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Productivity of various barley (*Hordeum vulgare* L.) cultivars under semi-arid conditions in southern Russia

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Abstract. Drought is a significant factor limiting crop production in arid conditions. In the dry climatic weather situation of southern Russia, ten-year laboratory trials and subsequent field experiments were laid out on various barley varieties collected across the globe during 2007–2017 period. This study was conducted to ascertain from the collection of barley cultivars of the entire world which one is best suited to stressful climatic conditions by being tolerant to drought, heat and salinity which can be adopted for barley breeding. According to the results obtained, the varieties that are tolerant to dry climatic conditions are as follows: Alga (Lithuania), Brenda, Henni (Germany), Décor (Great Britain), Furat 5 (Syria), Vakula (Ukraine), Ataman (Belarus) and Vladimir (Russia); heat resistant varieties are: Brenda (Germany), Alga (Lithuania), Furat 5 (Syria), Ataman (Belarus), Vladimir and Ratnik (Russia); Salt-resistant varieties: Alga (Lithuania), Henni (Germany) and Vladimir (Russia). The selected varieties did not show any sign of adverse weather effect resulting in stable grain productivity throughout the entire duration of this research over the years, they had large grain size and stable 1,000 grains weight. However, the yield of selected cultivars varied over the years which was about 1.1–1.4 t ha^{-1}.

Key words: salt tolerance, heat resistance, drought tolerance, barley.

INTRODUCTION

Barley (*Hordeum vulgare L.*) regarded as one of the most important cereal grain crops is cultivated all over the world. Barley is a cereal crop with good adaptation to drought stress, and it can be surveyed as a genetic model plant to illustrate drought resistance mechanisms (Baum et al., 2007; Baik & Ullrich, 2008; Arshadi et al., 2018a). An investigation of the billion dollar natural disaster in the US indicated that combined accordance of heat and drought stress was more detrimental than when either of the stresses occurred singly (Mahalingam, 2017).

Barley possesses some special properties that enable it to adapt desirably into different unfavorable climatic conditions compared to other crops, ranging from dry land conditions to arctic regions of the earth with longer winter period and reduced sunlight on different continents. The phenomenon of diminishing barley yields under poor water supply situations is well known (Zare et al., 2011; Hossain et al., 2012), therefore, drought stress reduces barley grain yield by negatively affecting the yield components which are determined at various plant development stages (Beigzadeh et al., 2013¸ Vadez, 2014). Several studies also illustrated that high temperature and drought have adverse effects on spring crops, but also that low temperature is equally a significant constraint of the late sown crop in sub-tropical climates (Hossain et al., 2011; Hakim et al., 2012; Hossain et al., 2012) and early sowing in temperate spring crops (Timmermans et al., 2007).

Drought stress is a significant abiotic factor that can diminish photosynthesis efficiency by reducing leaf expansion, hence, causing premature leaf senescence and lower food production. Almost, 15 million km^2 of land surface area is dedicated to crop production (Ramankutty et al., 2008), of which 16% is predicted to be managed by irrigation. In many parts of the world, including the western parts of Asia and southern Russia (Medvedev, 1999), plants frequently encounter drought stress due to the irregular distribution of rainfall (Siebert et al., 2005).

Numerous summarizing papers on crop breeding for drought environments have been recently published (Fleury et al., 2010; Passioura & Angus, 2010; Kosova, 2014). Thereby, parameters such as drought, salt and heat resistance are important, as well as the productivity and stability of crops in difficult climatic conditions paramount in arid regions were grain crops are largely cultivated. Drought factor is responsible for the greatest amounts of damage to agricultural products among all other environmental stresses (Ceccarelli, 2010; Arshadi et al., 2016; Arshadi et al., 2018b). A rise in the frequency of drought stress can be expected because of climate change (Ceccarelli, 2010).

Understanding the relationships between yield and yield components may assist breeders to identify key traits that are involved in crop yield under temporal drought stress conditions. Screening various barley genotypes under drought stress conditions is one of the main factors for exploring 158 genetic variations to improve stress tolerant barley varieties (Haddadin, 2015).

One important option for evaluation of genotypes in different environments is that in most cases the effect of environment is great but difficult to document (IPGRI, 1994; Zargar et al., 2017). Only the effect of genotype and the interaction between genotype and environment are important in selection of stable genotypes, both genotype effect and the interaction of genotype and environment must be examined simultaneously (Yan & Kang, 2003). Nevertheless, the study and illustration of the barley selection value cultivars for tolerance to abiotic stresses and the ability to adapt under extreme conditions become urgent and vital.

The objective of this study was to select barley cultivars that have considerable stress tolerance which can be incorporated in crop improvement research, from the available genetic pool of various countries such as Russia, Ukraine, Belorussia, Lithuania, Finland, Sweden, Denmark, Syria, Turkey, Great Britain, France and Germany based on the hottest, drought and salt-tolerant varieties with desirable yield and yield component.

MATERIALS AND METHODS

Present study was conducted during the ten-successive cropping seasons of 2007–2017 in the semi-arid conditions of the southern Russia, Astrakhan region. The research station is located at 42°58′ N, 47°28′ E and 130 m altitude. Samples of soil were taken randomly from different spots at 0–15 cm to record the initial characteristics of the experimental field. The soil was characterized as loamy with 1.5% of organic matter and with a pH of 7.1. Fig. 1 shows the average annually rainfall and mean annually temperature data recorded in vicinity of the experimental field.

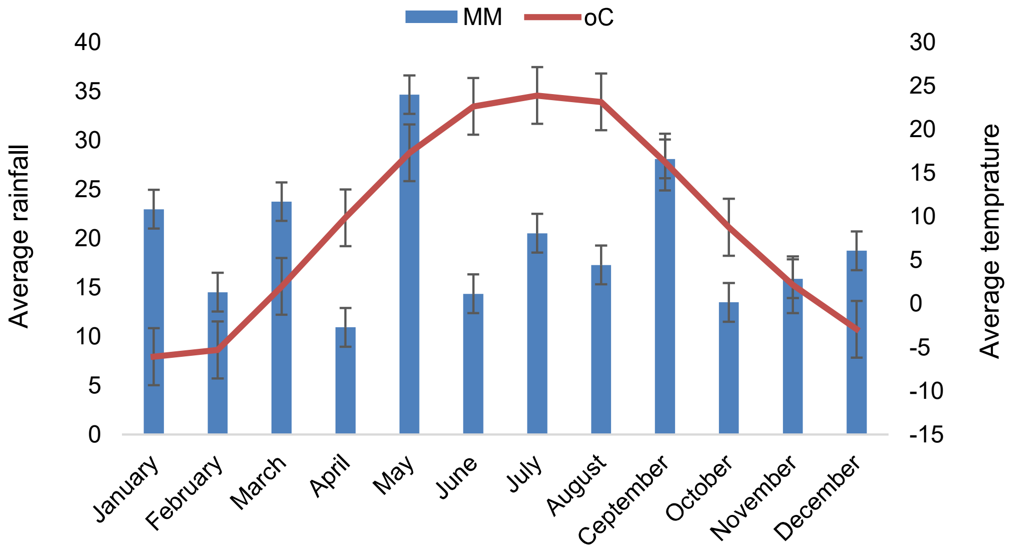

Figure 1. Average rainfall and temperature during experimental seasons.

Mentioned experiments were conducted once each year, throughout the ten-year duration, in the form of randomized complete block design with four replications. Several barley cultivars from various countries of the world (Russia, Ukraine, Belarus, Lithuania, Finland, Sweden, Denmark, Syria, Turkey, Great Britain, France and Germany) were studied and evaluated in a research that lasted for 10 agronomical years. For open field experiments, different planting dates ranging from 25 March to 5 April were set as a response to the climate changes during the 10-year period of study. In Laboratory experiments during 2007–2009, 100 barley seeds were sown per petri dish, the standard seed variety was barley Uzhniy (translated to Southern in Russian). All examined varieties were spring malting barley which were resistant to different environmental stresses.

Observations and Measurements

Under laboratory conditions, the drought resistance was determined by the percentage of seed germination in different sucrose solutions as follows: 0.3, 0.4, 0.5 and 0.6 mol with a high osmotic pressure (10, 14 and 18 atmospheres) (Shulmeyster, 1988).

The heat resistance was determined by the germination of seeds after their heating at a temperature of 58 °C. Evaluation of samples for salt tolerance was determined by the percentage of seed germination in sodium chloride solution (NaCl), for this purpose, healthy seeds were selected which were placed separately in grades into gauze bags with a label inside and treated with formalin solution (1 mL per 300 mL of water) for 3–5 minutes, then lightly dried and put into 100 seeds in a Petri dish in four replicates (Udovenko, 1988). Pre-Petri dishes and filter paper were calcined in a thermostat at 150 °C for one hour.

In each Petri dish, 6–7 mL of 10% NaCl solution was poured; seeds were germinated at 22 ± 2 °C for 6 days in thermostats. After the germination was completed, the number of sprouted seeds was determined for each variant and the percentage of germinated seeds was calculated, in salt solutions, taking as 100% the number of seeds sprouted in distilled water. Samples in the field experiment were also evaluated for drought resistance by determining the morphological and physiological parameters such as leaf drop, wax plaque, leaf color, water content of the 3_{rd} leaf into the tube exit phase.

RESULTS AND DISCUSSION

Barley (*Hordeum vulgare*) is rather well-tolerant to drought, salinity and other dehydrative stresses. It has a very large and diverse genotype pool including several landraces adapted to arid and semiarid climates.

The drought resistance of barley samples under laboratory conditions was determined by their ability to germinate in sucrose solutions of C12H22O11. By increasing concentration of the solution and, accordingly, the osmotic pressure, seeds germination diminished significantly. The following samples showed the highest percentage of seed germination (more than 50%) were obtained at 18 atmospheres: Alga (Lithuania), Loubi (Sweden), Adora (France), Pirania (France), Arabian white (Syria) Furat 3, Furat 4, Furat 5, Furat 6 (Syria), Décor (Graeat Britain) Vakula (Ukraine), Ataman (Belorussia), Chill (Denmark), Mamluk, Vladimir, Yaromir and Sonet (Russia) (Table 1). Drought resistance represents a complex quantitative trait illustrated by a multitude of genes and quantitative trait loci (QTLs) which depend on the composition of a given population, plant growth stage and other factors. Yield component under drought stress conditions is influenced by both constitutive QTLs, i.e. QTLs affecting yield irrespective of environmental conditions, and drought-responsive QTLs, i.e. QTLs affecting yield only under drought situations (Collins et al., 2008; Kosova et al., 2014). Barley releases large genotypic variability as well as the effect of genotype × environment interactions by several traits (characteristics related to the flowering stage) affecting the resulting drought resistance (Kosova et al., 2014).

During the experiment, incidents of droughts were observed in all the years of research at various phases of the development of barley varieties. For the entire 10 years of study, yield results of 23 varieties exceeded the parameters of the standard cultivar Uzhniy (Southern), 0.9 t ha^{-1}. The most yielding ones were Alga (Lithuania), Loubi (Sweden) Décor (Great Britain), K-24723 (Turkey), Submedicum, Sonet, Ratnik, Pyramid (Russia), Arabian white and Furat 5 (Syria) from 1.2 to 1.4 t ha^{-1} (Table 2). The drought resistance in the flowering and earing stages was determined by the number of grains per spike.

Table 1. The most stable barley varieties according to the results of laboratory trails in solutions of different concentrations

Origin	Variety	The percentage of sprouted seeds at a sucrose concentration			Sustainability Group
		10 atm	14 atm	18 atm	
Russia	Standard Uzhniy	83	56	40	2
Lithuania	Alga	92	91	82	3
Sweden	Loubi	97	88	80	3
France	Adora	98	89	70	3
France	Pirania	97	90	71	3
France	Concerto	76	58	43	2
Germany	Brenda	80	53	44	2
Germany	Grace	81	57	50	2
Syria	Arabian white	94	71	69	3
Syria	Furat 3	92	89	82	3
Syria	Furat 4	95	90	76	3
Syria	Furat 5	96	87	79	3
Syria	Furat 6	100	91	74	3
Great Britain	Décor	82	74	51	2
Ukraine	Vakula	88	81	78	3
Belorussia	Ataman	97	91	78	3
Denmark	Chill	81	70	55	2
Russia	Ermak	76	70	50	2
Russia	Mamluk	81	71	54	2
Russia	Vladimir	97	91	78	3
Russia	Yaromir	80	72	56	2
Russia	Sonet	100	91	75	3
$LSD_{0.05}$		0.04	0.04	0.02	

The most drought-resistant are those with less variability in the number of years. In the experiments conducted, samples from these varieties were observed: Alga (Lithuania), Adora (France), Henni, Brenda (Germany), Furat 3, Furat 5, Arab white (Syria), K-24723 (Turkey), Ratnik (Russia) and series other samples (Table 2). Drought resistance in grain stage was determined by the degree of reduction in the grains mass under drought condition. The most drought-resistant can be accredited as those in which the mass of 1,000 grains shows less variability by the years. Under water deficit conditions plants may use different mechanisms to alleviate the stress. For example, Kamboj et al. (2015) compared different barley genotypes under salinity stress, and found that the pathway of abscisic acid is among the most important physiological mechanisms determining barley tolerance under stress. Barley response under water deficit conditions is correlated with changes in plant physiological and morphological parameters as different barley genotypes indicate significant differences.

In our experiments, on average, the following varieties were distinguished based on the years of study in following indicators: Alga (Lithuania), Adora (France), Henni (Germany), Décor (Great Britain), Vladimir, Ratnik and Pyramid (Russia). For the basis of results comparison obtained at the field and laboratory analyzes, we were able to identify varieties that are resistant to drought in arid conditions [(Alga (Lithuania), Brenda, Henni (Germany), Décor (Great Britain), Furat 5 (Syria), Vakula (Ukraine), Ataman (Belarus) and Vladimir (Russia)]. The isolated samples can be used for further selection when creating drought-resistant varieties for arid conditions. As stated by Subhani et al. (2015) drought tolerance indices which provide the measure of yield losses under drought conditions in contrast to normal conditions have been used to screen the drought tolerant genotypes.

Table 2. The most drought-resistant varieties in field conditions during 2007–2017 Agronomical years

Origin	Variety	Yield ($t\ h^{-1}$)	Weight 1,000 grains (g)	Number of grains per spike
Russia	Standard Uzhniy	0.9	30.4	19.9
Lithuania	Alga	1.3	48.4	22.1
France	Adora	1.1	45.1	23.1
France	Tabora	1.1	36.4	23.2
Germany	Henni	1.2	41.4	23.5
Germany	Brenda	1.4	31.8	21.4
Syria	New arabian 9	0.6	36.2	21.8
Syria	Arabian white	1.2	39.1	22.3
Syria	Furat 3	0.7	31.2	23.0
Syria	Furat 4	0.5	35.4	22.8
Syria	Furat 5	1.2	29.8	20.7
Syria	Furat 7	1.1	32.6	21.7
Sweden	Loubi	1.3	31.6	20.2
Finland	Jnari	1.1	33.7	22.4
Great Britain	Décor	1.3	41.9	22.8
Ukraine	Vakula	1.1	39.5	23.5
Belorussia	Ataman	1.1	39.4	23.7
Turkey	24723	1.3	36.6	23.4
Turkey	9265	1.0	32.1	20.5
Russia	Ermak	0.9	36.7	20.7
Russia	Granal	0.8	25.5	21.1
Russia	Pastbishny	1.1	36.7	19.5
Russia	Submedicum	1.2	31.2	19.4
Russia	Zernogradets, 770	1.1	27.5	19.7
Russia	Priazovsky 9	1.1	33.1	20.0
Russia	Sokol	0.9	28.6	19.1
Russia	Vladimir	1.3	40.7	21.2
Russia	Sonet	1.2	39.5	20.1
Russia	NUR	0.9	27.2	19.9
Russia	Ratnik	1.2	33.3	22.1
Russia	Piramida	1.2	44.7	21.8
$LSD_{0.05}$		0.04	1.4	0.9

In this regard, Lalic et al. (2017) stated that barley production, within the productive area of the world, is commonly exposed towards a number of stressful factors which significantly affect grain yield and quality, especially in malting barley. The most common biotic and abiotic stress factors in our conditions have been caused by various factors such as soil salinity, low temperatures, drought and high temperatures. Hence, water shortage and drought stress are considered as the most principal environmental factors, reducing the productivity of crops in many arid and semi-arid areas, which are intensively influenced by climate changes (Wassmann et al., 2009). This matter is more noticeable when we find out that higher than one fourth of the earth land areas are arid and semi-arid areas (Mardeh et al., 2006).

Abiotic stress factors such as drought, salinity, extreme temperatures, chemical toxicity and oxidative stress pose a serious threat towards plant varieties in agriculture. The heat resistance of the samples was evaluated by the reaction of the variety of samples in both laboratory and field conditions. The reaction of the samples to sudden sharp increase in temperature accompanied by a strong wind, low relative humidity of the air, which causes the phenomenon of whitening of the top of the ear, the entire ear or the tips of the leaves was observed.

Stress factors do not usually affect plants independently, but in different combinations under field conditions and the effect of joint stress factor action does not equate the sum of separate stress factor effects (Mittler, 2002; 2006). Regarding the plant phenological phase affected by drought, different kinds of stress may occur as following: pre-flowering water deficit (regions of South America); grain-filling (post-anthesis) water deficit (Mediterranean regions); continuous water deficit (Reynolds et al., 2005).

Dry wind situation was observed during the entire duration of the research over the years, which can cause whitening and die-off at the tips of plant leaves. By the degree of whitening of the leaves, we estimated the field heat resistance of the samples. The most resistant to dry wind (5–7 points) were varieties from France (Adora), Germany (Brenda), Lithuania (Alga), Syria (Furat 5), Belarus (Ataman), Russia (Vladimir, Ratnik). It should be noted that among the samples studied, those found in the period of the most intense heat and drought folded their leaves into a tube which is seen as way of response by desert plants and some steppe grasses to reduce transpiration by 46–63%, thereby saving a considerable amount of moisture (Knezevic, 2004). Among the samples studied, such signs were different: Alga (Lithuania), Furat 5 (Syria), Ratnik (Russia). In laboratory conditions, the samples were evaluated for heat resistance by heating the seeds at a temperature of 58 °C. High heat resistance, where the energy of germination and when germination was at 100%, was shown by the following samples: Alga (Lithuania), Loubi (Sweden), Sega (Denmark), Ataman (Belarus) (Table 3).

No less important factor is salinity, which limits the productivity of crops and has a profound effect on the vital activity of plants. For the life of plants under saline conditions, of particular importance is the change in the water-osmotic regime, especially the degree of osmoregulation. Many authors are of the opinion that an increase in the osmotic potential of plant cell sap is a protective-adaptive response in conditions of salinity (reviewed in Chaves et al., 2003; Yamaguchi-Shinozaki & Shinozaki, 2006). In cultivated plants, salinization leads to changes in the stomatal apparatus, while the size of the stomata decreases, and their number per unit area increases.

The adaptation of plants to the conditions of salinization is carried out in many ways, the most important of which is osmoregulation and specialization (modification of transport processes). Therefore, to obtain salt-tolerant plant forms, it is necessary to carefully study the transport of ions, depending on the ionic composition of the medium and the genotype. Salt-resistant species have the ability to accumulate sodium ions (Na^+) in vacuoles, absorb it from the xylem and transport it to the medium. Peculiarities of potassium-sodium metabolism on plasmalemma and the accumulation of Na^+ and Cl^- ions in vacuoles of cells and in cell walls have been noted in some studies, where it was suggested that there is a highly efficient mechanism for pumping out Na^+ ions in salt-tolerant plants.

The increased salt tolerance of plants is due, firstly, to the excretion of Na^+ and Cl^- ions from young leaves, and secondly, by the predominantly basal migration of Na^+ from the leaves and its excretion into the substrate and, thirdly, by the restriction of movement of Cl^- from the root to the stem (Zohary, 2000; Kosova, 2014).

Table 3. The most heat-resistant barley cultivars by the results of laboratory trials

Origin	Variety	Energy of germination (%)	Germination (%)
Russia	Standard uzhniy	92	93
Russia	Zernogradsky 584	90	95
Russia	Sonet	48	91
Russia	Vladimir	99	100
Russia	Priazovsky 9	74	80
Russia	Mamluk	89	100
Belorussia	Ataman	100	100
Lithuania	Alga	100	100
Sweden	Loubi	100	100
Sweden	Halikko	95	98
Denmark	Sega	100	100
Denmark	Chill	89	95
France	Adora	95	93
France	Pirania	96	100
France	Tabora	98	97
France	Concerto	70	89
Germany	Brenda	99	97
Germany	Henni	97	97
Syria	Arabian black	90	92
Syria	Arabian white	91	97
Syria	Furat 5	99	100
Syria	Furat 7	83	87
Turkey	9265	94	97
	$LSD_{0.05}$	0.05	0.06

It is known that high concentrations of salts directly or indirectly suppress protein synthesis, destroy the structure and inhibit the activity of enzymes of primary nitrogen assimilation. This leads to the accumulation of amino acids in plant tissues, a sharp increase in some of them – tyrosine, leucine, phenylalanine adversely affects the vital activity of plants. Along with this in the tissues of plants on salinization glycolysis and the pentose-phosphate cycle are intensified. In response to the action of salt stress in the plant, low-molecular compounds such as proline, betaine, polyamines, organic acids, sugars, and peptides are formed and accumulated (Udovenko, 1988; Zohary, 2000; Knezevic, 2004). At present, in order to increase the resistance of plants to adverse factors, a search for salt tolerance donors is necessary.

The salt tolerance of a variety is determined by the amount by which its yield diminishes in saline conditions, in comparison with the yield of this variety on a non-saline background. Therefore, the level of salt tolerance of the variety is higher, the lower its productivity decreases with salinity of the substrate. In conditions of excessive salinity of the soil, the seed germination and the intensity of plant growth often decrease. We determined the salt tolerance of plants by germinating seeds in salt solutions. Average data for ten years of study are presented in Table 4.

Table 4. Salt-resistant of barley varieties (germination, %)

Origin	Variety	Average	Control
Russia	Standard Uzhniy	59	100
Belorussia	Ataman	97	100
Belorussia	Paletan	67	100
Ukraine	Vakula	76	100
Lithuania	Alga	100	100
Finland	Jnari	89	100
Sweden	Loubi	93	100
Sweden	Halikko	91	100
Denmark	Sega	99	100
Denmark	Chill	97	100
Great Britain	Décor	84	100
France	Adora	26	100
France	Pirania	95	100
France	Tabora	77	100
Germany	Brenda	83	100
Germany	Henni	100	100
Germany	Grace	98	100
Russia	Yaromir	85	100
Russia	Mamluk	92	100
Russia	Vladimir	100	100
Russia	Ptiazovsky 9	73	100
Russia	Zernogradsky 584	93	100
Russia	Ratnik	91	100
Russia	Sonet	75	100
Syria	Arabian white	77	100
Syria	New arabian	81	100
Syria	Furat 3	91	100
Syria	Furat 4	93	100
Syria	Furat 5	89	100
Syria	Furat 7	90	100
	$LSD_{0.05}$	0.04	0.08

Abiotic stress leads towards morphological, physiological, biochemical and molecular changes which negatively affect the plant growth and productivity. Drought, salinity, extreme temperatures and oxidative stress are commonly connected and can induce similar cell damage. For example, drought and salinization are primarily expressed as osmotic stress where they affect homeostasis and ion distribution inside the cell (Serrano et al., 2001). High temperatures accompanied by oxidative stress, salinity or drought may cause denaturation of functional and structure proteins. Barley is one of the most extensively cultivated cereals in the Mediterranean region, and although water stress reduces its productivity (Lopes et al., 2004) it is, among the main temperate cereals, the one that adapts best to water shortage (Sanchez-Diaz et al., 2002).

The varieties Alga (Lithuania), Henni (Germany), Vladimir (Russia), having 100% germination in salt solution turned out to be more salt tolerant. Germination at the level of 90% or higher was achieved by varietal samples from Denmark (Sega, Chill), Germany (Grace), Byelorussia (Ataman), France (Pirania) and a number of others that can be used as sources for selection for the salt tolerance of barley.

CONCLUSIONS

When creating varieties that meet modern requirements, one of the important things to look for is its genetic sources, which is especially important for soil and climatic conditions of arid territories. Our long-term studies of the collection of barley cultivars made it possible to identify the most drought-, heat- and salt-resistant samples, and the most valuable samples were identified by comparing the results of laboratory and field tests. So, the most drought-resistant, in the arid conditions of the south of Russia, were the varieties: Alga (Lithuania), Brenda, Henni (Germany), Décor (Great Britain), Furat 5 (Syria), Vakula (Ukraine), Ataman (Belarus), Vladimir (Russia). According to the heat resistance, Brenda (Germany), Alga (Lithuania), Furat 5 (Syria), Ataman (Belarus), Vladimir, Ratnik (Russia) stood out. For salt tolerance, we had varieties: Alga (Lithuania), Henni (Germany), Vladimir (Russia). All the varieties identified by us can be used by breeders as sources of resistance for the traits under study in further breeding.

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