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Natalia Atanasova GEORGIEVA[1], Valentin Ivanov KOSEV[1], Nikolay GENOV[2], Marko B. POPOVIĆ[3], Vuk RADOJEVIĆ[4], Vera M. POPOVIĆ[5,6]

ECONOMIC PRODUCTION AND COMPARATIVE EVALUATION OF BROAD BEAN ACCESSIONS UNDER ORGANIC CULTIVATION

SUMMARY

Vicia faba L. is determined as the main grain legume grown in Europe, with increasing in-terest from the organic sector. Cultivars suitable for organic cultivation conditions should meet a complex of traits and parameters. Based on a comparative evaluation of 11 faba bean accessions under organic cultivation conditions, it was found that they differed in vegetation duration, habitus, productivity, stability, biochemical composition and tolerance to *Botrytis fabae*. In herbaceous forage direction, BGP was most suitable accession. The same was characterized by a fast growth rate (0.94 cm/day), high values in terms of height and aboveground biomass (88.5 cm and 43.02 g/plant^{-1}, respectively), and the highest tolerance to *B. fabae* (I=11.4%). In grain direction, with suitable characteristics for organic production, Fb 04 (rank 2) was identified. It was distinguished by high seed productivity (22.71 g/plant^{-1}) and stability (YSi=8.00+), forage quality (crude protein - CP=235.60 g/kg^{-1} DM, dry matter) and moderate resistance to *B. fabae* (I=16.5%). Also, accession Fb 04 had good performances in the herbaceous-forage direction. The results of this study showed that the comparative evaluation of accessions under organic cultivation conditions gives promising outcomes, and BGP and Fb 04 may be recommended for organic faba bean production.

Keywords: *Vicia faba* L.; productivity; organic farming; *Botrytis fabae*.

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[1]Natalia Anastasova Georgieva, Valentin Ivanov Kosev, Institute of Forage Crops, Pleven, Agricultural Academy, BULGARIA; https://orcid.org/0000-0002-6364-1310; https://orcid.org/0000-0003-3292-4200;

[2] Nikolay Genov, Institute of Viticulture and Enology, Agriculture academy, Pleven, BULGARIA, https://orcid.org/0000-0001-9562-6353;

[3] Marko B. Popović; University of Novi Sad, Faculty of Economics in Subotica, 21000 Novi Sad, REPUBLIC OF SERBIA;

[4] Vuk Radojević, University of Novi Sad, Faculty of Agriculture, 21000 Novi Sad, Rep. of SERBIA

[5]Vera M. Popović (corresponding author: vera.popovic@ifvcns.ns.ac.rs), Institute of Field and Vegetable Crops, Maxim Gorky 30, 21000 Novi Sad, REPUBLIC OF SERBIA;

[6]Vera M. Popović, University of Bijeljina, Faculty of Agriculture, Pavlovića put bb, Bijeljina, BOSNIA AND HERZEGOVINA

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INTRODUCTION

Climate and economic changes on a global and national scale define the crucial importance of sustainable agriculture (Georgieva, 2017; Stupar *et al.,* 2023; Sekulić *et al.,* 2023). Building a sustainable farming system has agricultural, economic and environmental aspects. Stable production in sustainable agriculture is inextricably linked to the implementation of systems requiring less utilization application of pesticides and fertilizers or their complete elimination. The most demanding production system is organic farming defined by EU Directive 2092/91. It restores and maintains soil fertility, moreover it ensures ecosystem balance, reduces the negative impact of agriculture on climate change and implies production of quality food products in perfect harmony with nature (Niggli *et al*., 2009; Uhr *et al*., 2014; 2017).

Sustainable resource management can guarantee agricultural production's stability and quality. Health-safe products, economic advantage, conserving the environment and health can be attained by organic farming. Over 96 million hectares of agricultural land are handled organically by at least 4.5 million farmers in 188 countries. In 2022, sales of organic food and beverages were close to 135 billion euros worldwide. Oceania (36 mill. ha, or 47%) and Europe (17.8 mill. ha, or 23%) have the biggest organic agricultural land areas, followed by Latin America (9.9 mill. ha, or 13%), Asia (6.5 mill. ha, or 8.5%), Northern America (3.5 mill. ha, or 4.6%), and Africa (2.7 mill. ha, or 3.5%), (Popović *et al*., 2013; 2023).

Increased production of grain legumes in Europe will contribute to a greater supply of protein and have a positive effect by providing direct and indirect environmental benefits (De Notaris *et al.,* 2023). Incorporating the variety *Vicia faba* L. in an organic farming system improves soil fertility. The high efficiency in achieving symbiosis with the specific Rhizobium bacteria and the accompanying biological nitrogen fixation is associated with reduced need for fertilizers and increased biological activity of the soil. Further, incorporating plant residues from grain legumes into the soil as a green fertilization improves the growth and yield of subsequent crops in the crop rotation. Faba bean can fix up to 200 kg N/ha and incorporation of plant residues into the soil improve its properties, including organic matter content, bulk density and porosity (O'Donovan *et al*., 2014; Adekiya *et al*., 2017).

In addition to the positive characteristics of faba bean is its high productivity (Maalouf *et al*., 2015; 2021; Minguez *et al.,* 2021) and nutritional value (Avramidou *et al.,* 2023). The seeds contain up to 35% protein and are a good source of macro and micro nutrients (K, Ca, Mg, Fe, Zn) and other bioactive compounds such as polyphenols, carotenoids and carbohydrates. The protein content is approximately 29% of the dry weight, which is higher compared to other legumes (Knudsen *et al*., 2020; Warsame *et al.,* 2018). This makes it one of the main sources of protein for people in the Middle East, Latin America and Africa as well as for livestock feed in many developed countries (Burstin *et al*., 2011). According to De Notaris *et al.* (2023) *Vicia faba* is the main grain legume grown in Europe with increasing interest from the organic sector. Known as the primary source of dietary protein, the dry common bean

(*Phaseolus vulgaris* L.) is a legume that is enjoyed by people all over the world (Shellie-Dessert and Belis, 1991).

According to some authors (Lammerts *et al*., 2002; Popović *et al.,* 2013; 2022; Uhr *et al.,* 2014; Bozhanova *et al.,* 2014; Bozhanska *et al.,* 2024) the choice of cultivar is the crucial factor for a well-functioning system of organic farming. Overall, organic farmers need cultivars with stable and permanent yields which are tolerant to climate change (Uhr *et al.,* 2014; 2017), as well as cultivars with high quality, regardless of the reduced levels of investments (Konvalina *et al.,* 2009; Mihailović *et al.,* 2019).

However, modern varieties do not meet the needs and requirements of a system with reduced levels of production inputs. The majority of cultivars used in organic farming were developed for a conventional system with high inputs. Therefore, when developing "biological" cultivars, great attention should be paid to a complex of characteristics such as high stability, good productivity, favourable biochemical composition, tolerance to pests, competitiveness against weeds, etc. (Wolfe, 2002; Wolfe *et al*., 2008; Karkanis *et al*., 2018). Thus, one variety should combine as many of these traits and parameters as possible to ensure wider and stable production in specific environmental conditions (Flores *et al*., 2013; Asadova *et al.,* 2016).

The yields of *Vicia faba* L. are influenced by both biotic and abiotic influences. In order to determine the most promising faba bean varieties for use in organic farming as a significant source of protein for food and feed, we assessed the combined effects of faba bean types and climate on crop productivity and seed quality. Faba beans are important in animal feed and help in protein autonomy. There are logistical, technical, and sociological barriers to the promotion of faba beans (Segers *et al*., 2022).

The aim of this study was a comparative evaluation of faba bean accessions on a complex of characteristics and determine of suitable ones for organic farming conditions. Most impacting parameters yield were examined, these results show improvement of varietal resilience in European countries.

MATERIAL AND METHODS

Study Area

The field experiment was carried out at the Institute of Forage Crops-Pleven (43°24′28″N, 24°37′13″E) from February to June during the period 2019-2021. This region has a typical temperate continental climate with an average annual temperature of 12-13 °C and an annual precipitation of 548 mm. In agrometeorological terms, the conditions during the period 2019-2021 are characteristic of the region of Central Northern Bulgaria. The main climatic parameters amount of precipitation and temperature during the studied period are characterized by a strong fluctuation and uneven distribution during the vegetation period of the plants.

Figure 1 presents the data on the average monthly temperatures and the amount of precipitation by month during the growing season. The year 2019 was the most favorable with average monthly air temperatures for May 17.00 °C, June 22.3 °C and July 15.4 °C, and the rainfall was 67.8 mm, 72.1 mm and 66.0 mm, respectively. The second year (2020) is relatively similar to 2019 in terms of temperature regime (July of 14.6 °C), but with an amount of precipitation causing some dryness. The third year (2021) is characterized as cooler in the initial months of the crop vegetation and with a normalization of the temperature regime in the month of June, close to normal (20.45°C) and precipitation for May and June between 64.0 and 69.00 mm.

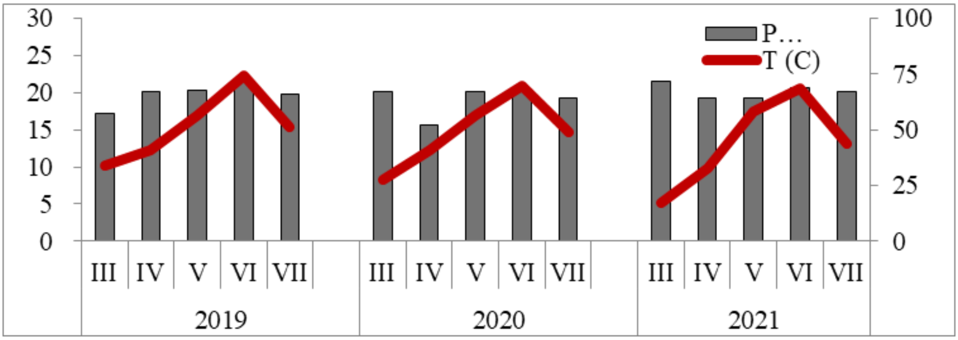

Figure 1. Climatic characterization of the experimental period, P-precipitation, mm, and T - temperature, °C, 2019-2021

In terms of geomorphology, the region is characterized by a flat-hilly relief. The soil type is leached chernozem with a slightly alkaline reaction (pH=7.2) with a sandy-clay composition. The soil reserves of hydrolyzable nitrogen are low, medium with phosphorus and very good with potassium. The content of the main nutrient elements in the soil is indicated in Table 1.

Table 1. Content of the main nutrient elements and humus in the soil

Depth (cm)	N_2 (mg/1000 g)	P_2O_5 (mg/100 g)	K_2 (mg/100g)	Humus (%)
0-20	15.60	8.63	39.90	2.24
20-40	14.28	6.79	38.70	1.95
40-60	8.86	4.48	34.10	1.36

Experimental Design

The objects of research were 11 faba bean (*Vicia faba*) accessions (Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP). The strip-plot design method with three replications was used. The sowing was carried out by hand at a rate of 40 seeds per m2. Plants were grown under organic farming conditions without the use of fertilizers and pesticides. The working plot of each genotype was 4m^2 in size.

Data Collection

During the growing season, weeds were removed manually and following indicators were recorded: plant height (PH, cm), average daily growth rate (ADGR, cm/day), aboveground biomass (AGB, g DM-dry matter/plant) (at full pod formation) and duration of vegetation period (days).

The biometric characteristics of plants at full maturity included: first pod height (FPH (cm), pods number/plant, seeds number/plant, 1000 seeds mass (g), seed weight/plant (g), pod length (cm) and pod width (cm). The seed chemical composition was determined as crude protein (CP) by Kjeldahl method and crude fiber (CF) by Weende system (AOAC, 2010). To assess the degree of attack by Botrytis fabae, a 5-point scale of EAVAS (Executive agency for variety testing, approbation and seed control) was used: 0 - healthy plants, without infestation (Immune); 1 - infested plants 0.01-5.00% (Resistance), 2 - from 5.01 to 20.00% (Moderately Resistance), 3 - 20.01-50.00% (Susceptible), 4 - above 50.00% (High Susceptible). To determine the disease atack the results were transformed by the McKinney (1923a; 2023b) formulas follows:

I - percentage index of atack (%);

E(nk) - sum of the works of the number of atacked plants or organs (n) in the corresponding attack ball (k);

N - the total number of plants examined (organs);

K – the highest grade in the corresponding scale;

$$I=(E(nk).100)/N.K, \tag{1}$$

Data Processing

The ecological stability of the studied accessions was performed using the following analyzes and parameters: regression analysis – according to Eberhart and Russell (1966), where the regression coefficient (bi) was calculated; variance analysis – through ecovalence (Wi2) Wricke (1962) and stability variance (σ^2) Shukla (1972) and non-parametric analysis – by the yield and stability index (YSi) of Kang (1993). The coefficient of variation (CVi, %) (Francis and Kannenberg, 1978) was used for adiitional evaluation. Also, a GGE biplot model that uses a single decomposition of the first two principal components (PC1 and PC2) was also applied Yan (2002). All experimental data were processed statistically using the computer software GENES for Windows XP (Cruz, 2009) and Statgraphics Plus (1995) for Windows Ver. 2.1.

RESULTS

Growing season

The growth and development of faba bean accessions during the three experimental years underwent under different environmental conditions, which is a prerequisite for their objective assessment. The vegetation period of 2019 and 2021 was characterized by favorable conditions for the crop development. Considerably less favorable were the conditions in 2020 (14.6 °C and 99 mm). The average duration of the growing season of faba bean accessions was 89 days. Most of them demonstrated a shorter vegetation of 88 days (Fb 02, Fb 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98), and the longest one (93 days) was the vegetation period in BGP, Figure 2.

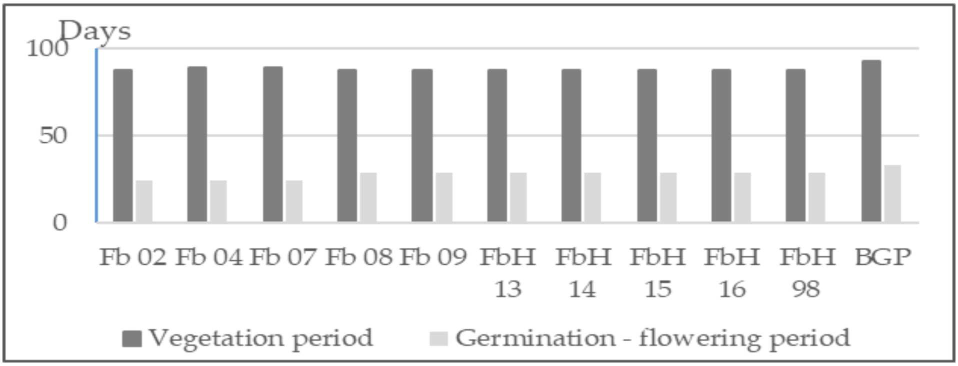

Figure 2. Duration of vegetation period in faba bean accessions (Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions)

Morphological characteristic

The data regarding the morphological characters PH, ADGR and AGB had variation coefficients from 14.2 to 15.9%, Table 2. On average, for the 3-year experimental period, PH and ADGR rate ranged from 49.1 to 85.5 cm and from 0.58 to 0.94 cm/day, respectively.

Table 2. Morphological parameters in faba bean accessions

Accessions	**AGB**		**PH**		**ADGR**		**Average arithmetic rank**
	g plant^{-1}	rank	cm	rank	cm/day	rank	
Fb 02	41.02^{ef}	4	60.3^{e}	4	0.71^{ef}	4	4
Fb 04	43.10^{f}	1	63.4^{f}	2	0.73^{fg}	3	2
Fb 07	34.67^{c}	9	54.8^{b}	9	0.64^{b}	8	9
Fb 08	41.72^{f}	3	53.8^{b}	10	0.63^{b}	9	7
Fb 09	37.48^{d}	6	56.8^{c}	8	0.67^{c}	7	7
FbH13	30.53^{b}	10	59.7^{de}	5	0.70^{de}	5	7
FbH 14	38.27^{de}	5	58.8^{de}	6	0.69^{cd}	6	6
FbH 15	36.42^{cd}	8	58.4^{cd}	7	0.69^{cd}	6	7
FbH 16	36.93^{cd}	7	62.7^{f}	3	0.74^{g}	2	4
FbH98	23.39^{a}	11	49.1^{a}	11	0.58^{a}	10	11
BGP	43.02^{f}	2	85.5^{g}	1	0.94^{h}	1	1
VC (%)	15.9		15.4		14.2		
min	23.39		49.1		0.58		
max	43.10		85.5		0.94		
average	36.39		61.37		0.71		
IV	19.71		36.4		0.36		

Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP-faba bean accessions; AGB-aboveground biomass, PH-plant height, ADGR-average daily growth rate; IV - Interval variation

Regarding the specified parameters, BGP significantly exceeded the average values for the group, respectively, by 41.8 and 34.8%. The same genotype was distinguished by in-creased biomass accumulation, in which case the difference compared to the average group value was 16.4%.

According to the analysis of variance, genotype, environment, and their interaction had a significant effect on the variation of all traits except pod length and width (Table 3).

For the first trait, the influence of environment factor was not significant, and for the second trait – the influence of the genotype and genotype × environment interaction. Variation of the traits of plant height, 1st pod height, pods and seeds/plant, and seed weight/plant was determined to the greatest extent by the environmental factor.

Although the effects of genotype and Genotype × environment - G × E interaction in this study were less pronounced than the environmental effect, they were statistically significant. G×E interaction is determinant for the manifestation of 1000 seeds mass. The existence of a significant influence of the three factors is a prerequisite for stability evaluation. The assessment of stability under changing environmental conditions enables a complex evaluation of the accessions and their further use for breeding purposes.

Table 3. ANOVA regarding main quantitative traits in faba bean accessions

Source of variation	**Deg.of Freed.**	**Mean squares**			
		PH	**FPH**	**PNP**	**SNP**
Environment, E	2	2671.71**	114.24**	161.44**	1821.44**
Genotype, G	10	260.16**	15.22**	17.75**	125.47**
G × E	20	89.738**	29.47**	7.91**	84.36**
		SWP	**TSM**	**PL**	**PW**
Environment, E	2	1436.51**	600.06**	1.41^{ns}	1.73**
Genotype, G	10	30.64**	1240.29**	3.93**	0.15^{ns}
G × E	20	122.59**	4961.23**	1.96**	0.61^{ns}

PH - plant height (cm), FPH - 1st pod height (cm), PNP - pods number/plant, SNP - seeds number/plant, SWP - seed weight/plant, TSM - 1000 seeds mass (g), PL - pod length, PW - pod width; * significance at P < 0.05; ** - P < 0.01; *** - P < 0.001; ns – nonsignificant

The quantitative characterization of the main biometric traits showed that the accessions differed in their genetic endowments (Table 4).

BGP was of interest due to the high values of plant height, number of pods and seeds/plant. Fb 08 and FbH 14 were distinguished by the highest seed weight/plant, and the differences between them were statistically insignificant. Fb 04 and FbH 15 were characterized by 1000 seeds mass essentially exceeding that of FbH 98 and BGP. Regarding the traits of pod length and width, the differences between the individual genotypes were insignificant.

Table 4. Biometric characteristic of faba bean accessions

Accessions	FPH	PNP	SNP	SWP	TSM	PL	PW
Fb 02	24.18	7.55	19.68	22.41	121.70	9.073	2.151
Fb 04	25.10	7.87	20.15	22.71	124.92	8.801	2.057
Fb 07	22.52	6.20	19.82	21.30	111.51	10.941	2.034
Fb 08	20.28	9.18	25.02	24.92	102.33	9.108	1.941
Fb 09	24.08	6.28	20.82	20.92	102.20	10.537	2.022
FbH 13	21.68	5.37	18.10	17.35	103.43	10.077	2.002
FbH 14	20.70	6.90	19.32	23.59	120.28	9.228	1.725
FbH 15	22.93	5.87	17.35	20.58	124.74	9.728	1.828
FbH 16	25.88	7.20	19.87	21.47	114.52	10.578	2.134
FbH 98	18.38	5.55	15.69	13.14	84.27	8.474	1.625
BGP	21.37	13.95	39.60	20.97	57.36	6.915	1.435
CV (%)	10.03	32.65	30.22	15.34	19.16	12.23	11.75
$LSD_{0.05}$	0.86	0.90	2.07	2.13	3.72	0.54	0.053

Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions; FPH - 1st pod height (cm), PNP - pods number/plant, SNP - seeds number/plant, SWP - seed weight/plant, TSM - 1000 seeds mass (g), PL - pod length, PW -pod width, CVi, %-coefficient of variation, LSD- Fisher's Least Significant Difference test

Stability assessment

The variation coefficient calculated for seed weight/plant showed a strong variability of the trait for all genotypes – from 36.37% (at FbH 98) to 58.11% (FbH 16) (Table 5).

Table 5. Stability parameters in faba bean accessions

Accessions	CVi	bi	Wi^2	σ^2	YSi
Fb 02	40.76	0.95 ^{ns}	0.08	0.35	10.00+
Fb 04	46.43	1.06 ^{ns}	0.11	0.30	8.00+
Fb 07	44.53	0.83 ^{ns}	0.77	0.92	2.00
Fb 08	43.14	1.20 ^{ns}	1.07	1.46	13.00+
Fb 09	55.24	1.08 ^{ns}	0.16	0.21	4.00+
FbH 13	42.34	0.64*	3.48	5.90	-6.00
FbH 14	50.99	1.05 ns	0.06	0.37	5.00+
FbH 15	39.57	0.63*	3.62	6.14	-4.00
FbH 16	58.11	1.34*	3.15	5.28	5.00+
FbH 98	36.37	0.56**	5.28	9.19	-9.00
BGP	41.50	1.66***	11.81	21.16	6.00+

02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions; CVi - coefficient of variation,]bi - regression coefficient, Wi2 - ecovalence , σ2 - stability variance, YSi - yield and stability index

The linear regression coefficient for some of the genotypes was not significant. Therefore, a strong assessment of stability based on this parameter cannot be done. Accessions that have lower values are evaluated as more stable because they interact less with the environmental conditions. It can be noted that FbH 98 (bi=0.56), FbH 15 (bi=0.63) and FbH 13 (bi=0.64) exhibited stability. The values of "bi" for BGP (1.68) and FbH 08 (1.28) were statistically significant but higher than 1.

Therefore, these genotypes can be considered unstable. Parameters based on the ecovalence Wi2 and stability variance σi2 (OAAC, 2010; Wricke, 1962). Shukla (1972) identified FbH 14, Fb 02, Fb 04, Fb 09 and Fb 07 as the most stable. The remaining genotypes exhibited instability to one degree or another. BGP, FbH 98, FbH 15 and Fb 08 were in a position of greater instability.

The summarizing criterion for stability "YS'" of Kang (1993), considering both stability and productivity, gave a high positive estimation to Fb 08 (13.00+) and Fb 02 (10.00+), followed by Fb 04 (8.00+) and BGP (6.00 +). They combined high values of seed weight/plant and good stability during the different years. The ranks of the stability parameters defined Fb 02 as the best one since it always occupies one of the first three positions (Table 6). Fb 04 was also of interest, followed by Fb 08, which had the first position according to the ranking of "bi" and "YSi" parameters. However, the same accessions did not perform well according to the other parameters, occupying the sixth rank. FbH 14 had a similar manifestation. It was distinguished by high productivity but did not have good positions in some of the parameters.

Table 6. Ranking of stability parameters in faba bean accessions

Accessions	CVi	bi	Wi^2	σ^2	YSi
Fb 02	3.00	1.00	2.00	2.00	2.00
Fb 04	8.00	1.00	3.00	3.00	3.00
Fb 07	7.00	1.00	5.00	5.00	8.00
Fb 08	6.00	1.00	6.00	6.00	1.00
Fb 09	10.00	1.00	4.00	4.00	7.00
FbH 13	5.00	2.00	8.00	8.00	10.00
FbH 14	9.00	1.00	1.00	1.00	5.50
FbH 15	2.00	2.00	9.00	9.00	9.00
FbH 16	11.00	2.00	7.00	7.00	5.50
FbH 98	1.00	3.00	10.00	10.00	11.00
BGP	4.00	4.00	11.00	11.00	4.00

Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions. CVi - coefficient of variation, bi - regression coefficient, Wi2 - ecovalence, σ2 - stability variance, YSi - yield and stability index

GGE biplot analysis

The GGE biplot analysis provides information on the relationship between the productivity level and the degree of its stability (Figure 3). The first two principal components PC1 (94.60%) and PC2 (5.40%) can be considered reliable because they explain 100% of the reasons for variation in the faba bean accessions. For an assessment of each tested genotype, the starting point is the small circle in the biplot center, which represents the so-called "mid" coordinate. BGP, FbH 15, and Fb 07 are located in the small concentric circle, and their productivity was around the group average. However, they have an advantage over others because they exhibit stability over a wider range of environmental conditions. FbH 16 also occupies a good position. It has a relatively high productivity (21.47 g), but its low PC2 value is an indication that it can adapt to more specific environmental conditions.

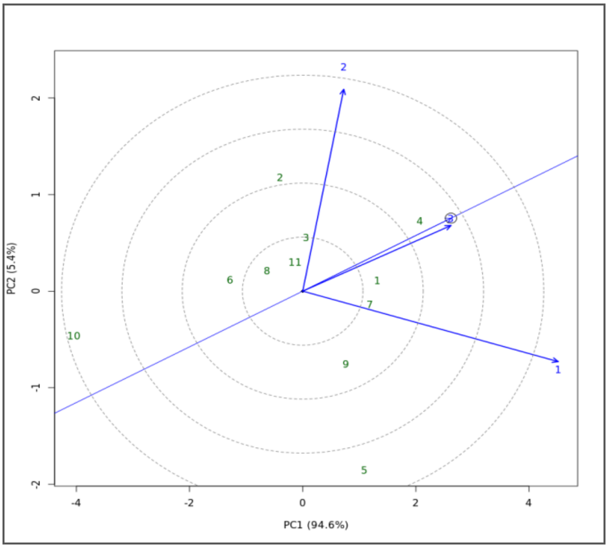

Figure 3. GGE biplot regarding productivity in faba bean accessions - Fb 02, 2 - Fb 04, 3 - Fb 07, 4 Fb 08, 5 - Fb 09, 6 - FbH 13,7 - Fb H 14, 8 - FbH 15, 9 - FbH 16, 10 - Fb 98, 11 - BGP; Vectors 1, 2 and 3 are 2019, 2020 and 2021, respectively

Genotypes characterized by productivity values above the group average and PC2 values close to zero are highly adapted to different environmental conditions. In the present study, Fb 02 (22.41 g) and FbH 14 (23.59 g) are highly productive and located near the smallest concentric circle. The location of Fb 08, which is at the far right of the coordinate system, shows that it is the most productive (24.92 g). However, it falls into a concentric circle at a greater distance from the center, which determines its lower stability. The projection of Fb 04 in the coordinate system suggests that it exhibits a level of stability similar to Fb 08 (its variation under experimental conditions is analogous). The interest in Fb 04 is dictated by the fact that this variety is in the group of high-yielding genotypes (22.71 g). FbH 13 is weakly productive but stable, and FbH 98 occupies the last position in terms of productivity and stability. The analysis shows the importance of contrasting environmental conditions for the differentiation of genotypes according to their productivity and stability.

Reaction to Botrytis fabae

Vicia faba is attacked by many diseases, including fusarium (Fusarium spp.), bacteriosis (*Xanthomonas sp*.), downy mildew (*Peronospora fabae* Jacz.), rust (Uromyces fabae (Persson) de Bary), ascochytosis (Ascohyta fabae *Spegazzini*), chocolate spot (*Botrytis fabae* Sard.), etc. (Stancheva, 2002). During the 3-year experimental period, periodic observations were done to establish the tolerance of the 11 accessions to chocolate spot under a natural background of infestation. Disease symptoms were observed only in 2020, as the optimum conditions for its development being a moderate temperature of 15-18 °C and high relative humidity (over 90%) during several consecutive days (Stancheva, 2002). Characteristic chocolate, rounded, slightly indented spots were formed on both sides of the leaf surface. Similar spots, but elliptical in shape, appeared on stems and pods. The infestation index, calculated according to the formula of McKinney (1923), showed susceptibility to B. fabae in the majority of the studied accessions (Fb 02, Fb 07, Fb 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16) and high susceptibility in one of them (FbH 98) (Figure 4). BGP and Fb 04, with an infestation index of 11.4 and 16.5%, respectively, were determined as moderately resistant to chocolate spot.

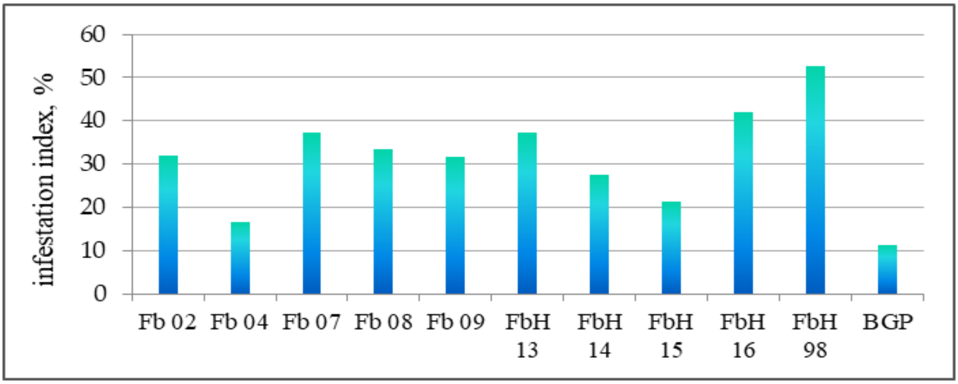

Figure 4. Reaction of faba bean accessions to Botrytis fabae Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions

Biochemical analysis

The seed biochemical analysis concerning CP and CF content showed mean values of 215.96 and 111.74 g/kg^{-1} DM, respectively (Figure 5). Fb 04 and FbH 13 were characterized by a more favorable biochemical composition, in which the CP content was 9.1 and 7.8% higher compared to the average group value. The same accessions were also distinguished by a decreased content of CF, with differences of 5.0 and 7.5%, respectively. Significantly higher protein content, above the group average, was also found in Fb 02, Fb 07 and Fb 16. The complex evaluation regarding main characteristics and parameters (Table 7) determined BGP as the most suitable (rank 1) for organic cultivation conditions in herbaceous forage direction.

It was characterized by a fast growth rate (0.94 cm/day), high values in terms of height and aboveground biomass (88.5 cm and 43.02 g/plant^{-1}, respectively), and the highest tolerance to B. fabae (I = 11.4%).

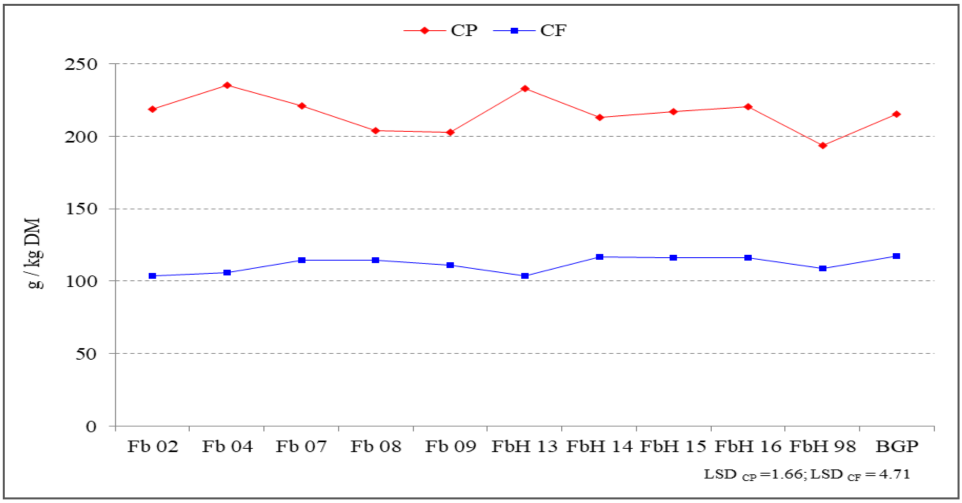

Figure 5. Biochemical composition of seeds in faba bean accessions; Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP - faba bean accessions, g/kg DM - Dry matter content and chemical compositionM CP - crude protein, CF-crude fiber

Table 7. Ranking in terms of main characters and parameters in faba bean accessions

Accessions	AGB	PH	TO	T	Average arithmetic rank	SWP	CP	S	T	Average arithmetic rank
Fb 02	4	4	4	6	5	4	5	2.00	6	4
Fb 04	1	2	3	2	2	3	1	3.00	2	2
Fb 07	9	9	8	8	9	6	3	8.00	8	6
Fb 08	3	10	9	7	7	1	9	1.00	7	5
Fb 09	6	8	7	5	7	8	10	7.00	5	8
FbH 13	10	5	5	8	7	10	2	10.00	8	8
FbH 14	5	6	6	4	5	2	8	5.50	4	5
FbH 15	8	7	6	3	6	9	6	9.00	3	7
FbH 16	7	3	2	9	5	5	4	5.50	9	6
FbH 98	11	11	10	10	11	11	11	11.00	10	11
BGP	2	1	1	1	1	7	7	4.00	1	5

Fb 02, Fb 04, Fb 07, F b 08, Fb 09, FbH 13, FbH 14, FbH 15, FbH 16, FbH 98, BGP-faba bean accessions. AGB - aboveground biomass, PH- plant height, ADGR - average daily growth rate, T-tolerance to Botrytis fabae, SWP- seed weight/plant, CP- crude protein, S- stability according to YSi

In grain direction, as exhibiting suitable characteristics for organic production, Fb 04 (rank 2) was identified, which was distinguished by high seed productivity (22.71 g/plant^{-1}) and stability (YSi=8.00+), forage quality (CP=235.60 g/kg DM) and moderate resistance to B. fabae (I=16.5%). Also, accession Fb 04 had good performances in the herbaceous-forage direction.

DISCUSSION

Promising and crucial for faba bean farmers are the Botrytis fabae tolerant accessions that shown good and consistent plant height and grain yield performances in the current investigation. The genotype's performance must be consistent and the winning genotype must be repeatable in the same areas in order to define a mega-environment (Gauch *et al.,* 2013).

A genotype that consistently performs well and has one of the highest yields throughout test settings is considered desirable (Yan and Kang, 2003). Accessions exhibiting strong and stable plant height performance are crucial for the areas where faba beans are mostly farmed for animal feed since plant height and biological yield are highly connected (Maalouf *et al.,* 2015; Kubure *et al.,* 2016).

The duration of the vegetation season is determined by the cultivar and environmental conditions (Animasaun, 2015). The studied accessions were characterized by a low variability of the duration of the germination-ripening period (CV=1.7%), which, expressed in absolute values, was from 88 to 93 days. Similarly, Horaicu *et al.* (2024) found a vegetation of 80-90 days for conditions in Romania. Other researchers reported a more substantial variation in the number of days to maturity for different faba bean genotypes: 112 - 154 days in the Central Region of Saudi Arabia (Ammar et al., 2015), 112 - 132 days in India (Kumar *et al*., 2023), and 112 - 173 days in New Zealand (Martini *et al.,* 2012). In testing 6 genotypes at 4 locations, (Lake *et al.,* 2019) recorded 136-182 days from sowing to maturity for Australian conditions. Varieties with early ripening can avoid severe drought during the summer period. The short growing season is an important characteristic of annual legumes, given the changes in the global climate (Tesfahun, 2018) and the established permanent trend towards warming and drying in Northwest Bulgaria, where the study was carried out (Zhekova *et al*., 2022).

Morphological traits determining better plant competitiveness against weeds in organic farming include greater height, faster daily growth rate and early biomass accumulation (Uhr *et al*., 2014). Paolini and Faustini (2005) also indicated that suitable cultivars for bioproduction are those with medium and greater height as well as with rapid biomass accumulation, which is associated with greater competitive ability. BGP met these requirements to the greatest extent, followed by Fb 04 and Fb 02.

In terms of some of the main quantitative traits related to productivity, the variation in absolute values was as follows: pod numbers – from 5.37 to 13.95 (VC=32.65%), seed numbers – from 15.69 to 39.60 (VC=30.22), seed numbers per plant – from 13.14 to 24.92 g (VC=15.34). A wide range of variation in different agro-morphological characteristics was reported by (Ammar *et al.,* 2015) in a study of 40 faba bean genotypes of different origin (England, Spain, Egypt, Sudan, etc.) in the Riyadh area (Saudi Arabia): from 81.4 to 139.5 cm for plant height, from 8.8 to 44.3 for pods number, from 23.3 to 100.8 for seeds number and from 14.9 to 70.8 g for seed weight/plant. Yüce *et al.* (2023) indicated the following range values for plant height – 25-59 cm, pods number – 1-33, seeds number – 2.40-106, seed weight/plant – 1.80-224.9 g and 1000 seeds mass – 480-2140 g. In a similar experiment, (Abou-Khater *et al*., 2022) also observed a strong variation in the indicated traits. According to the authors, variability is due to the genetic constitution of the genotype and its response to environmental conditions.

In the present experiment, we found that seed productivity (seed weight per plant), as well as all other quantitative traits (except pod length), were highly influenced by environment. In agreement with our findings, previous studies have also found the main factors determining faba bean seed yield to be environmental (Fikere *et al.,* 2008; Temesgen *et al.,* 2015). Opposite results were obtained by Wang *et al.,* (2023) and Neda *et al.* (2021), according to which the genotype is decisive for the manifestation of most quantitative traits. According to Neda et al. (2021), this is indicative of the presence of a high level of genetic diversity in the studied collection and that the breeding methods applied in the future would be effective for trait improvement.

Chocolate spot is one of the most important economic disease that damages the foliage, limits photosynthetic activity and faba bean production (Torres *et al.,* 2006). According to Harrison (1988) and De Notaris *et al.* (2023), plants under organic conditions are particularly affected, as damage caused by the necrotrophic fungus B. fabae can lead to complete defoliation at moderate temperatures and high humidity (Harrison, 1988). Finding cultivars with expressed tolerance to the disease is one of the most effective methods of control, especially in organic farming conditions. However, according to Adhikari (2023), a high tolerance level is difficult to establish because resistance to B. fabae is controlled by multiple genes. According to Gela *et al.* (2022), a cultivar (PBA Amberley) with well-expressed tolerance to the disease was developed in Australia. Considerable differences were found by Beyene *et al.* (2014), who tested 10 cultivars and 50 local populations. The highest level of resistance was observed in ILB-4726, ILB-938 and BPL-710. According to the authors, the resistance is highly heritable, suggesting that phenotypic breeding could be used to improve tolerance to chocolate spot in faba bean. In assessing 11 faba bean genotypes, (El-Abssi *et al.,* 2024) observed high resistance in 6 of them (Nubaria-3, Nubaria-4, Nubaria-5, Sakha-4, Giza-3, Triple White), and medium and low resistance in the remaining genotypes (Giza-843, Misr-3, Sakha-1, Sakha-3, Wadi-1). In the same study, stability was evaluated using different methods and parameters: regression coefficient (bi) and deviation mean square Finlay from linear regression (S2d) were calculated according to Eberhart and Russell (1966), ecovalence (Wricke, 1962) and AMMI's stability value (ASV) (Purchase, 1997). The results showed that Sakha-1, Misr-3, Nubaria-4 and Nubaria-5 demonstrated stable productivity in all tested environments. Finlay *et al.* (1963) used the regression coefficient to assess stability in a collection of 9 faba bean cultivars. The regression coefficient in Gracia (1.12), Pyramid (1.11), and Vertigo (1.19) was considerably higher than 1, indicating larger G×E responses than average. In contrast, Kontu (0.72), Snowdrop (0.62) and SSNS-1 (0.90) demonstrated regression coefficients significantly less than 1, indicating lower sensitivity to the environment. The remaining cultivars (Lynx, Mistral, Taifun) had regression coefficients that did not differ significantly from 1, indicating broad adaptability. Similarly, Yansen *et al.* (2022) estimated the ecological stability of 20 faba bean genotypes and identified several groups with different productive capabilities and specific responses to the environment. They found that genotypes G06, G08, G10, G13, G16, G18, and G20 combined high productivity with stability in different growing environments. G15 had the highest yield but was characterized by high variability and fell into the group of unstable genotypes. According to Abou-Khater *et al*. (2022), an assessment of ecological stability should be done based on several different parameters to obtain a clear idea of the suitability of a given genotype to specific growing conditions. After evaluating 37 faba bean accessions, the authors identified 5 genotypes (IG12983, IG13945, IG13906, IG106453, FB2648) with good productivity and stability. In the present experiment conditions, five stability parameters were calculated, which do not give an unambiguous assessment of the stability of the tested accessions. Our final evaluation was based to a greater extent on Kang's stability index, which considers both stability and productivity. As we have pointed out in previous studies (Mohammed *et al.,* 2023), the differences in stability assessments for individual parameters are due to the fact that different assessment methods are based on different concepts of stability.

Some researchers (Georgieva *et al.,* 2024; Rubiales *et al.,* 2012) recommended the application of GGE biplot analysis for better visualization of results in yield and stability evaluation. According to (Papastylianou *et al.,* 2021) and (Flores *et al.,* 2013; Božović *et al*., 2020; 2022; Rakašćan *et al*., 2021; Popović *et al.,* 2024), the GGE biplot is a good statistical tool for analyzing data from testing genotypes in multiple environments. They viewed the graphical representation of genotype-environment interaction effects using the GGE biplot and believe that this is a way of better exploring the relationships between test environments and the performance and stability of genotypes.

The seed biochemical analysis of the studied accessions in terms of CP and CF content showed a variation from 193.90 to 235.60 g/kg^{-1} DM (CV=5.7%) and from 103.40 to 117.30 g/kg^{-1} DM (CV=4.8%), respectively. Considerably higher CP values have been reported in the conditions of previous investigations: 24.60-30.68% (Papastylianou *et al.,* 2021), 24.7 – 37.2% (Duc *et al*., 1999), 26.6 - 34.9%, 31.8 - 39.7% (Alghamdi, 2009) etc. Obviously, the cultivar and environmental conditions are determinant for this.

CONCLUSIONS

A comparative evaluation of 11 faba bean accessions under organic cultivation conditions was carried out. It was found the accessions differed in vegetation duration, habitus, productivity, stability, biochemical composition and tolerance to Botrytis fabae. For productivity parameters, the current analysis demonstrates a considerable genotype × environment interaction, underscoring the necessity of choosing both broadly suited and genotypes that are well adapted to a particular environment.

The complex evaluation regarding main characteristics and parameters determined BGP as the most suitable (rank 1) for organic production in herbaceous forage direction. The same was characterized by a fast growth rate (0.94 cm/day), high values in terms of height and aboveground biomass (88.5 cm and 43.02 g/plant^{-1}, respectively), and the highest tolerance to B. fabae (I=11.4%).

In grain direction, with suitable characteristics for organic production, Fb 04 (rank 2) was identified. It was distinguished by high seed productivity (22.71 g/plant^{-1}) and stability (YSi=8.00+), forage quality (CP=235.60 g/kg^{-1} DM) and moderate resistance to *B. fabae* (I=16.5%). Also, accession Fb 04 had good performances in the herbaceous-forage direction.

The tolerant germplasm found in this study must be crossed with other cultivars specialized to certain habitats in order to create superior Botrytis fabae tolerant cultivars that are widely adapted to many large environments. Additionally, these lines could be crossed with other cultivars to accumulate economically valuable features in new kinds of faba beans.

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