Comprehensive assessment of the breeding material of winter wheat for resistance to moisture deficiency and productivity

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Abstract. The North Caucasus, occupying 12% of the total agricultural land fund of Russia, produces a fifth of the grain. However, frequent droughts hinder the production of stable high yields of winter wheat in this region. Their probability here is 25-50%. In addition, almost every year in the second half of the growing season, winter wheat crops to one degree or another experience a negative effect of moisture deficiency. The article presents the results of laboratory and field studies of the breeding material of winter soft wheat on drought resistance and productivity. Determination of plants resistance to moisture deficiency in the laboratory experiment was carried out based on the seeds ability to sprout in highly osmotic sucrose solutions, which allowed to identify samples with high water absorption capacity. The criterion for drought resistance in field conditions were the varieties productivity, the selection drought susceptibility indices (DSI), plants productivity index (PPI), stress resistance and genetic flexibility. Based on the study results, the main methods for assessing drought resistance are recommended. These include a laboratory method for sprouting seeds in osmotic sucrose solutions and direct method for calculating drought resistance according to the plant productivity index.

1. Introduction

Winter wheat selection for drought resistance is of particular importance in the context of global warming. Climate changes for the foothills were reflected in the temperature increase and a decrease in precipitation during the autumn-winter period. Precipitation is extremely uneven, mainly in May and June. Winters have become with little snow and warm, and there is an annual soil drought during the autumn growing season of winter grain crops [1].

Winter wheat is considered a relatively drought-resistant crop that uses water effectively due to its well-developed root system. However, the lack of moisture in every critical period of water consumption (the stage of sprouting, autumn tillering, the period from booting to heading, grain plumpness) leads to slowing down the processes of morphogenesis and yield depression, including by reducing a spike length, grain number per spike, 1000-grain weight. In addition, dry weather during stages of sprouting and autumn tillering reduces the crops readiness for overwintering [2-3].

When selecting for drought resistance, it is important to identify plants that are able to use moisture sparingly in the first stages of development in conditions of its lack.

There is a whole group of indices to assess the level of drought resistance: according to the area of...
leaf apparatus during the grain formation and plumpness, water-holding capacity of leaves, the coleoptile length, intensity of transpiration, etc. [4-5]. Many methods are time-consuming, cumbersome, and unacceptable in field conditions.

Indirect methods to assess relative drought resistance include a method for determining seed sprouting in a solution with high osmotic pressure that simulates a lack of water (for example, a sucrose solution). Varieties that can germinate under osmotic stress and form a powerful primary root system can later be more drought-resistant in natural field conditions. This method allows to identify promising drought-resistant material at early stages of organogenesis, which is important when selecting winter varieties of autumn drought-resistant crops [6].

2. Materials and methods

11 samples of winter wheat were used as the research material. The phenological observations were performed by the method of State Strain Testing [7]. Statistical processing of the results was performed using the method of Dospekhov [8]. Parameters of stability and environmental plasticity were calculated using the method of Eberhart and Russell as presented by Pakudin and Lopatina [9]; the linear regression coefficient (bi), or plasticity coefficient was calculated. The varieties resistance to stress (Ymin – Ymax) and genetic flexibility ((Ymax + Ymin)/2) were determined by Rossieille and Hemblin as presented by Goncharenko [10]. The drought susceptibility index was calculated using equation given by Fischer and Maurer as presented by Yanchenko et al. [11]:

\[ DSI = \frac{1 - \frac{Y}{Y_P}}{1 - \frac{X}{X_P}} \]  

where \( DSI \) – the drought susceptibility index; \( Y \) – yield of the variety in a dry year; \( Y_P \) – yield of the variety in a good year; \( X \) – average yield for all varieties in a dry year; \( X_P \) = average yield for all varieties in a good year.

When assessing genotype-environment interaction by quantitative indicators of productivity, we used the developed plant productivity index (PPI) [12]:

\[ PPI = \frac{GN \cdot GW}{SL} \]  

where \( GN \) – grain number, pcs., \( GW \) – grain weight per spike, g, \( SL \) – spike length, cm.

The drought resistance was assessed in laboratory conditions according to the seeds ability to germinate in highly osmotic sucrose solutions (10%, 15%, 20%).

3. Results and discussion

Adaptive selection and seed production are an integral part of adaptive crop production, and they play a leading role in the agriculture biologization and ecologization. The peculiarity of adaptive selection is its regional character and ecological focus on more complete compliance of the variety with soil and climatic cultivation conditions [13-14]. The main directions of adaptive selection are: orientation of the selection on real productivity and stability at all stages of the selection process [15-16].

The efficiency and speed of selection for adaptability depends on the amount of incoming information that characterizes the genotypes. For this, different methods describing productivity, drought resistance, environmental stability, plasticity, resistance of varieties and hybrids, etc. are used to assess the general and specific adaptive capacity of the breeding material [17-18].

It is possible to assess the breeding material for drought resistance directly in the field by direct indicators, comparing the grain yield and quality of varieties in dry and favourable in humidity years.

Indirect methods for assessing drought resistance include the method of seeds sprouting on osmotic sucrose solutions of different concentrations. The high percentage of sprouted seeds, length of their roots and coleoptile reflects the ability of the variety to use the scarce reserves of soil moisture, which is very important for our region during the annual soil drought in the autumn-winter period.

The purpose of our research was a comprehensive assessment of the breeding material for drought resistance, productivity and adaptability to the conditions of the foothills in the North Caucasus.

To assess the breeding material for drought resistance, we selected the method of seeds sprouting
on osmotic sucrose solutions. The advantage of this method is its representation and informativity.

Table 1 shows the results of the experiment on sprouting winter wheat seeds on sucrose solutions of 10%, 15% and 20% concentration with an osmotic pressure of 600, 1000, and 1400 kPa, respectively, simulating conditions of physiological soil drought. The method allows to determine the relative drought resistance of winter wheat breeding samples at the early stages of ontogenesis by number of sprouted seeds in solutions with high osmotic pressure. The standard is a drought-resistant and heat-resistant variety Albatros odessky. According to the results of the experiment, none of the studied breeding samples exceeded the standard in drought resistance (table 1).

**Table 1.** Assessment of winter wheat breeding samples for relative drought resistance by the ability of seeds to germinate on highly osmotic sucrose solutions.

| Variety           | Control Germination, % | Root length, cm | 10% Germination, % | Root length, cm | 15% Germination, % | Root length, cm | 20% Germination, % | Root length, cm |
|-------------------|------------------------|-----------------|--------------------|-----------------|--------------------|-----------------|--------------------|-----------------|
| Albatros odessky  | 100                    | 6.0             | 93.9               | 2.6             | 89.2               | 1.2             | 59.5               | 0.5             |
| Veldava           | 100                    | 5.9             | 90.0               | 2.8             | -                  | -               | -                  | -               |
| Pylypivka         | 100                    | 5.6             | 88.8               | 2.6             | -                  | -               | -                  | -               |
| Malvina           | 98.2                   | 5.7             | 82.2               | 1.9             | -                  | -               | -                  | -               |
| Areal             | 97.5                   | 5.3             | 80.0               | 1.4             | -                  | -               | -                  | -               |
| Malvina           | 99.4                   | 4.8             | 73.0               | 1.5             | -                  | -               | -                  | -               |
| Antonina          | 98.0                   | 5.0             | 72.0               | 1.5             | -                  | -               | -                  | -               |
| Alauda            | 96.3                   | 4.7             | 76.8               | 1.8             | -                  | -               | -                  | -               |
| Solara            | 97.8                   | 4.9             | 79.5               | 1.7             | -                  | -               | -                  | -               |
| Don 93            | 98.6                   | 5.3             | 68.1               | 1.3             | -                  | -               | -                  | -               |
| Zorepad           | 98.3                   | 5.2             | 82.6               | 2.2             | -                  | -               | -                  | -               |

All the studied varieties could not sprout on sucrose solutions up by 10%, while the seeds of Albatros odessky variety showed 60% germination on the sucrose solution with the osmotic pressure of 1400 kPa or 20%, they also had a maximum root length: 6.0, 2.6, 1.2, 0.5 cm, respectively. More than 80% germination on 10% sucrose solution was shown by the varieties Veldava, Pylypivka, Zorepad, Malvshka, Areal. The root length was 2.8, 2.6, 2.2, 1.9, 1.4, respectively. Germination at the level of 80% was observed in the varieties: Solara, Alauda, Malvina. Variety Don 93 showed less than 70% germination.

Regression coefficients (bi) were calculated to describe the response to changes in growing conditions. This coefficient describes the average response of the variety to changing environmental conditions and indicates their plasticity, as well as stress resistance indices, genetic flexibility of the variety, homeostaticity and variances of the varieties stability (table 2).

The table shows the environmental condition indices (lj) to characterize the cultivation conditions. Index values can have positive or negative signs. Favourable conditions to form productivity have a positive sign lj=0.1 (2019), less favourable climatic conditions – j= -0.04 and -0.06 (2017-2018).

Varieties differed in average yield. High yield was observed in the varieties: Areal (1.06 kg/m²), Malvina (0.87 kg/m²), Antonina (0.86 kg/m²), Albatros odessky (0.82 kg/m²). The highest stress resistance (Ymin-Ymax) was observed in the varieties: Albatross odessky (-0.03), Pylypivka (-0.04), Don 93 (-0.06), Zorepad (-0.07), Malvina (-0.08). Veldava variety was characterized by low responsiveness to improving environmental conditions in the studied set of varieties.

Productivity obtained under contrasting conditions is described by the formula (Ymax + Ymin)/2 and reflects the average yield of the variety under contrasting (stressful and non-stressful) conditions and characterizes the genetic flexibility of the variety, i.e. its ability to compensate for losses. Genetically flexible genotypes were varieties: Areal, Antonina, Malvina with indices 1.1; 0.87 and 0.87, respectively. These varieties have a high degree of compliance between the genotype and environmental factors (table 2).

The regression coefficient of productivity indicators of bi varieties describes their response to
changing cultivation conditions. In the case of a high coefficient value \(bi>1\), the variety will be characterized by greater responsiveness. Responsive to improving growing conditions varieties are more demanding to high levels of agricultural technology, and will give maximum response. If the regression coefficient \(bi<1\), the variety will respond weaker to changes in environmental conditions. When \(bi = 1\), there is the compliance between the yield of the variety and growing conditions.

**Table 2.** Average yield and adaptation parameters of winter wheat varieties.

| Varieties      | Yield, kg/m² | Average, Xi | DSI | Ymin-Ymax | Ymax+Ymin/2 | bi   | PPI |
|---------------|--------------|-------------|-----|-----------|-------------|------|-----|
| Albatros odessky | 0.83         | 0.80        | 0.8 | 0.6       | -0.03       | 0.82 | 1.46| 9.8 |
| Veldava       | 0.63         | 0.67        | 0.68| 0.8       | -0.13       | 0.66 | 0.3 | 6.4 |
| Pylypivka     | 0.70         | 0.81        | 0.76| 0.9       | -0.04       | 0.72 | 0.46 |7.4 |
| Malvina       | 0.68         | 0.94        | 0.78| 3.5       | -0.26       | 0.78 | 1.91|9.3 |
| Areal         | 0.97         | 1.21        | 1.06| 2.5       | -0.27       | 1.1  | 1.61|10.0|
| Malvina       | 0.87         | 0.91        | 0.87| 0.5       | -0.08       | 0.87 | 0.41|8.9 |
| Antonina      | 0.83         | 1.0         | 0.86| 2.1       | -0.26       | 0.87 | 1.46|7.7 |
| Alauda        | 0.75         | 0.90        | 0.79| 1.4       | -0.11       | 0.75 | 0.67|6.5 |
| Solara        | 0.63         | 0.84        | 0.71| 3.1       | -0.20       | 0.70 | 2.49|7.8 |
| Don 93        | 0.79         | 0.83        | 0.79| 0.6       | -0.06       | 0.77 | 0.34|6.8 |
| Zorepad       | 0.80         | 0.85        | 0.81| 0.8       | -0.07       | 0.78 | 0.41|8.0 |
| Average, \(X_j\) | 0.77         | 0.89        | 0.81|           |             |      |     |
| Condition indices | -0.04        | -0.06       | 0.1 |           |             |      |     |

The drought susceptibility index (DSI) reflects the varieties stability in unfavourable for moisture availability years. The lower its value, the more stable the variety. DSI values obtained in the calculation according to equation (1) up to one had the following varieties: Albatros odessky, Malvina, Veldava, Pylypivka, Don 93, Zorepad.

The PPI index correlates well with the actual productivity of varieties \(r=0.63\), the higher the index, the higher the productivity. The index is calculated based on three-year average productivity values according to equation (2). High PPI values were shown by varieties: Areal (10.0), Albatros odessky (9.8), Malvina (9.3), Malvina (8.9). Due to its good drought resistance, Veldava is characterized by stable production over the years and high stress resistance. The results of the laboratory experiment are more comparable to the results of field tests on PPI index.

**4. Conclusion**

Selection of winter grain crops for the foothills of the Central Caucasus is aimed at the adaptability of varieties to the cultivation conditions, high and stable productivity. Adaptive, high-yielding varieties must be resistant to autumn and spring drought, lodging and diseases. The success of selection in creating drought-resistant varieties depends largely on the correct assessment of the resistance level of the created varieties and hybrids.

The results obtained give grounds to assert that when assessing for drought resistance, it is necessary to use a set of methods that can be used to assess the drought resistance of winter wheat varieties at the early stages of plant development, and to identify genotypic differences in the adaptation ability of varieties. These methods include: indirect, laboratory method for assessing drought resistance for seeds sprouting on highly osmotic sucrose solutions. Germination, number and length of roots, coleoptile length are considered. Direct method for calculating drought resistance by productivity elements. The most informative is the plant productivity index PPI, since it has a close correlation with productivity, helps to identify resistant genotypes to bio - and abiotic stressors, i.e. allows to judge the adaptive properties of the breeding material and can be used as an adaptation marker. The highest relative drought resistance and stable productivity were characterization for varieties: Albatros
odessky, Malyshka, Areal, Malvina, Zorepad. The selected samples can be considered promising for further use in selection for drought resistance in the foothills of the Northern Caucasus.

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