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OPTIMAL PARAMETERS OF MODEL BROAD BEAN CULTIVAR FOR THE CENTRAL PART OF THE DANUBE PLAIN, BULGARIA

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Abstract

In order to increase the productive potential of crop plants, a selection of economically valuable traits is needed, the combination of which in the breeding process will lead to the development of the desired genotype. The purpose of the present study was to establish the impact of main quantitative traits on broad bean productivity (in organic production conditions) and to select parental components with increased adaptability and stability. The experimental activity was carried out in the Institute of Forage Crops (Pleven, Bulgaria), during the period 2016-2018, with source collection of 17 accessions of broad bean. A linear equation of regression was used to determine the effect of quantitative traits on seed productivity. The optimal parameters of model broad bean plant with high seed weight was characterized by the following traits: plant height — 69 cm to 90 cm, 1st pod height — 22 cm to 36 cm, pod number per plant — 9 to 14, seed number — 22 to 35, pod length — 7 to 11 cm, pod width — 15 to 19 mm, and 100 seeds weight — from 80 g to 120 g. The obtained results showed that the traits of seed number (R = 0.72) per plant, pod number (R = 0.48), 100-seed weight (R = 0.28) and 1st pod height (R = 0.25) had the greatest and statistically significant impact on the seed productivity. Accessions FbH 14, FbH 16, BGE 032012, FbH 15, and Fb 2486 were distinguished as highly adaptable regarding seed productivity, and Fb 1903 and BGE 041470 were determined as low adaptive. Accessions Fb 1896, Fb 2486, BGE 032012 and BGE 043776 combined good adaptability with low variability and were suitable as parental components for use in the combinative breeding.

Keywords: model, broad bean, regression, traits, plant height, pod size, pod number, 100-seed weight, seed productivity

Broad bean is an annual legume plant known in botany as *Vicia faba* L. It is known by different names (Horse bean, Broad bean, Faba bean, Fava bean, Windsor bean, Tick beans), most of which refer to a separate subgroup rather than the whole species [1, 2]. Broad bean is one of the oldest crops, worldwide it is third most important forage grain legume after peas and soybeans [3]. The long history of growing, wide spread in diverse environments, and different breeding methods have turned the broad bean into one of the most variable species, possessing a wide range of variations in plant architecture, leaf shape and size, seed size, color and shape [4, 5].

Studies in the field of legume breeding have made essential progress in recent years with regard to the creation of new varieties with increased productivity and ecological adaptability [6]. Despite successes in this line, the need for further improvement and development of new varieties continues to be a major task due to the changing environmental conditions and the lack of suitable varieties for them [7]. New challenges present the requirements that impose on cultivars the production systems with reduced levels of inputs (and in particular the organic and biodynamic production systems) and the main problem with these systems - low productivity.

Crop breeding is a prolonged process that is dependent on a number of factors [8]. The ideotypic breeding distincts from the traditional one in that the breeders mean to change exactly certain traits in order to increase the productivity and adapt the plants to the particular environment of growing [9].

In order to enhance the productive potential of crop plants, a selection of economically valuable characteristics is needed. Their combination in the breeding process will lead to the creation of the desired genotype [10]. Of particular importance for enhancing the efficiency of the selection activity is information on the interrelationships among the quantitative signs in the plant population. One of the commonly used methods for clarifying dependencies is through applying correlation and regression analysis [10, 11].

This study compares the variability of quantitative traits in a number of breeding varieties of forage beans of different origins and local populations and determines optimal parameters of a highly productive variety for organic technologies. The most promising donors are identified for creating a variety corresponding to the model for these conditions.

The purpose of the study was to establish optimal parameters of model broad bean cultivar for the central part of the Danube plain and to select parental components with increased adaptability for the needs of combinative breeding.

Materials and methods. Seventeen accessions of broad bean (*Vicia faba* L.) (FbH 13, FbH 14, FbH 15, FbH 16, BGP, Fb 1896, Fb 1903, Fb 1929, Fb 2481, Fb 2486, Fb 3270, BGE 002106, BGE 029055, BGE 032012, BGE 041470, BGE 043776, BGE 046721) with different origin were objectives of this study (collection of the Institute of Forage Crops, Pleven, Bulgaria). The introduced accessions were local cultivars and the Bulgarian ones were local populations. A starting point in the formation of the initial collection was the choice of samples with high seed productivity. The experimental activity was carried out in the Institute of Forage Crops (Pleven) during the period 2016-2018. The variants were located in randomized block method [12], with a size of the experimental plot of 4 m^2 and a threefold repetition of the variants. The sowing was manual, with a sowing rate of 30 seeds m^2. Accessions were cultivated under organic farming conditions, without application of fertilizers and pesticides. The biometric characteristics at harvesting included the following traits: 1st pod height (cm), plant height (cm), pods number per plant, pod length (cm), pod width (cm), seeds number per plant, seed weight per plant (g), 100 seeds mass (g).

The data were processed by regression analysis of variance for each trait for determining the influence of factors of genotype (accession) and environment. The phenotypic variability of the broad bean traits was evaluated by the nonparametric method [13], and the general adaptability (A) was calculated [14]. All experimental data were processed statistically with using the computer software GENES 2009.7.0 for Windows XP (ftp://ftp.ufv.br/dbg/biodata/) [15].

Results. The studied samples (breeding varieties and local populations) are listed in Table 1.

1. **Broad bean *Vicia faba* L. accessions included in the study** (Institute of Forage Crops, Pleven, Bulgaria, 2016-2018)

Accessions	Status	Origin
Fb 1896	Cultivar	Portugal
Fb 1903	Cultivar	Portugal
Fb 1929	Cultivar	Portugal
Fb 2481	Cultivar	Portugal
Fb 2486	Cultivar	Portugal
Fb 3270	Cultivar	Portugal
BGE 002106	Cultivar	Spain
BGE 029055	Cultivar	Spain

Continued Table 1

BGE 032012	Cultivar	Spain
BGE 041470	Cultivar	Spain
BGE 043776	Cultivar	Spain
BGE 046721	Cultivar	Spain
FbH 13	Landrace	Bulgaria
FbH 14	Landrace	Bulgaria
FbH 15	Landrace	Bulgaria
FbH 16	Landrace	Bulgaria
BGP	Landrace	Bulgaria

A task of each breeding program is to approximate the biometric values of the plant to theoretically calculated and optimal parameters. The results of the regression analysis (Table 2) showed that the linear component in the regression of seed productivity with respect to the studied quantitative indicators was significant.

2. Regression analysis of seed productivity regarding main quantitative traits in broad bean *Vicia faba* L. cultivars and landraces (Institute of Forage Crops, Pleven, Bulgaria, 2016-2018)

Source	Sum of Square (SS)	Degrees of freedom (df)	Mean Square (MS)	*F*-ratio	p-value
Model	5.31038	7	0.758625	27.43	0.00001
Residual	4.01082	145	0.027661		
Total	9.32120	152			

3. Regression coefficients (R) of seed productivity regarding main quantitative traits in broad bean *Vicia faba* L. cultivars and landraces (Institute of Forage Crops, Pleven, Bulgaria, 2016-2018)

Parameters	Estimate (R)	Standard error	*t*-statistic	p-value
Constant	−29.72	1.9816	−14.9986	0.0000
Plant height	−0.09*	0.0282	−3.2561	0.0014
1st pod height	0.25**	0.0571	4.3878	0.0000
Pods number	0.48*	0.1360	3.5531	0.0005
Seeds number	0.72**	0.0487	14.7781	0.0000
Pod length	0.44	0.2265	1.9346	0.0550
Pod width	0.27	1.4198	0.1876	0.8514
100 seeds mass	0.28**	0.0138	20.6404	0.0000

* and ** Regression coefficients are statistically significant at $p = 0.01$ and $p = 0.001$, respectively.

Based on the data from the biometric analysis of the collection of accessions, a statistical model of broad bean plant under the climatic conditions of Central Northern Bulgaria was developed. A regression equation (Table 3) was presented, which expresses the impact of each individual trait on seed productivity:

$$Y = 0{,}883 - 0{,}09X_1 + 0{,}25X_2 + 0{,}48X_3 + 0{,}72X_4 + 0{,}44X_5 + 0{,}27X_6 + 0{,}28X_7,$$

where Y is seed productivity, X_1 is plant height, X_2 is 1st pod height, X_3 is pods number per plant, X_4 is seeds number per plant, X_5 is pod length, X_6 is pod width, X_7 is 100 seeds mass.

The graphical representation of the relationships between the seed productivity and studied quantitative components allowed statistical results to be obtained (with sufficient approximation) and main dependencies between the quantitative traits to be established (Fig. 1). Of the investigated characteristics, only plant height had a negative impact ($R = -0.09$) on productivity. The negative interaction of this characteristic was very low and expressed at values lower than 69 cm and higher than 90 cm.

The increase in the height of 1st pod placement had a slight positive effect ($R = +0.25$, $p < 0.001$) on seed productivity of the broad bean, with the optimal limits of this trait in the study conditions between 22 and 36 cm. The influence of the pods number (R = +0.48, $p < 0.01$) was also statistically significant and favorable, especially when ranging from 9 to 14 pods.

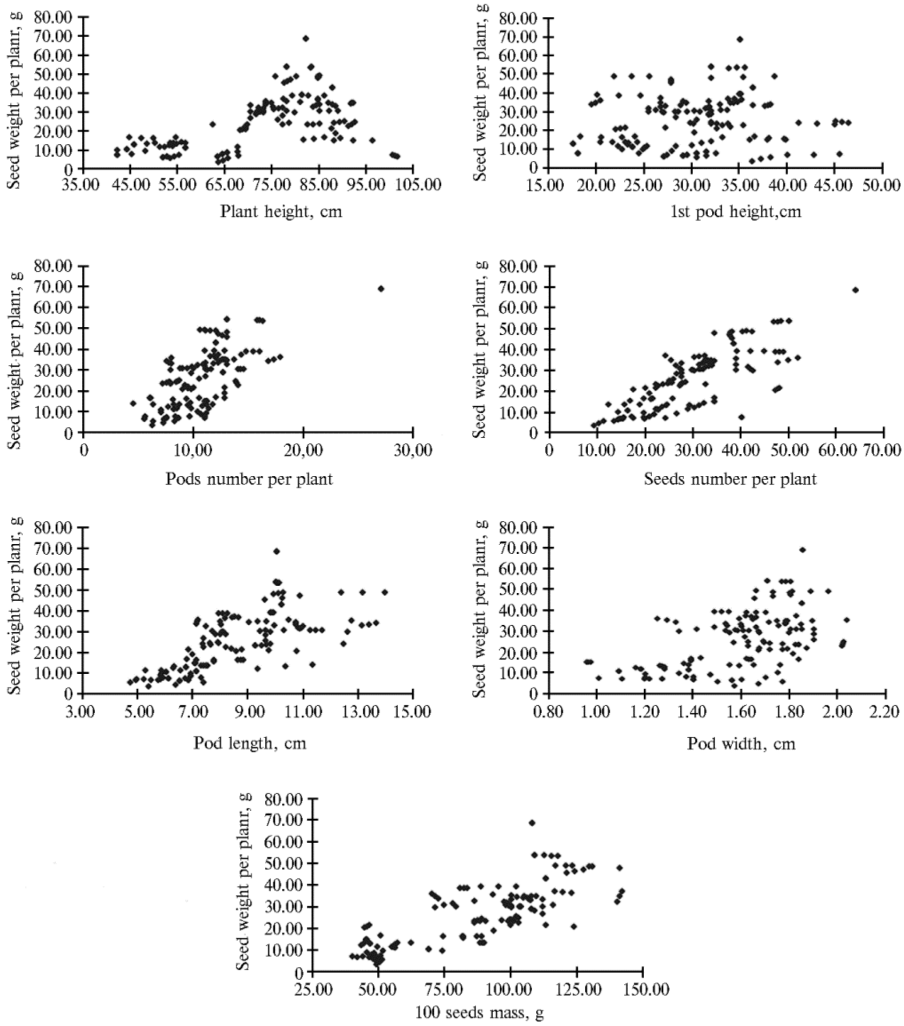

Fig. 1. Dependencies (R) **between seed productivity per plant and quantitative traits in broad bean *Vicia faba* L. cultivars and landraces** (Institute of Forage Crops, Pleven, Bulgaria, 2016-2018).

The impact of the seeds number was significantly positive and with the greatest heaviness (R = +0.72, $p < 0.001$), suggesting that increasing the number of seeds will be crucial for the seed weight of the plant. Its optimal values, which had a favorable effect on seed productivity, ranged from 22 to 35 seeds.

Other traits that had a positive impact on productivity were the length and width of pods. The regression coefficients for both traits (R = 0.44, R = 0.27) were insignificant as the pod width was almost twice smaller than that of pod length. According to the data obtained, it could be assumed that these signs will not play an essential role in the expression of the seed weight. Seed productivity would decrease if the plants form pods with a length and a width beyond the range 7-11 cm and 15-19 mm, respectively.

Another characteristic, with significant influence (R = +0.28, $p < 0.001$) on the broad bean productivity, was the mass of 100 seeds. The beneficial impact of this indicator occurs at values ranging from 80 to 120 g. Seed productivity will decrease with a reduction or increase in the mass of 100 seeds beyond the indicated limits.

According to the analysis carried out, the model of a broad bean plant for the climatic conditions of Central Northern Bulgaria for the purpose of realizing high seed productivity should contain parameters within the following limits: plant height — from 69 to 90 cm, 1st pod height — from 22 to 36 cm, pods number per plant — from 9 to 14, seeds number — from 22 to 35, pod length — from 7 to 11 cm, pod width — from 15 to 19 mm, and 100 seeds mass — from 80 to 120 g.

It should be noted, however, that the full performance of productive potential depended not only on the individual influence of each parameter on the seed weight but also on the complex interrelationships between the individual traits and their combination in the plant [16].

Modern principles of modeling of varieties should be applied differentiated and to be adapted to the specifics of the respective soil-climatic conditions [17]. For example, the development of a model in lupine required studying the morpho-physiological nature of indicators influencing the productivity and sustainability to stress factors. The analysis conducted by the author showed that plant productivity depends to a large extent on the number of seeds and pods per plant. The studies of some authors [16] related to cultivar model in chick pea showed that the plant should have the following main characteristics: height — 38-43 cm; pods number — 25-45; seeds number — 25-45 и mass of 1000 seeds — 28-45 g. A similar investigation in fodder peas [18] found that the plant model was characterized by an average height of 60-70 cm, 8-10 pods, 30-40 seeds and 160-260 g regarding the mass per 1000 seeds. The author stated that the number of seeds per plant, height of 1st pod and 1000 seeds mass had the greatest impact on the grain yield of peas.

Adaptability is defined by the ability of plants to form high yields under different environmental conditions. Adaptive potential of species and cultivars is based on modifying genotypic variability and is characterized by the terms “plasticity” and “stability” [19]. To evaluate the adaptability in the present study conditions, the coefficient of general adaptability (Fig. 2) was calculated according to the values of which the production capabilities of accessions can be estimated. Selective value represents those that have a high general adaptation (coefficient A has maximum values) and at the same time, they exhibit low variability of the trait. The obtained data showed that almost all broad bean accessions have positive coefficients of general adaptability. Accessions with the highest adaptation can be arranged in the following order: FbH 14 > FbH 16 > BGE 032012 > FbH 15 > Fb 2486 > BGE 046721. Fb 1903 and BGE 041470 are characterized by the lowest (poorly negative) adaptive ability.

An important condition for ensuring sustainable and organic forage production is the use of cultivars with increased stability of the yield [20]. The conditions under organic farming are much more diverse than in traditional farming, so varieties must be much more adaptable, and yield stability is as important as its magnitude [21]. Some of the varieties that have been developed in conventional conditions have stable yields also in the organic farming system, but they have to be tested for selecting such ones with stable yields, suitable for the conditions of organic farming [20]. The stability assessment in the present study (see Fig. 2), according to the parameter of Kang [13], showed that accessions BGE 043776, Fb 2486, BGE 002106, Fb 2481 and Fb 3270 exhibited good stability and low variability (YSi varied from 14 to 20). In contrast, FbH 14, BGE 029055 and FbH 13 occupied the last positions, defining them as the most unstable in productivity.

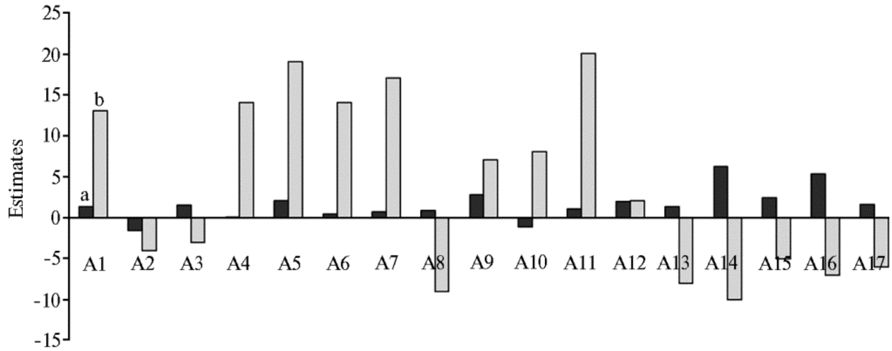

Fig. 2. Coefficient of general adaptability (a) **and index of stability** (YS*i*, b) **regarding seed productivity in broad bean *Vicia faba* L. accessions**: from left to right Fb 1896, Fb 1903, Fb 1929, Fb 2481, Fb 2486, Fb 3270, BGE 002106, BGE 029055, BGE 032012, BGE 041470, BGE 043776, BGE 046721, FbH 13, FbH 14, FbH 15, FbH 16, BGP (A1-A17, respectively) (Institute of Forage Crops, Pleven, Bulgaria, 2016-2018). The a and b values are for A1 — 1.30 and 13, respectively, for A2 — –1.6 and –4; for A3 — 1.53 and –3; for A4 — 0.05 and 14; for A5 — 2.03 and 19; for A6 — 0.39 and 14; for A7 — 0.69 and 17; for A8 — 0.82 and –9; for A9 — 2.75 and 7; for A10 — –1.17 and 8; for A11 — 1.08 and 20; for A12 — 1.90 and 2; for A13 — 1.34 and –8; for A14 — 6.23 and –10; for A15 — 2.42 and –5; for A16 — 5.31 and –7; for A17 — 1.61 and –6.

Thus, a linear equation of regression was used to determine the effect of quantitative traits on seed productivity in broad bean accessions. The optimal parameters of model broad bean plant with high productivity in organic production conditions was characterized by the following traits: plant height — from 69 to 90 cm, 1st pod height — from 22 to 36 cm, pods number per plant — from 9 to 14, seeds number — from 22 to 35, pod length — from 7 to 11 cm, pod width — from 15 to 19 mm, and 100 seeds mass — from 80 to 120 g. The obtained results showed that the traits of seeds number ($R = 0.72$) per plant, pods number ($R = 0.48$), mass of 100 seeds ($R = 0.28$) and 1st pod height ($R = 0.25$) had the greatest and statistically significant impact on the seed productivity. The accessions distinguished in high adaptability regarding seed productivity were FbH 14, FbH 16, BGE 032012, FbH 15, Fb 2486, and Fb 1903, and BGE 041470 were determined as low adaptive. Accessions Fb 1896, Fb 2486, BGE 032012 and BGE 043776 combined good adaptability with low variability and were suitable as parental components for use in the combinative breeding.

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