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PRODUCTIVENESS AND NODULE ABILITY OF DIFFERENT VARIETIES OF COMMON BEAN (*Phaseolus vulgaris* L.) IN URALS CONDITIONS

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Abstract

Common bean (*Phaseolus vulgaris* L.) has a high nutritional value, its seeds contain a significant amount of protein and essential amino acids and vitamins. Furthermore, it can accumulate organic nitrogen in the soil due to nitrogen fixation. On the territory of the forest-steppe zone of Urals (Bashkortostan) in small plot experiments in homogeneous soil conditions during five years the elements of yield structure of four cultivars of common bean (Gornal, Ufinskaya, Zolotistaya and Elsa) were studied. In different soil and climatic conditions the distribution character (skewness) of seed production and nodule activity were compared. Correlations between agro-meteorological factors, nodules number and productivity were determined. In one of these experiments there were watering and using of start doses of fertilizers (PK)₄₅. The remaining experiments were carried out in a natural agricultural background without irrigation. The seeds yield of local cultivars (Gornal, Ufinskaya, Zolotistaya) in homogeneous soil conditions on leached chernozem (Ufa district) ranged from 18 to 22 kg/ha. High seed productivity of a new cultivar Elsa was mentioned. In the experiments without irrigation (Ufa, Iglinitskiy, Chishminskiy, Bakalinskiy areas) the seed weight of different cultivars changed depending on the agro-meteorological conditions from 4 to 17 g/plant, being doubled at watering. An average range of seed production variation for all years was 50 % for Zolotistaya cultivar, 53 % for Elsa, 57 % for Ufinskaya and 76 % for Gornal cultivars. The close relationship ($r = 0.61$) between the productivity of beans and the sum of active temperatures above 15 °C was revealed. Greater flexibility to the amount of heat was shown in the locally bred varieties Zolotistaya and Ufinskaya at $r = 0.46$ and $r = 0.59$, respectively, greater dependence on abiotic factors was demonstrated by Gornal and Elsa varieties at $r = 0.78$ and $r = 0.84$, respectively. Similar relations were revealed when the analysis of correlative links was made between the duration of the period of above 15 °C temperatures and the seed productivity. Thus, correlation was detected at $r = 0.42$ and $r = 0.20$ for Zolotistaya and Ufinskaya cultivars, and at $r = 0.51$ and $r = 0.69$, for Gornal and Elsa, respectively. In different conditions there were from 5 to 29 nodules formed at a plant. The average variation of nodule activity between all cultivars during all years was 15.3 %. However, for each cultivar under different soil and climatic conditions the individual average coefficients of variation differed, being 44 % for Gornal, 59 % for Zolotistaya, 65 % for Ufinskaya and 18 % for Elsa varieties. In most experiments the positive skewness prevailed in both the number of nodules and productivity. Normal distribution and the negative skewness for all cultivars were observed in the experiment with watering, and occurred more frequently in plants of Zolotistaya cultivar. Number of nodules per plant and seed production correlated ($r = 0.75-0.87$) only under optimal water regime and mineral nutrition. On the gray forest soil the plants formed a symbiosis with local rhizobia, and on the chernozem soil the symbiotrophic nitrogen nutrition prevailed over mineral nitrogen one. The revealed high intravarietal variability of common bean plants and the asymmetric distribution of symbiotic activity and productivity suggest the possibility for selecting lines to improve the efficiency of symbiosis. A randomly formed supernodulating hybrid L20 of cultivar Elsa was discovered to be promising for further breeding.

Keywords: bean cultivars, seed production, nodulation, agroclimatic factors, inside and between cultivar variability, skewness, South Urals.

The common bean (*Phaseolus vulgaris* L.) is distinguished from the other grain legume crops by its nutritional value and wide scope of application. Its food value is determined by significant (17-32 %) protein content in seeds, as well as by the presence of essential amino acids and vitamins. The bean has a

high potential as a soil-amendment crop. As known, it can accumulate more than 60 kg of biological nitrogen/ha per year due to nitrogen fixation. The bean is also used as a medical plant [1, 2]. In Russia, this crop is not referred to traditional ones, but it is successfully cultivated on individual farms.

By now, in the Republic of Bashkortostan (RB), new bean varieties Ufinskaya [3] and Zolotistaya [4] have been included in the State Register of Selection Achievements Permitted for Use along with previously released variety Gornal. Optimum seeding rates, seeding time and other agricultural methods of cultivation in the conditions of the Cis-Ural region have been developed for these varieties [5]; however, their symbiotic activity has not been practically studied yet. As is known [6], high intra- and intervarietal diversity with regard to symbiosis characters, which is typical for many cultivated forms of legumes, pre-determines the directional selection of genotypes in order to improve symbiotic activity. It is one of the most important conditions for creation of systems of adaptive plant growing and environmentally sustainable crop farming [7].

Our work was aimed at investigating the productivity of different bean varieties and their nodule-forming capacity in symbiosis with local rhizobium races in conditions of the forest-steppe zone of the Cis-Ural region.

Technique. Four bush varieties of the common bean have been studied in field trials (Gornal, Ufinskaya, Zolotistaya and Elza). Variety Gornal bred at the Lgovskaya breeding station and in the All-Russia Research Institute of Legumes and Groat Crops was used as a standard. Ufinskaya and Zolotistaya are local varieties included in the State Register for the RB in 1998 and 2000, respectively [3, 4]. Variety Elza was obtained in France (k-14693 according to the catalogue of VIR, N.I. Vavilov Research Institute of Plant Industry, St. Petersburg). Field trials in the territory of the RB were carried out within five years (2003-2007) in various agrometeorological conditions.

On plot № 5 located in the Ufa area on leached chernozem, the following productivity characters were assessed in 2003-2007 (5 trials): grain weight, yielding capacity, number of seeds per plant and weight of 1,000 seeds for varieties Gornal, Ufinskaya, Zolotistaya and Elza. In this case, a total account of all plants on 1 m² was applied. Within the same years, nodular activity and seed productivity of bean plants were compared on four plots (№ 1, № 2, № 3, № 4; 8 trials).

In 2004, in the Ufa area, all four varieties were studied on gray forest, heavy clay-loam soil (plot № 2) with irrigation and application of starter doses of PK₄₅ fertilizers. In the other cases, studies were carried out on the natural agricultural background without irrigation.

In 2003-2004, in the Iglino area, only variety Ufinskaya was cultivated; in 2005, in the Bakaly area there were only varieties Ufinskaya, Zolotistaya and Gornal. In 2006, the same varieties were assessed in the Iglino area, and also they were compared with tests of two varieties, Ufinskaya and Gornal, in the Ufa area. In 2006, varieties Zolotistaya and Elza were studied in the Chishmy area, and in 2007, they were cultivated in the Iglino area. Nodules (medium and large) and seed weight were taken into account for each plant at the end of the vegetation period at the bean maturation stage by analyzing 40-60 plants and determining a pattern of character distribution by asymmetry coefficients and variation coefficients.

In all trials, the bean was seeded by hand in wide rows (inter-row spacing of 45 cm) at the seeding rate of 15 viable seeds per linear meter, which corresponds to 333,000 pcs/ha. Seeding time was the 1st decade of June, except for seeding in the Chishmy area in 2006, when this term was carried over to the end of May; harvesting time was 2nd decade of September. The plot size was from 3

to 8 m². The trials were carried out in 4 replicates.

The data were processed statistically, using the standard programs of the Microsoft Excel software. The tables show arithmetical average values and standard errors.

Results. The bean is a warm-weather crop. Even germination of its seeds occurs at 12–15 °C; optimum temperature for plant growth and development is 20–25 °C, but successful bean setting is possible at 15 °C. In the years when the experiments were carried out, the dates when temperature crossed 15 °C fell within the period from mid-May to mid-June (Table 1). By this reason and in connection with the possibility of late-spring frosts in the conditions of the Southern Urals, we mainly adhered to the recommended seeding time [5] in the first decade of June. The sum of active temperatures is above 15 °C, and the normal duration of this period in the territory of the RB, according to data from the Bashkir Administration for Hydrometeorology and Environmental Monitoring, is within 70–100 days, and 72–101 days are required for complete bean ripeness for released varieties, which corresponds to the conditions of the region.

1. The characteristics of meteorological conditions in the period of the studies (Republic of Bashkortostan)

Year	Area	Ground frosts, date	T _{air} crossing 15 °C, date	T _{ef} > 15, days	T _{ef} > 15, °C	Precipitation (summer), mm	HTC
2003	Iglino	9.06	23.06–09.09	78 (84)	377 (237)	158 (200)	1.6
	Ufa	29.04	22.06–09.09	79 (90)	389 (265)	193 (172)	2.6
2004	Iglino	19.05	25.05–04.09	102 (84)	407 (237)	273 (200)	2.7
	Ufa	20.05	24.05–04.09	103 (90)	465 (265)	177 (172)	1.7
2005	Bakaly	n/a	11.05–20.08	102 (89)	353 (226)	204 (184)	1.1
	Ufa	17.04	11.05–20.08	99 (90)	386 (265)	167 (172)	n/a
2006	Iglino	20.05	01.06–12.09	103 (90)	391 (237)	155 (200)	1.0
	Chishmy	n/a	31.05–13.09	104 (94)	315 (267)	318 (167)	1.2
	Ufa	20.05	02.06–11.09	101 (90)	310 (265)	313 (172)	1.0
2007	Iglino	07.06	14.06–11.09	89 (84)	358 (237)	186 (200)	1.6
	Ufa	07.06	14.06–12.09	90 (90)	419 (265)	142 (172)	1.2

Note: n/a — not available, T_{air} — air temperature, T_{ef} — effective temperature, HTC — hydrothermal coefficient. Figures in brackets indicate normal values, i.e. long-term average annual values of the corresponding characteristics.

Refer to Table 2 for agrochemical soil parameters on the experimental plots.

2. The agrochemical characteristics of the plots where the field experiments were carried out (Republic of Bashkortostan, 2003–2007)

Plot №	Area	Soil	Humus content, %	Content of N _{total} , %	pH
1	Iglino	Gray forest, heavy clay-loam	3.9	0.25	6.1
2	Ufa	Gray forest, heavy clay-loam	3.8	0.26	6.1
3	Bakaly	Typical chernozem, medium clay-loam	8.5	0.46	6.8
4	Chishmy	Dark-gray forest, medium clay-loam	4.4	0.28	6.4
5	Ufa	Leached chernozem	6.7	0.37	6.4

3. Yielding capacity and productivity indices for different varieties of the common bean (*Phaseolus vulgaris* L.) cultivated on leached chernozem ($\bar{X} \pm x$; Ufa area, Republic of Bashkortostan; 2003–2007)

Variety	Seed weight, g/plant	Number of seeds, pcs/plant	Weight of 1,000 seeds, g	Yielding capacity, centner/ha
Gornal	7.2±0.9	22.3±2.0	314±17.0	18.7±2.2
Ufimskaya	8.4±0.9	24.8±2.0	337±15.9	22.0±2.5
Zolotistaya	7.6±1.0	23.2±1.8	322±21.8	19.7±2.5
Elza	7.6±2.0	43.7±5.3	174±13.6	19.9±5.0

Note: Cv of seed weight — 30.1 %, Cv of number of seeds — 20.4 %, Cv of weight of 1,000 seeds — 14.1 %; LSD₀₅ (least significant difference) for yielding capacity — 1.1 centner/ha. Data for variety Elza are given for 2003–2005.

The yielding capacity of released varieties Gornal, Ufimskaya and

Zolotistaya in trials on leached chernozem (plot № 5) for five years of studies was 18.7-22.0 centner/ha (Table 3) The highest productivity was observed for variety Ufinskaya. Relatively late-maturing variety Elza was distinguished by producing more seeds per plant; however, it had low yielding capacity due to poor bean filling and low germinating ability.

In the tests performed on other plots (Table 4), bean productivity was higher, which could be explained by specific features of the accounting process and trial conditions. In 2004, irrigation was used on plot № 2, which promoted the formation of seed weight from 18.5 to 27.0 g/plant in complete ripeness. Due to optimum moisture content, seed productivity doubled as compared to that of variety Ufinskaya cultivated without irrigation in the same year on plot № 1 in similar agrometeorological conditions. In trials of 2005-2007 without irrigation, seed weight was from 5 to 15 g/plant (8.8 on average) for variety Ufinskaya, from 4 to 17 g/plant (9.2 on average) for variety Gornal, from 6 to 14 g/plant (10.3 on average) for variety Zolotistaya, and from 11 to 16 g/plant (13.3 on average) for variety Elza. Narrower range of productivity variation on average for all years was observed for varieties Zolotistaya ($Cv_{av} = 50 \%$) and Elza ($Cv_{av} = 53 \%$); variation for Ufinskaya and Gornal was 57 % and 76 %, respectively.

4. The intervarietal diversity of nodule-forming and seed productivity characters for common bean (*Phaseolus vulgaris* L.) plants of different varieties ($X \pm x$, Republic of Bashkortostan)

Trial (year, plot)	Variety	Number of nodules			Seed weight		
		pcs/plant	As	Cv	g/plant	As	Cv
2003, № 1	Ufinskaya	10.8±0.7	161	39	8.8±0.6	59*	51
2004, № 1	Ufinskaya	24.5±0.7	135	23	10.8±0.7	188	48
2004, № 2	Ufinskaya	13.0±1.5	35*	61	18.5±1.0	210	31
	Zolotistaya	13.4±0.8	-134	36	19.3±0.8	39*	24
	Gornal	12.4±1.4	-31*	58	27.2±1.7	103	30
	Elza	15.3±1.1	82*	32	26.7±2.5	51*	43
	Ufinskaya	6.2±1.1	129	108	15.4±1.4	131	58
2005, № 3	Zolotistaya	4.7±1.0	288	131	14.2±1.3	105	58
	Gornal	5.2±1.1	297	122	17.4±2.4	727	86
	Ufinskaya	27.3±1.8	163	55	5.0±0.5	430	75
2006, № 1	Zolotistaya	21.9±2.8	250	76	6.1±0.7	202	67
	Gornal	18.4±2.2	237	78	6.2±0.6	190	65
	Ufinskaya	4.9±0.8	279	94	5.9±0.7	292	80
2006, № 2	Gornal	13.0±1.4	193	66	3.9±0.8	556	121
	Zolotistaya	29.4±1.8	86*	53	12.7±0.6	218	43
	Elza	21.4±2.5	1,000 (276) ^a	92	15.6±1.3	222	66
2006, № 4	Zolotistaya	11.5±1.2	98*	64	8.0±1.0	73*	57
	Elza	16.4±1.5	312	70	10.9±0.7	312	50

Note: № 1 — Igolino area, № 2 — Ufa area, № 3 — Bakaly area, № 4 — Chishmy area; As — asymmetry coefficient, % of critical value, Cv — variation coefficient, %; a — high asymmetry coefficient was due to the presence of a spontaneous creeping hybrid with 130 nodules in the sample, the figure in brackets indicates the asymmetry coefficient of the character in the population without this plant.

* Values corresponding to normal distribution ($p < 0.05$).

Based on the comparison of our data on productivity with the results of the experiments carried out in 2007-2008 on 11 common bean varieties in the south forest-steppe conditions of Western Siberia [8], it may be noted that the varieties tested in Siberia produced larger seed weight than varieties in the Cis-Ural region (on average of 5.6-35.0 and 12.0-20.0 g/plant, respectively).

With the regional climatic parameters being similar, experiments in the Omsk Region were distinguished by earlier time of bean seeding (2nd and 3rd decades of May). If frosts are not expected in Cis-Ural conditions according to a long-term forecast, it could be recommended to reschedule seeding dates from June to the last decade of May. We carried out such an experiment in 2006 on plot No. 4 in the Chishmy area. This lead to doubling of bean seed productivity as compared to plots №№ 1 and 2, not only due to better climatic conditions

(hydrothermal coefficient, HTC, was equal to 1.2 in the Chishmy area, and 1.0 in the Ufa and Iglino areas), but also due to a longer vegetation period and additional use of soil moisture in the early periods of plant development.

The analysis of correlation between the bean seed productivity and sum of active temperatures above 15 °C ($r = 0.61$ for all varieties) has revealed that the degree of this correlation is dissimilar for different varieties. Greater adaptability (independence from heat) was observed for varieties Zolotistaya and Ufimskaya ($r = 0.46$ and 0.59 , respectively); varieties Gornal and Elza were less adaptive ($r = 0.78$ and 0.84 , respectively). Similar regularities were found as a result of the analysis of correlative relationships between the duration of the period with temperatures above 15 °C and seed productivity: at $r = 0.42$ and $r = 0.20$ for varieties Zolotistaya and Ufimskaya, respectively; and at $r = 0.51$ and $r = 0.69$ for varieties Gornal and Elza, respectively.

An important reserve for increasing the adaptive potential of bean varieties is breeding of the varieties having high productivity due to symbiotrophic nutrition [9, 10]. Thus, the bean lines selected according to increase in their nodule formation rate surpassed the parent varieties in seed weight (by 74 %) and protein content (by 27 %) [11]. In our experiments aimed at studying the nodular potential of the varieties, the number of nodules in a bean maturation phase was 5–29 pcs/plant (see Table 4). The intervarietal variation of average nodule numbers per plant for the years of the studies was 15.3 %. It should be noted that the best bean variety specimens from VIR's collection had by 40–115 nodules per plant [12]. Based on the results of the trials carried out in the Omsk Region in 2006, high nodule-forming capacity (over 40 nodules) was observed for bean varieties Lika, Sekunda, Rashel and Zolushka [13]. We may suppose that the potential of breeding of the bean varieties and lines adapted to the conditions of the RB for high symbiotic activity is far from being exhausted.

In order to assess prospects for segregation of bean genotypes with the highest symbiotic activity within the variety, we considered the distribution pattern and intervarietal diversity of nodule formation rate and productivity characters by year within each plot (see Table 4). In most of the experiments, right-hand asymmetry ($As > 0$) prevailed with regard to both the number of nodules and productivity for different varieties. This coincides with the observations of other researchers [6, 14] and may be associated with the absence of previous plant selection for a symbiotrophic type of nutrition, the lack of highly active microsymbionts complementary to the host's genotype among local rhizobia, as well as with the influence of environmental factors limiting symbiotic efficiency (available nitrogen content or moisture deficit that reduces the exudation of attractants for nodule bacteria in the rhizosphere and outflow of fixed nitrogen to the above-ground organs of plants). It seems that moisture content conditions in our experiments have made a decisive contribution to the pattern of nodule-forming character distribution, because, in case of artificial irrigation with starter doses of potassium-phosphorus fertilizers in the Ufa area (plot № 2) in 2004, for all varieties, either a normal distribution pattern or uncommon negative asymmetry (mainly for variety Zolotistaya) was identified for the nodule-forming character. It should be noted that variety Zolotistaya demonstrated normal distribution by the number of nodules more often than the other varieties. The study of this variety is of interest with regard to identification of the genotypic properties which provide efficient attraction and/or selection of active bacterial partners by the macrosymbiont.

In order to breed the legume varieties and lines which are able to actively use symbiotically consumed nitrogen, it is important to determine correlation between the size of the nodule-forming apparatus and seed productivity. We

revealed close correlative relationship between the number of nodules in the maturation phase and the weight of seeds from one plant ($r = 0.75$ for variety Ufimskaya, $r = 0.87$ for varieties Zolotistaya and Elza) only in a trial with optimum nutrition and moistening conditions (plot № 2, 2004). On chernozem, (plot № 3, 2005), nodule formation activity of plants was low and did not correlate with productivity. On gray forest and dark-gray forest soils, nodule formation was in general better, but the correlative relationship between it and seed productivity was not found as well.

The comparison of nodule formation activity for each variety in different soil and climate conditions has allowed us to identify the variation range for this character (44.0 % in Gornal, 59.3 % in Zolotistaya, 65.0 % in Ufimskaya, and 18.4 % in Elza). It is likely that such diversity is connected with high flexibility of local adaptive varieties with regard to a capability of changing the nitrogen nutrition type from symbiotrophic to autotrophic under varying environmental conditions. The range of intervarietal diversity with regard to symbiotic activity ($C_{v_{av}} = 63-81\%$ for different varieties) offers opportunities for the directional selection of the high-efficiency intervarietal lines that actively use the potential of symbiotic nitrogen fixation.

As noted by N.S. Tsyganok [16], if principles of environmental and geographical remoteness and parent form contrast are met, hybridization is the most successful approach that allows us to obtain varieties with the required characters. The pea breeding pattern aimed at improving nitrogen fixation, which has been presented by K.K. Sidorova et al. [17], combines the use of hybridization with supernodular mutants, segregation of individual lines in F_2 , recurrent selection of successful lines with supernodulation in F_3-F_7 , and selection of individual and individual-group lines and plants. In our experiments on plot № 4 in 2006, we revealed a plant specimen of variety Elza that had formed a 5 m long stem (with the average value being 0.7 m) and produced more than 130 nodules. Taking this plant into account, a character distribution asymmetry coefficient was equal to 1,000 % of the critical value, or 276 % without taking it into account (see Table 4). It is likely that this plant turned out to be a spontaneously cross-pollinated hybrid with a creeping bean form. Its seeds (line L20) were selected for further study of the heritability of the character associated with high nodule-forming capacity and nondeterministic growth. Three generations of this and two other lines, L42 and L44, selected by high productivity have been field-tested [18].

So, all the bean varieties studied by us are good candidates for cultivation in the Cis-Ural region. It has been demonstrated that a close correlation exists between the bean productivity and the sum of active temperatures above, as well as the duration of the period of these active temperatures, which substantiates the account of adaptive characters, such as early ripeness and flexibility under changing environmental factors, as well in moisture deficit conditions observed in the Cis-Ural region, in the variety breeding process. Varietal features have been noted with regard to variation of these characters. It has been established that using artificial irrigation or rescheduling seeding dates from June to the end of May can double the seed yield. On gray forest soil, the plants of the tested varieties formed a symbiosis with local rhizobia, but the nodule formation rate did not correlate with the yielding capacity. High coefficients of correlation between the nodule-forming capacity of plants and seed productivity have been revealed only in a trial with the moisture regime and mineral nutrition conditions which are optimal for symbiosis. Under the same conditions, uncommon negative asymmetry with regard to the number of plant nodules and seed productivity was noted along with normal distribution of these characters for all varieties. On chernozem, the sym-

biotrophic type of nutrition was inferior to the autotrophic one. The high intravarietal plant diversity with regard to symbiotic activity of all varieties indicates that it is possible to select lines for improving symbiosis efficiency. We have found a spontaneous supernodulating hybrid L20 of variety Elza, which is promising for further breeding.

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