Bulgarian Journal of Agricultural Science, 27 (No 6) 2021, 1136–1142

Comparative assessment of broad bean (*Vicia faba* L.) accessions regarding some main traits and parameters

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Abstract

Kosev, V. & Georgieva, N. (2021). Comparative assessment of broad bean (*Vicia faba* L.) accessions regarding some main traits and parameters. *Bulg. J. Agric. Sci., 27 (6)*, 1136–1142

With an aim to be conducted a comparative assessment of 17 broad bean accessions regarding main traits and parameters, a field trial was carried out at the Institute of Forage Crops (Pleven, Bulgaria) during the period 2016-2018. The randomized block method was used. The results showed that, the factor of genotype had the strongest impact on the phenotypic performance of main quantitative traits (plant height, 1st pod height, number and weight of seeds per plant, 100 seeds mass, pod length and pod width) in the accessions studied. In pod formation, the interaction genotype-environment had the largest influence. Based on values of the coefficient of early-ripeness, the accessions can be divided into the following groups: ultra early-ripening accessions – BGE 029055 (1.00); early-ripening ones – Fb 2481, BGE 041470, BGE 043776, BGE 046721 (1.24), FbH 15 (1.33); mid-ripening ones – BGP (1.34); Fb 1896, Fb 1903, Fb 1929, BGE 032012 (1.43), Fb 2486 (1.62); late-ripening ones – FbH 14, FbH 16 (1.76), Fb 3270 (1.81), FbH 13 (1.95), BGE 002106 (2.00). The variability regarding main quantitative traits was low (2.83-7.26%) and within the following limits: plant height – 64-79 cm, 1st pod height – 22-35 cm, pods number per plant – 8-15, seeds number – 22-41 and 100 seeds mass – 10.29-34.93 g. FbH 14 (7.36 t ha^{-1}), Fb 2486 (6.50 t ha^{-1}) and BGE 041470 (6.82 t ha^{-1}) were distinguished by the highest seed yields. For an additional characteristic of the accessions, the index of individual seed productivity, seed index and index of attraction were used. BGE 041470 had high values in the three indices. The studied accessions represent valuable germplasm and can be used as parental forms in the broad bean breeding.

Keywords: broad bean; accessions; early-ripeness; quantitative traits; yield

Introduction

Broad bean is one of the oldest crops in the world, and the third most important grain legume (Mihailovic et al., 2005). It is grown for various purposes because of its high nutritional value as the protein content ranges from 27 to 34% (Hacisferogullari et al., 2003). Broad bean, like other grain legumes, is a good source of carbohydrates, phosphorus, potassium, iron, and vitamin B complex (Singh et al., 2014).

According to Singh et al. (2012), in conditions of global warming and climate change, broad bean is one of the best performing crops because of its remarkable ability to develop under different climatic conditions along with its wide adaptability to a number of soils. In addition, its key role in crop rotation, decreasing energy costs, improving soil physical properties and reducing the amount of weeds and diseases have long been established (Singh et al., 2012). Unfortunately, broad bean has not yet been used sufficiently, although it is agronomically considered as an alternative to cereals, with a potential for free nitrogen fixing of up to 300 kg N / ha (Singh et al., 2013).

Nowadays, broad bean is cultivated in 64 countries, in an area of 2463966 ha (FAO, 2017). In Bulgaria, its potential is not fully realized. The main reasons for the slight distribution are the underestimation of the advantages of this crop, the lack of varieties in the Official variety catalogue and the yield instability.

Duc et al. (2010) reported a high degree of genetic variability in broad bean (due to a high percentage of out crossing) regarding floral biology, yield potential, seed size and composition, tolerance to biotic and abiotic stresses. Globally, the collection of broad bean germplasm stored in different gene banks is more than 30000 accessions (Singh et al., 2013). Characterization and preliminary assessment are one of the important techniques that help clarify the agromorphological diversity in this crop (Singh & Bhatt, 2012). The main breeding directions are seed yield and seed yield stability, seed quality as well as resistance to drought and pathogens (Singh et al., 2013).

The purpose of the study was a comparative assessment regarding main traits and parameters of broad bean accessions in the Central Northern Bulgaria conditions.

Material and Methods

The experimental activity was conducted at the Institute of Forage Crops (Pleven, Bulgaria) during the period 2016-2018. Seventeen broad bean (*Vicia faba* L.) accessions were studied: BGE 002106, BGE 029055, BGE 032012, BGE 041470, BGE 043776, BGE 046721 (originating in Spain), Fb 1896, Fb 1903, Fb 1929, Fb 2481, Fb 2486, Fb 3270 (Portugal) and FbH 13, FbH 14, FbH 15, FbH 16, BGP (Bulgaria). The randomized block method (Barov, 1982) was used, at a size of the experimental plot of 4 m^2, in three replications. Sowing was done manually, with a rate of 30 seeds per m^2. The field trial was conducted in a field for organic production, without the use of fertilizers and pesticides. It was done a biometric characteristic which included the following traits: 1^{st} pod height, plant height, pods number per plant, pod lenght, pod width, seeds number per plant, seed weight per plant, 100 seeds mass.

The obtained data were processed by two-factor analysis of variance for each trait for determining the impact of the factors of genotype (accession) and environment. For each accession, the following parameters were calculated: index of individual seed productivity (IISP) (seed weight per plant/total biomass per plant), seed index (SI) (seed weight per plant/inflorescence number per plant), index of attraction (IA) (seed weight per plant/vegetative biomass per plant) (Taranenko & Yacishen, 2014). As a criterion for evaluating the degree of early-ripeness was accepted the date of inflorescence beginning as for quantitative evaluation was used the coefficient of early-ripeness (Kuzmova, 2002). As a criterion for assessing the degree of early-ripeness is accepted the date of the beginning of flowering as for quantitative assessment is used a coefficient of early-ripeness (Kuzmova, 2002). The value of this coefficient for ultra-early-ripening cultivars is up to 1.17; for early-ripening ones – from 1.17 to 1.33; for mid-ripening ones – from 1.34 to 1.66, and for late-ripening cultivars – more than 1.66. All experimental data were processed statistically with using the computer software Statgraphics Plus for Windows Version 2.1 and Genes 2009.7.0 (Cruz, 2009).

Results

The meteorological conditions during the study period differed both in terms of temperature regime and, amount and distribution of rainfalls during the different months. In spite of the smaller amounts of rainfalls during the active period of vegetation in 2016 (272.0 mm) and 2017 (283.4 mm), their distribution by months was more uniform and favorable to the broad bean development. During 2018, a strong adverse effect on plant productivity had a long drought period, as well as intensive rainfalls at the end of the growing period, which has led to a plant lodging and yield decrease. The average sum of active temperatures in the broad bean accessions studied in 2016 was 1565.1°C, in 2017 – 1638.5°C and in 2018 – 1689.8°C.

The impact of the factor of year, genotype and their interaction was presented in Table 1.

For all traits, significant differences were found between the studied accessions. The factor of the year was statistically insignificant for plant height and seed yield (Table 2). Genotype-environment interaction was significant for all traits and non-significant for seed yield.

Regarding the performance of the trait of plant height, the genotype (accession) had the highest relative share of influence (87.09%) (Figure 1). The impact of the same factor was also the most tangible with respect to most of the remaining signs: 1^{st} pod height (65.63%), seeds number (60.24%), seed weight per plant (79.06%), 100 seeds mass (74.55%), pod length and width (52.72%; 53.46%), as well as in terms of seed yield (98.60%). The part of variation due to the genotype for these traits considerably exceeded the part due to the interaction genotype-environment. For pods number per plant, with the largest share of the total variation (65.63%) was the interaction genotype × environment, which was al-

Table 1. ANOVA regarding studied traits in broad bean accessions

Source of variation	DF	Plant height	1st pod height	Pods/ plant	Seeds/ plant	Seed weight/ plant	100 seeds mass	Pod length	Pod width
		Mean squares							
Year	2	9.23^{ns}	96.78**	16.06**	283.28**	274.14**	332.92**	5.48**	0.26**
Replication × Year	6	3.16^{ns}	1.21^{ns}	0.28^{ns}	3.51^{ns}	2.01^{ns}	10.46^{ns}	0.141^{ns}	0.02**
Accession	16	1870.0**	248.32**	54.33**	712.53**	1671.90**	6058.0**	20.21**	0.29**
Accession× Year	32	138.00**	58.98**	30.42**	217.46**	204.32**	1013.0**	8.72**	0.11**
Error	96	4.14	1.817	0.37	4.69	1.98	15.17	0.19	0.003
Variation coefficient		2.83	4.47	5.74	7.26	5.48	4.68	5.28	3.61

*/ ** significant at 0.05/0.01 level

Table 2. ANOVA regarding seed yield in broad bean accessions

Source of variation	DF	Sums of squares	Mean squares	F-count	F-table		P-value
					5%	1%	
Year	2	1568.70	784.35	0.00^{ns}	3.09	4.83	0.9822
Replication × Year	6	8454212.04	1409035.34	32.31**	2.19	3.00	0.0000
Accession	16	2209328.34	138083.02	148.44**	1.75	2.19	0.0002
Accession × Year	32	29767.06	930.22	0.02^{ns}	1.56	1.88	1.0000
Error	96	4186334.51	43607.65				
Variation coefficient			38.21%				

*/ ** significant at 0.05/0.01 level

most eight times stronger than that of the genotype. Consequently, long-term researches are needed to improve this characteristic.

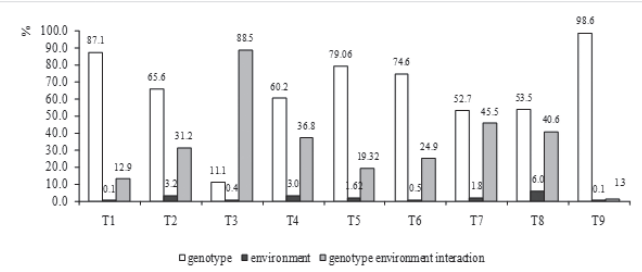

Fig. 1. Influence of factors of genotype, environment and interaction genotype × environment on studied traits

T1 – plant height; T2 – 1st pod height; T3 – pods/plant; T4 – seeds/ plant;T5 – seed weight/plant; T6 – 100 seeds mass; T7 – pod length; T8 – pod width; T9 – seed yield

In the present study, the year was a factor that determined trait formation to the least extent. Its influence ranged from 0.05% (plant height) to 5.99% (pod width). This was also confirmed by the variation coefficient values obtained. As a whole, the studied traits were characterized by low variability: from 2.83% (plant height) to 7.26% (seeds number per plant). The seed yield as a complex quantitative indicator showed a high level of instability with a variation coefficient of 38.21%.

The duration of the vegetation season determined the suitability of a cultivar for growing in a certain geographical region. The value of this indicator depended both on the cultivar characteristics and the meteorological conditions. On average, for the three-year study period, broad bean accessions could be divided into the following groups of early-ripeness: BGE 029055 – ultra early-ripening accession (1.00); Fb 2481, BGE 041470, BGE 043776, BGE 046721 (1.24), FbH 15 (1.33) – early-ripening ones; BGP (1.34), Fb 1896, Fb 1903, Fb 1929, BGE 032012 (1.43), Fb 2486 (1.62) – mid-ripening ones; Fb 3270 (1.81), BGE 002106 (2.00), FbH 13 (1.95), FbH 14, FbH 16 (1.76) – late-ripening ones (Figure 2).

Figure 3 presents the average values of the accessions for each quantitative trait. Maximum stem height (78-79 cm) was found in FbH 13, FbH 16, Fb 3270 and BGE 043776, and minimum (71 cm) – in Fb 1903, Fb 2481, FbH 14 and FbH 15. For most of the accessions included in the study, the height of 1st pod was at a level of 30 cm, as in Fb 2481, FbH 13, FbH 16, Fb 1929 and BGE 046721, the lowest pod was formed at a height of 34-35 cm.

Productivity was determined by the number of seeds and pods per plant, 100 seeds mass and seed weight per plant. The pods number per plant in accessions Fb 2486, BGE 029055, BGE 043776 and FbH 14 varied between 12-15. In the remaining accessions, the value of this indicator had lower values (8 – 11 pods), as the smallest number was in Fb

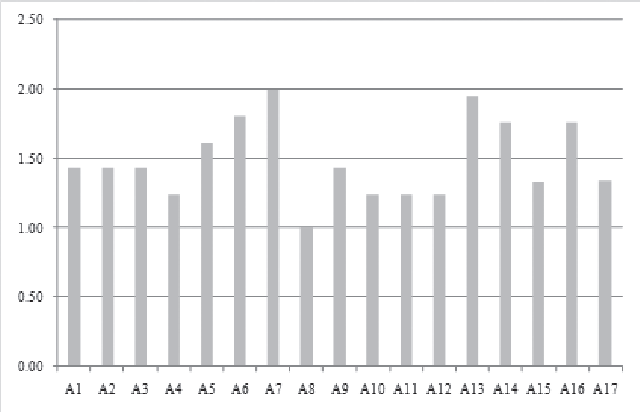

Fig. 2. Coefficient of early-ripeness in broad bean accessions
A1 – Fb 1896, A2 – Fb 1903, A3 – Fb 1929, A4 – Fb 2481, A5 – Fb 2486, A6 – Fb 3270, A7 – BGE 002106, A8 – BGE 029055, A9 – BGE 032012, A10 – BGE 041470, A11 – BGE 043776, A12 – BGE 046721, A13 – FbH 13, A14 – FbH 14, A15 – FbH 15, A16 – FbH 16, A17 – BGP

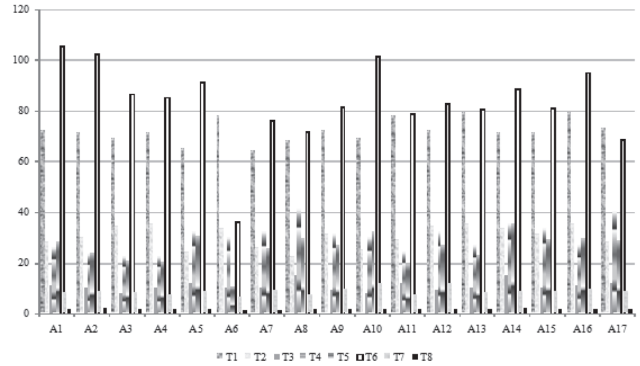

Fig. 3. Main quantitative traits in broad bean accessions
A1 – Fb 1896, A2 – Fb 1903, A3 – Fb 1929, A4 – Fb 2481, A5 – Fb 2486, A6 – Fb 3270, A7 – BGE 002106, A8 – BGE 029055, A9 – BGE 032012, A10 – BGE 041470, A11 – BGE 043776, A12 – BGE 046721, A13 – FbH 13, A14 – FbH 14, A15 – FbH 15, A16 – FbH 16, A17 – BGP
T1 – plant height; T2 – 1st pod height; T3 – pods/plant; T4 – seeds/plant;T5 – seed weight/plant; T6 – 100 seeds mass; T7 – pod length; T8 – pod width

1929 and BGE 041470. The greatest amount of seeds was recorded in BGE 029055 (41) and BGP (40), and the least one – in Fb 1903 and Fb 2481 (22).

Individual plant productivity can best be characterized by determining seed weight per plant. FbH 14, BGE 041470 and Fb 2486 exceeded the others regarding the seed weight per plant (30.28 – 34.93 g). They can be recommended as potential parental forms in combinative breeding. The plants of Fb 3270 and BGE 043776 were distinguished by the lowest seed weight (10.29 g and 18.83 g, respectively), at an average value of 25.70 g for the group. In terms of 100 seeds mass, Fb 1896 significantly exceeded the remaining accessions (105.48 g). Fb 1903 and BGE 041470 occupied the next positions, with values of 102.34 g and 101.38 g, respectively. The lowest was the seed mass in Fb 3270 (36.28 g) and BGP (68.6 g).

The results obtained in terms of pod length showed that the plants of BGE 046721 (11.54 cm) and BGE 041470 (11.49 cm) had the longest pods. There were no significant differences between the accessions regarding this trait.

From the studied collection of accessions, with the highest average yields of seeds were characterized FbH 14 (7.36 t ha^{-1}), BGE 041470 (6.82 t ha^{-1}) and Fb 2486 (6.50 t ha^{-1}) which occupied first, second and third positions according to the rank analysis (Figure 4). In contrast, Fb 3270, BGE 043776, Fb 1929, Fb 2481, FbH 13 and Fb 1903 were distinguished by high variability and seed yield below the average (5.47 t ha^{-1}) for the group, which according to the ranking analysis gives them the last six positions (12-17).

In assessing the source breeding material and the selection of suitable parental components, the following indices were used: IISP, SI and IA (Figure 5). Concerning the index

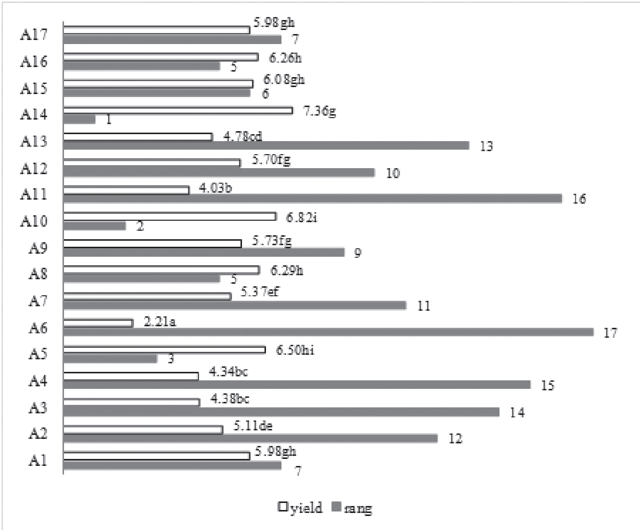

Fig. 4. Seed yield and rank of the broad bean accessions
A1 – Fb 1896, A2 – Fb 1903, A3 – Fb 1929, A4 – Fb 2481, A5 – Fb 2486, A6 – Fb 3270, A7 – BGE 002106, A8 – BGE 029055, A9 – BGE 032012, A10 – BGE 041470, A11 – BGE 043776, A12 – BGE 046721, A13 – FbH 13, A14 – FbH 14, A15 – FbH 15, A16 – FbH 16, A17 – BGP

of IISP, broad bean accessions showed a certain similarity as values for this parameter did not exceed one. However, accessions BGE 032012, Fb 2486, BGE 041470 and BGE 046721 may be pointed out as genotypes with the highest individual seed productivity (0.50 – 0.53). In terms of IA, the differences between the accessions were relatively more noticeable, as BGE 032012, BGE 041470 and BGE 046721 were in the position of more attractive genotypes. Judging by the values of SI, this index supported the evaluation of the previous two indices as regards accessions BGE 041470 (3.86), BGE 046721 (2.99) and BGE 032012 (2.86).

The calculated indices were used as indicators that characterize the productivity of the accessions studied. Strong positive correlations were established of IISP, SI and IA indices with seed weight per plant (r = 0.656; r = 0.710; r = 0.710), 100 mass seeds (r = 0.573; r = 0.665; r = 0.666) and pod length (r = 0.628; r = 0.889; r = 0.889). SI and IA indices correlated positively also with pod width (r = 0.528; r = 0.529) and for IISP, the correlation coefficient was low (r = 0.294) and statistically insignificant. The interactions of the studied indices with the number of seeds per plant were positive but weak and non-significant. It should be noted that some yield components had a negative impact on the indices. The plant height manifested a strong negative effect on the indices, especially for IISP (r = –0.706). Also, the traits of 1st pod height (r = -0.404; r = –0.138; r = –0.137) and pods number (r = -0.184; r = –0.396; r = –0.395) had a similar effect on the indices (Table 3).

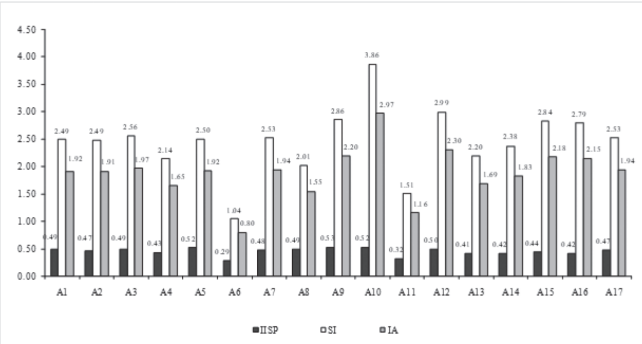

Fig. 5. Index of individual seed productivity (IISP), seed index (SI) and index of attraction (IA) in broad bean accessions

A1 – Fb 1896, A2 – Fb 1903, A3 – Fb 1929, A4 – Fb 2481, A5 – Fb 2486, A6 – Fb 3270, A7 – BGE 002106, A8 – BGE 029055, A9 – BGE 032012, A10 – BGE 041470, A11 – BGE 043776, A12 – BGE 046721, A13 – FbH 13, A14 – FbH 14, A15 – FbH 15, A16 – FbH 16, A17 – BGP

Discussion

According to several researchers (Bulintsev & Telih, 2016; Bezuglova & Kazydub, 2017), most of the regionalized broad bean cultivars did not meet the requirements of the modern production of this culture. Many of these cultivars are characterized by prolonged vegetation period, lodging tendency, yield instability. Bezuglova (2015) pointed out that the lack of varieties that are well adapted to concrete soil and climatic conditions, as well as the small production of seeds, considerably impeded the dissemination of broad bean in many regions of the world.

According to Petrova & Angelova (2013), the broad bean collection of *V. faba* species in Bulgaria, stored at the Institute of Plant and Genetic Resources (Sadovo) is limited and included mainly old varieties of different origins and local populations. The evaluation of the available genetic material showed a wide range of variation in all indicators, with coefficients of variation of 17.15 to 156.03%. The highest coefficient of variation had the mass of 100 seeds, followed by the number of seeds per plant. The accessions formed from 5 to 55 pods per plant at a height of 67.9 to 118.3 cm. The seed number and seed weight per plant ranged from 16.9 to 148.7 and from 22.85 to 109.9 g, respectively. Considerably less variability of quantitative traits was found by Fikreselassie & Seboka (2012) when evaluating 25 broad bean genotypes. In these genotypes, the pods number was in the range of 10.70 to 13.64, the seeds number – from 31.11 to 39.50, and the yield of a plot of 5 m^2 – from 603.40 to 881.80 g. According to the same authors, the grain yield (kg ha^{-1}) and seeds number per plant demonstrated the most substantial variation, which was confirmed in this study.

Table 3. Correlation dependencies between main traits and indices in broad bean accessions

Indices	T1	T2	T3	T4	T5	T6	T7	T8
IISP	-0.706**	-0.404	-0.184	0.227	0.656**	0.573*	0.628**	0.294
SI	-0.393	-0.138	-0.396	0.091	0.710**	0.665**	0.889**	0.528*
IA	-0.391	-0.137	-0.395	0.090	0.710**	0.666**	0.889**	0.529*

*/ ** significant at 0.05/0.01 level

T1 – plant height; T2 – 1st pod height; T3 – pods/plant; T4 – seeds/plant;T5 – seed weight/plant; T6 – 100 seeds mass; T7 – pod length; T8 – pod width

IISP – index of individual seed productivity; SI – seed index; IA – index of attraction

Kadermas (2014) underlined the importance of correlation interpretation as it enables the structure, direction and strength of dependence between traits to be established. Thus, the found correlation coefficients provide a basis for forecasting, facilitate the selection and speed up the breeding process. In support of this opinion was also the study of Pivovarov & Dobrutskaya (2000).

According to data of ICARDA (2008), replacing local varieties with improved ones was led to an increase of 18% in Egypt, 8% in Sudan and 42% in Ethiopia. For high-yield varieties suitable for the conditions of South-East Ethiopia, the region of Sinana and Agarfa (Bale Zone), reported by Mitiku1 & Wolde (2015). In both locations, maximum grain yield was recorded in Shallo variety (4886.8 kg/ha), followed by Gebelcho and Mosisa (4362.2 kg/ha). For another Ethiopian region (Chencha Woreda, Southern Ethiopia), Zebire & Tadesse (2018) have recommended Moti and Gora which exceed the productivity of Gebelcho. Based on the performances of yields and farmers' preferences, Mogiso and Mamo (2018) determined varieties Tumsa (5.36 tons ha^{-1}) and Hachalu (5.86 tons ha^{-1}) as the most suitable for the ecological conditions of Kaffa area (Ethiopia). Based on yielding performance and farmers' preferences, Mogiso & Mamo (2018) determined the varieties Tumsa (5.36 tons ha^{-1}) and Hachalu (5.86 tons ha^{-1}) as the most suitable for the ecological conditions of Kaffa area (Ethiopia). The excess over the average for the studied group was 16.4 and 8.1%, and was due to their large number of pods and higher seed weight per plant. In the present experimental conditions, the increase in accessions FbH 14, BGE 041470 and Fb 2486 was 34.7, 24.7 and 18.9% compared to the mean for the tested group.

Broad bean is susceptible to drought. Adapted material can overcome terminal drought through early-ripeness, but at this stage, there is no strategy to be effective against unpredictable, periodic drought (Link et al., 2008). In the conditions of the present study, accessions BGE 029055, Fb 2481, BGE 041470, BGE 043776 and BGE 046721were characterized by a lower coefficient of early-ripeness (respectively a shorter vegetation period) and can be used as sources of early maturation in the breeding process.

The breeding objectives for broad bean entirely depend on the economic and agro-ecological conditions and the geographical region and use. For the production of fodder, mainly small-grained varieties are bred. The classic breeding in broad bean has remarkable achievements such as non-shattering, yield stability, improved yield and lodging resistance (Link et al., 2008). Some researchers (Taranenko & Yacishen, 2014) considered that breeding should focus on characteristics that contribute to a greater extent to yield and are less dependent on the environment. Such characteristics are the index of individual seed productivity, the seed index and the index of attraction. They have the following advantages: minimal variability, high inheritance, and high interdependence with yield. The creation of new genotypes by use of the presented indices would provide a change in the plant architectonics of new genotypes, which causes a change in the intensity of physiological processes in direction of transfer of assimilates to the generative mass and intensification of the productiveness even under stress conditions. With respect to the indexes considered, our results showed good performances of BGE 041470 (with values for IISP, SI, IA respectively 0.52, 3.86, 2.97), as well as of BGE 046721 (0.50, 2.99, 2.30) and BGE 032012 (0.53, 2.86, 2.20).

Conclusions

The factor of genotype had the strongest impact on the phenotypic performance of main quantitative traits (plant height, 1st pod height, number and weight of seeds per plant, 100 seeds mass, pod length and pod width) in 17 broad bean accessions. In pod formation, the interaction genotype-environment had the largest influence.

Based on values of the coefficient of early-ripeness, the accessions can be divided into the following groups: ultra early-ripening accessions – BGE 029055 (1.00); early-ripening ones – Fb 2481, BGE 041470, BGE 043776, BGE 046721 (1.24), FbH 15 (1.33); mid-ripening ones – BGP (1.34); Fb 1896, Fb 1903, Fb 1929, BGE 032012 (1.43), Fb 2486 (1.62); late-ripening ones – FbH 14, FbH 16 (1.76), Fb 3270 (1.81), FbH 13 (1.95), BGE 002106 (2.00).

The variability regarding main quantitative traits was low (2.83-7.26%) and within the following limits: plant height – 64-79 cm, 1st pod height – 22-35 cm, pods number per plant – 8-15, seeds number – 22-41 and 100 seeds mass – 10.29-34.93 g. With high seed yields were distinguished FbH 14 (7.36 t ha^{-1}), Fb 2486 (6.50 t ha^{-1}) and BGE 041470 (6.82 t ha^{-1}), which the same accessions exceeded the others and concerning seed productivity per plant.

For an additional characteristic of the accessions, the index of individual seed productivity, seed index and index of attraction were used. BGE 041470 had high values in the three indices.

The studied accessions represent valuable germplasm and can be used as parental forms in the broad bean breeding.

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Received: July, 20, 2020; *Accepted:* October, 1, 2020; *Published:* December, 2021