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Evaluation of variation for some yield components in snap bean (*Phaseolus vulgaris* L.) varieties

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Abstract
Snap bean is a type of common bean with fresh fleshy tender pods having reduced fiber content in pod-wall and is considered an important legume vegetable used for cooking or canning. The biological material was composed by 20 varieties of bushing snap bean genetically and ecologically differentiated. The experimental design was a randomized block with three replications. From each plot five randomly selected plants were evaluated for the following pod traits: weight, length, width, thickness and firmness. The objective of this study was to assess the variability of some pod traits in 20 varieties of snap bean to identify the suitable genitors for breeding activities. Based on the five pod traits the 20 varieties of bushing snap bean were grouped into five clusters with a 27 % average phenotypic diversity. The present work shows that some varieties can be considered a valuable material for several pod traits, that could be successively used in further breeding program of bushing snap bean including diallel crossing methods and will be relevant as a good base for the development of new cultivars.

Keywords: ANOVA**,** bushing snap bean, clustering, pod traits, principal component analysis.

Introduction

Snap and dry beans are considered a valuable source of protein and calories worldwide [2]. The consumption of snap beans is highly recommended both in low carbohydrate diets, and for diabetics given its low glycemic index [4, 14]. Given its high nutritional value, which includes several compounds like proteins, vitamins, and minerals, snap bean is considered the most grown vegetable legume mainly in Europe, North America, or Asia [8]. Breeding for different pod traits is a one of the major objectives of snap bean improvement programs [22]. The use of genetic diversity is very important for the efficient selection of superior genotypes for all crops, including snap beans. The pods size has a high influence on the amount and commercial value of snap bean yield, which can affect both the consumer satisfaction and the market price [16]. Pod morphology encompasses factors like straightness, thickness, length, cross-section shape, and color, and dictates the subsequent utilization of the product in either the fresh market or processing [10, 19]. Several pod traits like length, width, weight, thickness and firmness are quantitatively inherited [11, 16, 18, 19, 24, 25] and highly influenced by the environmental conditions [3]. The pods can regulate seed growth and its maturation, and also explore how the duration of pod development could be manipulated to increase the quantity and nutritional properties of pods yield [1].

The consumption of snap beans is highly recommended both in low carbohydrate diets, and for diabetics given its low glycemic index [4, 14]. There are many kinds of snap bean pods differing in shape, size and color, as such the preferences of the consumers vary with country and also within regions of a country [9]. The ideal pod characteristics depend on the market requirements. Generally, the dark green, cylindrical, straight pods that mature to a uniform size are preferred for canning and packaging sector [20]. The most important characteristics of snap bean are deemed to be low fiber of pod wall, lack of pod suture strings, a thickened and succulent pod walls. Unlike the pods of dry bean genotypes, the pods of snap bean genotypes have been selected for a round pod cross-section and a long cylindrical seed shape [13]

During the breeding of this species, the selection pressure for pod traits in snap beans has been very intense, generating a large phenotypic difference between snap bean varieties [6]. Common and snap bean are considered some of the most diverse species with different growth habits, plant heights, pods, seeds, etc [7]. This rich genetic pool can be utilized in breeding activities for increasing the amount and quality of yield [17]. Thus, the breeding programs of this species aim to identify genes associated with high yield and combine them with genes governing tolerance to different environmental stresses [15].

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Given the complexity of pod traits inheritance, the improvement of these is considered a time-and resource intensive activity that requires the existence of a suitable biological material. The first steps in a breeding program of snap beans are the characterization and assessment of the candidate parents. The objective of this study was to assess the variability of some pod traits in 20 varieties of snap bean to identify the suitable genitors for breeding activities.

Material and Method

The biological material was composed by 20 varieties of bushing snap bean genetically and ecologically differentiated. The experiment was conducted at University of Life Sciences" King Michael I" from Timisoara, on a on a black chernozem during 2022. The plots were composed of four rows with 4 m length and 0.9 m width that makes a plot area of 3.6 m^2. The spacing of 40 x10 cm between rows and plants was used. All standard technological practices for snap beans were uniformly applied. During the experiment the rainfall deficit was supplemented by drop irrigation.

The experimental design was a randomized block with three replications. From each plot five randomly selected plants were evaluated for the following pod traits: weight, length, width, thickness and firmness. The data were first analyzed using ANOVA as per method for randomized block design, while the varieties mean were compared using Least Significant Difference Test as described by Ciulca [5]. Also, different multivariate statistical methods like Jaccard similarity coefficients, principal component, and UPGMA clustering, were used. The distance matrix was computed for cluster analysis using the un-weighted pair-group method with arithmetic averages (UPGMA), with the Neighbor program of the Phylip package, version 3.5c.

Results and Discussion

Considering the results of the ANOVA from Table 1, it can be seen that there are statistically significant differences between the snap bean varieties for all five studied pod traits. According to the F values, the highest variability between snap bean varieties was observed for pod width, while the lowest was observed for pod thickness. The obtained results were not affected by the heterogeneity of the environmental conditions at the level of the experiment, which was in all cases low and insignificant. The narrow sense heritability ranged from 44.8% in case of pod firmness to 92% for pod width, considered the most stable trait.

Table 1. Analysis of variance for pod traits in snap bean (*Phaseolus vulgaris* L.) varieties

Source of variation	DF	Pod weight SS	Pod weight MS	Pod weight F value	Pod length SS	Pod length MS	Pod length F value	Pod width SS	Pod width MS	Pod width F value
Total	59	165.02			107.00			4.81		
Replications	2	4.50	2.25	2.46	1.22	0.61	0.97	0.02	0.01	1.75
Varieties	19	121.73	6.41	7.00**	81.88	4.31	6.85**	4.68	0.25	35.62**
Error	38	34.79	0.92		23.90	0.63		0.26	0.01	
		σ^2_G=1.83; σ^2_P=2.75; h^2_{BS}=0.667			σ^2_G=1.23; σ^2_P=1.86; h^2_{BS}=0.661			σ^2_G=0.08; σ^2_P=0.09; h^2_{BS}=0.92		

Source of variation	DF	Pod thickness SS	Pod thickness MS	Pod thickness F value	Pod firmness SS	Pod firmness MS	Pod firmness F value
Total	59	0.524			4.892		
Replications	2	0.017	0.009	1.84	0.044	0.022	0.47
Varieties	19	0.337	0.018	3.74**	3.065	0.161	3.44*
Error	38	0.180	0.005		1.783	0.047	
		σ^2_G=0.004;σ^2_P=0.009;h^2_{BS}=0.477			σ^2_G=0.038;σ^2_P=0.085;h^2_{BS}=0.448		

For pod weight, the 20 snap bean varieties recorded values from 4.55 g in 'Processor' to 9.11 g in 'Marconi', with an amplitude of 4.56 g, associated with a relative high variability (CV=21.42%) at the inter-population level (Table 2). Regarding the comparisons between snap bean varieties, it can be observed that 'Marconi', 'Supe Nano Yellow' and 'Plador' express significantly higher pod weight than 82.35% from other varieties. Also, six varieties presented values of this trait over 7 g, above the experience mean, respectively.

Pod length shoved a lower variability (CV=9.51%) compared to pod weight, associated with an amplitude from 10.47 cm in 'Processor' to 15.11 cm in 'Contender' variety. Nine varieties achieved a pod length higher compared to overall mean, while three varieties have had values below 11 cm. Furthermore, 'Contender' variety displayed a significant increase with more than 1.52 cm over the 95 % from other varieties. 'Nassau', 'Marconi', 'Roquencourt', 'Plador', 'Minidor', 'Super Nano Yellow', and 'Berggold' varieties had significantly close values of this trait, over 13 cm.

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Table 2. Mean values of pod traits in snap bean (*Phaseolus vulgaris* L.) varieties

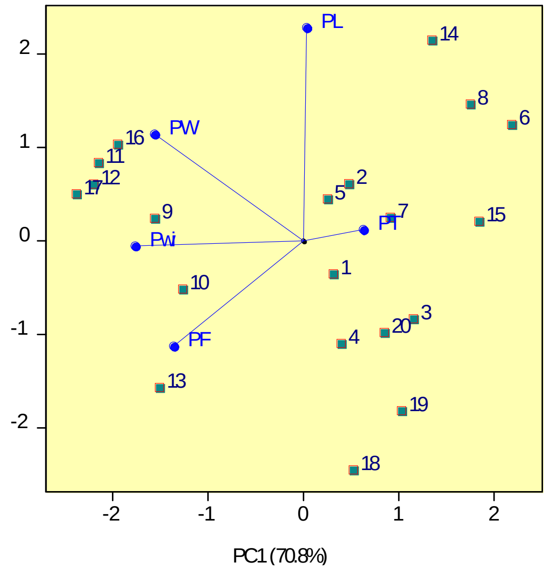
Varieties	Pod weight (g)	Pod length (cm)	Pod width (cm)	Pod thickness (cm)	Pod firmness (kg/cm^2)
Aurie de Turda	6.78±0.14 cdefg	11.87±0.19 efg	1.10±0.02 cd	0.80±0.03 abc	2.23±0.18 bc
Berggold	7.32±0.24 bcde	13.12±0.24bcde	0.93±0.02 d	0.82±0.02 ab	2.26±0.23 abc
Brittle Wax	5.54±0.56 ghi	11.90±0.39 efg	0.87±0.02 de	0.83±0.02 a	2.32±0.11 abc
Ileana	5.15±0.15 hi	12.12±0.26defg	0.87±0.04 de	0.59±0.09 h	2.40±0.49 abc
Minidor	7.15±0.22 cdef	13.24±0.22 bcd	0.89±0.01 de	0.76±0.01 abcdef	2.34±0.04 abc
Roquencourt	5.65±0.17 fghi	13.34±0.43 bcd	0.82±0.03 e	0.68±0.03 defgh	1.77±0.05 d
Sondella	6.90±0.28 cdefg	12.44±0.44 cdef	0.86±0.03 de	0.76±0.01 abcdef	2.14±0.05 bc
Voletta	5.85±0.21 efghi	14.39±0.23 ab	0.72±0.01 f	0.72±0.01 bcdefg	2.05±0.18 cd
Doge	8.26±0.81 abc	12.55±0.14 cdef	1.42±0.04 ab	0.67±0.01 efgh	2.32±0.16 abc
Meraviglia di Venezia	7.60±0.21 abcd	11.70±0.27 fgh	1.41±0.04 ab	0.68±0.03 defgh	2.32±0.22 abc
Plador	8.91±0.44 a	13.40±0.31 bcd	1.50±0.02 a	0.68±0.01 defgh	2.40±0.07 abc
Super Nano Yellow	8.98±0.17 a	13.14±0.16bcde	1.49±0.04 a	0.70±0.02 cdefg	2.44±0.08 ab
Tytania	7.24±0.74 bcde	10.85±0.32 gh	1.47±0.04 a	0.77±0.04 abcde	2.52±0.2 ab
Contender	6.67±0.67 defgh	15.11±0.34 a	0.81±0.03 ef	0.78±0.03 abcd	2.08±0.16 cd
Domino	5.34±0.65 ghi	12.79±0.13 cdef	0.72±0.01 f	0.69±0.03 defgh	2.05±0.21 cd
Marconi	9.11±0.85 a	13.52±0.89 bc	1.34±0.07 b	0.62±0.02 gh	2.36±0.1 abc
Nassau	8.74±0.98 ab	13.59±0.82 bc	1.35±0.06 b	0.63±0.01 gh	2.59±0.14 a
Processor	4.55±0.28 i	10.47±0.14 h	0.93±0.03 d	0.64±0.03 gh	2.44±0.11 ab
Velodrom	4.65±0.68 i	10.73±0.36 gh	0.94±0.03 d	0.66±0.05 fgh	2.24±0.08 abc
Wotter	6.06±0.43defghi	11.84±0.81 efg	0.81±0.04 ef	0.86±0.04 a	2.45±0.12 ab
Mean	6.82±0.22	12.61±0.17	1.06±0.04 cd	0.72±0.01	2.29±0.04
$LSD_{5\%}$	*1.58*	*1.31*	*0.1*	*0.11*	*0.36*

The pod width expresses the highest differences between the 20 snap bean varieties on the background of CV=27.02%. As such, this trait ranged from 0.72 cm at ‘Voletta’ and ‘Domino’ to 1.5 cm in ‘Plador’ variety, given that eight varieties achieved a pod with over the general mean, and 10 varieties achieved values of 0.8-1 cm. The pod width for eight varieties exceeded 1 cm. In this regard, ‘Plador’, ‘Super Nano Yellow’, and ‘Tytania’ varieties had significantly wider pods than the other varieties, except for ‘Doge’ and ‘Meraviglia di Venezia’ varieties.

Regarding the pod thickness, the 20 snap bean varieties recorded values from 0.59 cm in ‘Ileana’ to 0.86 cm in ‘Wotter’, with an amplitude of 0.27 cm, associated with a relative low variability (CV=10.65%) at the inter-population level. Given the comparisons between snap bean varieties, it can be observed that ‘Wotter’ and ‘Brittle Wax’ express significantly higher pod weight than 67% from other varieties. Also, nine varieties presented values of this trait over 72 cm, above the experience mean, respectively.

The pod firmness shoved the lowest variability (CV=8.55%) compared to other pod traits, associated with an amplitude from 1.77 kg/cm^2 in ‘Roquencourt’ to 2.59 kg/cm^2 in ‘Nassau’ variety. Twelve varieties achieved a pod firmness higher compared to overall mean, while only one had value below 1 kg/cm^2. Furthermore, ‘Nassau’ variety displayed a significant increase with more than 0.36 kg/cm^2 compared to ‘Aurie de Turda’, ‘Sondella’, ‘Voletta’, ‘Contender’, ‘Domino’ and ‘Roquencourt’ varieties.

Given Figure 1, it can be seen that the first two principal components account for 99.03% of the variability for the five pod traits in snap bean varieties. It was established that ‘Plador’, ‘Marconi’, ‘Super Nano Yellow’ and ‘Nassau’ varieties had the highest pod weight and the lowest pod thickness when compared to other varieties considered their projections on the different traits' vectors. Despite their lower values of pod weight, width and firmness, the ‘Contender’, ‘Voletta’ and ‘Roquencourt’ varieties had the longest and thickest pods. Against a background of small pods size, ‘Tytania’ variety had the highest firmness. In the case of ‘Processor’, ‘Velodrom’ and ‘Ileana’ varieties the lowest values of pod length and weight were correlated with a high firmness. ‘Dodge’ and ‘Meraviglia di Venezia’ varieties showed values above the mean for pod weight, width and firmness and lower values for pod length and firmness.



1-Aurie de Turda; 2-Berggold; 3-Brittle Wax; 4-Ileana; 5-Minidor; 6-Roquencourt; 7-Sondella; 8-Voletta; 9-Doge; 10-Meraviglia di Venezia; 11-Plador; 12-Super Nano Yellow; 13-Tytania; 14-Contender; 15-Domino; 16-Marconi; 17-Nassau; 18-Processor; 19-Velodrom; 20-Wotter.
PW-Pod weight; PL-Pod length; Pwi-pod width; PT-Pod thickness; PF-pod firmness.

Figure 1. Biplot of first two principal components for pod traits in snap bean varieties

The highest phenotypic similarity for the five pod traits (Figure 2) was observed between varieties: 'Plador' and 'Super Nano Yellow' (99.77%); 'Doge' and 'Meraviglia di Venezia' (98.88%); 'Brittle Wax' and 'Wotter' (98.87%); 'Berggold' and 'Minidor' (98.73%); 'Processor' and 'Velodrom' (98.62%). The highest diversity regarding the studied pod traits was registered among varieties: 'Roquencourt' and 'Tytania' (41.03%); 'Roquencourt' and 'Nassau' (39.16%); 'Roquencourt' and 'Super Nano Yellow' (38.92%); 'Plador' and 'Processor' (37.43%); 'Roquencourt' and 'Plador' (37.23%). Following the hierarchical classification (Figure 2, Table 3), the 20 varieties were grouped into five clusters. Of these, most varieties (6) were included in clusters I and IV, while cluster V contains only one variety.

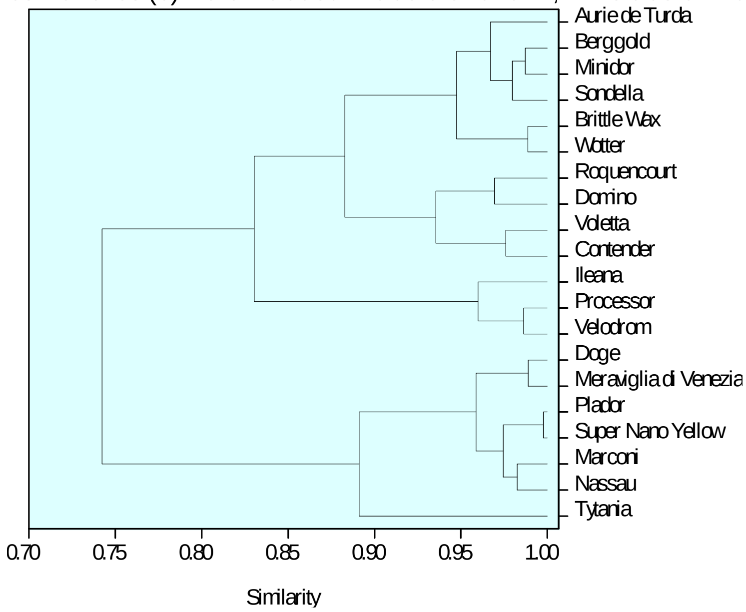


Figure 2. UPGMA clustering of snap bean varieties based on pod traits

On the background of a 95% similarity, the varieties of the first cluster registered lower values than overall mean for most of the traits except for thickness and firmness of the pods (Table 4). The four varieties included in the second cluster showed an approximately 6% diversity of pod traits, being characterized by long and thick pods with lower values than the mean for the other traits. At the level of the third cluster, an approximately 97% similarity was observed, associated with the highest values of pod firmness on the background of low values of the other traits. Among the varieties of the fourth cluster, a diversity of approximately 4% was shown, associated with high and above-mean values for most traits except for pod thickness.

Table 3. Distribution of 20 snap bean (*Phaseolus vulgaris* L.) varieties into different clusters

Cluster	No. of varieties	Varieties included
I	6	Aurie de Turda, Berggold, Minidor, Sondella, Brittle Wax, Wotter
II	4	Roquencourt, Domino, Voletta, Contender
III	3	Ileana, Processor, Velodrom
IV	6	Doge, Meraviglia di Venezia, Plador, Super Nano Yellow, Marconi, Nassau
V	1	Tytania

Table 4. Cluster means for the pod traits of snap bean (*Phaseolus vulgaris* L.) varieties

Cluster	Traits				
	PW	PL	Pwi	PT	PF
I	6.63	12.40	0.91	0.81	2.29
II	5.88	13.91	0.77	0.72	1.99
III	4.78	11.11	0.91	0.63	2.36
IV	8.60	12.98	1.42	0.66	2.41
V	5.68	10.63	0.78	0.69	1.96

PW-Pod weight; PL-Pod length; Pwi-pod width; PT-Pod thickness; PF-pod firmness.

According to the result from table 5, it was observed that the snap bean varieties ‘Wotter’, ‘Contender’, ‘Brittle Wax’ and ‘Voletta’ generate the highest differences between pod traits, having high contributions to total diversity. The lowest variability was recorded in case of ‘Marconi’, ‘Doge’, ‘Meraviglia di Venezia’ and ‘Plador’. Also, it has been seen that ‘Wotter’ variety expresses the highest contribution to the diversity inside the first cluster, and Contender variety for the second cluster, respectively. ‘Processor’ has the highest contribution at the level of third cluster, while ‘Nassau’ variety it was highlighted in this regard for the fourth cluster.

Table 5. Analysis of variance for snap bean (*Phaseolus vulgaris* L.) varieties regarding the diversity based on pod traits

Varieties	Between groups		Within groups		F Test
	SS	DF	SS	DF	
Aurie de Turda	55.38	1	2.62	3	63.32**
Berggold	65.62	1	2.21	3	89.20**
Brittle Wax	75.17	1	3.79	3	59.58**
Ileana	60.55	1	9.17	3	19.80*
Minidor	65.85	1	2.92	3	67.68**
Roquencourt	53.52	1	1.89	3	85.07**
Sondella	58.37	1	1.97	3	89.06**
Voletta	72.12	1	2.22	3	97.33**
Doge	35.90	1	3.94	3	27.37*
Meraviglia di Venezia	36.61	1	4.40	3	24.97*
Plador	36.75	1	4.61	3	23.94*
Super Nano Yellow	37.93	1	4.72	3	24.13*
Tytania	44.48	1	9.57	3	13.94*
Contender	74.08	1	2.63	3	84.39**
Domino	64.71	1	1.06	3	183.49**
Marconi	35.24	1	7.60	3	13.92*
Nassau	43.15	1	11.48	3	11.28*
Processor	59.79	1	10.73	3	16.72*
Velodrom	55.87	1	4.99	3	33.60*
Wotter	80.66	1	6.55	3	36.96*

Regarding variance analysis for studied pod traits in the 20 snap bean varieties (Table 6), it has been noted that the highest and significant variance was recorded in case of pod width follow by pod weight. Also, it is possible to identify valuable genes combinations for this trait in the segregating generations. The lowest

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variability among varieties was observed for pod length and thickness, whose improvement is difficult through this set of varieties.

Table 6. Analysis of variance for the contribution of pod traits to the diversity between snap bean (*Phaseolus vulgaris* L.) varieties

Trait	Between groups		Within groups		F Test
	SS	DF	SS	DF	
Pod weight	12.16	1	6.12	18	35.77**
Pod length	0.04	1	18.30	18	0.04
Pod width	16.89	1	1.72	18	176.31**
Pod thickness	3.25	1	19.37	18	3.02
Pod firmness	5.47	1	14.10	18	6.98*

In the case of varieties Plador, Super Nano Yellow, Marconi, Nassau, the association of pod length, weight and firmness indicates that these traits are under a similar genetic control or are controlled by linked genes [13]. This information are very useful for breeders in order to increase the efficiencies of selection for genotypes with desirable processing traits. The wide range of variability and the phenotypic diversity between snap bean varieties indicate that these traits are suitable for improvement through an effective phenotypic selection, to achieve high genetic gain [6]. Based on cluster analysis, the use of contrasting varieties for crossing can increase the possibility to complement different favorable alleles in new superior genotypes [21].

Conclusions

Based on the five pod traits the 20 varieties of bushing snap bean were grouped in to five clusters with a 27 % average phenotypic diversity. The present work shows that some varieties can be considered a valuable material for several pod traits, that could be successively used in further breeding program of bushing snap bean including diallel crossing methods and will be relevant as a good base for the development of new cultivars. By crossing phenotypical differentiated varieties like: ‘Roquencourt’ and ‘Tytania’; ‘Roquencourt’ and ‘Nassau’; ‘Roquencourt’ and ‘Super Nano Yellow’; ‘Plador’ and ‘Processor’; ‘Roquencourt’ and ‘Plador’, allows to obtain snap bean genotypes with useful gene combinations for different pod traits related to yield.

References

[1] Bennett, E.J., Roberts, J.A., & Wagstaff, C. (2011), *The role of the pod in seed development: strategies for manipulating yield*. New Phytol., 190, pp. 838-853.
[2] Broughton, W.J., Hernandez, G., Blair, M., Beebe, M., Gepts, P., Vanderleyden, J., et al. (2003), *Beans (Phaseolus spp.)-model food legumes*. Plant Soil, 252, pp. 55–128.
[3] Campa, A., Murube, E., & Ferreira, J. (2018), *Genetic diversity, population structure, and linkage disequilibrium in a Spanish common bean diversity panel revealed through genotyping-by-sequencing*. Genes, 9, pp. 518.
[4] Chaurasia, S. (2020), *Green Beans*. In Nutritional Composition and Antioxidant Properties of Fruits and Vegetables; Jaiswal, A.K., Ed.; Elsevier: Amsterdam, The Netherlands, Chapter 17; pp. 289–300.
[5] Ciulca, S. (2006), *Metodologii de experimentare în agricultura si biologie (Experimental methodologies in agriculture and biology).* Agroprint, Timisoara, Romania.
[6] da Costa Vaz D., Morais Junior, O.P., & Peixoto, N. (2017), *Agro-morphological characterization and genetic divergence assessment in bush snap bean genotypes*. Pesq. Agropec. Trop., Goiânia, 47(2), pp. 134-144.
[7] Dawo, M.I., Sanders, F.E., & Pilbeam, D.J. (2007), *Yield, yield components and plant architecture in the F3 generation of common bean (Phaseolus vulgaris L.) derived from a cross between the determinate cultivar “Prelude” and an indeterminate landrace*. Euphytica, 156, pp. 77–87.
[8] Delfini, J., Moda-Cirino, V., Dos Santos Neto, J., Ruas, P. M., Sant'Ana, G. C., Gepts, P., et al. (2021), *Population structure, genetic diversity and genomic selection signatures among a Brazilian common bean germplasm.* Sci. Rep. 11 (1), 2964.
[9] Escribano, M.R., Santalla, M., & de Ron, A.M. (1997), Genetic diversity in pod and seed quality traits of common bean populations form North-Western Spain. Euphytica, 93, pp. 71-81.
[10] Fatima, S., Rani, S., Shafi, S., Zaffar, A., Riyaz, I., Altaf W.M., & Sofi, P.A. (2024), *Pod physical traits significantly implicate shattering response of pods in beans* (*Phaseolus vulgaris* L.). Biologia plantarum, 68, pp. 107-116.
[11] García-Fernández, C., Campa, A., Garzón-Soler, A., Miklas, P., Ferreira, & J.J. (2021), *GWAS of pod morphological and color characters in common bean*. BMC Plant Biol. 21, pp. 184.

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https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
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[12] García-Fernández, C., Jurado, M., Campa, A., Bitocchi, E., Papa, R., & Ferreira, J.J. (2024), *Genetic control of pod morphological traits and pod edibility in a common bean RIL population.* Theor. Appl. Genet. 137, 6.
[13] Hagerty, C.H., Cuesta-Marcos, A., Cregan, P., Song, Q., McClean, P., & Myers, J.R. (2016), *Mapping snap bean pod and color traits, in a dry bean × snap bean recombinant inbred population.* J. Amer. Soc. Hort. Sci., 141(2), pp. 131-138.
[14] Hosseinpour-Niazi, S., Mirmiran, P., Hedayati, M., & Azizi, F. (2015), *Substitution of red meat with legumes in the therapeutic lifestyle change diet based on dietary advice improves cardiometabolic risk factors in overweight type 2 diabetes patients: A cross-over randomized clinical trial.* Eur. J. Clin. Nutr. 69, pp. 592–597.
[15] Karavidas, I., Ntatsi, G., Vougeleka, V., Karkanis, A., Ntanasi, T., Saitanis, C., Agathokleous, E., Ropokis, A., Sabatino, L., Tran, F., et al. (2022), *Agronomic Practices to Increase the Yield and Quality of Common Bean (Phaseolus vulgaris L.):* A Systematic Review. Agronomy, 12, 271.
[16] Li, M., Wu, X., Wang, B., Wu, X., Wang, Y., Wang, J., et al. (2023), *Genome-wide association analysis reveals the optimal genomic regions for pod size in bean*. Front. Plant Sci. 14.
[17] López-Pedrouso, M., Bernal, J., Franco, D., & Zapata, C. (2014), Evaluating two-dimensional electrophoresis profiles of the protein phaseolin as markers of genetic differentiation and seed protein quality in common bean (*Phaseolus vulgaris* L.). J. Agric. Food Chem., 62, pp. 7200–7208.
[18] Murube, E., Campa, A., Song, Q., Mcclean, P., & Ferreira, J.J. (2020), *Toward validation of QTLs associated with pod and seed size in common bean using two nested recombinant inbred line populations*. Mol. Breed. 40, 7.
[19] Njau, S.N., Parker, T.A., Duitama, J., Gepts, P., & Arunga E.E. (2024), *QTL mapping for pod quality and yield traits in snap bean* (*Phaseolus vulgaris* L.). Front. Plant Sci. 15, 1422957.
[20] Saballos, A., & Williams, M.M. (2024), *Genome-wide association study identifies candidate loci with major contributions to the genetic control of pod morphological traits in snap bean.* J. Amer. Soc. Hort. Sci., 149(1), pp.1-14.
[21] Silva, A.R.D., & Dias, C.T.D.S. (2013), *A cophenetic correlation coefficient for Tocher's method.* Pesquisa Agropecuária Brasileira, 48(6), pp. 589-596.
[22] Singh, B.K., Singh, B. (2015), *Breeding perspectives of snap bean* (*Phaseolusl vulgaris* L.). Vegetable. Sci. 42, pp. 1–17.
[23] Singh, D.K., Singh, D., & Singh, S.S. (2018), *Studies of genetic variability, heritability and genetic advance for yield and related traits in French bean* (*Phaseolus vulgaris* L.). J. Pharmacognosy. Phytochem. 7, pp. 236–240.
[24] Wu, J., Wang, L., Fu, J., Chen, J., Wei, S., Zhang, S., et al. (2020), *Resequencing of 683 common bean genotypes identifies yield component trait associations across a north–south cline*. Nat. Genet. 52, pp. 118–125.
[25] Yuste-Lisbona, F., González, A., Capel, C., García-Alcázar, M., Capel, J., Ron, A., et al. (2014), *Genetic variation underlying pod size and color traits of common bean depends on quantitative trait loci with epistatic effects*. *Mol*. Breed. 33, pp. 1–14.