Breeding of *Vicia faba* L. in relation to drought resistance

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Breeding of *Vicia faba* L. in relation to drought resistance

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Abstract. The collection of broad beans for a number of years in the soil and climatic conditions of the city of south of the central chernozem region of Russia on the territory of the National Research University "BelGU" have been studied. The Yu.N. Kurkina field method was used to determine the drought tolerance of bean plants. An analysis of the totality of ecological and morphological traits of forage bean varieties of different origins revealed varieties with pronounced xeromorphicity with low plant heights and narrow leaves. The varieties with high drought resistance have been identified. During the period when fruits are already forming in the lower nodes of plants, and pollination and fertilization are taking place in the flowers of the upper tiers, excess moisture negatively affects the emerging seed yield. A strong correlation was found between the productivity of the green mass and the amount of precipitation at the beginning of flowering. Seed productivity of beans is negatively reflected by high temperatures during the periods of germination and budding, and low temperatures during ripening of fruits and seeds. The productivity of green mass is more strongly influenced by temperature than precipitation

1. Introduction

The main stimulus for the evolution of plants was the struggle for moisture. There is a close relationship between the influence of moisture conditions and light on the internal structure of a plant - xeromorphic features of the structure are formed in plants in connection with strong lighting and constant heating. The structure of the leaf reflects the effect of various environmental factors on the plant. The leaves of a xeromorphic plant, in comparison with a mesophyte, are characterized by a greater length of vessels per unit area, smaller sizes of epidermal and stomata cells, a greater number of stomata and hairs per unit area, a thicker outer membrane of epidermal cells, less sinuous lateral walls of the epidermis, and a highly developed wax coating, less developed mesophyll and spongy parenchyma cells, poorly developed intercellular spaces, more developed mechanical tissues [1].

Plants are able to exist only in a certain, sometimes rather narrow, temperature range. At the same time, many biological processes obey the Van't Hoff temperature coefficient, that is, they double their intensity when the temperature rises by 10 ºC. Therefore, one of the main environmental factors that reduce the yield of agricultural crops is soil drought - a special weather regime associated with a prolonged absence of precipitation, an increase in temperature and a decrease in the relative humidity of the air.

Drought and high temperatures contribute to the development of unidirectional processes in plant cells - evaporation of the easily mobile fraction of water and an increase in the content of bound water. Lack of water accelerates aging, and excess increases the duration of the growing season, delaying the development of the organism. During drought, the hydration shells of proteins are thinned or lost, which leads to a violation of their tertiary and quaternary structure and a decrease in the activity of enzymes. Due to dehydration, cell membranes lose their bilayer structures, significant conformational changes appear in them, and membrane permeability increases.

Plants try to adapt to arid conditions through osmoregulation, which, being an adaptive property, is expressed in the accumulation of osmotically active compounds in tissues. Progressive drought leads to an increase in energy costs for maintaining cell life, in particular for the synthesis of osmotics and stress proteins. In general, increased plant osmoregulation correlates with the maintenance of grain yield in the field during drought. Various plant strategies are known to avoid damage during a temporary moisture deficit: drought-resistant varieties of beans more effectively maintain tissue hydration by closing the stomata. Another reason may be differences in carbon assimilation and accumulation and energy requirements for maintaining the structure and functioning of cells [2].

During a period of high-temperature stress in the vegetative organs of beans, so-called "osmoprotectors" are synthesized - substances that accumulate in cells and perform a protective function in relation to intracellular structures. Under conditions of water stress (in the process of proline synthesis), organic acids are the source of the carbon skeleton: citrate, malate, and lactate, and a high content of the latter is noted in all plant organs; as well as in the guard cells of the stomata of bean plants, the concentration of abscisic acid increases [3].

During a drought, dehydration and overheating lead to inhibition of growth, a shift in the passage of phenological phases, a decrease in the intensity of plant photosynthesis, and the accumulation of products of partial destruction in them. Drought-resistant plants are those that are able to undergo ontogenesis (growth, development and reproduction) in arid conditions. At the same time, different plant species and varieties react to drought in different ways: some varieties avoid it, accelerating development, while others slow down the passage of the stages of organogenesis [4]. Thus, the presence of ecological groups Vicia faba in relation to water and the degree of their drought tolerance are important aspects of the stability of agroecosystems, therefore, their study became the purpose of this study.

2. Material and Methods

For a number of years (1999-2020), in the soil and climatic conditions of the city of Belgorod (south of the Central Chernozem region of Russia) on the territory of the National Research University "BelGU", a collection of beans (200 varieties) have studied. Sowing of the faba bean's varieties and care were carried out manually in accordance with the method of B.A. Dospekhov (1979) and the requirements of zonal agricultural technology without the use of fertilizers and pesticides. A wide-row sowing method was used, with a seeding rate of 0.3 million / ha. Crop care included post-sowing crust control, inter-row cultivation as the crops became clogged and after rains. The area of the accounting plot was 2 m2 with 2 replicates.

For the convenience of ecological analysis of bean samples, a 4-point 5-step scale of the severity of xeromorphic traits (XT) was used, where score 0 corresponded to the absence of xeromorphic traits (typical mesophytes), score 1 - their minimal severity, and score 4 - the maximum manifestation of xeromorphic traits. As the layer of leaves rises, signs of xeromorphism predominate in them; therefore, we analyzed the leaves of one layer.

To determine the drought tolerance of bean plants, we used the previously proposed field method [5, 6]. The method is based on an assessment of the wilting of the leaves of bean plants according to the following scale (in points): 0 - no withered leaves (high drought resistance); 1 - wilting of single leaves (relative drought resistance); 2 - wilting of up to 50% of the leaves, possibly the beginning of drying (insufficient drought resistance); 3 - wilting of more than 50% of the leaves, their mass drying (lack of drought resistance). Plants with indices of 0 and 1 point are considered promising in terms of the complex of the most pronounced adaptively significant traits, including drought resistance. The method makes it possible to evaluate bean plants only during the drought period, when the mechanisms of adaptation to the action of an unfavorable factor are activated.

It is necessary to distinguish between leaves that have dried out under the influence of drought and as a result of the natural aging process, which is characteristic of the lower nodes and is accompanied by yellowing and drying of the entire leaf blade at the same time. During drought, first the wilting of the leaves is observed, then drying, starting from the edges of the leaf blade, which can remain green for several days. We also used a generally accepted gravimetric method for determining the water-holding capacity of leaves (determined in the laboratory).

3. Results and Discussion

The complex of traits of faba bean's samples of different ecological and geographical origin were evaluated according to this scale and assigned an appropriate score and shown in table 1.

Table 1. Ecological and morphological characteristics of varieties of forage beans

Sample name, origin	Leaf length (cm)	Leaf width (cm)	Leaf index *	XT (point)	Plant height (cm)	Drought resistance (point)	Water loss (%)
986 Por (Georgia)	4.2±0.1	3.3±0.2	1.3	0	110	2	19.2
Ukko (Finland)	4.3±0.2	2.7±0.1	1.6	0	132	3	19.6
Pistach 10386 (Holland)	4.4±0.9	2.9±0,4	1.5	0	130	2	18.8
356533 (Libya)	4.1±0.1	2.8±0.2	1.4	0	118	2	20.9
Batrom (Ukraine)	3.8±0.1	2.3±0.2	1.7	1	104	1	16.9
Lankaran 1 (Azerbaijan)	3.8±0.4	2.5±0.4	1.5	1	105	2	20.5
К-2044 (Russia)	4.1±0.2	2.4±0.2	1.7	2	110	1	15.6
Fatima (Canada)	4.3±0.1	2.3±0.1	1.9	2	114	3	17.4
К-1538 (India)	4.1±0.4	2.1±0.2	1.9	2	120	1	16.8
c. Wefo (Bulgaria)	4.7±0.3	2.6±0.1	1.8	2	130	2	16.6
Green (China)	4.5±0.1	2.5±0.1	1.8	2	125	1	15.8
Bijeli bob (Yugoslavia)	4.4±0.1	2.6±0.1	1.7	2	134	2	16.1
Haba (Чили)	4.4±0.1	2.1±1.1	2.1	3	114	1	15.8
Giza-1 (Egypt)	3.8±0.2	1.7±0.1	2.2	3	114	1	15.0
Green Jack (Russia)	4.5±0.1	1.9±0.1	2.3	3	116	1	11.1
Afghan (Afghanistan)	3.4±0.4	1.4±0.2	2.4	3	113	0	13.7
Sinable 361561 (Peru)	3.7±0.3	1.5±0.1	2.5	3	118	2	18.0
Velena (Russia)	4.1±0.1	1.3±0.1	3	4	120	1	14.6
№ 495 (Ukraine)	3.3±0.1	1.6±0.1	2	4	105	0	13.2
К-1903 (Ethiopia)	4.1±0.2	2.01±0.1	2	4	100	1	14.6

According to the results of evaluating the studied samples of beans, 4 samples were assigned to typical mesophytes (0 points) (see table), the tall plants of which have relatively wide leaves. The most pronounced xeromorphicity (4 points) is possessed by the new domestic variety Velen from Russia, samples No. 495 from Ukraine and K-1903 from Ethiopia, the plants of which are distinguished by the narrowest leaves and low height. Most of the successfully grown bean samples are mesophytes with moderate xeromorphic traits (2-3 points).

Over a number of years, the drought resistance of 200 collection samples of beans of different ecological and geographical origin was assessed. The proposed method for assessing drought tolerance allowed hundreds of bean plants to be worked out per day, as a result of which promising forms were isolated and selected, among which the variety Aquadul turned out to be highly drought tolerant, forms No. 132, Afghan, No. 495; slightly less resistant varieties Green Jack and Velena, variety Felissa and forms VF 2 9083, No. 10386, K-1903, Giza-1, as well as a sample of local selection K-2044.

The assessment of the water-holding capacity of the leaves of the selected varieties and forms (by the gravimetric method), which was carried out in parallel with field tests, confirmed our data.

Over the years of research, severe droughts were noted in 2002, 2007, 2010, 2012 and 2017. It should be noted that adult bean plants successfully tolerated the dry period. But depending on the genotype, they reacted differently to these unfavorable conditions. In many forms, a decrease in plant height and a decrease in seed productivity were observed.

The varieties and forms that are promising in terms of drought resistance and are listed in Table 2, with a high potential for seed productivity, can be recommended for further breeding work. Samples of beans that are less resistant to dry conditions can be grown in household plots, taking into account the need for watering in years with extreme moisture availability.

Table 2. Productivity of drought-resistant samples (P = 0.95)

Sample name, origin	Productivity of seeds, g / plant			Productivity of green mass, g / plant		
	2012	2017	mean annual	2012	2017	mean annual
Aquadul (Holland)	20.8	23.2	25.3	140.3	148.6	293.8
Afghan (Afghanistan)	13.5	15.1	17.5	90.1	120.9	251.7
Giza-1 (Egypt)	13.4	16.1	32.5	110.3	129.3	263.8
Grot (Czech)	12.2	10.3	29.4	200.1	198.8	212.1
K-1456 (Russia)	27.5	27.1	52.9	165.5	200.7	219.2
Pistach (Holland)	8.8	19.0	31.3	155.0	209.2	257.7
Radiomutant 8 (Russia)	16.4	8.9	24.3	201.1	187.9	343.9
Tulunsky (Russia)	17.2	24.8	35.9	100.3	134.4	156.7
Express (France)	32.8	9.2	29,3	110.2	100.1	222.1
№340058 (Somalia)	13.8	10.1	26.8	120.0	103.2	136.9
Collection limits	6.6-32.8	6.0-24.8	8.1-59.9	50.2-200.1	43.3-209.2	133.3-368.8

The noted drought-resistant varieties and forms of beans are productive both in terms of seeds and green mass. Note that the varieties Grot, Radiomutant 8 and Express, productive in dry years, in wet years 2003, 2008, 2014 and 2020. greatly reduced the productivity of seeds (up to 0 g / plant).

Thus, it is advisable to use an express method for assessing bean plants for drought tolerance in the field on a four-point scale of leaf wilting when analyzing a large volume of source material for a limited period of time and identifying breeding forms promising for this trait. Efficient use of the biopotential of beans is mainly limited by unfavorable moisture conditions during the growing season. Fluctuations in yields from year to year are most often caused by a mismatch between the moisture reserves in the soil and the needs of plants for it. Therefore, when creating adaptive varieties of beans, it is important to identify the nature of the dependence of productivity on the main meteorological factors - air temperature and precipitation amount (hydrothermal conditions). Long-term field trials of beans in the

Belgorod region made it possible to carry out a correlation analysis of hydrothermal conditions and productivity of seeds and green mass.

Temperature begins to play an important role about a month before sowing, when it affects the readiness of the soil for sowing. From the germination phase to the beginning of flowering, air temperature negatively correlates with the future productivity of both seeds and green mass. During this period, overheating is unacceptable; therefore, this is a critical period in the development of plants in relation to high temperatures. Later, during the mass flowering, the temperature does not strongly affect the formation of the productivity elements of the bean plants.

The amount of precipitation in March has a long-term effect on the productivity of both seeds and green mass. Most likely, the moisture accumulated in the soil at this time is used at the first stages of organogenesis - during the swelling and germination of seeds. In the period of emergence, as follows from the table, water logging is unacceptable. During the budding period, and especially at the beginning of flowering, there should be a sufficient amount of moisture.

From the second decade of flowering to the end of the growing season, the correlation coefficient of precipitation and seed productivity reverses sign and increases, which indicates a negative effect of precipitation (especially its excess) on plants at this time. Thus, when fruits are already forming in the lower nodes of plants, and pollination and fertilization are taking place in the flowers of the upper tiers, excess moisture negatively affects the emerging seed yield ($r = -0.9$).

That should be noted that it is better to harvest the beans for green mass about 20 days after flowering. At the beginning of flowering, the amount of precipitation has a very positive effect on the final productivity index of the green mass ($r = + 0.9$), which makes it possible to distinguish this period as critical in relation to the lack of moisture. Seed productivity of beans is negatively reflected by high temperature during the periods of germination ($r = -0.8$) and budding ($r = -0.9$), and low temperature - during ripening of fruits and seeds; while at the beginning of flowering plants are more sensitive to a lack of moisture, and during the emergence of seedlings and ripening of fruits and seeds - to its excess. The productivity of green mass is more strongly influenced by temperature ($r = -0.9$) than precipitation ($r = -0.4$).

To analyze the combined effect of temperature and precipitation on the productivity of beans, the hydrothermal coefficient was used, which significantly (at $p <0.05$) correlated with the productivity of beans. In May and June, a positive correlation of the hydrothermal coefficient with the productivity of seeds ($r = + 0.7$ and $r = + 0.9$, respectively) and green mass ($r = + 0.4$ and $r = + 0.9$, respectively) was noted. The hydrothermal coefficient has the most positive effect on the productivity of green mass and seeds in June, during the budding period – beginning of flowering of beans ($r = + 0.9$), while in the next month, during the period of flowering and fruit formation, the relationship changes its sign to the opposite ($r = - 0.6$ and $r = -0.8$ respectively).

The influence of temperature and precipitation on the productivity of beans is not the same during the growing season. The time from germination to the beginning of flowering is a critical period in the development of plants in relation to high temperatures, and the beginning of flowering - to a lack of moisture. At high values of the hydrothermal coefficient at the beginning of the growing season, good productivity of the beans can be predicted.

Bean cultivars, mesophytes with moderately pronounced xeromorphic characters, combining drought resistance with high productivity, as well as to determine the periods of ontogenesis that are critical in relation to high temperature and lack of moisture. In addition, the use of the hydrothermal coefficient makes it possible to predict the productivity of beans even at the early stages of plant development.

The combination of field and laboratory methods for assessing drought resistance contributed to the selection of promising samples of beans, and taking into account periods critical in relation to hydrothermal conditions in plant development will increase the effectiveness of crop selection in this direction.

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