



Эффективность бактерий-антагонистов *Bacillus* и *Pseudomonas* в качестве агентов биоконтроля сетчатой пятнистости озимого ячменя в полевых условиях

Асатурова А.М., Жевнова Н.А., Сидоров Н.М., Кремнева О.Ю.

Федеральный научный центр биологической защиты растений

Краснодар, Россия

✉ e-mail: n.zhevnova@mail.ru

Сетчатая пятнистость листьев ячменя – широко распространенная в мире болезнь зерновых культур, наносящая значительный экономический ущерб. Преимущественным способом борьбы с ней остается химическая защита, имеющая множество негативных последствий. Необходимо отметить, что возбудитель болезни – гриб *Pyrenophora teres* – относится к классу патогенов с высокой вероятностью развития множественной резистентности сразу к нескольким химическим фунгицидам. В связи с этим в работе исследовано защитное действие штаммов *Bacillus velezensis* BZR 336 g и BZR 517, а также *Pseudomonas chlororaphis* BZR 245 F на двух сортах ячменя озимого с различной устойчивостью к возбудителю сетчатой пятнистости в условиях двухлетних полевых испытаний. Установлено, что обработка указанными штаммами снижала развитие сетчатой пятнистости в среднем на 26–30% в условиях центральной зоны Краснодарского края. В 2022 г. штаммы смогли конкурировать по эффективности с химическим эталоном. Выявлено, что на восприимчивом сорте Романс снижение развития болезни при обработке штаммами было более выраженным – в среднем 25,7–38,8% при 20,9–25,3% на устойчивом сорте Иосиф. Определено, что обработка жидкими культурами штаммов перед посевом и в период вегетации эффективнее, чем другие способы. В 2018 г. обработка семян и растений штаммами была эффективнее других способов: на сорте Иосиф – в среднем на 6–8%, на сорте Романс – на 8–24%. В 2022 г. обработка семян и растений штаммами была в среднем на 12–17 (Иосиф) и 35–38% (Романс) эффективнее, чем другие методы обработки. Биологическая эффективность штаммов зависела от климатических факторов. В благоприятных погодных условиях максимальное снижение развития болезни отмечено при использовании штамма рода *Pseudomonas*, в условиях нестабильного метеорологического фона наибольшую эффективность продемонстрировали биоагенты рода *Bacillus*. Результаты исследований показали, что биологические методы борьбы с сетчатой пятнистостью листьев озимого ячменя достаточно эффективны и требуют дальнейшей реализации. Биологические средства защиты растений помимо подавления вредоносности фитопатогенов будут способствовать получению экологически безопасной продукции в совокупности со снижением пестицидного пресса на агроценозы.

Ключевые слова: *Pyrenophora teres*, *Bacillus*, *Pseudomonas*, бактерии-антагонисты, биологическая защита растений, зерновые культуры

Efficacy of *Bacillus* and *Pseudomonas* antagonist bacteria as biocontrol agents of barley net blotch in field conditions

Asaturova A.M., Zhevnova N.A., Sidorov N.M., Kremneva O.Yu.

Federal Research Center of Biological Plant Protection

Krasnodar, Russia

✉ e-mail: n.zhevnova@mail.ru

Barley net blotch is a widespread disease of cereal crops worldwide, causing significant economic losses. The predominant method of controlling it remains chemical defense, which has many nega-

tive consequences. It should be noted that the causative agent of the disease, the fungus *Pyrenophora teres*, belongs to the class of the pathogens with a high probability of developing multiple resistance to several chemical fungicides at once. In this regard, the protective effect of *Bacillus velezensis* strains BZR 336 g and BZR 517, as well as *Pseudomonas chlororaphis* BZR 245 F on two varieties of winter barley with different resistance to the causative agent of net blotch in two-year field trials was investigated. It was found that treatment with the above strains reduced the development of net blotch on average by 26–30% in the conditions of the central zone of the Krasnodar Territory. In 2022, the strains were able to compete in efficiency with the chemical reference. It was found that the reduction of disease development was more pronounced on the susceptible variety Romance when treated with the strains, with an average of 25.7–38.8% compared to 20.9–25.3% on the resistant variety Iosif. It was determined that treatment with liquid strain cultures before sowing and during the growing season is more effective than other methods. In 2018, seed and plant treatment with the strains was more effective than other methods: on the variety Iosif by an average of 6–8% and on the variety Romance by 8–24%. In 2022, seed and plant treatments with the strains were on average 12–17 (Iosif) and 35–38% (Romance) more effective than other methods of treatment. The biological efficacy of the strains depended on climatic factors. In favorable weather conditions, the maximum reduction of disease development was observed with the use of strain of the *Pseudomonas* genus, in conditions of unstable meteorological background the greatest efficiency was demonstrated by bioagents of the *Bacillus* genus. The results of research have shown that biological methods of controlling winter barley net blotch are quite effective and require further implementation. Biological means of plant protection in addition to suppressing the harmfulness of phytopathogens will contribute to the production of environmentally safe products in conjunction with the reduction of pesticide pressure on agrocenoses.

Keywords: *Pyrenophora teres*, *Bacillus*, *Pseudomonas*, antagonist bacteria, biological plant defence, cereal crops

Для цитирования: Асатунова А.М., Жевнова Н.А., Сидоров Н.М., Кремнева О.Ю. Эффективность бактерий-антагонистов *Bacillus* и *Pseudomonas* в качестве агентов биоконтроля сетчатой пятнистости озимого ячменя в полевых условиях // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 10. С. 69–77. <https://doi.org/10.26898/0370-8799-2024-10-7>

For citation: Asaturova A.M., Zhevnova N.A., Sidorov N.M., Kremneva O.Yu. Efficacy of *Bacillus* and *Pseudomonas* antagonist bacteria as biocontrol agents of barley net blotch in field conditions. *Sibirskii vestnik sel'skokhozyaistvennoi nauki* = *Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 10, pp. 69–77. <https://doi.org/10.26898/0370-8799-2024-10-7>

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest

The authors declare no conflict of interest.

Благодарность

Исследования выполнены согласно государственному заданию Министерства науки и высшего образования Российской Федерации в рамках НИР по теме № FGRN-2022-0006.

Acknowledgements

The research was carried out according to the state assignment of the Ministry of Science and Higher Education of the Russian Federation within the framework of the research work under the topic No. FGRN-2022-0006.

INTRODUCTION

Net blotch of barley, caused by the heterothallic ascomycete *Pyrenophora teres* Drechsler (anamorph: *Drechslera teres* Sacc. (Shoem.) = *Helminthosporium teres*), is one of the most harmful diseases and is found in almost all countries engaged in grain cultivation. This is due to the high adaptability of the pathogen and active

microevolutionary processes [1–4]. In years of epiphytotics, yield losses from this disease can reach 20–40% or more [2–4].

The disease affects leaves, leaf sheaths, and stems (see the figure). As the disease progresses, the photosynthetic area of the leaf decreases, which can lead to complete necrosis and desiccation of the plant. The widespread distribution



Сетчатая пятнистость листьев озимого ячменя
Winter barley net blotch disease

of the infection is facilitated by high humidity, the use of susceptible varieties, monoculture in crop rotation, and an abundance of plant residues [1–5].

Currently, the chemical method remains the most widely used approach to suppress the disease [1, 6]. However, due to the peculiarities of its genetic apparatus, the pathogen can quickly develop resistance to the most common and widely used fungicides. Resistance to fungicides of various chemical groups is observed everywhere due to the intensification of agricultural production [3, 4]. The practice of using chemical agents to combat diseases has shown that their economic efficiency is gradually declining. Pathogens resistant to pesticides are emerging, the costs of developing new drugs are increasing, and ultimately, this raises the cost of agricultural production. The constant use of chemical plant protection products disrupts biological balance, pollutes the environment, and leads to the accumulation of toxic residues in soil, water bodies, groundwater, and agricultural products [7].

Environmentally safe biopreparations based on microorganisms of various taxonomic groups are an alternative to the chemical method. The

advantages of biological plant protection agents include their safety for warm-blooded organisms and the environment, selectivity of action, absence or weak phytotoxicity, low probability of resistance development in case of long-term application [8–10].

Numerous studies confirm the effectiveness of microorganisms in the control of plant diseases, including the use of resistant varieties [4, 11–15]. Thus, E. O'Brien¹ reports on *P. fluorescens* strains MKB100 and MKB156, *Pseudomonas* sp. MKB158 and MKB194, which significantly (up to 46%) reduced disease development under natural conditions on two barley varieties. A study by A. Perello et al.² showed up to 56% reduction of disease development caused by the taxonomically similar pathogen *P. tritici-repentis* using biocontrol strains on wheat leaves under field conditions. Some variants gave good protective effect even compared to fungicide treatment. M. Ghorbanpour et al. [16] evaluated the effect of *Pseudomonas* and *Bacillus* strains on the development of barley net blotch caused by *P. graminea* in field conditions for two years on three varieties differing in the degree of resistance. The level of disease development was reduced to 66%.

Conducting research in the direction of biologization of plant protection systems is promising in connection with the adoption of the Strategy for the development of organic production in the Russian Federation until 2030, which provides for the active development of agrobiotechnological direction³.

The purpose of this study was to investigate the ability of bacterial bioagents of two different genera (*Bacillus* and *Pseudomonas*) to control the development of net blotch on two winter barley varieties differing in disease resistance under varying environmental conditions.

¹O'Brien E. Biological control of *Pyrenophora teres*. Letterkenny, 2005, 104 p.

²Perello A., Moreno V., Monaco C., Simon M.R. Effect of *Trichoderma* spp. isolates for biological control of tan spot of wheat caused by *Pyrenophora tritici-repentis* under field conditions in Argentina // *Biocontrol*, 2008, N 53, pp. 895–904.

³Order of the Government of the Russian Federation from 04.07.2023, № 1788 r “On approval of the Strategy for the development of organic production in the Russian Federation until 2030” (<https://www.garant.ru/products/ipo/prime/doc/407297286/>).

MATERIAL AND METHODS

The research was conducted at the field experimental base of the Federal Research Center of Biological Plant Protection (FSBSI FRCBPP) in 2017–2018 and 2021–2022. Two winter barley varieties of the selection of the National Grain Center P.P. Lukyanenko, differing in the degree of resistance to net blotch were used: Romance (susceptible, the level of disease development 30–50%), Iosif (resistant, the level of disease development up to 20%) [12]. Plants were grown on the plots with the area of 5 m². The total area of the experiment amounted to 1100 m².

The research objects were strains from the bioresource collection of the “State Collection of Entomocariphages and Microorganisms” of the FSBSI Federal Research Center of Biological Plant Protection: *Pseudomonas chlororaphis* BZR 245 F, *Bacillus velezensis* BZR 336 g and BZR 517. The strains were selected by the method of stepwise screening and on the basis of experimental data were recognized as promising for the creation of biological preparations [13].

Liquid cultures (LC) of the above strains obtained by batch cultivation in New Brunswick Scientific Excella E25 shaker incubators (Enfield, USA) (180 rpm) were used in the study. Strains BZR 336 g and BZR 517 were obtained on the original optimized nutrient medium for 48 h at 25 °C and 36 h at 30 °C, respectively⁴. Cell concentration was maintained at the level of $2,8 \cdot 10^8$ – $4,1 \cdot 10^9$ CFU/ml.

BZR 245 F strain was obtained by the same method on King's B medium for 36 h at 26 °C, cell concentration $1,6 \cdot 10^8$ – $2,4 \cdot 10^9$ CFU/ml.

The strains were used in three ways:

- 1) pre-sowing seed treatment and subsequent treatment of vegetative plants;
- 2) treatment of vegetative plants;

3) seed treatment; treatment of vegetative plants was carried out in spring in the tillering phase (Z 26-21).

The application rates of LC strains were as follows: seed treatment with strain BZR 245 F – 2 l/t, BZR 336 g – 3 l/t, BZR 517 – 2 l/t, plant treatment – 2, 3 and 2 l/ha, respectively. Consumption of the working fluid was 10 l/t and 300 l/ha. Kinto Duo, SC (triticonazole + prochloraz, 20 + 60 g/l) was used as a chemical standard for seed treatment, Alto Super, SC (propiconazole + cyproconazole, 250 g/l + 80 g) for plant treatment. Alirin-B, L (*B. subtilis*, strain VIZR B-10) was used as a biological standard.

Disease development was evaluated visually in dynamics as the symptoms appeared. The level of disease development was recorded in percentages by determining the ratio of the affected areas to the total leaf area. The data obtained at maximum development of the disease are presented in the paper. Biological efficiency was calculated using the Abbott formula⁵

$$BE = (100 \cdot (P - p)) / P,$$

where BE – biological effectiveness, %; P – data in the control, %; p – data in the variant with a bioagent or benchmark application, %.

The growing season from October 2017 through June 2018 was favorable for the plants and biological agents (based on the weather archive, weather station No 34920⁶).

During this period, there were no sharp fluctuations in precipitation levels or air temperature. The autumn and winter were warm (5.2...12.2 °C). Plants received ample moisture during the initial stages of vegetation (70–148 mm of precipitation fell). Vegetation resumed in March. In the autumn of 2021, after sowing, the air temperature was low (down to –1.3 °C), and plants

⁴Asaturova A.M., Homyak A.I., Tomashevich N.S., Pavlova M.D., Zhevnova N.A., Dubyaga V.M., Kozitsin A.Ye., Sidorova T.M., Nadykta V.D., Ismailov V.Ya. Conditions for the cultivation of new *Bacillus* bacteria being micro bioproduct producers // Journal of pure and applied microbiology, 2015, N 9 (4), pp. 2797–2804.

⁵Abbott W.S. A method of computing the effectiveness of an insecticide // Journal of Economic Entomology, 1925, vol. 18, N 2, pp. 265–267.

⁶<https://rp5.ru/>

received little moisture (40–56 mm). During the winter, there were sharp fluctuations in temperature (from –12.1 to –19.0 °C) and precipitation (from 37 to 166 mm). The spring of 2022 was cold, and vegetation resumed in mid-April.

The material and technical base of USU “Technological line for production of microbiological plant protection agents of new generation”⁷ was used in the research. Statistical processing of data was carried out using Tukey HSD STATISTICA 13.2 test (StatSoft Russia). Repetition in all the experiments was threefold.

RESULTS AND DISCUSSION

Biological efficiency varied depending on the level of infection background, variety and the method of application of LC strains. In 2018, the development of net blotch was 4.8–5.8% on the resistant variety Iosif and 22.6–35.8% on the susceptible variety Romance. In 2022, the natural infection background was more aggressive with 63.1–66.4% on variety Iosif and 71.1–73.2% on variety Romance. In 2018, maximum reduction in disease development occurred with the use of chemical protection (irrespective of the method of application). In 2022, biological protection was most effective, in particular strains BZR 517 and BZR 245 F maximally reduced disease development (see the Table).

Pre-sowing seed treatment combined with treatment of vegetating plants proved to be more effective than other types of treatment. In 2018, when treating seeds and plants of the Iosif variety with the strains, the biological efficacy was 16.3–32.0%, which was on average 6–8% higher than when using other methods. For the susceptible variety Romance, the difference was more pronounced: on average, the strains suppressed the disease by 8–24% better when treating seeds and plants compared to other treatment methods. In 2022, the treatment of seeds and plants with the strains was on average 12–17% (Iosif) and 35–38% (Romance) more effective than other treatment methods (see the Table).

The efficacy of the strains varied. In 2018, the strain BZR 245 F reduced disease development by 15.2–59.9%, depending on the variety and treatment method, surpassing this indicator in variants using strains of the genus *Bacillus*. The efficacy of BZR 336 g and BZR 517 was lower, at 4.2–53.7%. In 2022, BZR 245 F showed maximum efficacy only on the resistant variety, while BZR 336 g and BZR 517 significantly suppressed pathogen development on both varieties: by 16.2–49.7% on the resistant variety Iosif and by 6.1–46.9% on the susceptible variety Romans. It is worth noting that the strains were able to compete in efficacy with the chemical standard in 2022 (see the Table).

It was observed that under field conditions, the biological efficacy of the strains depended on weather conditions. In the favorable weather conditions of 2017 and 2018, the strain BZR 245 F suppressed the development of net blotch more actively than the bacillary strains. The biological efficacy of the strain BZR 245 F was 24.6–59.9%, while that of strains BZR 336 g and BZR 517 was 4.2–50.3% (see table). In 2021–2022, the climatic conditions were less stable than in the previous research period. In 2022, the biological efficacy of strains BZR 336 g and BZR 517 was on average 7–19% higher than that of BZR 245 F, which was particularly noticeable on the susceptible variety Iosif. Additionally, under field trial conditions in 2022, the strains were able to compete in efficacy with the chemical standard.

CONCLUSION

It was found that treatment with the strains reduced the development of barley net blotch by an average of 30% in 2018 and by 26% in 2022. It is worth noting that in 2022, the strains were able to compete in efficacy with the chemical reference.

It was found that treatment with LC strains before sowing and during the growing season was more effective than other methods. In

⁷<http://ckp-rf.ru/usu/671367>

Развитие сетчатой пятнистости (R, %) и биологическая эффективность (BE, %) штаммов в условиях полевой экспериментальной базы ФГБНУ ФНЦБЗР
Development of net blotch (R, %) and biological efficacy (BE, %) of strains under the conditions of the field experimental base of the FRCBPP

Treatment method	Experiment option	2018				2022			
		Variety Iosif		Variety Romance		Variety Iosif		Variety Romance	
		R	BE	R	BE	R	BE	R	BE
Seed and plant treatment	Control	5,7 ^c	—	23,4 ^c	—	63,6 ^c	—	72,2 ^d	—
	Chemical standard	3,8 ^a	33,1	4,6 ^a	80,4	46,5 ^a	26,9	53,2 ^c	26,3
	Biological reference	4,2 ^a	27,3	10,1 ^{a, b}	57,0	44,3 ^a	30,3	34,5 ^{a, b}	52,2
	BZR 245 F	3,9 ^a	32,0	9,4 ^{a, b}	59,9	48,7 ^a	23,5	27,3 ^b	62,2
	BZR 336 g	4,2 ^a	26,7	11,6 ^{a, b}	50,3	43,9 ^a	30,9	42,3 ^a	41,3
	BZR 517	4,8 ^a	16,3	16,3 ^{b, c}	30,5	32,0 ^b	49,7	38,3 ^a	46,9
Plant treatment	Control	5,8 ^b	—	27,8 ^b	—	66,4 ^c	—	73,2 ^a	—
	Chemical standard	3,7 ^c	36,6	13,1 ^a	53,0	57,3 ^a	13,8	49,3 ^b	32,7
	Biological reference	5,3 ^b	9,1	20,4 ^{a, b}	26,6	53,4 ^{a, b}	19,6	55,3 ^{b, c}	24,4
	BZR 245 F	4,4 ^a	24,6	14,0 ^a	49,6	57,2 ^a	13,9	62,3 ^{a, c}	14,8
	BZR 336 g	4,6 ^a	21,7	16,8 ^a	39,4	50,4 ^b	24,1	63,0 ^{a, c}	13,9
	BZR 517	4,7 ^a	20,0	16,9 ^a	39,1	55,5 ^{a, b}	16,4	67,4 ^a	7,9
Seed treatment	Control	4,8 ^a	—	22,6 ^b	—	63,1 ^c	—	71,1 ^b	—
	Chemical standard	2,2 ^a	53,8	12,5 ^a	44,7	56,0 ^a	11,2	80,5 ^c	0,0
	Biological reference	3,3 ^a	30,1	15,7 ^a	30,7	57,9 ^{a, c}	8,2	65,8 ^{a, b}	7,4
	BZR 245 F	3,3 ^a	30,1	19,2 ^{a, b}	15,2	49,4 ^b	21,7	64,4 ^a	9,4
	BZR 336 g	4,6 ^a	4,2	13,8 ^a	38,9	43,6 ^d	30,9	50,5 ^c	29,0
	BZR 517	4,2 ^a	12,6	16,7 ^{a, b}	26,3	52,8 ^{a, b}	16,2	66,8 ^{a, b}	6,1

Note. Different letters indicate valid differences ($p < 0,05$) within a column according to the test Tukey HSD.

2018, treatment of seeds and plants of Iosif variety with the strains reduced development of net blotch by 6–8% more effective than other methods, on the Romance variety – by 8–24% more effective. In 2022, seed and plant treatment with strains was on average 12–17 (Iosif) and 35–38% (Romance) more effective relative to other treatments.

It was found that on the susceptible variety Romance the reduction of disease development when treated with the strains was more pronounced with an average of 25.7–38.8% with 20.9–25.3% on the resistant variety Iosif.

It was determined that in field conditions the

biological efficiency of the strains depended on the weather conditions. In a favorable weather period (2017-2018) strain BZR 245 F suppressed the development of net blotch more actively than *Bacillus* strains. In the less stable period (2021-2022), the biological efficacy of *Bacillus* strains was on average 7–19% higher than that of BZR 245 F, which was especially noticeable on the susceptible variety Iosif.

The conducted research has shown that biological methods of control of winter barley net blotch are quite effective and require further implementation in production conditions. Biological means of plant protection against diseases will not only

reduce the harmfulness of *P. teres*, but will also contribute to the production of environmentally safe products in conjunction with the reduction of pesticide pressure on the agrocenoses.

СПИСОК ЛИТЕРАТУРЫ

1. Мироненко Н.В., Орина А.С., Коваленко Н.М. Генетический полиморфизм штаммов ToxV+ *Pyrenophora tritici-repentis* // Экологическая генетика. 2021. Т. 19. № 2. С. 121–129. DOI: 10.17816/ecogen54718.
2. Volkova G., Yakhnik Ya. *Pyrenophora teres*: Population structure, virulence and aggressiveness in Southern Russia // Saudi journal of biological sciences. 2022. Vol. 29. N 10. P. 103401. DOI: 10.1016/j.sjbs.2022.103401.
3. Яхник Я.В., Волкова Г.В. Чувствительность возбудителя сетчатой пятнистости листьев (*Pyrenophora teres*) к двухкомпонентным фунгицидам на основе триазолового и стробилуринового классов // Известия Тимирязевской сельскохозяйственной академии. 2024. № 2. С. 127–138. DOI: 10.26897/0021-342X-2024-2-127-138.
4. Backes A., Guerriero G., Ait Barka E., Jacquard C. *Pyrenophora teres*: taxonomy, morphology, interaction with barley, and mode of control // Frontiers in plant science. 2021. N 12. P. 614951. DOI: 10.3389/fpls.2021.614951.
5. Мироненко Н.В., Лашина Н.М., Баранова О.А., Зубкович А.А., Афанасенко О.С. Гибридизация между формами *Pyrenophora teres* в природных популяциях России и Республики Беларусь // Микология и фитопатология. 2021. Т. 55. № 1. С. 51–58. DOI: 10.31857/S0026364821010074.
6. McLean M.S., Poole N., Santa I.M., Hollaway G.J. Efficacy of spot form of net blotch suppression in barley from seed, fertilizer and foliar applied fungicides // Crop Protection. 2022. N 153. P. 105865. DOI: 10.1016/j.cropro.2021.105865.
7. Azizbekyan R.R. Biological preparations for the protection of agricultural plants (review) // Applied biochemistry and microbiology. 2019. Vol. 55. N 8. P. 816–823. DOI: 10.1134/S0003683819080027.
8. Павлюшин В.А., Новикова И.И., Бойкова И.В. Перспективы и возможности микробиологической защиты растений для повышения уровня экологической безопасности в агроценозах (обзор) // Защита и карантин растений. 2022. № 4. С. 10–18. DOI: 10.47528/1026-8634_2022_4_10.
9. Clare S.J., Wyatt N.A., Brueggeman R.S., Friesen T.L. Research advances in the *Pyrenophora teres* – barley interaction // Molecular Plant Pathology. 2019. N 21 (2). P. 272–288. DOI: 10.1111/mp.12896.
10. Веселова С.В., Сорокань А.В., Бурханова Г.Ф., Румянцев С.Д., Алексеев В.Ю., Черепанова Е.А., Максимов И.В. Бактерии рода *Bacillus* как перспективный источник для создания биопрепаратов от патогенов и вредителей сельскохозяйственных культур // Труды Кубанского государственного аграрного университета. 2022. № 97. С. 40–45. DOI: 10.21515/1999-1703-97-40-45.
11. Rozanova I.V., Lashina N.M., Mustafin Z.S., Gorobets S.A., Efimov V.M., Afanasenko O.S., Khlestkina E.K. SNPS associated with barley resistance to isolates of *Pyrenophora teres* f. *teres* // BMC Genomics. 2019. N 20 (S3). P. 292. DOI: 10.1186/s12864-019-5623-3.
12. Волкова Г.В., Данилова А.В., Яхник Я.В., Гладкова Е.В., Тарачева О.В. Иммунологическая оценка устойчивости сортов озимого ячменя к листовым болезням на юге России // Российская сельскохозяйственная наука. 2021. № 5. С. 16–21.
13. Асатурова А.М., Жевнова Н.А., Павлова М.Д., Дубяга В.М., Томашевич Н.С., Хомяк А.И., Цыгичко А.А., Бондарчук Е.Ю., Сидорова Т.М. Эффективность инокуляции семян озимой пшеницы бактериями рода *Bacillus*, перспективными для создания биопрепаратов // Зерновое хозяйство России. 2019. № 2 (62). С. 8–12.
14. Hoyer A.K., Jorgensen H.J.L., Hodkinson T.R., Jensen B. Fungal endophytes isolated from *elymus repens*, a wild relative of barley, have potential for biological control of *Fusarium culmorum* and *Pyrenophora teres* in barley // Pathogens. 2022. Vol. 11. N 10. P. 1097. DOI: 10.3390/pathogens11101097.
15. Dimkic I., Janakiev T., Petrovic M., Degrassi G., Fira D. Plant-associated *Bacillus* and *Pseudomonas* antimicrobial activities in plant disease suppression via biological control mechanisms: a review // Physiological and molecular plant pathology. 2022. N 117. P. 101754. DOI: 10.1016/j.pmp.2021.101754.
16. Ghorbanpour M., Omidvari M., Abbaszadeh-Dahaji P., Omidvar R., Kariman K. Mechanisms underlying the protective effects of beneficial

fungi against plant diseases // Biological control. 2018. N 117. P. 147–157. DOI: 10.1016/j.bio-control.2017.11.006.

REFERENCES

1. Mironenko N.V., Orina A.S., Kovalenko N.M. Genetic polymorphism of ToxB+ *Pyrenophora tritici-repentis* strains. *Ekologicheskaya genetika = Ecological Genetics*, 2021, vol. 19, no. 2, pp. 121–129. (In Russian). DOI: 10.17816/ecogen54718.
2. Volkova G., Yakhnik Ya. *Pyrenophora teres*: Population structure, virulence and aggressiveness in Southern Russia. *Saudi journal of biological sciences*, 2022, vol. 29, no. 10, p. 103401. DOI: 10.1016/j.sjbs.2022.103401.
3. Yakhnik Ya.V., Volkova G.V. Sensitivity of the causative agent of net blotch of barley (*Pyrenophora teres*) to a two-component fungicide based on triazole and strobilurine classes. *Izvestiya Timiryazevskoy sel'skokhozyaistvennoy akademii = Izvestiya of Timiryazev Agricultural Academy*, 2024, no. 2, pp. 127–138. (In Russian). DOI: 10.26897/0021-342X-2024-2-127-138.
4. Backes A., Guerriero G., Ait Barka E., Jacquard C. *Pyrenophora teres*: taxonomy, morphology, interaction with barley, and mode of control. *Frontiers in plant science*, 2021, no. 12, p. 614951. DOI: 10.3389/fpls.2021.614951.
5. Mironenko N.V., Lashina N.M., Baranova O.A., Zubkovich A.A., Afanasenko O.S. Hybridization between *Pyrenophora teres* forms in natural populations of Russia and the Republic of Belarus. *Mikologiya i fitopatologiya = Mycology and Phytopathology*, 2021, vol. 55, no. 1, pp. 51–58. (In Russian). DOI: 10.31857/S0026364821010074.
6. McLean M.S., Poole N., Santa I.M., Hollaway G.J. Efficacy of spot form of net blotch suppression in barley from seed, fertilizer and foliar applied fungicides. *Crop Protection*, 2022, no. 153, p. 105865. DOI: 10.1016/j.cropro.2021.105865.
7. Azizbekyan R.R. Biological preparations for the protection of agricultural plants (review). *Applied biochemistry and microbiology*, 2019, vol. 55, no. 8, pp. 816–823. DOI: 10.1134/S0003683819080027.
8. Pavlyushin V.A., Novikova I.I., Boikova I.V. Prospects and opportunities of microbiological plant protection for increasing the level of ecological safety in agricultural plant communities (review). *Zashchita i karantin rasteniy = Plant Protection and Quarantine*, 2022, no. 4, pp. 10–18. (In Russian). DOI: 10.47528/1026-8634_2022_4_10.
9. Clare S.J., Wyatt N.A., Brueggeman R.S., Friesen T.L. Research advances in the *Pyrenophora teres* – barley interaction. *Molecular Plant Pathology*, 2019, no. 21 (2), pp. 272–288. DOI: 10.1111/mpp.12896.
10. Veselova S.V., Sorokan A.V., Burkhanova G.F., Rumyantsev S.D., Alekseev V.Yu., Cherepanova E.A., Maximov I.V. Bacteria of the genus *Bacillus* as a promising source for the creation of biological control agents against pathogens and pests of agricultural crops. *Trudy Kubanskogo gosudarstvennogo agrarnogo universiteta = Proceedings of the Kuban State Agrarian University*, 2022, no. 97, pp. 40–45. (In Russian). DOI: 10.21515/1999-1703-97-40-45.
11. Rozanova I.V., Lashina N.M., Mustafin Z.S., Gorobets S.A., Efimov V.M., Afanasenko O.S., Khlestkina E.K. SNPS associated with barley resistance to isolates of *Pyrenophora teres* f. *teres*. *BMC Genomics*, 2019, no. 20 (S3), p. 292. DOI: 10.1186/s12864-019-5623-3.
12. Volkova G.V., Danilova A.V., Yakhnik Ya.V., Gladkova E.V., Taracheva O.V. Immunological assessment of resistance of winter barley varieties to leaf diseases in the south of Russia. *Rossiyskaya sel'skokhozyaistvennaya nauka = Russian Agricultural Sciences*, 2021, no. 5, pp. 16–21. (In Russian).
13. Asaturova A.M., Zhevnova N.A., Pavlova M.D., Dubyaga V.M., Tomashevich N.S., Khomyak A.I., Tsygichko A.A., Bondarchuk E.Yu., Sidorova T.M. Efficiency of winter wheat seed inoculation by the *Bacillus* bacteria promising for the development of bio medicines. *Zernovoe khozyaistvo Rossii = Grain Economy of Russia*, 2019, no. 2 (62), pp. 8–12. (In Russian).
14. Hoyer A.K., Jorgensen H.J.L., Hodkinson T.R., Jensen B. Fungal endophytes isolated from *elymus repens*, a wild relative of barley, have potential for biological control of *Fusarium culmorum* and *Pyrenophora teres* in barley. *Pathogens*, 2022, vol. 11, no. 10, p. 1097. DOI: 10.3390/pathogens11101097.
15. Dimkic I., Janakiev T., Petrovic M., Degraasi G., Fira D. Plant-associated *Bacillus* and *Pseudomonas* antimicrobial activities in plant disease suppression via biological control mechanisms: a review. *Physiological and molecular plant pathology*, 2022, no. 117, p. 101754. DOI: 10.1016/j.pmpp.2021.101754.
16. Ghorbanpour M., Omidvari M., Abbaszadeh-Dahaji P., Omidvar R., Kariman K. Mechanisms underlying the protective effects of beneficial fungi against plant diseases. *Biological control*, 2018, no. 117, pp. 147–157. DOI: 10.1016/j.bio-control.2017.11.006.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Асатунова А.М., кандидат биологических наук, ведущий научный сотрудник, директор

✉ **Жевнова Н.А.**, кандидат биологических наук, старший научный сотрудник; **адрес для переписки:** Россия, 350039, Краснодар, п/о 39; e-mail: n.zhevnova@mail.ru

Сидоров Н.М., научный сотрудник

Кремнева О.Ю., кандидат биологических наук, ведущий научный сотрудник

AUTHOR INFORMATION

Anzhela M. Asaturova, Candidate of Science in Biology, Lead Researcher, Director

✉ **Natalya A. Zhevnova**, Candidate of Science in Biology, Senior Researcher; **address:** PO Box 39, Krasnodar, 350039, Russia; e-mail: n.zhevnova@mail.ru

Nikita M. Sidorov, Researcher

Oksana Yu. Kremneva, Candidate of Science in Biology, Lead Researcher

Дата поступления статьи / Received by the editors 02.08.2024
Дата принятия к публикации / Accepted for publication 12.09.2024
Дата публикации / Published 20.11.2024