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Study on diversity of *Phaseolus* spp. landraces with reference to global climate change

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The purpose of this study was to investigate the differences between *Phaseolus vulgaris* landraces and to determine their adaptation to local climatic conditions to enrich the genetic diversity of the collection of the Institute of Plant Genetic Resources (IPGR), Sadovo with original plant material better adapted to current climatic changes. The study was performed in four different geographical regions of Bulgaria (Troyan, Smilyan, Velingrad and Sadovo) with six traditional *P. vulgaris* landraces. It was demonstrated that genotype was a more dominant influence on morphological characteristics of landraces than climatic factors or genotype/environment interaction. Differences in the reaction of separate genotypes to fluctuations in meteorological conditions were established based on agro-climatic indices. Tolerance of the studied genotypes to drought was assessed using physiological indices. Accession A9E1270 had the best indices and high adaptability. The influence of meteorological conditions on its growth rate during all interphase periods, even under drought conditions, was insignificant, and its biological specifications had a determining role. A9E1206, A9E1211 and A9E1259 were identified as potential candidates; the quantity of rainfall had a strong influence on their development rate, but they developed more quickly under drought conditions.

Key words: Common bean, phenology, morphology, climatic factors, photosynthesis, leaf water potential, drought.

INTRODUCTION

Climate change, connected with global warming, was forecast 20 years ago (IPCC, 2007). It affects all spheres of the economy, particularly agriculture (Schneider et al., 2007). According to Adams et al. (1998), the effect of climate change on agricultural yield varies by crop and by region. Climate change includes higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Increased temperature leads to reduced yields and quality of many crops. Change in precipitation may benefit different areas by increasing soil moisture, while the reduction of rainfall could have the opposite effect. Higher concentration of CO_2 would result in higher net photosynthetic rates (Cure and Acock, 1986; Allen et al., 1987). The net change in crop yields is determined by

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the balance between these negative and positive direct effects on plant growth and development, and by indirect effects on crop production (Adams et al., 1998). These factors undoubtedly will result in new criteria for crops and regional distribution of cultivars. Flowering, fruit setting and maturity cycle of grain legumes were affected by different stress factors, as well as higher temperature and solar radiation (Munoz-Perea et al., 2006). Singh et al. (2009) reported on the severest and negative adverse effect of the most stressful conditions on seed weight and other seed characteristics of common beans such as seed shape, color, and coat brilliance or shininess. Cultivars not possessing good drought tolerance and better plasticity reduced their reproductive organs (pods and seeds) and other useful associated agronomic traits, thus substantially affecting yield production and quality (Suarez et al., 2008; Vallejo and Kelly, 1998).

P. vulgaris L. were introduced as a crop into Europe by the Spaniards after the discovery of Americas during the 15th century (Westphal, 1974). Common beans are the world's second most important legume crop after soybean, and it is well known that bean pods and seeds are an affordable and inexpensive source of protein, carbohydrates, dietary fiber, starch, minerals and vitamins. The use of common beans declined until a few decades ago, when their use began to be reevaluated for dietary reasons (Sathe, 2002; Mitchell et al., 2009; Zhu et al., 2012). FAO (www.faostat.fao.org 2011) statistics show that world production was approximately 23,250 million tons harvested from 29,211,491 ha. Europe's top common bean producing countries are Poland (34,896 tons), Greece (22,744 tons), Romania (21,351 tons), and Spain (12,952 tons). In Bulgaria the crop occupied an area of 954 ha, from which 1011 tons were produced.

In Europe the diversity of *P. vulgaris* germplasm is the result of adaptation to different agro-climatic and edaphic conditions as well as multiple inputs of material from Andean and Mesoamerican domestication centers (Araya, 2003). People still carry seeds from neighboring and far away regions into Europe and other continents; such unrecorded seed exchange has been occurring since the first visit of Europeans to the Americas (Zeven, 1997). Much unrecorded seed exchange between plant collectors, gardeners, and farmers must have taken place since the first arrival of common bean in Europe.

Common beans are very popular in Bulgaria; they are the most widely used legume in local cuisine, and beans are connected with local traditions and habits, usually based on production (Stoilova and Sabeva , 2006). Due to the good adaptation of common beans to soil types and climatic conditions, and their aesthetic and organoleptic traits, a large number of landraces were differentiated by type of plant, flower, form and size of seeds, as well as economic qualities (Gradinarov, 1939; Genchev and Kiryakov, 2005). Today common beans are widely cultivated in intensive agricultural systems and commercialized mainly in the Dobrudzha plateau, where new varieties displaced the old varieties and landraces. However, throughout the entire country Bulgarian farmers still grow old varieties and traditional landraces in low input agricultural systems, not only for personal consumption but also for sale as niche products or specialties in local markets. Unfortunately, the cultivation of these old varieties and landraces is generally practiced by older farmers, and as a result a large fraction of common bean landraces are endangered by the risk of extinction. Many authors have reported that landraces of many crops are the most threatened category of genetic resources, and are also the primary object of demands for compensation (Hawkes, 1983; Fowler and Mooney, 1990).

The climate in Bulgaria is formed under the influence of complex factors: Geographic (location, altitude and relief), radiation (solar radiation) and circulation (atmospheric circulation and cyclonic activity). Areas with an altitude above 1000 m are characterized by a mountain climate. The mean annual air temperature for the lowland parts of the country is 10 to 12°C. The highest mean monthly air temperatures are 21 to 24°C in July and August. Precipitation is unevenly distributed in the country and changes widely from 500 to 550 mm in the lowlands to 1000 to 1400 mm in places with a mountain climate.

Over the last three to four decades Bulgaria's climate has been changing, which is in accordance with global trends (Kouzmova, 1999; Peev et al., 2000; Peev and Kouzmova, 2001). In the 1990s and 2000s, drought in Southern Bulgaria was very severe, and included the years with the minimum precipitation of the century. With a few exceptions, the mean monthly air temperature deviated positively from the climatic norm and the rainfall-negative deviations in the direction of this reduction. 1994 and 2007 proved to be the warmest years of the 20th century, and 2000 the driest one of the 21st century to date.

All these peculiarities in the climate of Bulgaria have an impact on crop productivity and require more detailed study of historical and current agro-climatic conditions and global trends to correctly select appropriate varieties for a specific area.

To evaluate crop candidates for distribution, it is necessary to assess crop structure and cultivar composition based on their reaction to abiotic stress factors. The Institute of Plant Genetic Resources (IPGR) in Sadovo preserves a collection of about 2000 accessions of *P. vulgaris* from different geographical origins. During the last decade an effort was made to collect local landraces and old varieties to characterize, evaluate and preserve them at the IPGR National Genebank.

The objectives of this study were: (i) to study the differences between landraces using morphological and physiological techniques; and (ii) to determine their adaptation to local climatic conditions to enrich the

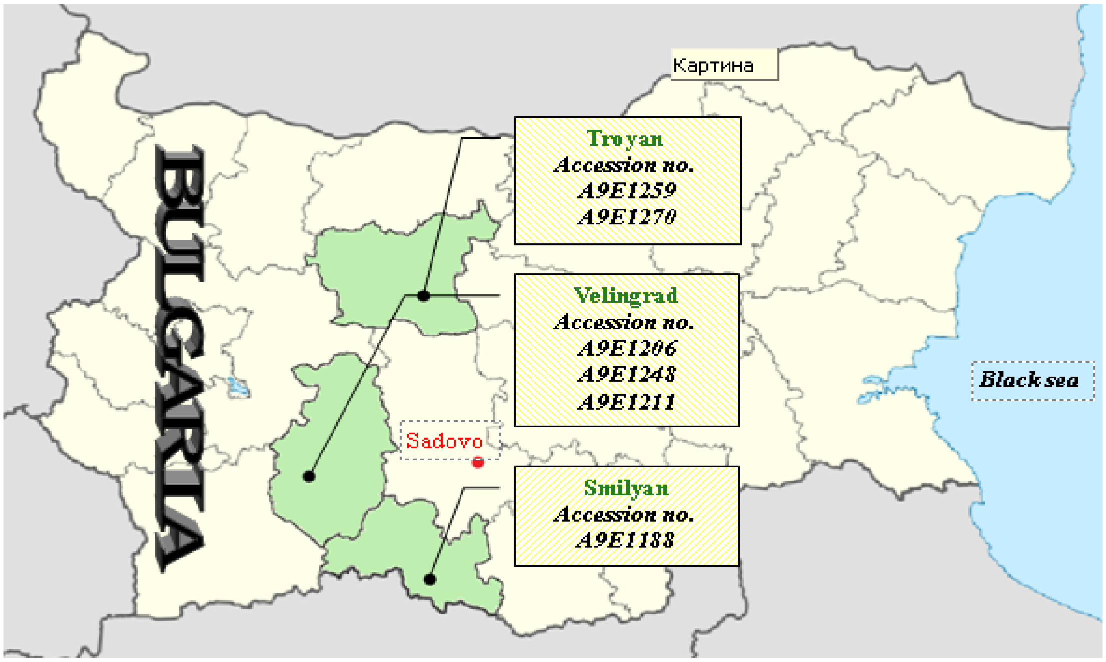

Figure 1. Geographical regions of Bulgaria included in the present study on the diversity of *Phaseolus* spp. landraces with reference to global climate change.

genetic diversity of the *P. vulgaris* collection with plant material, landraces, or primitive varieties of local origin that are better adapted to current climatic changes.

MATERIALS AND METHODS

Plant material

The study was performed in four different geographical regions (Troyan, Smilyan, Velingrad and Sadovo) with different householders and six traditional *P. vulgaris* landraces. These regions were located in the Rhodope and Balkan Mountains at different elevations, as follows: Troyan, 395 m/asl; Smilyan, 1010 m/asl; Velingrad, 745 m/asl and Sadovo, 153 m/asl (Figure 1).

The studied landraces were selected according to their importance, popularity and use in each region. The most traditionally grown bean landraces, still grown by older householders, were chosen. Six accessions were analyzed in this study (Table 1). The selection of the regions was based on previous collecting missions and knowledge that many farmers still used and maintained typical landraces on-farm to meet local market demand for high quality products. A complex morphological characterization was done during three vegetative cycles (2010-2012) (Table 1).

Field trials design

To trace the adaptive capacity of the studied landraces to agro-climatic conditions (especially to drought) two field trials at IPGR were carried out with irrigation and non-irrigated. The irrigated field trial was performed with irrigation once per week with 25 L m^{-3} water. The trials were a randomized complete block design with three replications. Each accession was grown in two row plots; each plot was 3 m^2 in size. In each plot 10 plants and 20 seeds per replication were randomly chosen for biometrics. Complex evaluation and characterization was done according to the International Board for Plant Genetic Resources (IBPGR) Descriptors of *Phaseolus* (1982).

Morphological and physiological evaluation

Observations were made on 11 different agro-biological and morphological characters (Table 2). Physiological analyses (the parameters of the leaf gas exchange - net photosynthesis /P_N/, transpiration intensity /E/, stomatal conductance /g_s/) were performed with a portable photosynthetic system LCA-4 (ADC, Hoddesdon, England). The measurements were conducted in natural environmental conditions. The measurements were made from 10:00 to 14:00, under approximate photosynthetic photon flux density (PPFD) of 1200 to 1900 μmol m^{-2} s^{-1}. Fully developed leaves of the same physiological age (from the middle portion of the shoot) were used for the analyses. The measurements were carried out on ten intact plants of each landrace. Leaf water potential /Ψ_l/ was measured on the same plants as gas exchange using a pressure chamber EL 540-305 (ELE-International Ltd., Hemel Hempstead, England), according to Turner (1988).

Climatic factors

The agro-meteorological conditions were traced in the studied regions by interphase periods. The air temperature and the quantity of rainfall have been taken as main factors, on the basis of which the main agro-climatic indices determining the development rate of the studied bean genotypes were outlined. The hydrothermal coefficient (HTC) was used for assessment of drought and dry conditions (Selyaninov, according to Kouzmova, 2003).

Physiological and climatic adaptation investigations were carried out for a period of two years, 2010 to 2011. During this period

Table 1. Number of accessions included in this study.

No.	Accession No	Status of sample	Geographical Origin	Local name
1	A9E1211	Landraces	Draginovo-Velingrad region	Elenski roga
2	A9E1248	Landraces	Grashevo-Velingrad region	Kadanka
3	A9E1206	Landraces	Kamenitsa-Velingrad region	Maslen bob
4	A9E1259	Landraces	Vrabevo-Troyn region	Byal bob
5	A9E1270	Landraces	Cherni Osam-Troyan region	Naplatar
6	A9E1188	Landraces	Smilyan region	Smilynski bob

Table 2. Quantitative descriptors used in the characterization of common bean landraces.

Morphological characters	Abbreviations	Morphological characters	Abbreviations
Beginning of flowering	BFL	Number of seeds per plant	Ns/s/pl
Flowering duration	FLD	Number of seeds per pod	Ns/s/pod
Days to maturity	DM	100 seed weight	100sw
Plant height	PH	Weight of seeds per plant	w/s/pl
Number of pods per plant	Ns/pod/pl	Yield (g/m^2)	Y/g/m^2
Pod length	Pl		

Table 3. Phenological observations of *Phaseolus vulgaris* accessions in Troyan, Velingrad and Smilyan regions with irrigation.

P. vulgaris **accession number**	**BFL (days^{-1})**	**FLD (days$^{-1)}$**	**DM (days^{-1})**
A9E1211^1	32.7	40.7	94.3
A9E1248^1	32.3	39.3	95
A9E1206^1	32.0	35.7	88.7
A9E1259^2	32.0	34.3	79.3*
A9E1270^2	32.7	34.0	82.7*
A9E1188^3	33.3	42.0	113.3*
Mean Standard	32.5	37.7	92.2
Genotype x Environment %	0.01	28.21	10.6
Genotype’s influence %	9.45	37.96	72.1
Environment %	90.53	33.83	17.3
LSD (0.05)	2.79	4.54	9.39

^{1}Velingrad, ^{2}Troyan, ^{3}Smilyan, *the mean difference is significant at the 0.05 level.

similar results were observed, thus average data from two reporting years is presented in this paper.

Statistical analyses were carried out by the SPSS-9 program for Windows. The correlation and regression analysis was used for meteorological data processing, with the help of a specially developed Excel program for processing of phenological data (Kouzmova, 2002).

RESULTS

The accessions from different trials needed a different number of days after emergence to enter into the next phase, the beginning of flowering (BFL) (Table 3 to 5). The results obtained showed differences in phenological observations and morphological traits among all accessions from the regional trial and the other two trials carried out at IPGR with and without irrigation (Tables 3 to 8). The longest period from emergence to beginning of flowering was shown by accessions from the experimental field of IPGR without irrigation, as follows: Accession A9E1248 (41 days), A9E1188 (38 days), and A9E1211 (37 days) (Table 5). The duration of the flowering period from the trial without irrigation was the shortest, ranging from 27 to 34.7 days, compared with the other two trials grown with irrigation (Tables 3 and 4). Accessions from the three locations in Troyan, Velingrad and Smilyan regions started the first phenological phase (BFL) after the least number of days, counting from

Table 4. Phenological observations of *P. vulgaris* accessions irrigated trials in Sadovo.

Accession No.	BFL (days^{-1})	FLD (days^{-1})	DM (days^{-1})
A9E1211[1]	33.0	33.2	81.3
A9E1248[1]	33.0	33.2	81.3
A9E1206[1]	30.0	33.0	77.3
A9E1259[2]	32.7	29.5	75.4
A9E1270[2]	39.7*	31.0	89.3
A9E1188[3]	34.7	29.7	81.3
Mean Standard	33.8	31.6	81.0
Genotype x Environment %	0.1	25.1	12.0
Genotype's influence %	7.1	37.5	69.1
Environment %	92.8	37.5	18.9
LSD (0.05)	5.8	3.03	15.45

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 5. Phenological observations of *P. vulgaris* accessions in non-irrigated trials in Sadovo.

Accession No	BFL (days^{-1})	FLD (days^{-1})	DM (days^{-1})
A9E1211[1]	37.0	29.0	78.3
A9E1248[1]	41.0*	29.3	77.0
A9E1206[1]	36.7	29.0	77.3
A9E1259[2]	33.0*	29.0	73.3
A9E1270[2]	36.0	34.7	74.3
A9E1188[3]	38.0	27.0	71.3
Mean Standard	37.0	29.7	77.3
Genotype x Environment %	0.013	26.2	9.5
Genotype's influence %	9.5	38.9	70.2
Environment %	90.5	34.9	20.3
LSD (0.05)	2.32	5.35	6.19

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

emergence until 50% of flowering plants; the duration of flowering period was the longest, ranging from 34 to 42 days (Table 3).

Results with a significant difference compared with the mean trial value (accepted as a mean standard) were shown only at the beginning of flowering (BFL) by two accessions: A9E1259 and A9E1248 (LSD 0.05) from the non-irrigated trial carried out at IPGR (Table 5). Duration of the flowering stage did not show any significant difference between all accessions in each trial (Tables 3 to 5). The longest period of vegetation and maturity was obtained by landraces in the regional trial, ranging from 79.3 to 113.3 days (Table 3). Accessions A9E1259 and A9E1270 from Troyan reached maturity over the shortest period of time, and A9E1188 from Smilyan had the longest vegetation cycle. These three accessions showed significant differences at the 0.05 level, compared with the mean standard value.

Morphological characters collected from accessions of these three trials showed big differences (Tables 6 to 8). The highest value of plant height was shown by accessions from the regional trial and the tallest accessions were A9E1248 from Velingrad, at 2.2 m with significant difference to the mean value, followed by A9E1188 at 2.0 m from Smilyan (Table 6).

Accessions of the other two trials at IPGR showed different results. The plants' height was shorter, with values between 1.2 and 1.7 m with mean standard value of 1.4 m from the trial with IS, and between 1.1 to 1.3 m with mean standard value of 1.2 m from the trial with NIS (Tables 7 and 8).

The degree of genotype influence on plant height (expressed by percentage) was higher than the other two factors of genotype x environment and environment (Tables 6 to 8). Similar results were obtained for the remaining morphological characters (number of pods per plant, number of seeds per plant, weight of seeds per plant and 100 seed weight). The biggest number of pods per plant were produced by accessions in the regional trial with mean standard of 14.8 pods/plant (Table 6),

Table 6. Morphological characteristics of *P. vulgaris* accessions obtained from Troyan, Velingrad and Smilyan regions with irrigation.

Ph. vulgaris/acc. No	PH (m)	Ns/pod/pl	PL (cm)	Ns/s/pl	Ns/s/pod	100sw (g)	W/s/pl (g)	Y (g m^{-2})
A9E1211[1]	1.9	13.6	13.6	52.5	5.5	67.3	45.7*	196.0*
A9E1248[1]	2.2*	21.2*	15.9	72.1*	5.4	69.3	40.9	207.3*
A9E1206[1]	1.9	10.8	16.8	47.0	5.6	71.4	29.2	158.3
A9E1259[2]	1.6	10.5*	13.5	45.9	5.2	34.4*	20.9*	133.3*
A9E1270[2]	1.8	10.1*	16.5	53.9	5.3	45.5*	28.4	119.7*
A9E1188[3]	2.0	22.7*	13.1	55.7	5.3	76.3*	34.9	176.7
Mean Standard	1.9	14.8	14.0	54.5	5.4	60.69	33.35	165.2
Genotype x Environment %	32.76	0.93	0.64	8.8	0.8	38.24	28.32	13
Genotype's influence %	47.26	76.2	41.1	61.1	30.06	47.45	53.35	77.1
Environment %	18.78	12.9	58.3	30.2	69.14	14.31	18.33	9.9
LSD (0.05)	0.15	4	3.6	11.15	1.49	12.09	7.61	25.75

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 7. Morphological characteristics of *P. vulgaris* accessions from irrigated trials in Sadovo.

Ph. vulgaris/acc. No	PH (m)	Ns/pod/pl	PL (cm)	Ns/s/pl.	Ns/s/pod	100sw (g)	W/s/pl (g)	Y (g m^{-2})
A9E1211[1]	1.5	11.3	11.2	37	4.8	49.8	27.5	143.7*
A9E1248[1]	1.5	11.3	11.2	37	4.8	49.8	27.5	143.7*
A9E1206[1]	1.7	9.5	10	23	4.8	38.8	13.4	82.7*
A9E1259[2]	1.2	13.1	10.8	42.2	4.3	36	15.6	145*
A9E1270[2]	1.2	9.8	11	23.2*	5.3	43.8	24.8	94*
A9E1188[3]	1.5	16.7*	12.6	88*	4.9	42.2	24.2	114.6
Mean Standard	1.4	11.9	11.2	41.7	4.8	43.3	22.2	120.2
Genotype x Environment %	27.1	16.7	1.3	15	5.5	31.9	20.2	25.3
Genotype's influence %	51.2	70.1	48.7	50.1	5.6	53.1	42.8	65
Environment %	21.7	13.2	50	34.9	88.9	15	37	9.7
LSD (0.05)	0.38	4.59	2.25	17.38	1.28	7.46	10.68	23.44

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

followed by accessions from the IS trial with mean standard of 11.9 pods/plant (Table 7) and the lowest value was recorded with accessions in the NIS trial, with mean standard value of 5.1 pods/plant (Table 8). The same results can be observed by the next important character, number of seeds per plant, with mean standard value of 54.5, 41.7 and 15.1 seeds per plant, respectively. The genotype influence was higher than the environment factor on these two characters, number of pods per plant and number of seeds per plant. The next morphological characters were related to seed size. The weight of seeds per plant, 100 seed weight, as well as seed yield depended mostly on the genotype influence. One hundred seed weight (100 sw) had different mean values, from different irrigated and non-irrigated trials (Tables 6 to 8). Genotype influence in all three trials was 47.45% (Table 6), 53.1% (Table 7) and 45.3% (Table 8) followed by genotype x environment interaction coefficients with values of 38.24, 31.9 and 43.3%, respectively. The highest seed yield production was obtained by A9E1248 with 207.3 g/m^{-2} from a regional trial (Table 6). Four accessions (AE1211, A9E1248, A9E1259 and A9E1270) showed a significant difference at 0.05 level with mean standard value of 165.2 g/m^{-2} (Table 6). The results from the IPGR trials showed higher production from the irrigated trial with mean value of 120.2 g m^{-2} compared with the non-irrigated trial, with a mean standard value of 36.4 g m^{-2} (Tables 7 and 8). The significantly positive difference in seed yield from the irrigated trial was shown by three accessions: A9E1211, A9E1248 and A9E1259 and the significantly lower seed yield by two of them, A9E1206 and A9E1270 (Table 7). The influence of genotype on this character was more dominant than environment factor or genotype x environment interaction in two trials with and without irrigation as shown by related coefficients 77.1, 65.0 and 70.6% (Tables 6 to 8). The correlation and regression dependencies between the development rate in the studied bean samples and the main agro-meteorological factors are shown in Table 9.

Table 8. Morphological characteristics of *P. vulgaris* accessions in non-irrigated trials in Sadovo.

Ph. vulgaris/acc. No	**PH (m)**	**Ns/pod/pl**	**PL (cm)**	**Ns/s/pl**	**Ns/s/pod**	**100sw (g)**	**W/s/pl (g)**	**Y (g/m^{-2})**
A9E1211[1]	1.1	6*	10	14.3	4.7	44	4.7	49.5*
A9E1248[1]	1.3	1.5*	8.6	5.0*	2.6	38.6	1.3	25.0
A9E1206[1]	1.2	6.6*	9.0	19.2*	3.6	40.2	8.6	40.3
A9E1259[2]	1.1	9.1*	9.6	27.7*	4.3	33.8*	8.0	37.5
A9E1270[2]	1.2	4.3	8.9	15.9	4.1	44*	5.1	46.5
A9E1188[3]	1.2	3.1	8.4	8.3*	3.4	37.4	2.6	19.5*
Mean Standard	1.2	5.1	9.1	15.1	3.8	39.6	5.0	36.4
Genotype x Environment %	30.8	12.1	0.52	10.2	0.8	43.3	25.6	17.3
Genotype’s influence %	48.9	76.5	42	57.8	3.5	45.3	50.1	70.6
Environment %	20.5	11.4	57.5	32.1	95.7	12.2	4.3	12.1
LSD (0.05)	0.29	0.89	1.08	10.83	0.86	1.20	3.09	11.72

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 9. Correlation and regression relationships on the influence of the main agro-meteorological factors on the rate of development of the studied bean genotypes.

	Germination - flowering		**Flowering – pod formation**		**Pod formation - maturing**	
Genotypes	**Regression equation of the type y=ax+b**	**Correlation coefficient (r)**	**Regression equation of the type y=ax+b**	**Correlation coefficient (r)**	**Regression equation of the type y=ax+b**	**Correlation coefficient (r)**
Mean air temperature (t, °C)						
A9E1211	y=0.9806t+13.622	0.2933	y=1.446t-18.872	0.8188	y=-10.401t+303.45	-0.8561
A9E1248	y=-4.3943t+127.25	-0.6602	y=-2.531t+73.71	-0.7851	y=-15.978t+430.43	-0.9447
A9E1206	y=-0.5407t+44.489	-0.2773	y=-2.176t+70.61	-0.3932	y=-10.120t+287.84	-0.8281
A9E1259	y=-2.6129t+92.578	-0.5284	y=0.9096t+4.237	0.2855	y=-8.084t+231.86	-0.6247
A9E1270	y=-0.9905t+57.592	-0.1568	y=-0.028t+16.80	-0.0141	y=-8.8092t+256.38	-0.9341
A9E1188	y=0.5281t+28.48	0.3672	y=-1.475t+43.92	-0.8359	y=-3.0584t+110.24	-0.9786
Sum of precipitations (R, mm)						
A9E1211	y=0.0788R+30.919	0.2674	y=-0.004R+13.1	-0.0224	y=0.2362R+14.103	0.9110
A9E1248	y=-0.069R+41.791	0.1319	y=0.2341R+3.75	0.8769	y=-0.4715R+117.1	-0.3886
A9E1206	y=0.0642R+30.671	0.4420	y=0.1043R+16.6	0.6466	y=0.1063R+26.47	0.3105
A9E1259	y=0.0752R+34.779	0.5796	y=0.107R+11.28	0.4977	y=0.0977R+25.204	0.2482
A9E1270	y=0.0361R+35.3	0.1661	y=0.0413R+14.9	0.2285	y=0.1218R+23.383	0.4352
A9E1188	y=-0.0232R+39.636	0.2263	y=0.2043R+8.97	0.9301	y=0.2436R+8.479	0.8906
Hydrothermal coefficient (H)						
A9E1211	y=-1.8713H+34.634	-0.0906	y=-6.5H+17.21	-0.6406	y=10.822H+32.526	0.2784
A9E1248	y=-23.415H+56.73	-0.7053	y=6.8596H+5.78	0.6896	y=-34.502H+95.756	-0.9606
A9E1206	y=3.1899H+31.399	0.3270	y=5.0828H+16.8	0.5334	y=-7.8744H+49.368	-0.3015
A9E1259	y=4.8236H+35.634	0.4580	y=1.2422H+14.3	0.1855	y=-10.618H+48.339	-0.3718
A9E1270	y=-2.0287H+38.27	-0.1378	y=0.3587H+15.9	0.0616	y=-0.473H+36.213	-0.0173
A9E1188	y=-1.3614H+40.147	-0.3972	y=9.0702H+6.28	0.9418	y=26.097H+2.1505	0.8884

У, Duration of the interphase periods (days); t, average air temperature (°C); R, sum of precipitations (mm); H,Hydrothermal coefficient (HTC); r, correlation coefficient.

During the period from sowing to germination there were no cultivar differences between the separate genotypes (unpublished data). However, in the remaining interphase periods differences in the reaction of the separate genotypes to the fluctuation of meteorological conditions were found. In the period from germination to flowering the air temperature was decisive for the growth rate only in A9E1248, where a strong negative correlation was

Table 10. Gas exchange and water potential (Ψ) in the leaves of common bean (*P. vulgaris*).

Variable	P_N	g_s	E	Ψ_l	P_N/E
A9E1211					
Velingrad (irrigated)	13.55^{a}	0.11^{b}	4.30^{b}	-3.3^{a}	3.11^{a}
Exp. field - Sadovo (irrigated)	16.69^{b}	0.15^{b}	2.14^{ab}	-3.1^{a}	7.79^{b}
Exp. field - Sadovo (non-irrigated)	11.95^{a}	0.07^{a}	1.16^{a}	-3.9^{ab}	10.30^{c}
A9E1248					
Velingrad (irrigated)	11.45^{b}	0.14^{b}	2.11^{ab}	-2.9^{a}	5.43^{ab}
Exp. field - Sadovo (irrigated)	18.49^{c}	0.12^{b}	2.95^{ab}	-3.1^{a}	6.27^{ab}
Exp. field - Sadovo (non-irrigated)	7.33^{a}	0.04^{a}	1.74^{a}	-5.0^{b}	4.21^{a}
A9E1206					
Velingrad (irrigated)	10.91^{a}	0.14^{b}	1.51^{a}	-3.3^{a}	7.23^{ab}
Exp. field - Sadovo (irrigated)	11.69^{ab}	0.16^{b}	2.28^{ab}	-3.1^{a}	5.13^{a}
Exp. field - Sadovo (non-irrigated)	10.94^{a}	0.06^{a}	1.39^{a}	-4.2^{ab}	7.87^{ab}
A9E1259					
Troyan (irrigated)	14.99^{b}	0.12^{b}	1.83^{b}	-3.0^{a}	8.19^{a}
Exp. field - Sadovo (irrigated)	14.52^{b}	0.15^{b}	1.87^{b}	-3.0^{a}	7.76^{a}
Exp. field - Sadovo (non-irrigated)	10.28^{a}	0.04^{a}	0.94^{a}	-3.6^{ab}	10.94^{b}
A9E1270					
Troyan (irrigated)	12.54^{b}	0.21^{b}	3.56^{b}	-3.1^{a}	3.52^{a}
Exp. field - Sadovo (irrigated)	10.33^{ab}	0.19^{b}	3.23^{b}	-3.6^{a}	3.20^{a}
Exp. field - Sadovo (non-irrigated)	9.55^{a}	0.07^{a}	1.67^{a}	-4.2^{ab}	5,72^{b}
A9E1188					
Smilyan (irrigated)	10.22^{b}	0.11^{a}	3.40^{ab}	-2.7^{a}	3.00^{b}
Exp. field - Sadovo (irrigated)	16.81^{c}	0.17^{a}	2.90^{a}	-3.1^{a}	5.79^{c}
Exp. field - Sadovo (non-irrigated)	7.69^{a}	0.13^{a}	3.95^{ab}	-4.3^{b}	1.95^{a}

P_N, Net photosynthesis (µmol $m^{-2}s^{-1}$); E, transpiration intensity (mmol $m^{-2}s^{-1}$); g_s, stomatal conductance (mol $m^{-2}s$)); P_N/E, water use efficiency; Ψ_l, leaf water potential (MPa)* Within the same column (for each genotype) values flanked by different letters (a, b, c) are significantly different for p=0.05. The results for each experimental field were statistically analyzed using Student's *t*-test then, the fields were compared by One-Way ANOVA using Tukey's test.

established. In A9E1259 both the air temperature and the quantity of rainfall influenced the growth rate, but the accessions developed faster under conditions of drought (Table 9).

In all remaining samples no correlation dependencies between the studied parameters were established. In the period from flowering to bean formation the air temperature and the quantity of rainfall were determining factors on the growth rate of A9E1248 and A9E1188, in which a very close correlation dependency was reported. However, the influence of rainfall on the growth rate of the beans during that period was completely different. A very close correlation dependency was reported in A9E1188 and A9E1211 (Table 9).

The assessment of the tolerance of different genotypes to drought under field conditions is connected with tracing changes in the plants' physiological status in the course of stress impact. The gasometric parameters (photosynthesis and transpiration rate, stomatal conductance) were used as indicators, as well as water regime parameters (predawn water potential) (Blum et al., 1998; Blum, 1999; Vassilev et al., 2010). The effect of drought on the different stages of plant development is reflected in inhibition of photosynthesis and growth, and is associated with changes in carbon and nitrogen metabolism and water exchange (Yordanov et al., 2000; Boutra and Sanders, 2001; Zlatev and Lidon, 2005).

Where dehydration is gradual, the initial decrease in the net photo-assimilation is due to stomatal limitations and at a later stage it is mostly due to mesophilic limitations and structural disturbances of the thylacoid membranes (Lawlor and Cornic, 2000). The applied methodology allows measurement of leaf gas exchange of the landraces traditionally grown in different areas and under controlled conditions at IPGR, Sadovo (Table 10).

Under irrigation the photosynthesis rate (P_N) is higher in landraces grown at Sadovo. The highest values were found in A9E1211, A9E1248 and A9E1188. The intensity of photosynthesis increased by 79.9% on average. The differences between landraces grown in different regions and in Sadovo under irrigation were probably due to different climatic factors and farming practices in the relevant areas. Without irrigation P_N decreased in all tested landraces. The most pronounced inhibition was demonstrated in A9E1188 and A9E1248. The indicated changes in P_N are comparable with those in the intensity of transpiration and stomatal conductivity (with exception of A9E1188). In A9E1211, A9E1259 and A9E1270 the water use efficiency in photosynthesis, expressed through the ratio P_N/E, increased as a result of the stronger inhibition of transpiration, compared with photosynthesis under irrigated conditions. The nature of changes in the parameters of the leaf gas exchange in A9E1248 and A9E1188 determined the decrease in the ratio P_N/E. The results showed that the leaf water potential, which is the main thermodynamic value of water exchange, decreased under non-irrigated conditions. Changes in leaf potential were most probably caused by some structural and functional modifications ensuring the plant's adaptation to drought.

DISCUSSION

The accessions used in this study were representative of observed field trials from each region with different local names and plant habits, pod and seed traits. We were able to select six landraces among 39 observed accessions with great morphological variability as well as different response to stress factors. These results are consistent with Rodino et al. (2006) and Freitas et al. (2011), who studied the morphology of common bean diversity on Madeira Island. They concluded that the accessions showed a high variability of the analyzed morphological characters and this reflects a wide range of environments in which crops evolved.

Plant systems, and hence crop yields, are influenced by many environmental factors, and these factors, such as precipitation and temperature, may act positively or negatively together with other factors in determining yield (Waggoner, 1983).

The results obtained from these samples had a great phenotypic stability and were well adapted to the agro-ecological conditions of the relevant region: Velingrad, Smilyan or Troyan. This adaptation is likely one reason why farmers still prefer to grow traditional landraces and continue to use traditional knowledge and practices. According to Blum (1988), physiological, morphological and phenological criteria could be used to select for improved adaptation to dry environment.

Mean days to maturity for all studied genotypes of the three different trials were similar in the whole experimental period of three years. The mean value of DM for regional field trials was 92.22 days and the longest vegetation period was registered for A9E1188 with 113.3 days (Table 3). There is a chance of mild to severe frost at the beginning of May (start of the growing season) and beginning of October (toward the end of growing season). Therefore, cultivars/landraces with more than 110 to 115 days maturity are under risk of frost during these months. Short-season cultivars/landraces with 95 to 100 days maturity with wide adaptation capacity would be more reliable for bean producers, especially in the Rhodope and Balkan Mountains. The results published by Singh et al. (2009) confirmed the strong emphasis on developing earlier maturing common bean cultivars because of a shorter growing season and less risk of frost at higher altitudes. Large differences for seed yield among six landraces of three different field trials during the studied period were observed. The highest value of mean grain yield was obtained by accessions from regional trials grown under the most favorable edapho-climatic conditions (temperature, precipitation and soil type) using IS with an average yield of production 163.22 g m^{-2} (Table 6). The landraces from regional trials with IS reached a 100 seed weight of 69.69 g, on average. Temperature increases lead to higher transpiration rates, shorter period of seed formation and consequently low production. Similar results can be observed from our research (Tables 7 and 8). The two field trials carried out at IPGR under unfavorable growing conditions with higher temperature and low air humidity during the whole vegetation cycle had lower values for reproductive traits including seed yield production, weight of seeds per plant and 100 seed weight. The plants from IPGR's trial with IS produced 120.2 g m^{-2} and 36.4 g m^{-2} seed yield, much less than the regional trial with IS (Tables 7 and 8). The same trend was registered on weight of number of seeds per plant and 100 seed weight (Tables 6, 7 and 8). The values of 100 seed weight at IPGR's trials with IS and NIS were much less than the first regional trial, at 43.3 and 39.6 g, respectively.

In the separate interphase periods, considerable differences in the reaction of the genotypes to the fluctuations of the meteorological conditions were reported. The air temperature and the quantity of rainfall were decisive for the growth rate, mostly for A9E1248 and A9E1188.

Following the physiological indices it is worth noting that the plants differ in terms of their stomatal role for the maintenance of the functional activity of their photosynthetic apparatus during the periods of drought (Ort et al., 1994). In some plants the stomatal control has a dominant share in the restriction of photosynthesis and they are characterized by increased efficiency of water use in the photosynthesis (P_N/E). In other plants maintaining their stomata "relatively" open due to the fact that they are able to compensate for the loss of water or due to loss of stomatal control, the water use efficiency may remain unchanged or may considerably decrease. Our research places A9E1211, A9E1259 and A9E1270 91-089 in the first group and A9E1188 in the second group.

Conclusions

A9E1270 proved to have the best indices and the highest level of adaptability, since the influence of climatic conditions on the growth rate in all interphase periods was insignificant, even under drought conditions. A9E1206, A9E1211 and A9E1259 also could be potential candidates; the quantity of rainfall had a strong impact on their growth rate, but they developed at an accelerated rate under drought conditions. The worst adaptability to drought and the strongest influence of climatic conditions were attributed to A9E1188 and A9E1248, in which the influence of climatic conditions on the growth rate was very strong, but the growth rate accelerated with the increase in the rainfall and was strongly maintained under drought conditions.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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