The influence of agroecological factors on diseases development and wheat productivity

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Abstract. In the research, long-term data characterizing the wheat productivity and degree of its affection by diseases were compared with the natural and climatic factors of the North-Western region of the Russian Federation. The comparative analysis of the protein growth stimulant (PGS) and organomineral fertilizers’ influence on productivity, yield structure, and disease resistance of the VIR soft wheat was carried out. The greatest influence on the potential (estimated) wheat yield growth was exerted by the preparations “Zerebra agro” and “Edagum”. Foliar spraying with the protein growth stimulant resulted in an increase in wheat yield by 31.5% compared to the control. After applying the protein stimulant, a decrease in the degree of wheat powdery mildew development by 15.7% was revealed compared with the control. Organo-mineral fertilizers had insignificant effects on the disease development. The “Zerebra agro” preparation had high biological effectiveness against wheat leaf diseases (brown rust, powdery mildew).

1. Introduction
Grain production is the leading branch of agriculture in the Russian Federation and it plays a crucial role in ensuring the country’s food security of Russia. In addition, grain crops are in the sphere of interests of industries that depend on raw materials and consumer factors, including livestock and poultry [1, 2]. The preservation of wheat during the growing season, as a strategic raw material for the food and processing industry, is extremely important for increasing the yield and improving the quality of grain.
Spring wheat is the main grain crop. However, despite its significance, wide distribution, and extensive experience in cultivation, the crop yield is unstable and largely depends on the prevailing weather conditions [3–5].

The productivity of the agrocenosis is related to the density of the stem and the productivity of an individual plant, the parameters of which depend on meteorological factors and agricultural conditions [6]. The problem of increasing grain production must be solved, first of all, by using varieties adapted to the natural and climatic conditions of a particular territory. The adaptation of plants to the conditions of cultivation can occur due to modification and genotypic variability, often used in breeding. As an adaptive feature of grain crops, we can consider their resistance to abiotic and biotic environmental factors: lack and excess of moisture, high and low temperatures, salinity and increased soil acidity, diseases and pests, and reactions to the level of soil fertility [7]. The important features of the current phytosanitary state of grain crops are changes in the genetic structure of populations of phytopathogenic micromycetes, the appearance of new particularly dangerous infections that are not characteristic of this territory, as well as the transformation of the natural and climatic complex. Under these conditions, research aimed at finding and improving sources of resistance to major wheat diseases, as well as identifying factors that most contribute to the manifestation of this resistance in natural (field) conditions, is becoming very relevant [8].

One of the ways to reduce the volume of fertilizer application without compromising plant nutrition is the use of biostimulants in crop production that enhance plant growth, development, and increase their adaptive potential to cultivation conditions (Halpern M. et al, 2015) [9]. The use of bioregulators is promising for optimizing the phytosanitary condition of various agricultural crops, including neutralizing the side effects after the use of chemical plant protection products [10].

2. Statement of problem

In the research, long-term data characterizing the wheat productivity and the degree of its affection by diseases were compared with the natural and climatic factors of the North-Western region of the Russian Federation, botanical features and the origin of the samples. The effect of organo-mineral fertilizers and protein growth stimulant on the productivity and wheat resistance to diseases was studied.

3. Materials and methods.

To assess the long-term dynamics of development and harmfulness of wheat pathogens (2009–2019), 1445 samples provided by the Department of wheat genetic resources of VIR were cultivated. The stages of data processing experience included: obtaining pilot performance, creating a database in the form of coding tables, reflecting the quantitative relationship between the variables experience and individual factors (year of study, experiments name, meteorological research, bio-geographical features of the accessions, identified diseases, etc.) and mathematical processing of experimental results. Software program MS Excel, SPSS, and Statistica were used in the work.

Wheat productivity was studied in the phases of earing–flowering and maturation by a set of indicators that characterize the morphological characteristics of plants and the structure of the crop [11].

The intensity of wheat diseases was studied using both common criteria (disease development, reaction type) and additional criteria (in particular, the pustules number per leaf, the pustule area – for the rust pathogens, the number of spots with plaque, the area of spots with plaque – for powdery mildew, etc.). The complex of pathogenesis indicators using allowed us to expand the range of statistical data analysis methods applicable to the study, and to increase the accuracy of the experiment in determining the biological effectiveness of organo-mineral fertilizers.

The comparative analysis of the protein growth stimulant and organo-mineral fertilizers effectiveness in relation to the wheat productivity and diseases resistance on Leningradskaya 6, K-64900 cultivar was carried out. In the experiment the preparations "FlorGumat", "EdaGum", "Fitop-Flora-S" and "Zerebra agro" were used as organo-mineral fertilizer. The protein growth stimulant was
obtained from the by-products of slaughtered animals processing (split beef cuttings) by chemical hydrolysis (RF Patent No. 2533037)]. Currently, the protein stimulant of plant growth and development is being actively tested on cereals at the megafaculty of biotechnologies and low-temperature systems of ITMO University and at the plant protection and quarantine department of Saint-Petersburg State Agrarian University. The characteristics of the preparation and the methodology for its production are presented in the work of L. E. Kolesnikov, M. I. Kremenevskaya, and others [11]. When using this stimulant, in particular, for fruit and berry crops, their earlier maturation, increased yield and improved crop quality, and increased protective mechanisms of phytoimmunity were noted [12].

4. Results and discussion.
At the first stage of research, the long-term dynamics data about pathogens development on VIR soft wheat accessions collection (2009-2019) was studied and their harmfulness was assessed. The greatest development of wheat brown rust was registered in 2014: \( R_b = 44.7 \pm 1.1\% \) and in 2010: \( R_b = 40.1 \pm 1.1\% \) (fig. 1). The minimal development of the disease \( R_b = 5.1 \pm 0.6\% \) was registered in the period of 2016, which was characterized by a lower temperature (July \(-19.0°C\), August \(-17.2°C\)), a greater rainfall amount (July \(-151 mm\), August \(-189 mm\)).

![Figure 1. Wheat brown and yellow rust development on the soft wheat affected by Puccinia triticina Eriks (A – uredinii, B – urediniospores) and Puccinia striiformes Westend (C – uredinii, D – urediniospores); E- long-term dynamics of wheat brown rust.](image)

A strong wheat affection caused by yellow rust (fig. 1) was revealed in 2019. The meteorological conditions of this growing season were as follows: July \(-16.6°C(93 mm)\), August \(-17.0°C(49 mm)\). It should be noticed that in July of that year, the minimum average monthly temperature was recorded, and in August – the rainfall amount, while the optimal conditions for the development of the pathogen are the temperature range from 10°C to 16°C.

For 2009-2019, the tendency of increasing the damage degree caused by powdery mildew was revealed (fig. 2). The minimum level of disease development was registered in 2013 and 2016, while the maximum degree of disease intensity was in 2018. The average monthly degrees of temperature and rainfall in 2018 were in July \(-20.9°C(96 mm)\), in August \(-19.2°C(62 mm)\). July and August 2017-2019 were characterized by lower average temperatures of 2.02°C and 0.02°C, respectively, compared to the previous period of 2009-2016.

The highest rate of leaf wheat blotch development was observed in 2011 (fig. 2). The monthly average temperature and rainfall in 2011 were: July \(-22.5°C(97 mm)\), August \(-17.5°C(69 mm)\). It should be noticed that the temperature (3.3°C) and rainfall amount (9.9 mm) in July 2011 were higher than the average annual temperature of 2009-2019.
A strong intensity of the stem rust development was recorded in 2010. In 2009 and the time between 2014 and 2019, there was no signs of the disease development. July 2010 was characterized by the maximum monthly average temperature over a ten-year period of – 22.5°C.

The maximum rate of helminthosporous root rot caused by Bipolaris sorokiniana (Sacc.) Shoemaker was registered in 2018. In the same year, the maximum development of powdery mildew on the wheat collection was noticed. The average monthly values of temperature and precipitation in 2018 were: July – 20.9°C (96 mm), August – 19.2°C (62 mm).

The phytosanitary condition of wheat crops is directly related to its yield. The highest yield of soft wheat was recorded in 2016. In this year, as indicated above, the minimum values of the intensity of brown and yellow rust, powdery mildew and wheat root rot development were noticed. Wheat samples from the Eastern Europe had the highest yield.

The relationships between yield elements and various indicators of pathogenesis were studied by nonparametric correlation analysis. The intensity of root rot development resulted in a reduction of the total bushiness (r= -0.5; P=0.031); the flag leaf area (r= -0.8; P=0.01) and preflag leaf area (r= -0.3; P=0.04); the nodal roots length (r= -0.9; P=0.001); the nodal roots number (r= -0.4; P=0.04); the roots number (r= -0.8; P=0.01); the roots length (r= -0.9; P=0.01). The wheat brown rust rate increased with plant height growth (r= 0.96; P=0.04). The nodal roots length had been decreased (r= – 0.99; P=0.037) with increase in the wheat brown rust pustule area. The flag leaves area grew with the number of roots (r= 0.99; P=0.03) and the height of plants (r= 0.97; P=0.07), and pre-flag leaves grew with the number of nodal roots (r=0.99; P=0.01). Positive correlations between downiness of leaves and their affect intensity by yellow rust were determined (disease development: r= 0.3; P=0.001; number of pustules: r= 0.4; P=0.001).

At the second stage of the research, a comparative analysis of the effectiveness of the protein growth stimulant and organo-mineral fertilizers in relation to the wheat productivity and diseases resistance of Leningradskaya 6, K-64900 cultivar was carried out (fig. 3).

Foliar spraying with the protein growth stimulant resulted in an increase in wheat yield by 31.5% compared to the control. The flag and pre-flag leaf area was increased by 35.8% and 126.3%, respectively, when treating wheat with the protein growth stimulant, compared to the control.
The use of the protein growth stimulant led to an increase in spikelets number per spike by 13.8% and spike length (by 12.0%) compared to the control. The number of spikelets per spike and the spike length were higher with the protein stimulant treatments compared to the variants when organo-mineral fertilizers were applied. In addition, after treatment with the protein growth stimulant, an increase in the plant height by 12.1%, the in nodal roots length – by 29%, and in the plants vegetative part weight – by 17.8%, was revealed.

The grains number per spike and the weight of 1000 grains increased insignificantly – by 4.8% and 4.2%, respectively, when wheat was treated with a protein growth stimulant. The "EdaGum" preparation treatments had a significant effect on the grains number per spike increasing – by 31.9% compared to the control. At the same time, the treatments with "FlorGumat" and "Fitop-Flora-S" preparations led to a decrease in the 1000 grains weight by 34.3% and 7.7%, respectively.

It was noticed that the protein growth stimulant was more effective in increasing wheat yield than the preparations "Fitop-Flora-S" – by 32.2% and "FlorGumat" – by 63.3%. However, the preparations "Zerebra agro" and "Edagum" were more effective than the protein growth stimulant by 50.7% and 53.2%, respectively.

Figure 3. The potential yield and the area of flag and pre-flag leaves wheat cultivar of Leningradskaya 6, κ-64900 when using the protein growth stimulant and organo-mineral fertilizers

It is known that organo-mineral fertilizers activate cell metabolism and intensify physiological processes at different stages of plant development. The combined application of organic and mineral fertilizers increases the productivity of plants. Organic matter increases soil fertility, in particular, by improving its moisture capacity and porosity, optimizing the microbial balance. At the same time, the assimilation of available nutrients of mineral fertilizers by plants is more efficient [13]. At the same time, in the work of O.C. Turgay et al. [14], the heterogeneous effect of humic substances of different types and doses on different soil characteristics and wheat yield was established.

Silver nanoparticles can have an effect on the antioxidant protection system of plants [15]. Plant seeds treated with solutions of silver nanoparticles show the best indicators of germination and enzymatic activity [16].

It should be noticed that according to our experiments, conducted earlier, wheat yield in 2017-2018 increased on 64% of wheat accessions by 46.3% comparing with control, and the total nitrogen content in the leaves of 92% of wheat samples increased by 84.6%. In 2017-2018, after wheat plants treatments with the protein growth stimulant, an increase in grain size, their viability and roundness compared to the control (without treatments) was revealed by the microfocus radiography and optical analysis methods [11].

The protein growth stimulant treatment had not significant effect on brown rust development compared with the control, besides, in this case the pustules number increased on flag leaf leaf surface by...
54.4%. The greatest effectiveness in reducing the disease rate (by 23.4%) and the pustules number (by 87.8%) was found when using the "Zerebra agro" preparation.

After applying the protein stimulant, a decrease in the degree of wheat powdery mildew development by 15.7% (RM=15±1.3%) was revealed compared with the control (RM=30.7±5.8%), and in the number of leaf spots – by 52.5% (R_{pm}=13.7±0.9 PCs., in the control – R_{pm}=28.6±4.8 PCs.). Organo-mineral fertilizers had insignificant effects on the disease development, however, "Zerebra agro" caused significant reducing number of powdery mildew powder spots - by 51.2% (R_{pm}=14.0±3.4 PCs., in the control - R_{pm}=28.6±4.8 PCs.).

5. Conclusions
The stem and brown rust epiphytotic outbreak in 2010 may be associated with extreme weather conditions of the growing season. The air temperature in July and August 2010 was higher by 28.0% and 19.3%, and the amount of precipitation in this period was lower by 22.7% and 7.0% compared to the long-term average values in 2009-2019. At the same time, the maximum intensity of the brown rust development was revealed in 2014. The opposite trend was discovered in relation to yellow rust and powdery mildew damage. The greatest development of yellow rust was registered in 2019. The least development of the yellow rust and powdery mildew pathogens was observed on accessions from the Northern Europe and the Central Asia/Western Europe; the brown and stem rust – on accessions from the Central Asia, the East, Southeast Asia, Latin (South) America; wheat leaf blotch – from Russia (Asian part). The maximum wheat affection by brown rust was recorded on the accessions from Africa, powdery mildew, wheat leaf blotch and stem rust – from the Asia Minor, Anterior Asia, and the Near and Middle East. In 2016, the maximum biological yield of wheat at minimum values of the development intensity of brown and yellow rust, powdery mildew and root rot was revealed.

The application of the organo-mineral fertilizers and the protein growth stimulant in wheat cultivation in the North-Western region of the Russian Federation is aimed at preserving the potential of biological raw materials, and also involves their integrated use. In addition, reducing the harmfulness of wheat diseases is directly related to maintenance the needs of the food and feed sectors of the agro-industrial complex. The increase in the yield and wheat grain quality reached after the treatments with the studied preparations allows us to speak about the prospects of their use and the need for further research of the wheat biochemical composition to determine the range of applications of raw materials with specified properties in various sectors of the food industry.

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