Ecological selection of winter wheat as a measure of adaptation to climate change

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Abstract. The study presents the results of a five-year investigation (2018-2023) into the performance of winter wheat varieties Kuryanochka 19 and Rat' compared to the standard variety Lgovskaya 4. The research aimed to assess the environmental plasticity and adaptability of these new varieties under varying weather conditions. The best growing conditions were observed in the 2021-2022 season, with an environmental index of 1.2 and maximum yields of 8.28 t/ha for Kuryanochka 19 and 8.46 t/ha for Rat'. The study found that both varieties exhibited high resistance to environmental stress factors, with Kuryanochka 19 and Rat' showing minimum and maximum yields of -2.42 and -2.3, respectively. Additionally, they demonstrated genetic flexibility, with Kuryanochka 19 and Rat' exhibiting flexibility values of 7.07 and 7.31, respectively, compared to the standard Lgovskaya 4 with a value of 6.44. The varieties also displayed low coefficients of variation (11.9-13.4%) and high homeostaticity (51.5-51.6%). The Kuryanochka 19 variety was highly responsive to improved cultivation conditions, with a regression coefficient for the environment (b) of 2.17, whereas the Rat' variety was less responsive, with a b value of 0.65.

1 Introduction

The productivity of agricultural plants has now become increasingly dependent on weather conditions during the plant growing season. Over the recent period, there has been a clear trend towards an increase in air temperature and climate aridity [1].

To a large extent, the productivity of varieties, the size and quantity of the harvest are dependent on unregulated environmental factors, which determine the interannual variability of crop yields by 60-80%, even with the most intensive technologies, and therefore the role of environmental sustainability of plants in the realization of their potential has increased. yield [2].

The ecological system of plant breeding will most effectively and efficiently minimize the adverse effects of climate change on agriculture. The variety must have genetic "flexibility" to a wide range of soil and climatic conditions. The ecologically plastic variety is adapted to all external environmental factors. The creation of such agroecological varieties is an important breeding task. The choice of variety should be determined by the limiting factors of the region in which it will be cultivated [1,2,3].

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In this regard, the greening of plant breeding is not only an objective need of breeding theory and practice aimed at high productivity and sustainability of agrocenoses, resource and energy efficiency, high and environmentally friendly quality of products, but also an effective measure to combat climate change [4].

Evaluation of varieties in environmental variety testing for plasticity and yield stability, resistance to unfavorable growing conditions allows us to select from a large number of newly created varieties with high potential productivity varieties with the greatest degree of adaptation to the conditions of a particular region [5].

Winter wheat is the main grain crop in many regions. It produces higher yields than spring crops. The yield of winter wheat has especially increased in the last decade, when the main areas began to be occupied by highly productive, environmentally flexible varieties [3].

The basis for the creation of new varieties of winter wheat at the Kursk FARC is ecological selection, combining high potential productivity with resistance to abiotic and biotic stress. Thus, together with the leading breeding centers of the Federal State Budgetary Institution "Rostov Agrarian Research Center" and the Federal State Budgetary Institution "National Grain Center named after. P.P. Lukyanenko" varieties of winter wheat were created:

- Kuryanochka 19 is included in the State Register of Breeding Achievements in 2023 in 5,7,8 regions. It is characterized by stable yield, high drought resistance and frost resistance. Resistant to lodging, brown, stem and yellow rust, and snow mold. The variety is highly adaptive, greater returns are achieved when sowing in the medium-optimal time;
- Rat' is included in the State Register of Selection Achievements in 2024 in 5.7 regions. Intended for food purposes. Combines high yield and grain quality. Resistant to snow mold, root rot, brown and yellow rust. The Rat variety is superior to the Grom variety in terms of resistance to biotic environmental factors and ripens 5 days earlier than the standard Lgovskaya 4 variety. It is recommended for cultivation using fertilized non-fallow predecessors.

2 Materials and methods

The research material was new promising varieties of winter wheat. The studies were carried out on the basis of the Federal State Budgetary Institution "Kursk FARC". The research methodology is generally accepted in the selection process using statistical methods.

Indicators of environmental stability and plasticity were calculated using the S.A. method. Eberhart, W.A. Russell [6]. Stress resistance and average yield were determined using the equation of A.A. Russell, J.Hamblin [7], described by A.A. Goncharenko [8].

The material studied was grown in the fields of a special selection crop rotation according to the technical agricultural technology of the region. The soil of the experimental plot is represented by typical chernozem. The predecessor is pure steam. The registration area of the plot is 10 m^2, the experiment is repeated 6 times, the seeding rate is 4 million viable seeds per 1 ha. The arrangement of plots in the first tier is systematic, for the convenience of demonstrating the experiment; in the rest, it is randomized. The sowing method is continuous row. Seeder was SKS 6-10, row spacing was 15 cm.

The object of research is the winter wheat varieties Kuryanochka 19 and Rat'; the Lgovskaya 4 variety was used as a standard.

3 Results and discussion

The meteorological conditions of the growing season during the research period for the growth and development of winter crops varied from year to year. This made it possible to more widely and comprehensively study the influence of environmental stress factors on the studied varieties of winter wheat. However, similar negative agrometeorological phenomena were also observed.

Over the years of research, a clearly defined trend has emerged towards an increase in temperature and a decrease in precipitation during the growing season. This trend had a negative impact on the formation of the winter wheat harvest for the growing seasons 2017-2018, 2018-2019, 2019-2020, 2020-2021, and 2022-2023. Specifically, the lack of effective precipitation during the heading and flowering period, and dry hot weather during the grain filling period, negatively affected the harvest (Table 1).

Table 1. Meteorological conditions: April – July.

Years of research	**Average monthly temperature, ºC**				**Average monthly precipitation, mm**			
	April	**May**	**June**	**July**	**April**	**May**	**June**	**July**
2018	9.3	17.8	18.6	20.3	13.0	44.0	48.0	180.0
2019	8.2	16.2	21.2	18.6	18.1	82.3	24.1	53.0
2020	6.1	11.9	20.7	21.0	26.2	74.1	46.7	72.6
2021	7.8	14.6	20.1	23.1	29.0	76.0	101.0	30.0
2022	7.7	12.0	20.0	19.7	91.4	84.6	10.1	68.5
2023	9.5	14.4	17.5	20.2	49.5	10.8	65.7	125.7
Long-term average	6.7	13.8	17.3	18.9	35.0	50.0	59.0	71.0

Growing seasons 2018-2019 and 2020-2021 were characterized by a lack of moisture in the soil at the beginning of the growing season, which hampered the growth and development of plants, and in 2022-2023. on the contrary, prolonged rains in September and the first half of October made it difficult to sow winter crops. Therefore, sowing was carried out in the first ten days of October, which is one month later than the optimal time. Full shoots of winter wheat were observed 14-17 days after sowing. Thus, the plants went into winter with 1-3 leaves in the so-called “awl” state.

During the years of research, no critical frosts were observed during winter periods. Overwintering of winter crops mainly took place in satisfactory conditions, only in the winter of 2018-2019. Overwintering was complicated by heavy snow cover. With weak soil freezing, conditions were created for the occurrence of fungal diseases and weakening of plants. In the growing season 2019-2020. The overwintering period was characterized by positive air temperatures, which alternated with short-term decreases to small negative values. No stable snow cover has formed. There was growth and development of plants in winter and this led to accelerated consumption of sugars by plants. By the spring growing season, winter crops emerged weakened.

The environmental index by year was calculated based on the average yield of winter wheat varieties. With positive values of the environmental index, the most favorable weather conditions for the growth and development of plants developed, and the worst with negative values (Table 2).

The best conditions were observed in the growing season 2021-2022, where the environmental index i_j was 1.2; the seasons 2017-2018 (0.6) and 2019-2020 (0.1) also had a positive value of the environmental index, which characterizes them as favorable. Seasons 2018-2019, 2020-2021, 2022-2023 had negative environmental indices (-0.9, -0.8, -0.4, respectively).

Table 2. Productivity of winter wheat varieties by year.

Variety	Grain yield, t/ha						
	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**aver.** $\bar{x}$
Lgovskaya 4, st.	6.61	5.63	6.44	5.53	7.36	5.58	6.2
Kuryanochka 19	7.39	5.86	6.83	5.91	8.28	7.00	6.9
Rat’	8.17	6.16	7.60	6.60	8.46	6.62	7.3
Average – X_i	7.4	5.9	7.0	6.0	8.0	6.4	6.8
Environment index I_j	0.6	-0.9	0.1	-0.8	1.2	-0.4	-

Productivity is an important feature of a variety, which is given paramount importance in breeding work. It is caused by a different combination of quantitative traits, which are the result of a complex interaction between the genotype and the external environment. Highly productive varieties must successfully withstand stress factors, make maximum use of favorable conditions and stably maintain yield levels [9].

The yield of the studied winter wheat varieties varied significantly over the years from 5.86 t/ha to 8.46 t/ha. The standard variety Lgovskaya 4 has from 5.53 t/ha to 7.36 t/ha.

The highest yield for the variety Kuryanochka 19 was in 2022 - 8.28 t/ha, and the lowest in 2019 - 5.86 t/ha, for the variety Rat’ the highest in 2022 - 8.48 t/ha, and the smallest in 2029 – 6.16 t/ha.

Productivity depends to a certain extent on productive bushiness, weight of 1000 grains and the number of grains in an ear. Productive tillering plays a vital role in the formation of a high yield, as it is able to compensate for the loss of plants after overwintering and due to any other reasons during the growing season. The intensity of tillering depends on the growing conditions and varietal characteristics of winter wheat. Under favorable conditions (optimal temperature and soil moisture), the tillering period extends and the number of shoots increases [10]. High productive bushiness contributed to a good harvest. On average, over 6 years, the studied varieties stood out in terms of this indicator (Kuryanochka 19 -4.4 and Rat’ - 4.1 productive stems per plant) (Table 3).

Table 3. Economic and biological characteristics of soft winter wheat varieties, 2018-2023.

Variety	Productive tillering capacity, pcs.	Weight of 1000 grains, g	Number of grains, pcs
Lgovskaya 4	3.0	45.9	37.0
Kuryanochka 19	4.4	43.4	42.4
Rat’	4.1	44.6	36.1

The weight of 1,000 grains characterizes the grain size. The larger the grain, the greater the mass of 1000 grains. With equal size, a greater mass of 1,000 grains indicates a greater supply of nutrients in them [11]. Based on the weight of 1,000 grains of 43.4 g for the Kuryanochka 19 variety and 44.6 g for the Rat’ variety, on average for 2018 - 2023, we can conclude that these varieties of winter wheat have fairly large, well-formed grains.

The productivity indicator of the ear is also important for the formation of high yields. Large, well-grained ears during the research period were formed by the Kuryanochka 19 variety (42.4 grains per ear), for the Rat variety this indicator was 36.1 grains, which is slightly lower than standard variety Lgovskaya 4 (37.0 grains).

Along with high yield structure indicators, the studied varieties were distinguished by a high level of adaptability. The difference between the minimum and maximum yields was used to determine the stress resistance of the varieties (Table 3). Based on the obtained values, the studied varieties have a high degree of resistance Kuryanochka 19 ($Y_{min} – Y_{max}$ = -2.42), Rat' ($Y_{min} – Y_{max}$ = -2.3), which is not significantly lower than that of the standard variety Lgovskaya 4 ($Y_{min} – Y_{max}$ = -1.83).

Genetic flexibility was determined by the value $(Y_{min} + Y_{max})/2$, which showed the average yield of the variety under specific stress and favorable conditions. In the experiments carried out, the varieties Kuryanochka 19 and Rat had genetic flexibility of 7.07 and 7.31, respectively, the standard Lgovskaya 4 - 6.44. High values of this indicator indicate a high degree of correspondence between the genotype of the variety and the environmental factor.

Table 4. Adaptability indicators of winter wheat varieties, 2018-2023.

Variety	$(Y_{min} – Y_{max})$	$(Y_{min} + Y_{max})/2$	V,%	Hom	b
Lgovskaya 4	-1.83	6.44	11.9	51.9	0.47
Kuryanochka 19	-2.42	7.07	13.4	51.5	2.17
Rat'	-2.3	7.31	13.0	56.1	0.65

The studied varieties, including the standard, had low variability of 11.9% - 13.4%, which is the result of homestaticity.

Homeostaticity of the Kuryanochka 19 variety is 51.5, the Rat variety is 56.1, which is an important property in the system of relationship between the genotype and the external environment.

The Kuryanochka 19 variety was more responsive to improved cultivation conditions and the regression coefficient for the environment was b = 2.17. For the Rat' variety, the regression coefficient is below one (b = 0.65), i.e. it responded less to changes in cultivation conditions.

4 Conclusion

As a result of the research, it was found that the average value over the years of research for the yield of winter wheat varieties varied from 5.86 to 8.28 t/ha for the Kuryanochka 19 variety and 6.16 – 8.46 t/ha for the Rat' variety. The studied varieties have economically valuable traits indicating high productivity potential, such as: high productive bushiness and 1000 grain weight. At the same time, Kuryanochka 19 revealed 4.4 productive stems per plant and a weight of 1000 grains of 43.4 g, while in Rat' - 4.1 productive stems per plant and a weight of 1000 grains of 44.6 g. Also, the Kuryanochka 19 variety is distinguished by its ear productivity, on average 42.4 grains per ear.

The varieties studied showed a high degree of stress resistance - Kuryanochka 19 ($Y_{min} – Y_{max}$ = -2.42), Rat' ($Y_{min} – Y_{max}$ = -2.3), and genetic flexibility Kuryanochka 19 ($(Y_{min} + Y_{max})/2$ = 7.07), Rat' ($(Y_{min} + Y_{max})/2$ = 7.31). The Kuryanochka 19 variety showed high responsiveness to changes in environmental conditions (b = 2.17). The varieties Kuryanochka 19 and Rat had high levels of homeostaticity (Hom = 51.5 and 56.1) and low values of the coefficient of variation (V = 13.4 and 13.0%), respectively.

Summarizing the findings, we can conclude that ecological breeding methods are a promising direction in a changing climate.

References

1. Ch. Loyce, J.M Meynard, Industrial Crops and Products France, **6**, 271–283 (1997)
2. A.V. Alabushev, E.V. Ionova, *Drought resistance of winter wheat and spring barley varieties under regional drought conditions* (Voronezh, Legion LLC, 2019)

3. N.E Samofalova, N.P. Ilichkina, T.S. Bezuglaya, Grain economy of Russia **6(78)** 53-61 (2021)
4. H. G. Muhu-Din Ahmed, A.S. Khan, et al., Journal of Integrative Agriculture **18(11)** 2483–2491 (2019)
5. N.N. Belyaev, E. A. Dubinkina, Grain legumes and cereal crops **3(27)** 91-95 (2018)
6. S.A. Eberhart, W.A. Russell, Crop Science **6(1),** 36-40 (1966)
7. A.A. Russell, J. Hamblin, Crop Science **21(6)** 27-29 (1981)
8. M. V. Lopez , M Vega , R. Gracia, A. Claver, Industrial Crops & Products **159** 113107 (2021)
9. A. Emelyanova, E.V. Logvinova, BIO Web of Conferences **320** 01002 (2021). DOI: 10.1051/bioconf/20213201002
10. N. Jiang, et al., Rice **13(3)** 5-12 (2020)
11. H. Kabbaj, et al., Front. Plant Sci. **8** 1277 (2017)