

PARAMETRIC EVALUATION OF POD YIELD STABILITY IN BUSHING SNAP BEAN (*PHASEOLUS VULGARIS* L.)

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Abstract

In the context of climate change, the achievement of economically efficient yields largely depends on the cultivar's stability. A snap bean variety is considered more stable if it achieves a high green pod yield with a low variation of mean yield over diverse environments. The study was carried out to identify snap bean varieties that have high and stable yield across different years, to be used in breeding and sustainable production of this species. The plant material was composed of 20 varieties of bushing snap bean, genetically and ecologically differentiated. The varieties were evaluated for their green pod yield over three years using a randomized block design with three replications. To assess the performance of the varieties, a combined analysis of variance and yield stability statistics were determined. 'Sondella', 'Plador', 'Doge' and 'Maxidor' varieties, with relatively high pod yield expressed a good stability and can be used to develop new diverse cultivars with stable yields. 'Super Nano Yellow' variety expressed the highest sensitivity to the change of climatic conditions, being specific adapted to favorable conditions.

Key words: genotype x environment interaction, pod yield, snap bean.

INTRODUCTION

Consumers' preferences and palatability of snap bean are influenced by pod quality traits, while the pod yield related traits influence farmer's decision to cultivate new varieties (García-Fernández et al., 2024). The size of the pods holds significance not only for yield but also for commercial viability, impacting consumer satisfaction and influencing pricing in wholesale and retail markets (Li et al., 2023). As well as other yield traits like pod weight per plant and pods per plant, pod size traits such as length, thickness and width, exhibit quantitative inheritance (García-Fernández et al., 2021; Hagerty et al., 2016; Singh and Singh, 2015; Wu et al., 2020), being strongly influenced by environmental factors (Campa et al., 2018). Temperature is one of the most aggressive factors that affects snap bean yield, given that high temperatures cause a decrease of both marketable yield and pod quality (Richmond and Maness, 2024).

Yield stability expresses how stable the yield of a crop is over time, e.g., from year to year in case of temporal yield stability and over space, e.g., across different environments in case of

spatial yield stability (Weih et al., 2021). The temporal yield stability is relevant for farmers, because it determines economic predictability and reduces risk (Rieckling et al., 2021). Analyses of genotypes yield stability are very important in recent years given that the increased variability of climate is associated with a decreased stability of crop yields (Müller et al., 2018; Tigchelaar et al., 2018). The stability of yield for different crops has a global dimension in the context of food security (Kalkuhl et al., 2016).

Under the current climate changes, the effectiveness of plant breeding programs depends on their ability to deliver varieties that consistently exhibit superior yield and quality performance across diverse environmental conditions (Wondaferew et al., 2024). To reduce the magnitude of the genotype x environment interaction in snap bean, the pre-breeding manipulations resulted in gaining pod yield stability by using the isolation environment for planting and the yield performance per se for evaluating genotypes (Traka-Mavrona et al., 2002).

The performance of any traits is a combined result of the genotype, the environment and the

interaction between genotype and environment (Dinsa et al., 2022). The adaptability as related to crop plants applies not only to the plants' ability to survive but also to maintain yield stability under varying environments. Genotype x environment interaction can make it difficult to identify the best genotypes, since in instances of complex interactions like in the case of yield; some genotypes may be superior only in a certain environment (Marinho et al, 2013).

Two main contrasting concepts of stability, static and dynamic, are commonly used in plant breeding (Becker and Léon, 1988). According to the static concept, a stable genotype maintains a constant yield across environments, while in the dynamic concept a stable genotype implies a yield response correlated with the mean response of all tested genotypes in each environment (Annicchiarico, 2002). There are several statistical methods which allow assessing stability by means of identifying the varieties with the highest stability and the most predictable response to different environmental variations (Viella et al., 2011).

Yield stability is especially important for grain legume crops including snap bean, given that these crops are considered to be less stable than others (Reckling et al., 2020). Under the

current climate changes, the study was carried out to identify snap bean varieties that have high and stable yield across different years, to be used in breeding and sustainable production of this crop.

MATERIALS AND METHODS

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 Mihai I” from Timisoara, on a on a black chernozem during 2022-2024. The plots were composed of four rows with 4 m length and 0.9 m width that makes a plot area of 3.6 m². The spacing of 40 x 10 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. Based on the values of mean temperatures and rainfall presented in Table 1, it is observed that 2022 was the most favorable year, and 2024 characterized by higher temperatures in July-August associated with low levels of precipitation, was considered the most unfavorable

Table 1. Mean temperatures and precipitation from April to August during 2022-2024

Year	2022		2023		2024	
Month	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
April	15.1	51.3	17.1	67.7	21.9	16.2
May	22.8	56.2	25.2	22.2	24.6	25.1
June	26.8	37.6	30.6	15.9	30.5	48.5
July	31.9	28.2	32.5	10.4	34.9	14.3
August	30.9	28.4	31.7	39.7	33.2	3.2

The experimental design was a randomized block with three replications. From each plot five randomly selected plants were evaluated for pod yield. The data were 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 (2006).

In order to evaluate pod yield stability of the snap bean varieties, the following methods were used; ANOVA according to Eberhart and Russel (1966) model, associated with estimates of regression coefficient (bi) and deviations from regression (S_d^2); CV_i , coefficient of variation (Francis and

Kannenber, 1978); σ_i^2 , stability variance (Shukla, 1972); D_i , desirability index (Hernandez et al., 1993); R_{1i} , R_{2i} , ranks parameters (Langer et al., 1979); W_i^2 , ecovalence (Wrike, 1962); SFi , stability factor (Lewis, 1954); P_i , superiority index (Linn and Binn, 1988); D_i^2 , genotypic stability (Hanson, 1970).

RESULTS AND DISCUSSIONS

The pooled analysis of variance for pod yield displayed significant differences among varieties, years and variety x year interactions (Table 2). The highest difference was observed

for the main effect of variety (61.63%), while the differences related to year were about 21.66%, and variety x year interactions totally reach 16.71%. As such, the varieties did not differ only genetically but also some of these exhibited differential response to the climatic conditions during the three years. These results revealed that there is a genetic variability for pod yield associated with the presence of genotype x environment interaction. The magnitude of the linear components for environment and environment x year were higher than the pooled deviation, indicating that the prediction of stability for the studied

varieties could be reliable, as reported by Hosamani et al. (2010). Similar results regarding the significance of different linear components in snap bean were also reported by Pan et al. (2007) and Satish et al. (2017). The significance of the pooled deviation indicates that non-linear component of variety x year interactions was predominant. The high percentage of environmental variation indicates that the environment is a major factor influencing the yield performance of snap bean varieties, in accordance with the findings of Dinsa et al. (2022).

Table 2. Analysis of variance for stability (Eberhart and Russel Model) of pod yield in snap bean varieties during 2022-2024

Source of variation	SS	DF	MS	F
Variety (Var)	109484	19	5762	7.38**
Year (Env)	38483	2	19241	24.63**
Variety x Year	29685	38	781	1.71*
Env + (Var x Env)	68168	40	1704	
Env (Linear)	38483	1	38483	55.16**
Env x Var (Linear)	15732	19	828	1.19
Pooled Deviation	13953	20	698	4.59**
Pooled Error	51965	114	456	
Total	177651	59		

Considering the data from Table 3 it is noted that generally the climatic conditions of 2022 have favored the achievement of significantly higher yield, while in 2024 the achieved levels were lower than other years. Under the conditions from 2022 the pod yield recorded values between 70.83 g at ‘Roquencourt’ and 273.66 g at ‘Plador’ variety, amid a high variability among varieties performances. In this year the varieties ‘Plador’, ‘Doge’, ‘Super Nano Yellow’, ‘Minidor’, ‘Berggold’, ‘Voletta’ and ‘Ileana’ were highlighted, these achieved a pod yield of over 200 g. Given the conditions of 2023 the snap bean varieties showed smaller amplitude of pod yield, with the limits from 70.12 g at ‘Processor’ to 213.28 g at ‘Nassau’ variety. Against the background of significantly lower yields than the previous year, only the ‘Nassau’ variety exceeded 200 g, but also the varieties ‘Volleta’, ‘Dodge’ and ‘Plador’, properly capitalized on this year's conditions, achieving yields of approximately 190 g.

The variability of yield in 2024 was higher than that recorded in previous years, amid lower values ranging from 66.18 g in ‘Roquencourt’ to 231.35 g for ‘Plador’ followed by ‘Doge’ variety with 212.55 g, given that nine of the other varieties achieved yields over 100 g. Regarding the annual values of the achieved yields, it was found that the varieties ‘Sondella’, ‘Processor’ and ‘Velondrom’ did not show significant variations during the study, while for ‘Berggold’, ‘Meraviglia di Venezia’ and ‘Super Nano Yellow’ varieties the pod yields differ significantly from one year to another. Static stability is analogous with the biological concept of homeostasis, considering that a stable genotype tends to maintain a constant yield across environments. The term environmental sensitivity has also been used, considering that greater sensitivity corresponds to lower stability.

Table 3. Pod yield of snap bean varieties during 2022-2024

No.	Variety	Year			Variety mean
		2022	2023	2024	
1	Aurie de Turda	109.90 x	94.26 xy	73.76 y	92.64 jk
2	Berggold	213.45 x	146.95 y	107.24 z	155.88 de
3	Ileana	200.99 x	110.31 y	137.3 y	149.54 e
4	Minidor	223.08 x	131.45 y	125.45 y	159.99 cd
5	Maxidor	187.43 x	129.98 y	136.93 y	151.45 e
6	Roquencourt	70.83 x	80.62 y	66.18 x	72.55 m
7	Sondella	181.92 x	159.41 x	171.42 x	177.59 bc
8	Voletta	205.08 x	190.39 x	96.68 y	164.05 c
9	Doge	270.43 x	194.99 y	212.55 y	233.42 a
10	Meraviglia di Venezia	183.07 x	135.32 y	92.21 z	136.87 f
11	Plador	273.66 x	189.57 z	231.35 y	246.53 a
12	Super Nano Yellow	245.45 x	147.13 y	74.21 z	155.60 de
13	Tytania	137.41 x	71.83 y	83.82 y	97.69 ij
14	Contender	148.29 x	98.98 y	113.42 y	120.23 g
15	Domino	162.58 x	97.31 y	98.76 y	119.55 gh
16	Marconi	104.33 x	81.39 xy	67.18 y	84.30 l
17	Nassau	195.89 x	213.28 x	119.64 y	176.27 b
18	Processor	93.97 x	70.12 x	102.49 x	92.19 kl
19	Velodrom	120.53 x	97.11 x	118.43 x	115.36 hi
20	Wotter	147.62 x	118.82 x	64.49 y	110.31 i
	Year mean	173.80 A	127.96 B	114.68 B	

Different letters indicate significance at $p < 0.05$: x, y, z -for genotype x years comparisons.

a, b, c - for varieties comparisons; A, B, C - for years comparisons.

The highest type I stability was observed in the varieties ‘Roquencourt’, ‘Sondella’, ‘Processor’, ‘Velodrom’, which achieved constant values of yield according to the static concept, regardless of the environmental conditions in which they were tested (Becker

and Leon, 1988; Annicchiarico P., 2002). The lowest type I stability in terms of production was expressed at ‘Super Nano Yellow’, ‘Minidor’, ‘Berggold’, who achieved very different levels of yield during the study (Table 4).

Table 4. Stability statistics b_i , S_{di}^2 , CV_i , W_i^2 , σ_i^2 , D_i , for pod yield of snap bean varieties

No	Variety	b_i	S_{di}^2	CV_i	W_i^2	σ_i^2	D_i
1	Aurie de Turda	0.558	18.81	19.56	460.10	202.44	95.67
2	Berggold	1.795	47.29	34.43	1396.36	722.59	165.61
3	Ileana	1.458	108.09	31.14	1109.50	563.22	157.43
4	Minidor	1.879	5.74	34.20	1341.95	692.36	170.18
5	Maxidor	1.047	16.92	20.70	122.21	14.73	157.12
6	Roquencourt	-0.017	15.46	10.16	1849.33	974.24	72.45
7	Sondella	0.053	76.54	9.26	2046.59	1083.82	171.20
8	Voletta	1.433	493.68	35.85	3771.96	2042.36	171.82
9	Doge	1.000	166.17	16.17	1163.18	593.05	231.41
10	Meraviglia di Venezia	1.467	72.17	33.21	872.90	431.78	144.82
11	Plador	0.598	609.62	20.02	4539.12	2468.57	234.77
12	Super Nano Yellow	2.828	185.79	55.23	6927.41	3795.39	170.92
13	Tytania	1.146	32.31	35.75	262.11	92.45	103.90
14	Contender	0.796	31.31	21.09	289.58	107.71	124.54
15	Domino	1.269	9.62	31.18	188.94	51.80	126.43
16	Marconi	0.626	6.23	22.24	279.83	102.29	87.69
17	Nassau	0.800	554.72	28.26	3950.14	2141.35	180.61
18	Processor	-0.047	128.37	23.04	2745.41	1472.06	88.60
19	Velodrom	0.079	74.29	14.12	1947.88	1028.99	112.45
20	Wotter	1.231	144.66	38.27	1102.30	559.22	116.98

Type II stability according to the dynamic concept involves changing the performance of

a genotype in an anticipated direction from one year to another depending on climatic

conditions. The measure of dynamic stability depends on the specific set of tested genotypes (Linn et al., 1988). According to this concept, the highest dynamic stability was shown by the varieties ‘Doge’ și ‘Maxidor’, where the pod yield in the climatic conditions of the three years was parallel to the average yields of the other studied varieties.

According to Lin et al. (1988), a genotype is considered stable if the residual mean square from the regression model on the environmental index is small. The highest type III stability, respectively the minimum values of deviations from the regression line were observed at varieties: ‘Minidor’ ranked first, ‘Marconi’ ranked second, ‘Domino’ ranked third, ‘Roquencourt’ ranked fourth and ‘Maxidor’ ranked fifth, for which this regression model is appropriate to describe yield stability. The most unstable varieties with the highest S_{di}^2 values were ‘Plador’ ranked last, ‘Nassau’ ranked second last and ‘Voletta’ ranked third from last.

Low values of Shukla’s stability variance indicate high stability. The most stable varieties as indicated by this stability parameter were ‘Maxidor’ with a yield above the overall mean, while ‘Domino’ and ‘Tytania’ express high stability with yield below the overall mean. The

hybrids with poor stability according to this procedure were: ‘Super Nano Yellow’, ‘Plador’, ‘Nassau’ and ‘Voletta’, which achieved yields above the overall mean.

Genotypes with low ecovalence (W_i^2) have smaller fluctuations across environments and therefore are stable. The most stable varieties according to Wricke’s ecovalence were ‘Maxidor’, ‘Domino’, ‘Tytania’, ‘Marconi’ and ‘Contender’, who were ranked 9th, 13th, 16th, 19th and 12th for mean yield, respectively. The most unstable varieties according the ecovalence were ‘Super Nano Yellow’, ‘Plador’, ‘Nassau’ and ‘Voletta’.

Desirability index (D_i) is based on both the level of production and the regression coefficient, representing "the area under the linear regression function divided by the difference between the extreme values of the environmental indices" (Hernandez et al., 1993). According to this parameter, the varieties ‘Plador’, ‘Doge’, ‘Nassau’, ‘Voletta’, exhibit the highest levels of yield associated with good dynamic stability that allows them to effectively capitalize the favorable conditions for the cultivation of this crop. In ‘Roquencourt’, ‘Marconi’ and ‘Processor’ varieties, low pod yield values are associated with low type II stability.

Table 5. Stability statistics R_{1i} , R_{2i} , SF_i , P_i , D_i^2 , for pod yield of snap bean varieties

No	Variety	R_{1i}	R_{2i}	SF_i	P_i	D_i^2
1	Aurie de Turda	36.14	36.14	1.49	9866	578
2	Berggold	106.21	106.21	1.99	3123	4092
3	Ileana	90.68	63.69	1.46	3514	1360
4	Minidor	97.63	97.63	1.78	2754	2806
5	Maxidor	57.45	50.50	1.37	3257	738
6	Roquencourt	14.44	4.65	1.07	13143	89
7	Sondella	22.51	10.50	1.06	2071	288
8	Voletta	108.40	108.40	2.12	3037	7285
9	Doge	75.43	57.87	1.27	56	1633
10	Meraviglia di Venezia	90.86	90.86	1.99	4698	3307
11	Plador	84.10	42.32	1.18	154	2485
12	Super Nano Yellow	171.24	171.24	3.31	4023	11181
13	Tytania	65.58	53.59	1.64	9045	852
14	Contender	49.31	34.87	1.31	6301	405
15	Domino	65.27	63.82	1.65	6338	1176
16	Marconi	37.15	37.15	1.55	11019	505
17	Nassau	93.64	76.26	1.64	2364	5400
18	Processor	32.37	-8.52	0.92	10624	471
19	Velodrom	23.42	2.10	1.02	7470	230
20	Wotter	83.13	83.13	2.29	7654	3365

Based on rank parameters (R_{1i} , R_{2i}), it can be observed that the two values for most varieties

are very close (Table 5), which indicates that in general the varieties achieved extreme

productions against the background of the most favorable and unfavorable conditions during the study period (Das et al., 2010). As such, in this sense the highest yield stability was observed in the varieties ‘Roquencourt’, ‘Velodrom’, ‘Sondella’, while at the ‘Super Nano Yellow’, ‘Voletta’ and, ‘Berggold’ varieties, the climatic conditions had a higher influence, causing large yield variations.

According to the values of the stability factor (SFi) ‘Processor’, ‘Velodrom’, ‘Roquencourt’, ‘Sondella’, varieties showed constant yield values against the background of different climatic conditions in 2022 (the most favorable) and 2024 (less favorable). In the case of ‘Super Nano Yellow’, ‘Voletta’, ‘Wotter’ varieties, the higher values of the stability factor confirm that their yield was considerably influenced by the climatic conditions during the study period. According

to the performance measure (Pi) of Lin & Binns (1988), the genotypes with the lowest (Pi) values are considered the most stable. As such, the most stable variety ranked first for Pi and second for mean yield was ‘Doge’, followed by ‘Plador’ ranked second for Pi and first for mean yield. The most unstable varieties according to this statistic were ‘Roquencourt’, ‘Marconi’ and ‘Nassau’.

Genotypic stability (D_i^2) is based on the biological concept of stability and evaluates genotypes according to the deviation of their yield from the average yield of a genotype considered stable (Hanson, 1970). As such, according to this parameter the highest stability was observed in ‘Roquencourt’, ‘Velodrom’ and ‘Sondella’ varieties while ‘Super Nano Yellow’, ‘Voletta’, ‘Nassau’ and ‘Berggold’ varieties, showed a high yield variation over the three years.

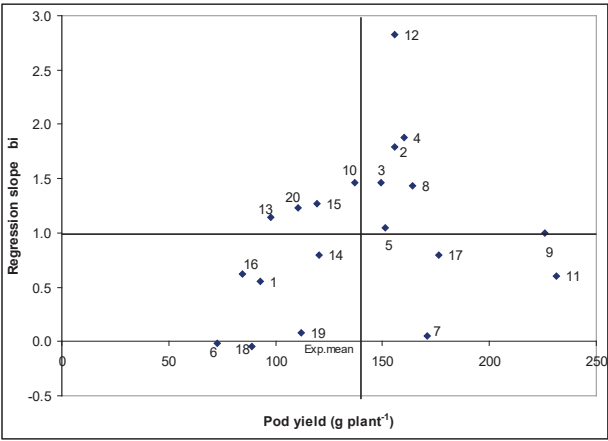


Figure 1. Mean values and regression coefficients for pod yield of snap bean varieties

Depending on the position of the varieties in Figure 1, it is observed that ‘Sondella’ variety presents a high static stability associated with a production above the average of the experience, while in ‘Roquencourt’, ‘Processor’, ‘Vellodrom’ the high stability is associated with values below the average. Varieties ‘Maxidor’ and ‘Doge’ show good dynamic stability, achieving values above the general average of experience and correlated with the favorability of environmental conditions. The varieties: ‘Super Nano Yellow’, ‘Minidor’, ‘Berggold’, ‘Ileana’ and ‘Voletta’,

express high yield instability being specifically adapted to favourable environmental conditions. According to Figure 2 ‘Plador’, ‘Doge’, ‘Sondella’ and ‘Maxidor’ varieties, located in the lower right part of the graph, with relatively high pod yield and low coefficient of variation are considered stable. The varieties ‘Berggold’, ‘Ileana’, ‘Minidor’, ‘Voletta’, ‘Super Nano Yellow’ and ‘Nassau’, located in the upper right part of the graph, with higher mean yield than overall average and high variability, showed a specific stability to favourable conditions.

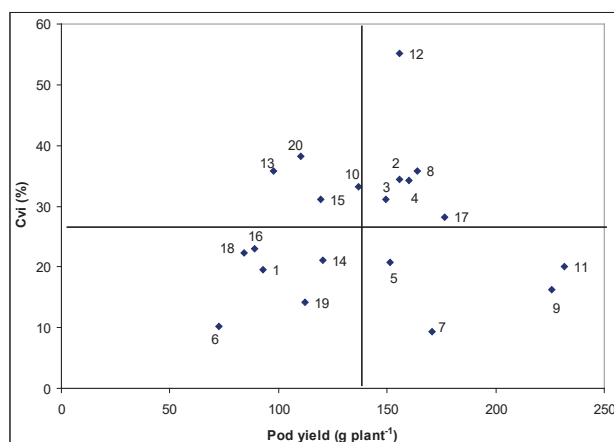


Figure 2. Mean values and variation coefficients for pod yield of snap bean varieties

Varieties with relatively low mean yield and low coefficient of variation like ‘Roquencourt’, ‘Velodrom’, ‘Contender’, ‘Aurie de Turda’, ‘Marconi’ and ‘Processor’, located in the lower left part of the graph, expressed a good stability but a lower yield potential. In the case of ‘Tyntania’, ‘Domino’ and ‘Wotter’, varieties located in the upper left part of the graph, the low mean yield and high coefficient of variation indicate that they are highly influenced by the variety x year interaction.

CONCLUSIONS

Based on the variety’s performances over the study period, it was seen that there is a considerable amount of variation available for the genetic improvement of snap bean cultivars and the enlargement of their genetic basis. The obtained results support the importance of evaluating the yield performances of different snap bean varieties across multiple climatic conditions.

Understanding the varieties specific responses to climatic variations and their effect on yield are useful information for farmers to select the most suitable varieties for growing.

‘Sondella’ variety was found to have the best stability over the different climatic conditions associated with a yield above the experience mean and could be used in the snap bean breeding programs for the development of high yielding stable genotypes over environments for future use. Also, ‘Plador’, ‘Doge’ and ‘Maxidor’ varieties, with relatively high pod

yield expressed a good stability and can be used to develop new diverse cultivars with stable yields. The above-mentioned varieties could be used for cultivation under unfavorable conditions.

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