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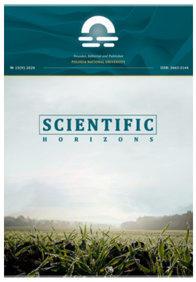

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Agrobiological assessment of green bean varieties by adaptability, productivity, and nitrogen fixation

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Abstract. Beans should be studied as an ecological object that can be used to replenish the reserves of nitrogen compounds in the soil and increase its biological activity. The goal was to conduct scientifically based zoning of varieties and assess their adaptive and productive potential in terms of productivity and nitrogen fixation. The study was conducted in the training and production department of the Uman National University of Horticulture during 2020-2022, using six varieties common in production. Standard methods of genetic and statistical analysis were used to investigate the parameters of

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adaptive variability. The study of phenological changes showed that, depending on the variety, it takes from 54 to 67 days before the onset of technical ripeness, and the variation of this trait is 8%. The shortest period before harvesting green beans was characterised by the varieties Zorenka and Casablanca. The variation of the growing season before the onset of biological ripeness was in the range of 90-108 days (CV=6%). According to the indicator of attachment of the lower bean, suitable varieties for mechanised harvesting were identified – Zorenka and Casablanca. Analysing the parameters of adaptability of the "bean weight" and "yield" indicators, a stable variety was found – Fruidor and highly productive varieties of intensive type Paloma, Laura, Zorenka, and Casablanca. The most productive variety was Zorenkya – 12.7 t/ha, and the least productive – Fruidor – 1.9 t/ha. In terms of seed yield, the varieties Purpurova Koroleva, Zorenka, and Casablanca stood out, the yield of which was at the level of 2.22-2.89 t/ha, which is 30.8-70.6% more than the standard. Analysing the dependence of the growth and development parameters of green bean plants, it can be seen that these traits depend more on the conditions (CVA, %) in which they were formed than on the genotypic component (CVG, %). The results obtained provide useful information on commercial and seed production, productivity and the nitrogen-fixing ability for introduction into industrial production or further breeding practice and prove that green bean varieties are suitable for both vegetable production and high-quality seeds, as well as for biologisation of production through the use of biologically fixed nitrogen

Keywords: *Phaseolus vulgaris*; nitrogen fixation; nutritional value; performance; protein; soluble sugars

INTRODUCTION

A promising task of growing green bean pods in unstable conditions of moistening of the Ukrainian Forest-Steppe is the introduction of elements of adaptive varietal technology for growing crops, since varieties as a dynamic biological system belong to one of the main places in solving the problem of yield growth. According to the FAO (State register..., 2023) legumes in world agriculture occupy about 15% of the acreage. The leading position is occupied by green bean pods (sugar or vegetable). The acreage of crops in the world over the past 10 years has grown by 200 thousand hectares and amounts to almost 30 million hectares.

Research conducted by Baruah *et al.* (2022), to assess the productivity of green beans in five different agroclimatic zones of India, aimed to assess the signs of growth, yield, and consumer preferences for organoleptic indicators and cost-effectiveness of cultivation. Among the three varieties, it was found that Arka Sukomal significantly exceeds most of the studied characteristics, such as the longest duration of the growing season (98 days), the maximum number of beans per plant (62.86) and the largest bean weight (13.18 g) and the highest yield (20.75 t/ha).

Thapa *et al.* (2022) note that when studying green bean varieties, the plant height was highest in Semi long ligh (332 cm) and lowest in Trishuli (294.48 cm). The total number of seeds was highest in Semi Long Green – 8.6 and lowest in Trishuli – 7. The highest yield was found in Trishuli – 2.69 t/ha, then Chaumase – 2.56 t/ha, Semi long green – 2.33 t/ha, and the lowest was in Semi Long Light – 1.51 t/ha. Analysing the results of the above-mentioned researchers, it can be seen that the research focused on tall (climbing) varieties of green beans, where an inverse relationship between plant height and yield can be traced, which is consistent with the results of Rinku & Sibani (2014) studies conducted with bush forms of green beans.

Mazur *et al.* (2017) and Mazur *et al.* (2020) studied the parameters of adaptive ability in the conditions of the Forest-Steppe of Ukraine and noted that the variety is the basis of cultivation technology, it is very difficult to combine the high weight of 1,000 grains with the stability of this indicator. Seed yield and the constituent structure of the crop are quantitatively inherited and highly dependent on the environment (Olifirovich & Olifirovich, 2020), so understanding the relationship between the crop and its components is important for establishing effective criteria for selection and seed production. Several studies of beans have found high correlations between yield and weight of 100 seeds, yield and number of beans and seeds per plant (Beebe *et al.*, 2013; Assefa *et al.,* 2015; Rao *et al.,* 2017). Thus, the components of the crop structure were used as selection criteria to improve grain yield.

The potential of green beans as a fresh vegetable is not fully used and is not produced in sufficient quantities to meet the needs of the population. A high yield can be achieved by selecting varieties that have high adaptability. The selection of this feature invariably affects a number of related features, which makes it necessary to determine the relationships between various performance components (Alice *et al.,* 2018, Reddy *et al.,* 2021, Bala *et al.,* 2022).

The purpose of this study was to identify varietal features of the development of parameters of adaptive capacity of green beans by indicators of the weight of pods, g/plant; yield of pods and seeds, t/ha; parameters of the nutritional value of the pods; development and functioning of the nodulation apparatus.

MATERIALS AND METHODS

The research was conducted at the experimental sites of the Department of vegetable growing, in the training and production department of the Uman National

University of Horticulture in 2020-2022, with geographical coordinates in Greenwich Mean Time 48°46' N, 30°14' E and an altitude of 245 m above mean sea level.

The soil of the experimental site is podzolic heavy loamy chernozem (World reference base for soil resources, 2014). The Uman weather station served as the database of meteorological data. The analysis of the presented data on air temperature and precipitation during the research period was generally characterised as favourable for the growth and development of soybeans. The weather conditions of the 2021-2022 agricultural year were characterised by a significantly lower level of precipitation compared to previous years and the average annual data, and the temperature regime was close to the average annual data. In general, weather conditions significantly affected the formation of productivity of vegetable soybeans. The growing season of 2020 was quite favourable for the growth and development of vegetable soybean plants, as it had a sufficient amount of precipitation and, accordingly, a sufficient amount of productive moisture reserves in the soil, which created optimal conditions from seed germination to the beginning of bean filling. Thus, the growing season of plants for 2021 was characterised as the most favourable due to a large amount of precipitation, especially during the flowering-bean filling phase. The growing season of 2022 was characterised as unfavourable for the growth and development of vegetable soybeans due to prolonged droughts and insufficient precipitation during critical periods and the phase of bean filling, respectively, the phenomenon of bean abortisation (Novak & Novak, 2021, 2022).

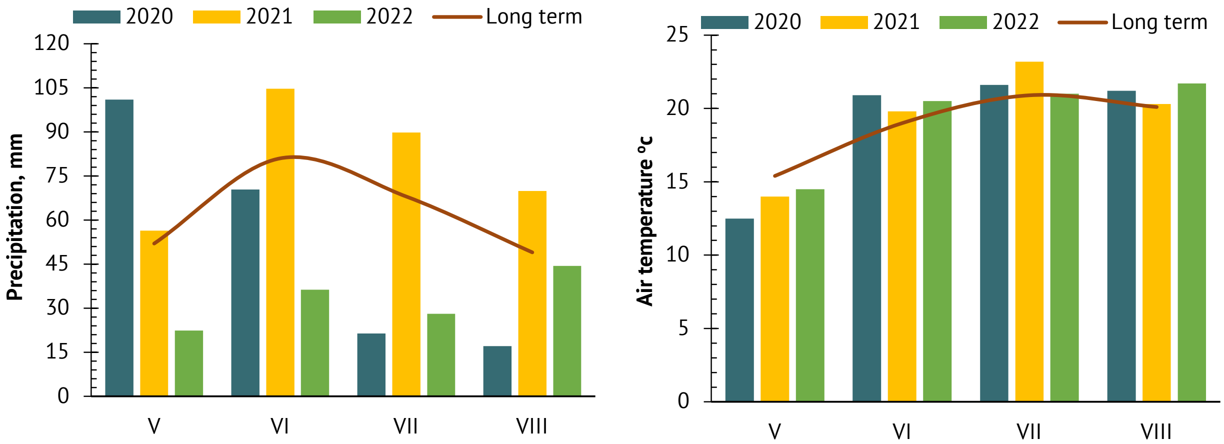

Figure 1. *Climate map for the research period (2020-2022)*

Biometric measurements (number of shoots, pcs./plant; number of beans per plant, and number of seeds, pcs./pod) and indicators of individual productivity (weight of beans, g/plant, seed weight, g/plant) were performed on 100 typical plants. All measurements and studies were carried out in the phase of technical ripeness of beans (harvesting) – BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry), seed yield was determined in the BBCH 99 phase.

Research on the adaptive and productive potential of green bean varieties was carried out according to the scheme, which included seven variants of green bean varieties: Paloma, Fruidor, Purpurova Koroleva, Laura, Zorenka, Casablanca, which were grown according to generally accepted technology. The standard (st) is the Laura variety because, at the time of research, it was the most tested and was the longest in the State register of plant varieties suitable for dissemination in Ukraine (State register of plant varieties suitable for dissemination in Ukraine, 2023).

The experiments were set up systematically, without repetition. The area of the experimental plot – 10 m^2. Bean seeds were sown in the second ten days of April according to the 45×10 cm scheme (222,000 pcs./ha). The predecessor of green beans in the experiment was winter garlic.

The leaf area was determined by the "notching" method using the equation:

$$S = \frac{K+Y}{P} * B, \qquad (1)$$

where: S – leaf surface area, cm^2; K – number of notches; Y – area of one notch, cm^2; P – weight of notches, g; B – weight of leaves, g.

Yield accounting was carried out in accordance with DSTU OOFFV-06 (2007) – by the method of dividing weighing during the period of technical ripeness with the division of products into standard and non-standard

The average weight of beans and green bean fruits was determined by the true weight method. Determination of the biochemical composition of green bean pods was carried out in the laboratory of mass analysis of the Uman National University of Horticulture.

Sugars were extracted from the ground (1 g) unripe beans with water and analysed using high-performance liquid chromatography (HPLC) using the HPLC Waters-2695 chromatrograph. Sugar content measurements were determined using a waters 410 differential refractometer using the method by Johansen *et al.* (1996):

- dry residue in beans – drying at 105°C in the drying cabinet SNOL58/350A according to DSTU 7804:2015 (2015);
- protein content – by the Kjeldahl method, in accordance with DSTU ISO 5983-2003 (2003);
- content of nitrates and nitrites – by spectrometric method according to DSTU ISO 6635: 2004 (2004);
- the number and weight of rhizobia on plant roots and the content of legoglobin (leghemoglobin) were determined according to G.S. Posypanov (1991), the amount of fixed nitrogen – according to Unkovich *et al.* (2008). To determine symbiotic productivity, the parameters of the total and active symbiotic potential (TSA) were used, which was calculated by the equation:

$$TSA = M_1 + M_2 T, \quad (2)$$

where: T – period between two adjacent analysis dates, days; M_1+M_2 – average weight of nodules with legoglobin for the period T, kg/ha.

Genetic and statistical processing of results

To systematise the results, the authors used a rank classification of genotypes based on the ratio of plasticity (bi) and stability parameters $\sigma^2 d$: 1) bi<1, $\sigma^2 d$>0 – shows the best results under unfavourable conditions, unstable; 2) bi<1, $\sigma^2 d$=0 – shows the best results under unfavourable conditions, stable; 3) bi=1, $\sigma^2 d$=0 – responds well to improved conditions, stable; 4) bi=1, $\sigma^2 d$>0 – responds well to improved conditions, unstable; 5) bi>1, $\sigma^2 d$=0 shows better results under favourable conditions, stable; 6) bi>1, $\sigma^2 d$>0 – shows the best results under favourable conditions, unstable. Genotypes with a coefficient bi>1 belong to high-plastic (relative to the average group), and for 1>bi=0 – to relatively low-plastic (*Finlay & Wilkinson,* 1963; *Eberhart & Russell,* 1966).

Homeostasis (variation of the trait) of varieties (Hom) was calculated by the equation:

$$H_{om} = \frac{\overline{X^2}}{\sigma}, \quad (3)$$

where: X̄ – arithmetic mean by variety; σ – generalised mean square deviation.

The breeding value of the variety was determined by the equation:

$$(Sc) = \bar{X} \times \frac{\bar{X}_{lim}}{\bar{X}_{opt}} \quad (4)$$

X̄ – arithmetic mean by variety; $\bar{X}_{lim}$ – limited arithmetic mean; $\bar{X}_{opt}$ – optimal arithmetic mean.

The multiplicativity coefficient (MC) was used to avoid a linear artefact of the regression coefficient, which allows comparing the variability of the feature:

$$MC = \frac{\bar{X}i + bi \cdot yi}{Xi}, \quad (5)$$

where X̄*i* – average value of the studied feature in *i*-th variety; *bi* – linear regression coefficient of *i*-th variety; *yi* – average value for all averages for all varieties *yi* for each *j*-th point of the experiment.

The ecological plasticity index was calculated by the equation:

$$EPI = \frac{\left(\frac{UV_1}{SUO_1} + \frac{UV_2}{SUO_2} + \dots + \frac{UV_n}{SUO_n}\right)}{n}, \quad (6)$$

where UV_1, UV_2, UV_n – value of the variety indicator in different years of testing; SUO_1, SUO_2, SUO_n – average value of the variety indicator in each of the experiment variants.

The annual adaptability coefficient (AC) was calculated using the equation:

$$AC = \frac{(Xij) \times 100 \times X)}{100}, \quad (7)$$

where Xij – yield of a certain variety in the year of testing; X –average variety yield of the year.

The absolute average adaptability coefficient (AAC) is calculated for the variety using the equation:

$$AAC = \frac{(XiC) \times 100 \times Xb)}{100}, \quad (8)$$

where XiC – average yield of the variety over the years of research, Xb – long-term average variety yield.

Stress resistance and compensatory ability of varieties were determined according to *Rossielle & Hemblin* (1981):

$$SR = Y_{min} - Y_{max} \quad (9)$$

$$CA = \frac{Y_{min} + Y_{max}}{2}, \quad (10)$$

where Y_{min} and Y_{max} – minimum and maximum values of the variety indicator.

In experiments, the phenotypic, genotypic, and ecological variability of varieties was determined using the following equations:

Genetic variance:

$$\sigma_G^2 = \frac{CM_p - CM_e}{r}; \quad (11)$$

Ecological variance:

$$\sigma_A^2 = CM_e; \quad (12)$$

Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2.$$

Coefficient of genotypic variation:

$$\frac{\sqrt{\sigma_G^2 \times 100}}{\bar{X}}; \quad (13)$$

Coefficient of phenotypic variation:

$$\frac{\sqrt{\sigma_F^2 \times 100}}{\bar{X}}; \quad (14)$$

Coefficient of ecological variation:

$$\frac{\sqrt{\sigma_A^2 \times 100}}{\bar{X}}, \quad (15)$$

where CM_p – generalised root-mean-square value of the population trait; CM_e – generalised root-mean-square error, r – number of repetitions.

Statistical processing of the obtained results was performed with the calculation of the arithmetic mean (x) of standard deviation (SD) calculated using Microsoft Excel 2019. Correlation dependencies were determined using the Statistica 12 software suite.

RESULTS AND DISCUSSION

Observations show that modern bean varieties are characterised by different growing seasons (60-180 days), which is conditioned by genetic characteristics. The speed of passing the main stages of organogenesis is important in the cultivation of crops. The faster the bean plants finish forming the vegetative mass and move on to fruiting, the longer the period of harvesting the pods. According to the "International classifiers of the CMEA for cultivated species *Phaseolus* L. the study included two groups of varieties – medium-early (51-55) and medium-ripening (61-70 days from germination to technical ripeness) (Fig. 2).

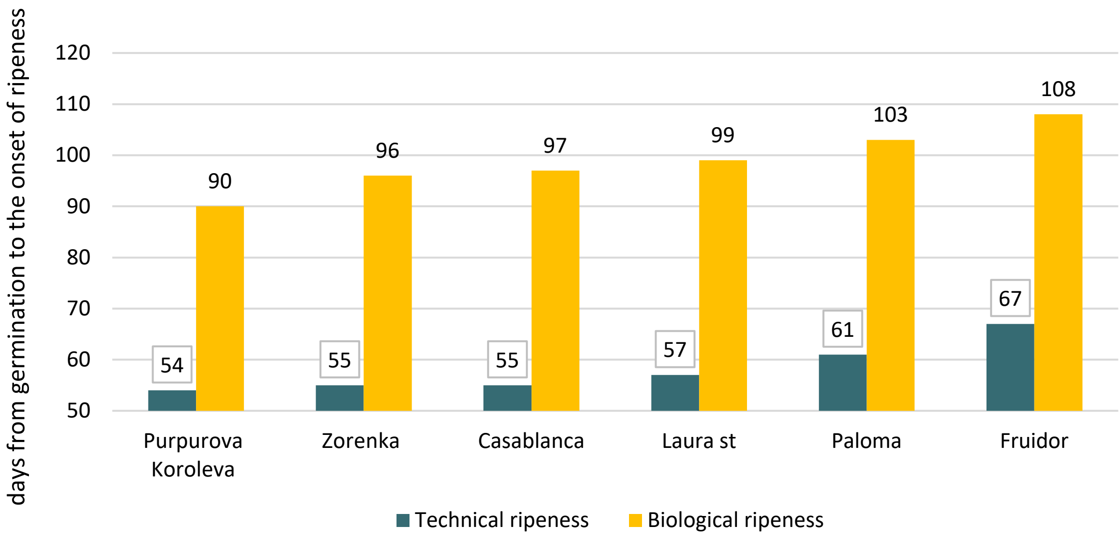

***Figure 2.** Duration of periods from the germination to the onset of technical/biological ripeness of green bean varieties (2020-2022)*

***Source:** obtained as a result of author's research*

Studies have established that the period from germination to the onset of technical ripeness of green bean varieties was 54-67 days, CV=8%. The shortest period before the onset of technical ripeness was characterised by the Purpurova Koroleva variety – 54 days, and the Zorenka and Casablanca varieties – 55 days.

The variation of the period from the germination to the onset of biological ripeness was 6% and was in the range of 90-108 days. The dynamics of the onset of biological ripeness remained the same as in the previous sign. Earlier-maturing varieties were Purpurova Koroleva – 90 days, and Zorenka and Casablanca – 96 and 97 days, respectively.

A study of the height of green bean plants showed that on average, the varieties differed significantly over the years. Thus, the highest were plants of the standard Laura and Paloma varieties – 49.7 and 49.3 cm, respectively. Plants of the Zorenka, Fruidor, and Casablanca varieties were 2.3-6.0 cm lower (4.7-12.1%). The Purpurova Koroleva variety can be attributed to the dwarf type, since the height of its plants was 40.7 cm, which is 9 cm less than the Laura variety (18.1%).

The suitability of the variety for mechanised harvesting depends on the height of attachment of the first bean, so this indicator was also considered. Thus, the lowest attachment of the first bean was observed in the varieties Purpurova Koroleva – 11.3 cm and Fruidor – 12.3 cm, and the highest in the variety Laura – 15.3 cm, but the beans of the varieties Purpurova Koroleva and Fruidor were tightly collected in internodes, while the variety Laura had more internodes and it is suitable for manual harvesting in several samples. Other varieties under study had a height of 1st bean attachment of 14.0-15.7 cm, which characterises them as varieties suitable for mechanised harvesting.

Among legumes, beans occupy one of the first places in terms of the variety of morphological features and their amplitude. This is due to its strong plasticity and high adaptability to growing conditions. Bean plants can form an area of leaves under optimal conditions up to 36-38 thousand m^2/ha. Other data indicate that the intensity of photosynthetic activity of beans can reach 4-5 $m^2/1m^2$. The productivity of the plant and sowing in general depend on a properly developed leaf apparatus and its functioning. Thus, the largest leaf area was developed by varieties of green beans Paloma (24.1 thousand m^2), Casablanca (27.3 thousand m^2), and Zorenka (28.1 thousand m^2), which is 5.1-22.7% more than the standard. A smaller area of the assimilation surface by 0.4% was formed by the Fruidor variety (Table 2).

Table 1. *Growth and development parameters of various varieties of green beans (2020-2022), (Lim±SD) (BBCH 75)*

Variety	Leaf area of crops, thous. m^2		Plant height, cm		Height of attachment of 1-st bean	
	Lim±SD	CV, %	Lim±SD	CV, %	Lim±SD	CV, %
Paloma	16.1-30.4±6.0	25	44-54±4.1	8	11-16±2.2	15
Frouidor	15.4-28.2±5.3	24	40-50±4.3	9	11-14±1.2	10
Purpurova Koroleva	18.8-28.0±3.8	16	37-45±3.3	8	10-12±0.9	8
Laura st	15.5-28.8±5.5	24	44-54±4.2	8	12-18±2.5	16
Zorenka	22.1-33.7±4.7	17	45-50±2.1	4	13-18±2.1	13
Casablanca	23.0-31.8±3.6	13	40-48±3.3	8	13-16±1.2	9
Xmed.	24.8		46		13.9	
σ_G^2	8.0		4.4		1.1	
σ_F^2	36.8		27.6		6.7	
σ_A^2	28.8		23.2		5.7	
CVG, %	11.4		4.5		7.4	
CVF, %	24.5		11.4		18.7	
CVA, %	21.7		10.4		17.1	
CVG/CVA	0.53		0.44		0.43	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Analysing the dependence of the growth parameters of green bean plants, it can be seen that these traits are more dependent on the conditions (CVA=21.7, 10.4 and 17.1%) in which they were formed, rather than on the genotypic component (CVG=11.4; 4.5 and 7.4%, respectively, according to the attribute). According to the number of shoots on the plant, a high bushiness index was noted in varieties Laura, Fruidor, and Casablanca – 3-8 shoots/plant. A dense, erect bush with a small number of shoots had varieties Purpurova Koroleva, Paloma, and Zorenka – 3-5 pcs./plant. A large number of beans on the plant were characterised by varieties Purpurova Koroleva and Paloma – 12.3 and 13.0 pcs., respectively. Zorenka varieties had a smaller number of beans than the standard (10 pcs.), Casablanca (9.3 pcs.) and Fruidor (5.7 pcs.), which is 9.1-48.5% less. According to the number of shoots and beans on the plant, the coefficient of variation of the environment (CVA) was in high limits – 31.9 and 35.8%, and the relationship between the coefficient of genetic and ecological variation (CVG/CVA) was noticeable (0.47 and 0.44), which indicates very favourable environmental conditions for growing this crop (Table 2).

Table 2. *Parameters of individual productivity of different varieties of green beans (2020-2022), (Lim±SD) (BBCH 75)*

Variety	Number of shoots, pcs./plant.		Number of beans, pcs./plant	
	Lim±SD	CV, %	Lim±SD	CV, %
Paloma	3-5±0.82	20	8-18±4.2	34
Frouidor	3-7±1.63	33	5-6±0.5	8
Purpurova Koroleva	3-4±0.47	13	11-15±1.6	13
Laura st	4-8±1.70	27	7-16±3.7	34
Zorenka	3-5±0.94	22	8-14±2.8	28
Casablanca	3-6±1.25	27	8-12±1.9	20

Table 2, Continued

Variety	Number of shoots, pcs./plant.		Number of beans, pcs./plant	
	Lim±SD	CV, %	Lim±SD	CV, %
Xmed.	4.7		10.2	
σ^2_G	0.5		2.6	
σ^2_F	2.7		16.0	
σ^2_A	2.2		13.4	
CVG, %	15.1		15.6	
CVF, %	35.3		39.1	
CVA, %	31.9		35.8	
CVG/CVA	0.47		0.44	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

According to the weight of green beans on the plant, the varieties Zorenka (59.7 g), Casablanca (38.0 g), and Paloma (31.7 g) and Purpurova Koroleva (31.7 g) were larger than the standard by 8.0-103.4%, or 2.3-30.0 g. The Fruidor variety was characterised by a lower indicator relative to the standard by 68.2% (Table 3).

Table 3. *Parameters of adaptive capacity and breeding value of vegetable bean varieties based on "bean weight", g/plant. (BBCH 75)*

Variety	Xmed, g/plant	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	KAA
Paloma	31.7	3.39	1.10	51.1	2.6	14.38	0.93	-27	30	0.95
Frouidor	9.3	0.69	0.01	4.4	0.8	1.37	0.31	-1	10	0.04
Purpurova Koroleva	31.7	2.12	0.35	51.0	2.6	5.25	1.04	-10	33	2.14
Laura st	29.3	3.33	1.06	43.8	2.4	14.97	0.86	-26	27	0.08
Zorenka	59.7	4.90	2.30	181.2	4.9	15.88	1.73	-58	57	1.07
Casablanca	38.0	3.52	1.18	73.5	3.1	13.00	1.13	-29	36	0.09
Xmed	33.3									
σ^2_G	55.7									
σ^2_F	441.7									
σ^2_A	386.0									
CVG, %	22.4									
CVF, %	63.1									
CVA, %	59.0									
CVG/CVA	0.38									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Genetic and statistical analysis of this indicator has shown that the most stable (in terms of indicators $\sigma^2 d$ and MC, Hom) was the Fruidor variety. By indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$ varieties Paloma, Laura, Zorenka, and Casablanca had a ratio of indicators $bi>1$, $\sigma^2 d>0$ – that is, they have better results under favourable growing conditions. Varieties Fruidor and Purpurova Koroleva had a ratio of indicators $bi<1$, $\sigma^2 d>0$, i.e., they had better results under unfavourable conditions and were unstable.

According to the indicator of stress resistance (SR), the Zorenka variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the varieties under study were characterised by a significant variation, but the Zorenka and Kasalanka varieties had the highest indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties.

On the basis of "seed weight" in terms of absolute adaptability, the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva and Zorenka. The Paloma variety is medium-adaptive and the Fruidor, Laura and Casablanca varieties are marked as low-adaptive. Low productivity of bean varieties is confirmed by high exposure to external conditions (CVA=59.0%) and low CVG/CVA=0.38 ratio.

The yield of green beans (pods) consists mainly of two structural elements – the number of plants per unit area and the weight of beans per plant. The "pod yield" attribute varied on average from 1.9 to 12.7 t/ha (by year from 1.8 t/ha (2022) for the Fruidor variety to 19.35 t/ha (2021) for the Zorenka variety). The yield of green bean varieties depended not only on the varietal characteristics of plants, but also on weather conditions. In the years with optimal water supply (2020-2021), this indicator reached its theoretical maximum, and in 2022 – a minimum.

According to the "pod yield", the varieties Zorenka (12.72 t/ha), Casablanca (8.05 t/ha), Paloma (6.74 t/ha), and Purpurova Koroleva (6.87 t/ha) were higher than the standard by 9.8-107.1%, or 0.6-6.6 t/ha. The Fruidor variety was characterised by a lower indicator relative to the standard by 68.4%, or 4.2 t/ha (Table 4).

Table 4. *Parameters of adaptive capacity and breeding value of green bean varieties based on "green bean yield", t/ha (BBCH 75)*

Variety	Xmed. t/ha	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	KAA
Paloma	6.7	1.61	1.06	10.4	2.4	3.99	0.93	-6	6	0.95
Frouidor	1.9	0.31	0.04	0.9	0.7	1.37	0.31	0	2	0.19
Purpurova Koroleva	6.9	0.98	0.35	10.8	2.5	1.97	1.08	-2	7	2.17
Laura st	6.1	1.61	1.04	8.6	2.2	4.24	0.83	-6	6	0.32
Zorenka	12.7	2.35	2.26	37.0	4.6	4.39	1.73	-14	13	4.20
Casablanca	8.1	1.76	1.26	14.8	2.9	3.99	1.12	-7	8	0.36
Xmed	7.1									
σ_G^2	3.0									
σ_F^2	22.1									
σ_A^2	19.1									
CVG, %	24.6									
CVF, %	66.5									
CVA, %	61.8									
CVG/CVA	0.40									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Genetic and statistical analysis of this indicator has shown that the most stable (in terms of indicators $\sigma^2 d$ and MC, Hom) was the Fruidor variety. By indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$ varieties Paloma, Laura, Zorenka, and Casablanca had a ratio of indicators *bi*>1, $\sigma^2 d$>0 – that is, they have better results under favourable growing conditions. The Fruitor variety had a ratio of indicators *bi*<1, $\sigma^2 d$ > 0, i.e., have better results under unfavourable conditions, unstable. The Purpurova Koroleva variety had a ratio of bi=1, $\sigma^2 d$>0 – responds well to improved conditions, unstable

According to the coefficient of ecological plasticity, the group of high-plastic varieties includes Paloma, Laura, Zorenka, and Casablanca; the group of low-plastic varieties includes Fruidor and Purpurova Koroleva.

According to the indicator of stress resistance (SR), the Zorenka variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the studied varieties were characterised by a significant variation, but the varieties Zorenka, Casablanca, Laura, and Paloma had the highest indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties.

On the basis of "pod yield" in terms of absolute adaptability (AA), the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva and Zorenka. The Paloma variety belongs to the medium-adaptive and the Fruidor, Laura, and Casablanca varieties are classified as low-adaptive. The low productivity of bean varieties is confirmed by the high influence of external conditions (CVA=61.8%) and the low CVG/CVA=0.40 ratio.

Seed yield consists mainly of two elements of productivity: the number of plants per unit area and the weight of seeds per plant. The parameters of this attribute on average were in the range of 0.47-2.89 t/ha (by year: from 0.33 t/ha in 2022 to 3.78 t/ha in 2021). In terms of seed yield, the varieties Purpurova Koroleva, Zorenka, and Casablanca stood out, the yield of which was at the level of 2.22-2.89 t/ha, which is more than the standard by 30.8-70.6 % or 0.5-1.2 t/ha (Table 5).

Table 5. *Parameters of adaptive capacity and breeding value of green bean varieties based on "seed yield", t/ha (BBCH 99)*

Variety	Xmed., t/ha	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	AC
Paloma	1.11	0.50	0.63	1.3	2.6	1.53	0.60	-1	1	0.61
Frouidor	0.47	0.35	0.09	0.2	1.1	1.18	0.26	0	0	0.67
Purpurova Koroleva	2.22	0.55	0.76	5.1	5.3	1.32	1.24	-1	2	2.64
Laura st	1.69	0.71	1.25	3.0	4.0	1.69	0.91	-1	2	1.82
Zorenka	2.89	0.69	1.20	8.6	6.9	1.39	1.60	-1	3	37.70
Casablanca	2.58	0.92	2.07	6.9	6.1	1.75	1.38	-2	3	2.55
Xmed	1.83									
σ_G^2	0.08									
σ_F^2	1.01									
σ_A^2	0.93									
CVG, %	15.2									
CVF, %	55.1									
CVA, %	52.9									
CVG/CVA	0.29									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Statistical analysis has shown that according to the indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$, Laura variety had a ratio of indicators *bi*>1, $\sigma^2 d$>0 – that is, it has better results under favourable growing conditions. Varieties Paloma, Fruidor, Zorenka, and Casablanca had a ratio of indicators *bi* < 1, $\sigma^2 d$>0, i.e., they had better results under unfavourable conditions and were unstable. The Purpurova Koroleva variety had a ratio of bi=1, $\sigma^2 d$>0 – responds well to improved conditions, unstable. According to the coefficient of ecological plasticity, the Laura variety belongs to the group of high-plastic varieties; all other varieties studied belong to the group of low-plastic varieties. Rather low seed productivity of bean varieties is confirmed by the significant influence of external conditions (CVA=52.9%) and a low ratio CVG/CVA=0.29.

According to the indicator of stress resistance (SR), the Casablanca variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the varieties under study were characterised by sufficient alignment, but the Zorenka and Casablanca varieties had the highest indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties. On the basis of "seed weight" in terms of absolute adaptability (AA), the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva, Zorenka, Laura, and Casablanca. Paloma and Fruidor varieties are medium-adaptive.

Vegetable crops, each of which has a unique biochemical composition, make our diet diverse and have a positive effect on health. The biochemical composition of green beans is not constant, it is subject to variability depending on the type and variety, and also varies under the influence of growing conditions.

Studies have shown that green bean varieties were characterised by a low variation in biochemical parameters (CV=1-9%). The sugar content in pods over the years was in the range of 1.91-2.78%. On average, over the years of research, the varieties Purpurova Koroleva (2.60%), Laura, and Fruidor (2.50%) were distinguished by this feature, which were at the standard level and/or exceeded it by 4.0%. Varieties Casablanca, Paloma, and Zorenka accumulated significantly less sugar compared to other varieties and the standard in particular – 2.00-2.40% (Table 6).

Table 6. *Content of individual components of the biochemical composition in the pods of green bean varieties (2020-2022), (X±SD) (BBCH 75)*

Variety	Proportion of sugars, %		Ascorbic acid content, mg/100 g		Nitrate content, mg/kg	
	X ± SD	CV, %	X ± SD	CV, %	X ± SD	CV, %
Paloma	2.10±0.07	3	16.03±1.13	7	148.3±3.7	3
Frouidor	2.50±0.02	3	21.41±1.43	7	145.1±6.4	4
Purpurova Koroleva	2.60±0.06	4	16.20±1.02	6	127.9±6.2	5
Laura st	2.50±0.03	1	16.02±1.42	9	136.3±4.1	3
Zorenka	2.00±0.08	4	13.22±0.91	7	145.8±4.7	3
Casablanca	2.40±0.07	4	14.05±0.89	6	151.2±6.0	4
Xmed.	2.35±0.21		16.20±2.60		148.3±7.96	3
	0.001		0.44		9.4	
	0.049		8.54		100.8	
	0.049		8.10		91.5	
CVG, %	1.47		4.12		2.1	
CVF, %	9.59		18.09		7.0	
CVA, %	9.48		17.61		6.7	
CVG/CVA	0.15		0.23		0.32	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

In terms of ascorbic acid concentration, the variation was average – CV=16%, and the parameters of this trait for years ranged from 11.97-22.57 mg/100 g, depending on the variety. According to the content of ascorbic acid, only one variety was distinguished, which accumulated significantly more than the standard – Fruidor (21.41 mg/100, which is 33.6% more than the standard). The Paloma and Purpurova Koroleva varieties accumulated slightly more ascorbic acid relative to the standard, while the Zorenka and Casablanca varieties had significantly lower ascorbic concentrations.

The concentration of nitrates on average varied little, and over the years ranged from 119.2-159.5 mg/kg, depending on the variety. With a low concentration of nitrates, the Purpurova Koroleva variety was distinguished, where this indicator was lower than the standard variety by 6.2% or 8.4 mg/kg. Varieties Paloma, Fruidor, Zorenka, and Casablanca were characterised by an increased content of nitrates relative to the standard by 7.0-10.9%.

The value of green bean varieties for vegetable purposes lies in the high content of protein and dry matter. In modern conditions, breeding work with green beans should be aimed at meeting the needs of the processing industry, which will expand the area of cultivation of the crop and the scope of its use. In the successful solution of this problem, the leading role belongs to quality selection. Genetic sources and donors of such traits are among the most scarce plant resources. In this regard, a scientifically based selection of green bean varieties with their subsequent introduction into industrial production is extremely important. According to this feature, the varieties Fruidor and Purpurova Koroleva with a protein content of 17.13 and 15.34% were distinguished.

The nutritional value of green beans is high and is conditioned by the content of various minerals, vitamins, macro- and microelements. It is well known that the biochemical composition of beans is not constant and is influenced by many factors. Studies have shown that the dry matter content was stable both in varieties individually (CV=3-5%) and over the years (CV=9%). In terms of "dry matter content", only one variety was distinguished – Paloma, in which this indicator was at the level of 11.00% and the standard prevailed by 22.2%. In the course of experimental studies, it was found that the protein content varied greatly in the range of 18-21% for varieties and 12% for years.

With an increased protein content, two varieties were identified – Fruidor (17.13%) and Purpurova Koroleva (15.34%), which exceeded the standard by 17.3 and 5.0%, respectively, which characterises them as promising sources of signs of nutritional value for breeding. Statistical processing data indicate a strong influence of environmental conditions on the formation of nutritional value parameters (CVA=9.23-24.24%, and CVG/CVA=0.21-0.52, although to obtain high productivity indicators, the CVG/CVA ratio must be close to 1. All presented varieties are recommended for use as sources of high taste qualities; suitable for canning and freezing; creating a conveyor of green beans (Table 7).

With a high content of carbohydrates and fats, two varieties are distinguished – Fruidor and Purpurova Koroleva. The conditional protein yield in the technical ripeness phase varied at 33%, in the biological ripeness phase – at the level of 42%, which confirms a strong differentiation of varieties according to the parameters of the biochemical complex. (Fig. 2).

Table 7. *Nutritional value of the pods of different green bean varieties (2020-2022), (X±SD) (BBCH 75)*

Variety	Dry matter, %	Protein, %	Carbohydrates	Fats	Energy, kcal. 100 g dry matter
			g/100 g dry matter		
Paloma	11.00±0.30	14.05±2.77	6.87±1.38	3.36±0.83	113.92±24
Frouidor	9.00±0.23	17.13±3.20	8.23±1.53	3.96±0.79	137.10±26
Purpurova Koroleva	9.30±0.49	15.34±3.06	7.70±1.51	3.71±0.86	125.53±26
Laura st	9.00±0.30	14.60±3.01	7.30±1.51	3.55±0.80	119.55±25
Zorenka	8.60±0.35	11.33±2.05	5.73±0.95	2.90±0.54	94.36±17
Casablanca	8.80±0.25	13.37±2.34	6.70±1.10	3.15±0.68	108.67±20
Xmed	9.30	14.30	7.09	3.44	
σ_G^2	0.03	2.56	0.61	0.19	
σ_F^2	0.77	13.37	3.05	0.89	
σ_A^2	0.73	10.82	2.45	0.70	
CVG, %	1.97	11.18	10.99	12.70	
CVF, %	9.44	25.57	24.65	27.37	
CVA, %	9.23	22.99	22.07	24.24	
CVG/CVA	0.21	0.49	0.50	0.52	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

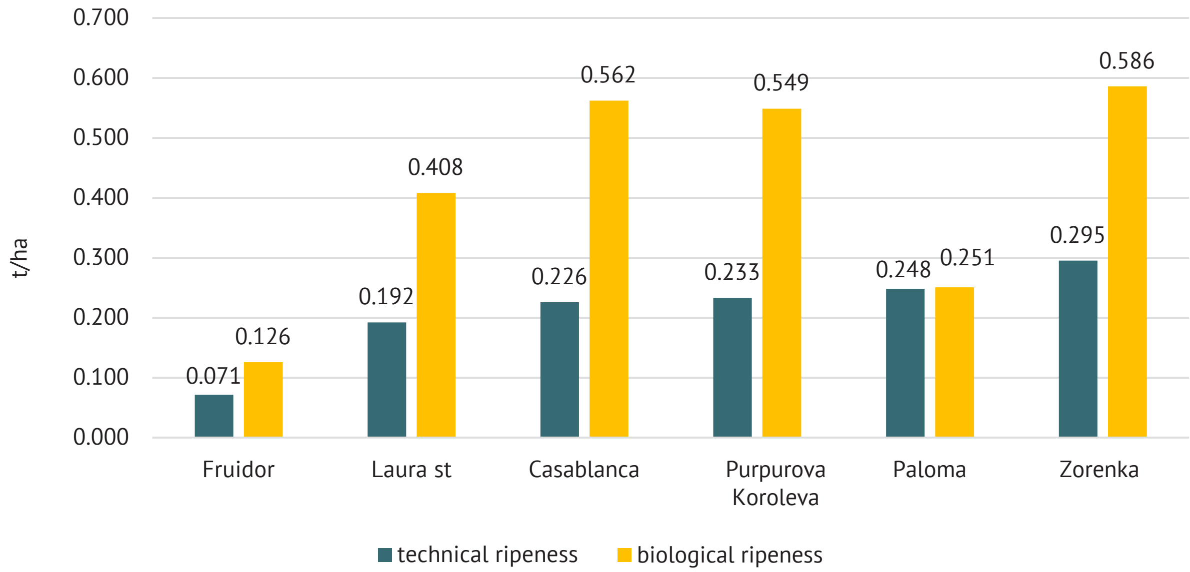

Figure 2. *Conditional protein yield from pods and mature green bean seeds depending on the variety (2020-2022), t/ha*
Source: *obtained as a result of author's research*

Thus, according to this feature, in the phase of technical ripeness of green bean pods, the Zorenka variety was distinguished with a maximum protein yield of 0.295 t/ha. In general, all the varieties under study, except for the Fruidor variety, prevailed over the standard. In the phase of biological ripeness, the dynamics were similar, but most varieties increased this indicator by 98.55-149.19%, and the Paloma variety by only 1.03%. In the phase of biological ripeness, according to the indicator of conditional protein yield, Casablanca, Purpurova Koroleva, and Zorenka varieties were identified, where this indicator was at the level of 0.549-0.586 t/ha.

From the results shown in Table 8, it can be seen that the varieties Paloma, Fruidor, and Casablanca formed the largest **total** number of nodules on one plant – 14.0-16.3 pcs./plant, all other varieties formed from 7.7 to 12.7 pcs./plant, which was significantly less than the above-mentioned varieties. By number of **active nodules** the same varieties (Paloma, Fruidor, Casablanca) stood out – 7.0-8.0 pcs./plant. In other varieties, this indicator ranged from 4.3-6.7 pcs./plant of active nodules.

The study revealed that the largest weight of **active** nodules (with legoglobin content) were formed by varieties Paloma, Fruidor, and Laura – 0.09 g/plant, in other varieties the weight of **active** nodules was in the range of 0.05-0.08 g/plant, which was 40.0-41.6% of the total weight of nodules. Thus, in the varieties that produced a small number of nodules, all nodules (or most of them) were active.

Table 8. *Development of the nodulation apparatus of green bean varieties (2020-2022) (X±SD)*

Variety	Number of nodules, pcs./plant		Mass of nodules, g/plant	
	total	active	total	active
Paloma	14.0±4.9	7.0±4.2	0.18±0.05	0.09±0.04
Frouidor	15.7±5.7	8.0±5.0	0.20±0.07	0.09±0.02
Purpurova Koroleva	7.7±2.1	4.3±1.9	0.12±0.02	0.08±0.01
Laura st	12.0±4.1	5.7±3.1	0.16±0.05	0.09±0.02
Zorenka	12.7±4.5	6.7±3.8	0.12±0.03	0.05±0.01
Casablanca	16.3±6.5	8.0±5.0	0.20±0.08	0.08±0.01
Xmed	13.06	6.61	0.16	0.08
σ_G^2	7.83	5.26	0.001	0.0002
σ_F^2	39.44	22.72	0.005	0.0008
σ_A^2	31.61	17.46	0.004	0.0007
CVG, %	21.43	34.69	19.25	16.11
CVF, %	48.10	72.10	43.26	36.55
CVA, %	43.06	63.20	38.74	32.81
CVG/CVA	0.50	0.55	0.50	0.49

Note: ** – st – standard*
Source: *obtained as a result of author's research*

One of the qualitative indicators of the symbiotic apparatus is the content of legoglobin in nodules. The activity of nitrogen fixation depends more on the content and concentration of legoglobin in the nodules than on their amount. Therefore, the study of the influence of varietal features of legoglobin accumulation is of high practical interest. A high concentration of legoglobin was noted in nodules of high weight – in the varieties Purpurova Koroleva, Laura, and Zorenka – 48.3-60.6 mg/g. The main reserve for increasing the yield of legumes is the scientifically based use of the nutritional potential of the soil, environmental conditions, and new varieties. It is known that at least half of the yield growth is achieved through the use of fertilisers. At the same time, biological nitrogen is an essential source of nutrition. As a result of research, it was revealed that the highest activity of the symbiotic potential was found in Paloma varieties – 3.3 thousand kg·days/ha, while the amount of fixed nitrogen was 51.5 kg/ha; Fruidor – 3.7 thousand kg·days/ha. and 54.6 kg/ha of fixed nitrogen; and Casablanca – 4.2 thousand kg·day/ha and 60.9 kg/ha of fixed nitrogen, respectively (Table 9).

Table 9. *Activity of the symbiotic apparatus of green bean varieties (2020-2022) (X±SD)*

Variety	Legoglobin content, mg/g	Active symbiotic potential, thous. kg×day/ha	Amount of fixed nitrogen, kg/ha
Paloma	44.5±3.7	3.3±0.8	51.5±19.1
Frouidor	43.9±4.7	3.7±1.0	54.6±24.4
Purpurova Koroleva	48.3±19.6	2.2±0.2	37.9±7.0
Laura st	51.9±12.7	3.1±0.7	50.0±16.2
Zorenka	60.6±9.7	2.6±0.3	36.6±10.5
Casablanca	40.6±5.2	4.2±0.9	60.0±25.9
Xmed	48.3	3.2	48.5
σ_G^2	38.93	0.17	114.06
σ_F^2	198.53	1.09	528.79
σ_A^2	159.59	0.93	414.73
CVG, %	12.92	12.88	22.05
CVF, %	29.17	33.14	47.47
CVA, %	26.15	30.53	42.04
CVG/CVA	0.49	0.42	0.52

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Like all previously analysed indicators, the activity of the symbiotic apparatus of green beans to a greater extent depended on the conditions in which the phenotype was formed – CVA=26.15 – 42.04%, rather than on varietal characteristics – CVG=12.88 – 22.05%, which is explained by the low ratio of CVG/CVA=0.42-0.52.

The obtained data on the indicator "height of attachment of the lower bean" (10-18 cm) coincide with the data given in the paper by Ovcharuk *et al.* (2021) – 8.2-16.8 cm and indicates the suitability of green bean varieties for mechanised harvesting in the technical ripeness phase. However, according to the indicator "the number of beans per plant, pcs." data provided by Ovcharuk *et al.* (2021) significantly predominate.

The findings of this study show a significantly lower yield of green bean pods compared to the data obtained by Vitanov *et al.* (2019), where the yield of green beans at a single harvest was 12.6-14.3 t/ha, and by Habtie *et al*. (2021) – 11.5-19.7 t/ha. In this study, a close level of yield was achieved only in the Zorenka variety – 12.7 t/ha. Analysing the indicators of individual productivity of green bean varieties, it can be seen that the results differ significantly from the results obtained by Hema and Rana (2020) in subtropical conditions. Thus, in terms of green bean yield, the studied varieties were less productive than those indicated by Hema and Rana (2020) – 18.3-49.9 t/ha; in terms of the number of beans on the plant, the results were similar – 9.66-21.10 pcs./plant, in our studies – 5-18 pcs./plant. However, in terms of the weight of beans from one plant, the data were low – 9.3-59.7 g/plant, while data noted by Hema and Rana (2020) – 91.68-249.92, which shows a strong differentiation of varieties in terms of productivity and a significant dependence on growing weather conditions.

In the author's studies, the yield of green bean seeds was 0.47-2.89 t/ha, as noted by Garbovska (2019), the yield of green bean seeds was obtained at the level of 1.6-2.4 t/ha, which is significantly higher than in this study, and these results also coincide with the results of Ovcharuk *et al.* (2021). This phenomenon is explained by higher air temperature and lower precipitation and relative humidity in the conditions of author's research, which significantly affects the level of tying and abortivity of bean fruits, which affects the yield.

In this study, the protein content was in the range of 11.33-17.13%, while in the results of Aquino-Bolaños *et al.* (2021), this indicator was between 3.3 and 9.6%. Aquino-Bolaños *et al.* (2021) report the sugar content of 4.86-12.5%, while the present study found significantly less sugar accumulation (in the range of 2.00-2.60%).

The development of the nodulation apparatus also differed significantly from the results published by Hema & Rana (2020). Thus, in this study, the number of nodules was 7.7-16.3 pcs/plant with a total weight of 0.12 to 0.20 g/plant, whereas in the results of Hema & Rana (2020), their number was 7.78-14.59 pcs./plant, weighing 0.075-0.150 g. The comparison of the findings with the results of other researchers showed a significant differentiation of varieties by morphological and economic characteristics, which is explained by genetic differences and soil and climatic conditions.

CONCLUSIONS

The results confirm the advantages of green beans as a dietary product with a high protein content in the technical ripeness phase – Purpurova Koroleva, Paloma, Zorenka, and Casablanca; Purpurova Koroleva and Zorenka – in the biological ripeness phase of the grain. The most valuable in terms of caloric content were green beans of the varieties Fruidor, Purpurova Koroleva, and Laura st – 113.92-137.10 kcal per 100 g of raw weight.

Varieties with the shortest period before the onset of technical ripeness are identified – Purpurova Koroleva, Zorenka, and Casablanca (54-55 days). Evaluating varieties by growth indicators, it was found that the leaf area of crops is the most variable indicator (CV=13-25% depending on the variety), and plant height is the most stable indicator (CV=4-8%). Varieties with a high attachment of the lower bean – 13-16 cm (Zorenka, Paloma and Laura) are also identified, which characterises them as suitable for mechanised harvesting. Varieties with compact, dense bushes that are suitable for repeated harvesting were found – Fruidor, Laura, and Casablanca. As a result of statistical data processing, it was found that plant growth indicators are more dependent on environmental conditions (CVA=10.4-35.8%) than on the genetic component (CVG=4.5-15.6%). According to the weight of green beans per plant, the varieties Zorenka and Casablanca were distinguished, which were characterised by a large weight and alignment of beans.

Assessment of the adaptability and stability of green bean varieties allows identifying varieties that belong to the intensive type. According to the results of research, varieties that are able to successfully adapt to limiting and stressful factors in Forest-Steppe conditions have been identified. Thus, in the conditions of using intensive technologies, it is advisable to grow varieties Paloma, Laura, Zorenka, and Casablanca, which had a ratio of indicators $bi>1$, $\sigma^2d>0$ – that is, they have better results under favourable growing conditions and were characterised by broad agro-ecological adaptability and belong to intensive varieties on the basis of "green bean yield".

From the data obtained, it can be seen that the yield depends on the number of beans per plant. The number of beans per plant was more dependent on environmental conditions than on varietal characteristics, and the same trend was observed in terms of seed weight per plant and bean and seed yields.

In the direction of nitrogen fixation in production or as a source of a trait in the breeding process, it is necessary to use the varieties Fruidor and Casablanca, in which the level of biologically fixed nitrogen is 54.6 and 60.0 kg/ha. As a result of an ecological study of green bean varieties, it was found that the conditions of the Ukrainian Forest-Steppe are suitable for obtaining high-quality raw materials for processing and seed production. Further research prospects consist in zoning the varieties under study in other zones of Ukraine and investigating the elements of seed production.

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest regarding the publication of this paper.

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Агробіологічна оцінка сортів квасолі спаржевої за адаптивністю, продуктивністю та азотфіксацією

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Анотація. Квасолю необхідно вивчати як екологічний об'єкт, за допомогою якого можна поповнити запаси сполук азоту в ґрунті та підвищити його біологічну активність. За мету ставилося провести науково обґрунтоване районування сортів та оцінити їх адаптивно-продуктивний потенціал за показниками продуктивносі та азотфіксації. Дослідження проводили в умовах навчально-виробничого відділу Уманського національного університету садівництва впродовж 2020-2022 рр., використовували шість сортів, поширених у виробництві. Для вивчення параметрів адаптивної мінливості використано стандартні методи генетико-статистичного аналізу. Дослідження фенологічних змін показало, що залежно від сорту до настання технічної стиглості проходить від 54 до 67 діб, а варіювання даної ознаки складає 8 %. Найкоротшим періодом до збору зелених бобів характеризувалися сорти Зоренька і Касабланка. Варіювання періоду вегетації до настання біологічної стиглості було у межах 90 – 108 діб (CV=6 %). За показником прикріплення нижнього боба виявлено придатні сорти до механізованого збору врожаю – Зоренька і Касабланка. Аналізуючи параметри адаптивності ознак «маса бобів» та «врожайність» виявлено стабільний сорт – Фруідор та високопродуктивні сорти інтенсивного типу Палома, Лаура, Зоренька і Касабланка. Найбільш врожайним був сорт Зоренькa – 12,7 т/га, а найменш врожайним – Фруідор – 1,9 т/га. За врожайністю насіння виділилися сорти Пурпурова королева, Зоренька та Касабланка врожайність яких була на рівні 2,22-2,89 т/га, що більше від стандарту на 30,8-70,6 %. Аналізуючи залежність параметрів росту і розвитку рослин квасолі спаржевої, видно, що дані ознаки в більшій мірі залежать від умов (CVA, %) у яких вони формувалися, аніж від генотипової складової (CVG, %). Отримані результати надають корисну інформацію щодо товарної й насіннєвої, продуктивності та азотфіксуючої здатності для впровадження у промислове виробництво або подальшої селекційної практики і доводять, що сорти квасолі спаржевої придатні як для отримання овочевої продукції, так і для якісного насіння, а також для біологізації виробництва шляхом використання біологічно фіксованого азоту

Ключові слова: *Phaseolus vulgaris*; фіксація азоту; харчова цінність; продуктивність; протеїн; розчинні цукри