

Winter hardiness and its phenotypic stability of breeding lines of winter soft wheat in the forest-steppe conditions of the Middle Volga region

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Abstract. The work is devoted to the study of winter hardiness and its phenotypic stability of breeding lines of winter soft wheat under varying environmental conditions. The factors influencing the winter hardiness of the crop in the research area are considered. A fairly high level of winter hardiness of the studied genotypes of winter soft wheat was established - 3.8-4.7 points. High ecological buffering in terms of phenotypic stability of winter hardiness was revealed for breeding lines of winter soft wheat number 7, 13, 23, 32 - $SF = 1.19-1.28$. Of interest for breeding practice is the breeding line of winter soft wheat number 13, which combines a high level of winter hardiness - 4.6 points and the highest value of phenotypic stability of this indicator - $SF = 1.19$.

1 Introduction

Winter hardiness is one of the most important indicators for a winter crop variety, characterizing its resistance to a complex of unfavorable factors of the winter period [1-2]. The concept of "winter hardiness" N.V. Tupitsyn et al. (2001) consider in a broader sense "...as resistance to stress factors not only in winter, but also in autumn (for example, damage by the Swedish fly, powdery mildew, etc., causing reduced winter hardiness) and spring (for example, March frosts, sharp temperature changes in April, etc.)" [3]. In the implementation of winter hardiness, like any other trait or property of winter soft wheat, the hereditary characteristics of the cultivated variety, or genotype, environmental conditions and their interaction (genotype-environment interaction) contribute. Research conducted by N.N. Zakharova in 2011-2016, it was found that the dominant influence on the winter hardiness of winter soft wheat in the forest-steppe of the Middle Volga region is exerted by environmental conditions - the contribution of this factor is 68.7%. The contribution of the genotype-environment interaction factor is also significant – 17.9% [4]. Due to the fact that the environmental conditions for winter soft wheat in the autumn, winter and spring periods of its cultivation develop differently each time, the phenotypically winter hardiness of the same genotype may vary.

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The purpose of the research was to study the winter hardiness of various breeding lines of winter soft wheat in variety trials of the Federal State Budgetary Educational Institution of Higher Education Ulyanovsk State Agrarian University, as well as the phenotypic stability of this indicator of the tested genotypes.

2 Materials and methods

The material for the research was 10 breeding lines of winter soft wheat of various crossing combinations, studied in 2018-2023. in variety testing of the experimental field of the Federal State Budgetary Educational Institution of Higher Education Ulyanovsk State Agrarian University. The variety Fotinya has been adopted as the standard in the study of winter soft wheat varieties in the Ulyanovsk region.

The soil of the experimental field is leached chernozem, medium deep, medium loamy in granulometric composition. The predecessor is pure steam. Plot area 12.0 m², five-fold repetition. Sowing was carried out within the recommended time frame for the crop under study - from August 25 to September 5 with a seeding rate of 5.0 million viable seeds per 1 ha. Variety tests were carried out according to the "Methods of state variety testing of agricultural crops" [5].

3 Results and Discussion

Successful cultivation of winter soft wheat in the research area depends on a combination of external factors from both warm and cold periods of the year. The pre-sowing period and the autumn growing season of the crop are of particular importance for the growth and development of winter soft wheat plants. The appearance of timely and friendly shoots of winter wheat is the key to its good overwintering and high yields. The winter hardiness of the crop also largely depends on the stage of autumn tillering.

Taking into account the climate warming trend, the autumn growing season of winter grain crops in the Ulyanovsk region is delayed in some years, which leads to overgrowth of plants. This provokes their reduced winter hardiness. A feature of the pre-sowing period of winter wheat (August) and post-sowing period (September-October) is the very high variability of precipitation - $V = 66.0$ and 51.9% , respectively [4]. Therefore, in the conditions of the Ulyanovsk region there is no guarantee of the annual receipt of timely and friendly shoots of winter wheat. Winter soft wheat plants often, under conditions of moisture deficiency, cannot develop well, prepare for the winter period, overwinter and, accordingly, realize their production capabilities.

In the current climatic conditions of the Ulyanovsk region during the cold season (November-March), there is a steady increase in the thickness of the snow cover in winter and an increase in the average daily temperature (Figure), which can cause damping off of winter crops. The results of assessing the hydrothermal conditions of the region during the cold season showed that the amount of precipitation increases by 1.69 mm per year, or 50.7 mm over 30 years, which is statistically significant with $R^2 = 0.1276$. The increase in air temperature during the cold period of the year occurs by 0.06 °C per year or by 1.8 °C over a 30-year period.

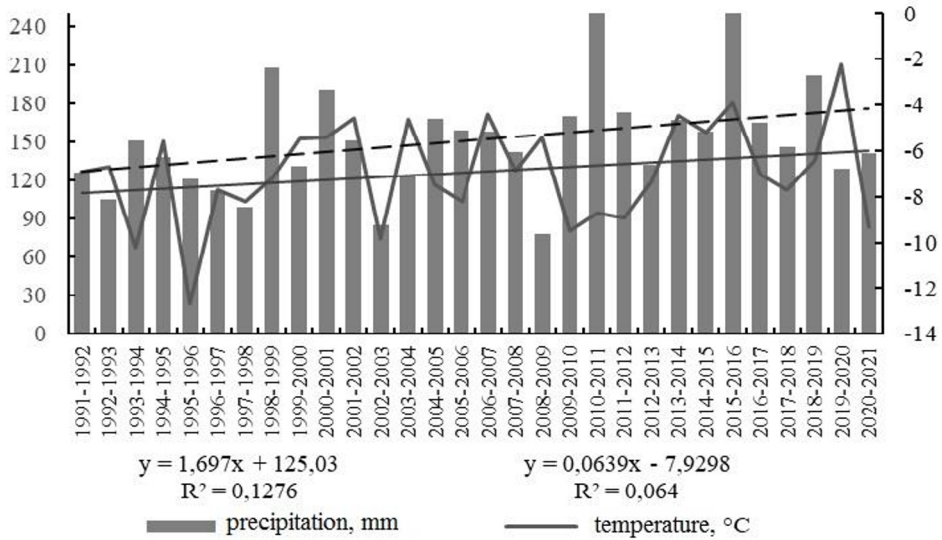


Fig. 1. Dynamics of temperature and precipitation during the cold season (November-March) in the Ulyanovsk region, 1992-2021. [4].

According to A.I. Belolyubtsev (2012), damping off occurs due to warm, unstable winters and long (3-4 decades) stay of plants under heavy snow cover (more than 30 cm), while maintaining soil temperature at the depth of the tillering node close to 0 °C. Under such conditions, the vital activity of winter crops remains increased, which leads to varying degrees of depletion of plants or their death, depending on the temperature of the upper layers of the soil, the condition of the plants in the fall and the degree of their hardening [6].

To avoid damping off of winter soft wheat, some scientists recommend shifting the sowing dates of winter crops in the Ulyanovsk region to a later period [7-8]. The problem of damping off of winter grain crops, apparently, can be solved by creating or selecting varieties with slow development during the autumn growing season, as well as those that are neutral to sowing dates, which makes it possible to sow them at the previously proposed dates [9].

Damping off of winter soft wheat of varying degrees was observed in 2018, 2019, 2021-2023. research. In 2020, overwintering conditions were optimal; there was no differentiation in variety testing between the studied breeding lines. The average winter hardiness of winter soft wheat in variety testing and the winter hardiness of the standard variety Fotinya is 4.4 points.

In the fall of 2017, moisture conditions and temperature regimes for winter soft wheat were favorable. Winter wheat plants went into winter well developed and slightly overgrown, which was the cause of damping off. On average, the winter hardiness of the crop in 2018 was assessed at 4.1 points (Table 1). The index of environmental conditions (I_j) in the winter hardiness of the crop is negative – -0.3 points. The highest values of winter hardiness in the year under study were shown by selection lines number 10 and 69 - 4.8-4.9 points, compared to the standard 4.2 points.

Table 1. Winter hardiness of breeding lines of winter soft wheat (score, 1-5) by years of research.

Variety, breeding line	2018	2019	2020	2021	2022	2023	Average
Fotinha, standard	4.2	3.8	5.0	5.0	3.8	4.7	4.4
6	3.5	4.3	5.0	4.3	3.3	4.0	4.1
7	4.0	4.6	5.0	4.5	4.0	4.6	4.5
10	4.8	4.3	5.0	4.7	3.3	4.8	4.5
13	4.5	4.2	5.0	4.4	4.6	4.6	4.6
17	3.5	3.0	5.0	3.8	3.3	4.1	3.8
23	4.0	4.3	5.0	5.0	3.9	4.9	4.5
25	3.0	4.5	5.0	4.7	4.7	4.0	4.3
32	4.0	4.9	5.0	4.9	4.3	4.7	4.6
62	4.3	4.4	5.0	4.8	3.7	4.9	4.5
69	4.9	3.7	5.0	4.8	4.5	5.0	4.7
Average	4.1	4.2	5.0	4.6	3.9	4.6	4.4
Environment index, <i>I_j</i>	-0.3	-0.2	+0.6	+0.2	-0.5	+0.2	-
HCP ₀₅ , point	0.7	0.5	-	0.5	0.5	0.4	-

An acute moisture deficit in the fall of 2018 led to weak and uneven germination of winter soft wheat. The plants of the studied crop were not able to fully prepare for winter. The winter period was mild, no severe frosts were observed, with a high snow cover. Stress for winter grain crops was a temperature drop of 30 °C in April. The index of environmental conditions (*I_j*) in the winter hardiness of the crop in the year under study is also negative - -0.2 points. Based on the current conditions in 2019, many breeding lines exceeded the Fotinha standard in winter hardiness - 3.8 points, with an average experience value of 4.2 points. These are wheat numbers 6, 7, 10, 23, 25, 32 and 62 with winter hardiness 4.3-4.9 points.

Favorable conditions in the autumn, winter and early spring periods of 2019-2020. research contributed to intensive tillering and excellent overwintering of winter soft wheat. All studied selection lines overwintered at 5.0 points - there was no differentiation in winter hardiness of winter soft wheat.

In the fall of 2020, the humidification conditions and temperature conditions were generally relatively favorable. Only at the end of the autumn growing season of winter soft wheat was a moisture deficit noticeable. The index of environmental conditions (*I_j*) in the winter hardiness of the crop in the year under study is positive – +0.2 points. The winter hardiness of the standard variety was 5.0 points, while the winter hardiness of the entire variety test was also high - 4.6 points (Table 1). A high level of winter hardiness (4.8-5.0 points) in the year under study was shown by selection lines of winter soft wheat number 23, 32, 62 and 69.

In 2021, the pre-sowing and sowing periods were dry, which led to unfriendly and late emergence of seedlings of winter soft wheat - a month after its sowing, which negatively affected the preparation of crop plants for winter. In winter, there was a fairly high snow cover (30 cm). The first assessment of overwintering of winter soft wheat breeding lines in 2022 did not reveal differences between the variety test options. The return of cold weather in April, when the plants had already begun to grow, led to their damage and made it possible to differentiate between the studied genotypes based on resistance to this stress. The index of environmental conditions (*I_j*) in the winter hardiness of the crop is negatively estimated at -0.5 points. High winter hardiness (4.0-4.7 points) was shown by selection lines of winter soft wheat number 7, 13, 25, 32, 69. Winter hardiness of the standard variety Fotinya was 3.8 points, with an average value of 3.9 points in variety testing.

In the fall of 2022, it was dry, which negatively affected the tillering processes and the accumulation of reserve substances in the tillering node. There were no severe frosts in winter, the snow cover was 25-30 cm. Stress factors in the winter and early spring period (in April) were temperature changes, which negatively affected the condition of the plants. However, the average winter hardiness according to variety testing under these conditions was quite high - 4.6 points, while the winter hardiness of the standard was also high - 4.7 points (Table 1). The index of environmental conditions (I_j) in the winter hardiness of the crop in the year under study is positive - +0.2 points. At the level of the standard and above, winter hardiness (4.7-5.0 points) was shown by selection lines number 10, 23, 32, 62 and 69. Maximum winter hardiness was noted in the selection line of winter soft wheat number 69 - 5.0 points.

A study of the winter hardiness of breeding lines of winter soft wheat showed that all of them, with the exception of breeding line number 17, are characterized by high winter hardiness - the average value of the indicator for the entire research period is above 4.0 points (Table 2). The highest value of winter hardiness was found in selection line number 69 - 4.7 points, in comparison with the standard and the average value in the experiment of 4.4 points.

Table 2. Ranking of winter hardiness of breeding lines of winter soft wheat, 2018-2023.

Variety, breeding line	Winter hardiness, point (1-5)			Phenotypic stability, SF
	Average	limits	+/- to standard	
69	4.7	(3.7-5.0)	+0.3	1.35
13	4.6	(4.2-5.0)	+0.2	1.19
32	4.6	(4.0-5.0)	+0.2	1.25
23	4.5	(3.9-5.0)	+0.1	1.28
62	4.5	(3.7-5.0)	+0.1	1.35
7	4.5	(4.0-5.0)	+0.1	1.25
10	4.5	(3.3-5.0)	+0.1	1.52
Fotinha, standard	4.4	(3.8-5.0)	-	1.31
25	4.3	(3.0-5.0)	-0.1	1.67
6	4.1	(3.3-5.0)	-0.3	1.52
17	3.8	(3.0-5.0)	-0.6	1.67
Average	4.4	(3.9-5.0)	-	1.28

The index of phenotypic stability (SF), as a parameter of ecological adaptability, is used to assess the ability of a particular genotype to create a different (narrow or wide) range of phenotypes under changing environmental conditions [10-11]. It is determined by the ratio of the highest value of a genotype trait to the lowest in varying environmental conditions. When $SF = 1$, the genotype is characterized by maximum phenotypic stability, since when it is grown in different environments, the characteristics remain constant. If $SF > 1$, then the phenotype is unstable and its phenotypic instability will increase as this criterion increases [12]. Relatively high ecological buffering in terms of phenotypic stability of winter hardiness was established for breeding lines of winter soft wheat number 7, 13, 23, 32 - $SF = 1.19-1.28$, with the phenotypic stability of this indicator of the standard variety Fotinya $SF = 1.31$. Low phenotypic stability of winter hardiness was established in the selection lines of winter soft wheat number 17 and 25 - $SF = 1.67$.

It is worth highlighting the selection line of winter soft wheat number 13, which combines a high level of winter hardiness - 4.6 points and the highest value of phenotypic stability of this indicator - $SF = 1.19$.

4 Conclusion

Thus, despite the variety of factors influencing the winter hardiness of winter soft wheat in the Ulyanovsk region, in variety testing during the research period, a fairly high level was established for the studied selection lines - 3.8-4.7 points. In 4 years of research (2018, 2019, 2022, 2023), the index of environmental conditions in the winter hardiness of the crop was negative - $SF = -0.2 - -0.5$, in the remaining 2 years it was positive - $SF = +0.2 - +0.6$. High ecological buffering in terms of phenotypic stability and winter hardiness was established for breeding lines of winter soft wheat number 7, 13, 23, 32 - $SF = 1.19-1.28$. Of interest for breeding practice is the breeding line of winter soft wheat number 13, which combines a high level of winter hardiness - 4.6 points and the highest value of phenotypic stability of this indicator - $SF = 1.19$.

References

1. K.V. Moiseeva, Productivity of winter wheat varieties, Agrarian Bulletin of the Urals, **9**, **163**, 30-34 (2017)
2. S.I. Gordey, I.V. Satsyuk, E.P. Urban, Directions and main results of breeding winter wheat (*Triticum aestivum* L.) in the Republic of Belarus, News of the National Academy of Sciences of Belarus. Agricultural Science Series, **57**, **4**, 444-453 (2019)
3. N.V. Tupitsyn, O.G. Zeynetdinova, S.V. Valyaykin, Breeding winter wheat for winter hardiness in the Ulyanovsk region, Grain crops, **1**, 25-27 (2001)
4. N.N. Zakharova, V.A. Isaichev, N.G. Zakharov, Fundamentals of adaptive selection of winter soft wheat in the forest-steppe of the Middle Volga region, Publishing house of Ulyanovsk State Agrarian University, Ulyanovsk, ISBN 978-5-6046667-9-1, 216 (2022)
5. Methodology for state variety testing of agricultural crops, Second issue, Cereals, cereals, legumes, corn and forage crops, Moscow, 194 (1989)
6. A.I. Belolubtsev, O.E. Sukhoveeva, I.F. Asaulyak, Agroclimatic assessment of winter wheat productivity on slope lands, News of the Timiryazev Agricultural Academy, **2**, 46-57 (2012)
7. N.V. Tupitsyn, S.V. Valyaykin, A.V. Zhirnov, Sowing dates for winter wheat, Agriculture, **4**, 20 (2004)
8. A.V. Dozorov, V.A. Isaychev, S.N. Nikitin, Adaptive landscape system of agriculture in the Ulyanovsk region, 2nd ed, Ulyanovsk, 448 (2017)
9. K.N. Biryukov, A.I. Grabovets, M.A. Fomenko, O.V. Besedina, The timing of sowing winter wheat is one of the decisive factors for stable, high-quality harvests on the Don, Grain farming in Russia, **3**, 56-61 (2013)
10. D. Lewis, Gene-environment interaction: A relationship between dominance, heterosis, phenotypic stability and variability, Heredity, **8**, **3**, 333-356 (1954)
11. V.G. Krivobochechek, S.V. Kosenko, I.F. Demina, Ecological variation and phenotypic stability of the yield of winter and spring soft wheat varieties in the forest-steppe of the middle Volga region, Niva Volga region, **3**, **52**, 16-21 (2019)
12. A.A. Goncharenko, Ecological stability of grain crop varieties and selection tasks, Grain farming in Russia, **2**, **44**, 31-36 (2016)