Physiological assessment of drought resistance and heat resistance of spring barley varieties by laboratory methods

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Abstract. One of the main conditions for the stable growth of grain production of spring barley is the expansion of sown areas, using varieties with high adaptive properties and capable of providing high yields in a changing climate. The purpose of the work is to determine the drought resistance and heat resistance of varieties and lines of spring barley using laboratory methods. The article presents studies of physiological indicators of resistance at an early stage of plant development to extreme environmental factors (drought and relatively high air temperatures). The physiological method of early diagnostics of seeds and seedlings provides information on the general initial level of physiological and biochemical processes in germinating seeds under stressful conditions and allows one to get an idea of the resistance of adult plants. Such a primary assessment gives grounds for the selection of promising samples for a deeper study of their stability. When determining the resistance of varieties and lines of spring barley to abiotic stressors, samples were identified that, in terms of a set of indicators (drought resistance, heat resistance, degree of depression, index of complex resistance and growth of germinal roots), values significantly exceeding the standard variety Ratnik (36.6; 91, 1; 2.13%; 184.3 rel. units and 2.78 cm, respectively): Zernogradsky 1717 (45.6; 84.0; 5.19%; 194.8 rel. units and 4.76 cm), Zernogradsky 1716 (4.3; 83.4; 5.43%; 188.0 relative units and 3.67 cm), Zernogradsky 1701 (36.2; 87.0; 3.17%; 15 relative units and 2.56 cm).

1 Introduction

Spring barley is a cereal crop that belongs to the spring breads of the first group. In the Russian Federation, it is the leading food, technical and fodder crop, the sown area is 7315.5 thousand hectares, and in the Rostov region it reaches up to 237.6 thousand hectares [1]. The national economic value of barley is determined by a number of positive features, such as relatively high yield, early maturity (short growing season from 70 to 80 days), good adaptability to various soil and climatic conditions, and versatile use of the crop [2].

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The Rostov region is characterized by a temperate continental climate with a combination of high air temperatures and lack of moisture. The amount of precipitation per year varies from 450 to 600 mm, the hydrothermal coefficient is from 0.80 to 0.85. The average annual temperature in the southern zone of the Rostov region is 9.8–10.8 °C.

Summer in the region is hot, while the absolute maximum temperature in some years reaches 40–41°C [3].

In recent years, there has been a steady increase in air temperature and a decrease in precipitation during the growing season of spring crops (April–July), coinciding with critical phases in the development of plants, which significantly reduce yields.

Plants of spring barley at different stages of development react differently to the deficit of soil moisture and temperature fluctuations [4]. The value of the transpiration coefficient (water consumption per unit of dry matter) is about 400, if the moisture retention in the soil is less than double hygroscopic moisture, then the growth and formation of plant organs completely stop. Barley has a poor development of the root system and its assimilating ability; it tolerates spring drought worse, therefore, optimal moisture is needed throughout the growing season [5–6]. The culture is most sensitive to insufficient moisture supply from the phase of entry into the tube, since during this period the reproductive organs begin to form. Precipitation deficiency leads to high sterility of flowers (pollen infertility) and a decrease in the number of grains, and ultimately to a significant decrease in productivity [7].

To obtain a stable yield with high grain quality, spring barley varieties must be adapted to adverse climatic conditions [8]. High-quality and valuable grain is a grain with a high protein content, which is formed at high temperatures in the grain filling phase. Most agricultural plants experience stress when there is a moisture deficit and temperature rises to 35–40°C, while the physiological functions of the plant are inhibited, and at a temperature of about 50°C, protoplasm coagulation and cell death occur, which leads to a decrease in plant productivity [9–10]. In connection with changing climatic conditions, there is a need to create and introduce into agriculture more resistant spring barley varieties with high productivity and grain quality. The combination of such properties in one genotype can only be obtained with a special selection of pairs for crossing and the use of field and laboratory methods for assessing the source material in the selection process [11–12].

Laboratory studies of plants at an early stage of ontogenesis, i.e. during the period of endosperm use, in breeding for the resistance of varieties for zones prone to spring droughts, which have a detrimental effect on seeds and seedlings of spring crops, allows one to judge the ongoing physiological and biochemical processes in germinating seeds under stress and get an idea of adult plants. The basis for determining the drought resistance of field crops is to determine the ability of seeds to germinate and the growth of seedlings in osmotic solutions simulating a lack of moisture, as well as to determine heat resistance after exposure to heat stress [13–15].

2 Purpose of the study

In laboratory conditions, determine the adaptive potential of drought resistance and heat resistance of varieties and lines of spring barley.

3 Materials and methods

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The resistance of accessions to abiotic stressors was determined by the ability of seeds to germinate under conditions of moisture deficiency and after heat stress. The assessment of relative drought resistance was carried out according to the method as presented by N. N. Kozhushko (All-Union Institute of Plant Industry, 1988) [14]. For this study, the seeds were germinated both in the experiment and control at a temperature of 20°C. In the experimental variant, a sucrose solution of 8 atm was used as an osmotic agent. The control was germinated in distilled water. On the fifth day, the number of germinated seeds in each variant was counted.

Drought resistance was determined by the method developed by M.A. Prygun, given the intensity of growth of germinal roots. Seeds of each variety in the amount of 25 pieces, in three repetitions, were laid out on filter paper, pre-sterilized at a temperature of 105°C for 1 hour 30 minutes, rolled up and placed in chemical cylinders with Knopp’s solution. Germination was carried out at a temperature of 20–22°C, and then, on days 7 and 12, the length of the main germinal root was measured. The evaluation criterion is the value of the relative growth of the main root of the plant [16].

The determination of the heat resistance of spring barley samples was carried out according to the method of G.V. Udovenko (All-Union Institute of Plant Industry, 1988), experience-heating seeds before germination in a water bath at a temperature of 54°C, and control under optimal conditions (temperature 20°C), exposure 20 minutes in both options. Germination was carried out in thermostats at a constant temperature of 20°C. Accounting for the results in the experiment and control was made on the 7th day.

The criterion for determining drought resistance and heat resistance is the number of germinated seeds after exposure to stress, in comparison with optimal conditions, germinated seeds include seeds with a main root no less than the length of the seed, and a sprout no less than half the length of the seed [14].

Seed germination ($B$) was determined by the formula,$$ B = \frac{E}{C} \ast 100 \% $$

where:

- $E$ – number of germinated seeds in the experiment.
- $C$ – number of germinated seeds in control.

An additional criterion for assessing heat resistance is an indicator of changes in the accumulation of dry mass of seedlings. To do this, on the seventh day, in parallel, taking into account the germination in the control and the experiment, the roots and sprouts were cut from the germinated seeds and placed in bottles, then in an oven for 3 hours at a temperature of 105°C. The material was cooled and weighed. The degree of depression in the accumulation of dry mass by seedlings after heating ($D$) is determined by the formula and is expressed in%:$$ D = 100 - \frac{y}{x} \ast 100 \% $$

where:

- $y$ – dry weight of seedlings in the experiment.
- $x$ – dry weight of seedlings in control.

The lower the degree of depression, the higher the heat resistance of the samples.
\[ CSI = 2a + b \]

where:
- \( a \) – seed germination in osmotic solutions.
- \( b \) – seed germination after heat stress (thermal testing).

Statistical processing of the obtained data was carried out by the method of analysis of variance [16], and plotting was performed in Excel.

4 Results and discussion

Under natural conditions, the process of seed germination is often accompanied by a lack of moisture, the choice of variety in this case will be of decisive importance for the further development of plants. The assessment of resistance to abiotic stressors (to lack of moisture and exposure to relatively high air temperatures) was carried out at the initial stage of plant ontogeny [17, 18]. The results of studies of drought resistance showed a variation of the trait from 14.2 (Zernogradsky 1685) to 45.4% (Zernogradsky 1717) (Figure 1).

Fig. 1. Distribution of spring barley accessions by drought tolerance (2020–2022)

According to the data obtained, the samples were divided into 2 resistance groups: moderately resistant (40–69%) and weakly resistant (0–39%). The lines Zernogradsky 1717 and Zernogradsky 1716 stood out, having the highest values of drought resistance, significantly exceeding the values of the standard variety Ratnik (HCP = 4.93%).

Heat resistance was determined by the ability of seeds to germinate after exposure to heat stress (heating the seeds before germination in a water bath at a temperature of 54°C). The value of this trait ranged from 61.2 (Zernogradsky 1721) to 91.1% (Ratnik). According to the heat resistance values, the samples were divided into 3 resistance groups: highly heat resistant (germination rate 80–100%), medium heat resistant (50–79%), and weakly heat resistant (0–49%). The group of highly heat-resistant samples was Ratnik (91.1%), Zernogradsky 1701 (87.0%), Zernogradsky 1717 (84.0%), Zernogradsky 1716 (83.4%), Zernogradsky 1686 (81.9%) (figure 2).
Fig. 2. Distribution of spring barley accessions by heat tolerance (2020–2022)

Exceeding the value of heat resistance of the Ratnik standard among the samples was not detected (LSD0.05 amounted to 3.46%). Values close to the standard (they belong to the group of highly heat-resistant ones) were noted in samples Zernogradsky 1701, Zernogradsky 1717, Zernogradsky 1716, Zernogradsky 1686, but their differences were unreliable.

In order to obtain more reliable and objective results for determining heat resistance, the criterion used was the value of the change in the accumulation of dry matter by seedlings after heating.

The indicators of depression during the accumulation of dry mass of seedlings after exposure to high temperatures among spring barley samples varied from 2.13 (Ratnik) to 17.03% (Zernogradsky 1721) (Table 1).

Table 1. The degree of depression of the dry mass of seedlings and the group of heat resistance (2020–2022)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Degree of depression, %</th>
<th>Sustainability group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratnik</td>
<td>2.13</td>
<td>I</td>
</tr>
<tr>
<td>Zernogradsky 1628</td>
<td>14.24</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1685</td>
<td>13.64</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1686</td>
<td>6.28</td>
<td>I</td>
</tr>
<tr>
<td>Zernogradsky 1701</td>
<td>3.17</td>
<td>I</td>
</tr>
<tr>
<td>Zernogradsky 1726</td>
<td>15.49</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1716</td>
<td>5.43</td>
<td>I</td>
</tr>
<tr>
<td>Zernogradsky 1717</td>
<td>5.19</td>
<td>I</td>
</tr>
<tr>
<td>Zernogradsky 1719</td>
<td>8.40</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1721</td>
<td>17.03</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1724</td>
<td>13.10</td>
<td>II</td>
</tr>
<tr>
<td>Zernogradsky 1683</td>
<td>11.59</td>
<td>II</td>
</tr>
</tbody>
</table>

LSD0.05 0.52
seedlings after thermal testing according to compared with control. This assessment showed that samples with low values for this indicator are more heat resistant. For a complete characterization of the samples in terms of drought resistance and heat resistance, the method of determining the index of complex resistance was used, which is based on the total amount of the number of seeds that can germinate after exposure to osmotic and thermal stress. According to the results of a comprehensive assessment, the samples Ratnik (184.3 rel. units), Zernogradsky 1717 (194.8 rel. units) and Zernogradsky 1716 (188.0 rel. units) had the maximum values of the resistance index (RI) (figure 3).

Fig. 3. Distribution of spring barley accessions according to the index of complex resistance (2020–2022)

Significant excess of the values of the standard variety Ratnik in terms of “index of complex resistance” was not revealed (LSD05 = 12.7 rel. units).

In the process of plant development, the root system plays an important role and is in close relationship with other organs of the plant body. Germinal roots germinate first in their biological capacity and use the available soil moisture reserves. In drought conditions, the role of the primary root system increases, the power of its development determines the formation and growth of nodal roots, as well as the entire plant. The greater the length of embryonic roots for a certain period of time, the better the plants will use moisture [19, 20].

The study of the primary root system on 12-day-old seedlings up to the phase of the first leaf deployment in breeding samples of spring barley was carried out. The increase in the length of the largest root (from the 7th to the 12th day) in the samples of spring barley ranged from 2.5 (Zernogradsky 1685 and Zernogradsky 1701) to 4.7 cm (Zernogradsky 1717) (table 2).

Table 2. Growth intensity of germinal roots of spring barley accessions (2020–2022)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Length of the main germinal root, cm</th>
<th>Increase in the length of the main germinal root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratnik, st</td>
<td>13.0</td>
<td>15.7</td>
</tr>
<tr>
<td>Zernogradsky 1717</td>
<td>15.4</td>
<td>18.4</td>
</tr>
<tr>
<td>Zernogradsky 1716</td>
<td>16.2</td>
<td>19.4</td>
</tr>
<tr>
<td>Zernogradsky 1686</td>
<td>17.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Zernogradsky 1719</td>
<td>17.8</td>
<td>20.8</td>
</tr>
<tr>
<td>Zernogradsky 1724</td>
<td>18.6</td>
<td>21.6</td>
</tr>
<tr>
<td>Zernogradsky 1721</td>
<td>19.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Zernogradsky 1726</td>
<td>20.2</td>
<td>23.2</td>
</tr>
<tr>
<td>Zernogradsky 1850</td>
<td>21.0</td>
<td>24.0</td>
</tr>
</tbody>
</table>
The largest increase in the length of embryonic roots compared to the standard variety Ratnik (2.7 cm and 20.8%) was noted in the samples: Zernogradsky 1717 (4.7 cm and 27.0%), Zernogradsky 1719 (4.6 cm and 26.0%), Zernogradsky 1724 (4.0 cm and 22.6%), and Zernogradsky 1716 (3.6 cm and 23.2%), which significantly exceeded the standard (LSD\_05 = 0.47 cm). The selected samples have high values of the relative growth of the main germinal root, which characterizes them as highly drought-resistant.

5 Conclusions

1. When assessing the drought resistance (simulated deficiency of soil moisture by osmotic agents) of spring barley samples, the Zernogradsky 1717 and Zernogradsky 1716 lines were distinguished, which have the highest values of this value, significantly exceeding the values of the standard variety Ratnik.

2. When determining the relative heat resistance, it was found that under the direct action of a temperature of 54°C, a wide range of variation in seed germination was observed. The maximum values of relative heat resistance and low levels of depression were recorded in varieties Zernogradsky 1701 (87.0 and 3.17%), Zernogradsky 1717 (84.0 and 5.19%), Zernogradsky 1716 (83.4 and 5.43%), Zernogradsky 1686 (81.9 and 6.28%), the values of which significantly exceed the standard variety Ratnik (91.1 and 2.13%), respectively.

3. The results of a comprehensive assessment (competitive stability index CSI) did not reveal a significant excess of the values of the trait of the standard variety Ratnik (LSD\_05 = 12.7 rel. units).

4. According to the intensity of growth of the main germinal root, samples Zernogradsky 1717 (4.7 cm and 27.0%), Zernogradsky 1719 (4.6 cm and 26.0%), Zernogradsky 1724 (4.0 cm and 22.6%) and Zernogradsky 1716 (3.6 cm and 23.2%), which significantly exceeded the Ratnik standard (2.7 cm and 20.8%) (LSD\_05 = 0.27 cm).

5. Selected accessions are recommended to be used as starting material in breeding programs.
References


16. B. Dospekhov, Methods of field experience (with the basics of statistical processing of research results), Ed. 5th, revised and additional, Moscow: Alliance, 351 (2014)


