamines, etc., due to the fact that the plant's immunity improves, the growth and development enhance, and faster response to various stressors forms (Falardeau et al., 2013; Xie et al., 2014; Maksimov et al., 2020). The second preparation Naturost-Aktiv, based on culture of *L. buchneri* also contributes to the increase in the growth parameters and grain productivity of barley of the Sonet variety. It should be noted that lactic acid bacteria are relatively poorly studied from the perspective of increase in the productivity of plants, and usually the studies of these organisms oriented towards their role in preparation of juicy fodders (Taylor et al., 2002). However, these microorganisms are rather competitive, which allows them to successfully live in soil and efficiently interact in the system with plants. Therefore, representatives of *Lactobacillus* genus increase the resistance of plants to stressors, pathogens (Kuwaki et al., 2004; Limanska et al., 2013), and induce growth and the development of plants (Limanska et al., 2013; Rzhetskaya et al., 2014), and also the antimicrobial and growth-stimulating activities of acidic-lactic bacteria were determined to be associated with their production of various metabolites (Kuwaki et al., 2004; Chicherin et al., 2014; Danilova et al., 2019), particularly valeric and butyric acids (Lapitskaya et al., 2009), and also these bacteria are able to synthesize phytohormones of the auxin group (Gummala & Broadbent, 1999), which correlates well with the results we obtained in the study.

## Conclusion

The study we conducted demonstrates the positive effect of bacterial preparations developed on the bases of *B. subtilis* and culture of *L. buchneri* on barley (*Hordeum vulgare* L.) of Sonet variety. The action of the

preparations is likely to be associated with the synthesis of phytohormones of the auxin group by the microorganisms, antifungal and antibacterial effects, and also mobilization of the elements of mineral nutrition. Microorganisms of the biological preparations, by actively participating in mutual relationships with the plants, have an effect on the growth and the development of barley. Soaking of seeds and spraying of the plants in the third leaf stage with biological preparations enhanced the growth processes and caused faster organogenesis, increase in the leaf area of plants, and finally grain productivity. Therefore, the weight of grains from one square meter increased by 13.3% after treatment with Naturost preparation and by 14.8% after application of Naturost-Aktiv. The data obtained during the study indicate the economic effectiveness of the biological preparations and allow us to recommend them for use in the conditions of the North-West of the Russian Federation. Currently, it is planned to test the biological preparations for the effect on grain and fodder crops in industrial conditions.

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