Analysis of winter wheat varieties suitable for cultivation in conditions of flooding

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Abstract. The purpose of the research is to study the reaction of winter wheat varieties to artificially simulated flooding and to identify forms resistant to this factor in the field conditions. In a series of laboratory experiments to study the adaptation of winter wheat seeds to lack of oxygen (hypo- and anoxia) in 2019-2021 and field studies in 2017-2021, the objects of research were 10 varieties of winter wheat. The depressing effect of laboratory hypoxia is manifested in severe germination depression and a large number of defective seeds. The number of rotted seeds ranged from 49.8 to 79.9%, the number of non-normal germinated seeds ranged from 1.3 to 8.4%. The following varieties were characterized by a low degree of germination process inhibition: Angelina (43.7%), Anfisa (41.6%), Boyarka (31.5%). Moreover, the coefficient of variation (CV) of germinating seeds over the years in these varieties was the lowest – 15.3-26.4%. A high degree of conjugacy of the selected varieties with the HTC_Min September was noted: plant germination in autumn (r=+0.864 ...+0.982), the number of preserved plants after overwintering (r=+0.229...+0.745), yield (r=+0.454 ...+0.622). The positive conjugacy of the $HTC_M$of March on the number of preserved plants after overwintering was revealed (r=+0.601). Field studies have shown that the largest number of preserved plants in the field were formed by the varieties Anfisa (77.8%), Boyarka (72.8%), and Angelina (74.4%). These varieties can be recommended for conditions of lowlands, poorly permeable soils, and other places where the soil may be waterlogged in autumn or spring, including accumulation and stagnation of precipitation.

1 Introduction

Multiple stressful manifestations of the external environment, such as flooding, drought, salinization, cold, exposure to high temperatures, and other factors, reduce the productivity of agricultural crops [1-2]. The complexity of breeding work to increase resistance to these stress types consists in the presence of a large complex of genes that control the response of plants to abiotic stresses, many of these genes are also characterized by complex regulation [3-4]. Currently, genetic improvement of agricultural crops to increase their resistance to

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abiotic stresses is an economically urgent task for the agro-industrial complex, an important crop of which is winter wheat. A significant indicator of the formation of the yield of winter grain crops is the choice of the optimal variety for a specific agricultural zone [5-7]. The importance of such a statement of the question is obvious, since the conduct of modern agriculture requires specialists to know not only the theoretical foundations of the problem, but also the ability to apply various physiological characteristics of the state of plants in extreme conditions. The adaptability of plants to hypoxia conditions is carried out at the morphological, cellular, biochemical, and genetic levels. The study of plant adaptation to lack of oxygen (hypo- and anoxia) is no less important than the study of their adaptive reactions to the action of other environmental factors [8]. In most works, significant differences in the response of varieties to stress have been demonstrated, various mechanisms, and above all, juvenile resistance, have been analyzed [9-11].

Breeders' interest in studying the effect of abiotic stress factors on winter wheat plants, including flooding, has arisen for a long time and with good reason, since it is important to solve issues of this nature. The depressing effect of excessive moisture affects the growth and development of wheat with a close occurrence of groundwater, especially in spring, when the waters rise high and cover young winter wheat crops. In lowlands in spring, winter wheat is often flooded with water, which is formed when snow melts. The degree of oppression depends on the excess moisture in the soil, as well as on the duration of the flooding period and the age of the plants.

Studies conducted by several Russian, Chinese, Japanese, Australian scientists, as well as at the International Wheat and Corn Center (CIMMYT) indicate that modern varieties are mostly unstable to flooding [12-13].

It is noted that the current situation in the development of breeding programs in recent years, and especially in regions with risky farming, is largely due to the lack of sensitive markers that allow objectively and accurately screening the initial breeding material to select the most resistant varieties to certain types of stress and their further inclusion in the hybridization program.

It is believed that plants adapted to one type of stress are often more adapted to other types of abiotic stresses. Thus, plants can withstand several types of stress factors that have an evolutionary advantage over these plants [14-15].

Thus, considering the above, the competent use of the appropriate varieties, considering the geographical and soil-climatic features of the region, is a necessary condition for obtaining stable yields of winter wheat.

The purpose of the research is to study the reaction of winter wheat varieties to artificially simulated flooding and to identify forms resistant to this factor in the field, with further recommendation of the selected varieties for cultivation and inclusion in a further breeding program to increase resistance to this stress factor.

2 Materials and methods

In a series of laboratory experiments in 2019-2021 to study the adaptation of winter wheat seeds to lack of oxygen (hypo- and anoxia) and field studies in 2017-2021, the objects of research were 10 varieties of winter wheat of local breeding, including 3 that are under State testing: Anfisa, Ivita, and Boyarka. A popular method of diagnosing an artificial stressor in the form of excess moisture in the laboratory by flooding seeds in water is the method of resistance identification proposed by E.K. Beletskaya [16]. The effectiveness of this assessment is justified not only by its short duration, but also by the fact that plants in the seedling phase are most sensitive to stress and differences between genotypes during this period, persist as a genetic trait in adult plants [12, 17-18].

The climate of the Ryazan region is typical for the central part of the European part of Russia belongs to the zone of unstable humidification, due to frequent dry periods and uneven precipitation by season. The hydrothermal conditions of 2017-2021 differed significantly in the temperature regime and the amount of precipitation that varied during the growing seasons. According to the meteorological data of the ISA-a branch of the FSBSI FSAC VIM, the average monthly indicators of precipitation and air temperature, as well as the average monthly values of the hydrothermal coefficient (HTC_M), as an indicator affecting the productivity of various crops, were calculated [19-20]. In field studies, the yield of winter wheat was considered in allotment crops with an area of 10 m^2, the repetition was 4-fold. The seeding rate is 5.0 million germinating seeds per hectare. The soil of the experimental site is dark gray forest, heavy loamy in granulometric composition. Agrochemical indicators: pH_{sol}. (GOST 26483-85) – 4.88 units; organic matter content (GOST 26213-91) – 5.60 %; content of mobile phosphorus (GOST R 54650-2011) — 378.0 mg/kg of soil, mobile potassium (GOST R 54650-2011) – 275.0 mg/kg of soil, nitrate nitrogen (GOST 26951-86) – 41.4 mg/kg, ammonium nitrogen (GOST 26489-85) – 4.43 mg/kg, exchangeable magnesium (GOST 26487-85) – 2.16 mmol/100g. Statistical processing of experimental data by methods of correlation and variational analysis was carried out using appropriate methods for these studies [21].

3 Results and discussion

Ryazan region is an agrarian region for which land reclamation has traditionally played an important role. Considering the geographical and soil-climatic features of the region, in which sandy loam podzolic-boggy soils predominate in its north and east, and chernozems in the south [22], these soils are characterized by high density, low water permeability, weak mobility of nutrients [23-25], and, consequently, higher harmfulness of the flooding process [12] (fig. 1).

Fig. 1. Soaking of winter wheat plants at production sites.

Using various methods for determining plant resistance, it is possible to identify the possibility of growing them in a particular ecological environment already at the early stages of growth and development [26]. As a result of laboratory studies on the ability to germinate in conditions of flooding of winter wheat seeds, significant varietal features of these cultivars are manifested. It can be argued that winter wheat is vulnerable to this stress. It was found that under conditions of artificial hypoxia, a delay in the development of germination begins to manifest, expressed in the suppression of seedlings and rotting of seeds (Table 1).

Table 1. Varietal reaction of winter wheat plants to the effects of hypoxia.

Sample	Number of seeds, %			
	normally germinating	Variation coefficient (C_V), %	defective	
			abnormally germinating	rotten
Danaya	29.9	66.7	8.4	61.7
Angelina	43.7	15.3	6.5	49.8
Inna	24.2	46.7	5.2	70.6
Moscovskaya 39	25.7	81.9	3.3	71.0
Viola	31.3	65.1	6.8	61.9
Galatea	25.0	91.6	2.4	72.6
Anfisa	41.6	22.6	5.8	52.6
Boyarka	31.5	26.4	7.8	60.7
Ivita	18.8	63.9	1.3	79.9
Galina	21.3	75.3	3.8	74.9
Average for varieties	**29.3**	**55.6**	**5.1**	**65.6**
Variation coefficient (C_V), %	27.8	-	46.0	14.9

The depressing effect of water stress on the studied cultivars was manifested, first, in a significant depression of germination and a large number of defective seeds (abnormally germinated and rotted). The number of rotted seeds ranged from 49.8 to 79.9%, the number of abnormal germinating seeds ranged from 1.3 to 8.4%. The highest ability of varieties to resist the effects of flooding was manifested in 2021 (average resistance at 32.4%), the lowest - in 2018 (11.7%). The following varieties were characterized by a low degree of germination process inhibition: Angelina (43.7%), Anfisa (41.6%), Boyarka (31.5%). Moreover, the coefficient of variation (C_V) of germinating seeds over the years in these varieties was the lowest – 15.3-26.4%, which is 50.2-71.1% higher than the average germination rates according to experiment.

The use of this method for preliminary testing of winter wheat genotypes for resistance to flooding and the selection of promising material for subsequent studies in the field of breeding were compared with the further study of these varieties in contrasting conditions of vegetation experiment. Field studies were associated with autumn vegetation and overwintering, as well as the most serious period of vegetation, which determines how productive the overwintering of winter crops will be - the turn of winter and spring, in our case – March-April months. This is due to the fact that with an increase in average daily temperatures and the imminent snow melting, meltwater begins to accumulate in low places of the relief, which floods the plants. With a long process of this flooding, unfavorable conditions are created for winter crops, including wheat.

Correlation analysis between the number of winter wheat plants during the growing season and monthly environmental conditions (HTC_M) revealed a high degree of dependence between them. Since sowing was carried out mainly on September 4-5, seedlings were observed on September 11-13, and the beginning of tillering was observed on September 24-29, the conditions of germination and the beginning of tillering of wheat plants depended on the HTC_M of September. This period is characterized by a number of important processes: formation of leaves, tillering node, formation of new shoots and nodular roots, accumulation of plastic substances that determine the resistance of plants to adverse conditions of overwintering. All the years of the study, September was characterized by optimal weather conditions for the growth and development of this crop. The HTC_M of September had a particularly strong effect on the germination of plants in autumn (r=+0.573), the number of plants preserved after overwintering (r=+0.556) and, in general, on the yield of winter wheat (r=+0.499) (Table 2). The varietal specific reaction for this period was also revealed. The highest degree of conjugacy of the studied indicators with the HTC_M of September was noted in the varieties of Anfisa, Boyarka, and Angelina selected by us during research: germination of plants in autumn (r=+0.864 ...+0.982), the number of preserved plants after overwintering (r=+0.229 ...+0.745), yield (r=+0.454...+0.622).

The turn of winter and spring varied greatly by year. The analysis of the obtained weather conditions for this period identified two contrasting years – 2020 and 2021. In 2020, the beginning of the resumption of spring vegetation was very early (I-II decade of March) from the last years of observations. The average daily temperature of this month is 10.3°C higher than the average annual values, and there was little precipitation - 7.6 mm. Intensive melting of a small amount of snow (the winter months were characterized by unstable snow cover up to 10-15 cm), considering sharp increase in active temperatures, provoked a short standstill of meltwater (2-3 days). The number of surviving plants after overwintering this year was the largest – 281-326 pcs/m^2.

The winter months of 2021 turned out to be snowy – a stable snow cover was formed, the height of which reached more than 40 cm. The March regime was characterized by sharp fluctuations in average daily temperatures. The average monthly air temperature was -1.7°C, which is 3.1°C higher than the average annual values. Several days were observed when the air temperature reached - 23 – -26 °C. In the 3rd decade of March, positive daily average air temperature values were already observed, which averaged +2.7°C. In this year, the beginning of the resumption of spring vegetation was late – I-II decade of April. The average daily temperature of this month is 4.7°C higher than the average annual values, and precipitation fell 152% more than the average annual data. This trend was also characterized by the second decade of April with precipitation exceeding by 206%. As a result, soils that already have a sufficient amount of meltwater received an additional source of precipitation in the form of rain, which, in turn, caused flooding and waterlogging of the soil during this period for a long time. The number of surviving plants after overwintering this year was the smallest – 155-263 pcs/m^2.

The positive conjugacy of the HTC_M of March on the number of preserved plants after overwintering was revealed (r=+0.601), and all the studied varieties were sensitive to this period, with a varietal reaction from r=+0.452 (Galatea) to r=+0.676 (Danaya, Viola).

Table 2. The number of germinated and preserved winter wheat plants and their conjugacy during the growing season with the HTC of September and April, 2017-2021.

Varieties	Number of plants per 1 m^2			Overwintering, %	Preservation, %	Yield, t/ha
	in autumn	in spring	before gathering			
Danaya	269.3	263	176.5	98.8	65.5	5.1
Angelina	251.5	278.7	187.0	97.8	74.4	4.9
Inna	278.0	284.7	179.5	99.2	64.6	5.0
Moscovskaya 39	291.8	289	192.0	98.7	65.8	4.0
Viola	264.8	248.3	159.0	97.4	60.0	5.7
Galatea	265.8	244	163.0	98.5	61.3	5.5

Anfisa	236.5	230.3	184.0	98.0	77.8	5.3
Boyarka	267.3	263.7	194.5	98.3	72.8	5.4
Ivita	266.8	248.7	192.0	98.6	72.0	4.9
Galina	256.3	250.7	181.5	98.8	70.8	4.7
average	**264.8**	**260.1**	**180.9**	**98.4**	**68.5**	**5.1**
Conjugacy with the HTC_M of September	+0.573*	+0.556*	+0.142	+0.338*	-0.429	+0.499*
Conjugacy with the HTC_M of March	-	+0.601*	+0.149	-0.243	-0.428	-0.07
Conjugacy with the HTC_M of April	-	+0.130	+0.305*	+0.104	-0.08	+0.058

* – Confidence probability $P \geq 0.95$

According to the meteorological data of the ISA-branch of the FSBSI FSAC VIM, the indicators of daytime air temperature and precipitation for the entire research period are calculated, characterized by extreme unevenness of their distribution over the phases of winter wheat development. Absolutely all the years of observations were characterized by an increased temperature regime in comparison with the average long-term values. A clear increase in daytime and average air temperatures during the research period in June-July, as well as a critically low amount of precipitation or its absence, gave rise to the development of soil and air drought.

The conducted field studies also showed that the largest number of preserved plants during the full vegetation of winter wheat were formed by the varieties Anfisa (77.8%), Boyarka (72.8%), and Angelina (74.4%). It should be noted that the selected varieties that are under State Variety Testing exceed the productivity of the standard Angelina variety by 0.4-0.5 t/ha and have increased overwintering.

4 Conclusions

Reclamation of moistened and wetlands is a costly measure. Therefore, the most rational method of eliminating losses is considered to be the creation of varieties that are immune to excess moisture, in which diagnostics of the condition of plants on provocative backgrounds becomes of great importance [12]. Data were obtained on the high negative effect of severe waterlogging on winter wheat plants, which manifests in the depressed state of seedlings and their defective development, including rotting and complete death of seeds. Based on the analysis of field data on the germination and preservation of plants during the growing season of the varieties studied by us, it can be stated that the varieties Anfisa, Boyarka, and Angelina isolated in the course of laboratory and field studies are the most resistant to flooding conditions and are characterized by increased spring preservation of plants in different periods of resumption of spring vegetation according to HTC_M. These varieties can be recommended for conditions of lowlands, poorly permeable soils, and other places where the soil may be waterlogged in autumn or spring, including accumulation and standstill of precipitation. It is also proposed to include these varieties in breeding programs of crossing to increase resistance to flooding.

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