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Interrelationships association and path-coefficient analysis for pod morphological traits in snap bean (*Phaseolus vulgaris* L.)

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Abstract
Snap bean is mainly used for its immature green pods and is cultivated all over the world with a wide geographical distribution. 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 the research was to determine the nature and extent of association among five morphological pod traits in 20 snap bean varieties, in order to perform the effective selection for the main pod traits related to yield. For this set of bushing snap bean varieties, the pod width exhibited the highest contribution to the achievement of pod weight, followed by pod length, while the pod firmness had the lowest influence. Given that only the relationships of pod width with their weight and firmness were significant, in the case of these snap bean varieties the selection for pod width brings a positive change of both pod weight and firmness. The relationship between the width and weight of pod was low and insignificant affected by the other traits. As such, the pod width can be used as an indirect selection criterion for pod weight.

Keywords: correlation**,** bushing snap bean, linear regression, pod traits.

Introduction

Snap bean is the vegetable form of the common bean (*Phaseolus vulgaris*) and is cultivated for their tender, immature pods [19]. Snap bean is considered the most commonly grown vegetable legume for human consumption [8]. It is widespread the believe that snap beans are in fact dry beans selectively bred after the Columbian Exchange and which subsequently have been subject to an intense selective breeding separately in Europe and China. The aim of these breeding was to increase several traits as low fiber content of pod wall and thick pod walls [16, 23, 26]. Besides the pod morphological traits, other characteristics, such as content of insoluble fiber, the phenophase in which the pod traits are preserved, size and development rate of seeds, and flavor, also affect the pod quality in snap bean and determine their future use as fresh vegetables or as processed foods [3, 23].

Snap beans include a group of common beans selected for succulent pods, with low fiber content (< 20 %). The large phenotypic diversity of snap bean genotypes is a result of the intense selection pressure for pod traits [4]. Through a stepwise process the snap beans are derived from dry beans in association with different pod changes: low pod wall fiber content, succulent pods, different pod shapes and colors, the absence of suture strings [6, 23].

Snap bean (*Phaseolus vulgaris* L.) improving programs have the task of developing varieties which meet the vegetable processing industry standards and of course that of the consumer, and exceed the performance of the existing cultivars [21]. The snap bean express diverse morphological pod traits, including shape, thickness, length, and color, which plays an important role in determining the suitability of pods for fresh markets or processing. Several pod dimensions like length, width, and thickness affect the amount of yield and the ease of harvest [24]. The pod size has long been of interest to breeders given it is an important yield and also quality trait in snap bean [25]. The improvement of pod size in the new varieties requires a consistent understanding of the genetic basis of this trait, and the correlations with other pod morphological traits. In this regard associations with QTL and genes have been identified in different bean germplasms [6, 7, 9, 10, 14).

The analysis of correlation helps the breeders in the determination of the relationship between several traits and gives them a good understanding of the contribution of each trait in the genetic makeup of the yield. The path analysis offers an effective means of finding out the direct and indirect causes of association and permits an examination of the correlations and measure the relative importance of each trait. This information is usefully in increasing the efficiency of selection of different complex traits [18]. The objective of the research was to determine the nature and extent of association among five morphological pod traits in 20 snap bean varieties, in order to perform the effective selection for the main pod traits related to yield.

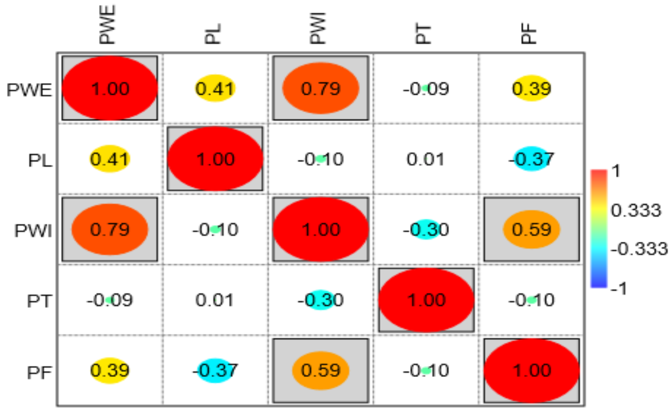
Material and Method

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 bean 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 obtained results concerning the five pod traits were statistically processed using analysis of variance for multiple regressions with four independent variables. Based on Pearson phenotypic correlation, the path coefficient which expresses the direct and indirect effects of the pod traits (independent variables) on pod weight (dependent variable) was calculated using the method given by Ciulca [3].

Results and Discussion

Positive correlations were identified between most of the pod traits, except for the relation between pod length and width, pod width and thickness, pods weight and thickness, pods thickness and firmness, respectively (Figure 1).



PWE -Pod weight; PL-Pod length; PWI-pod width; PT-Pod thickness; PF-pod firmness.

Figure 1. Correlations between pod traits in snap bean (*Phaseolus vulgaris* L.) varieties

Considered that only the relationships of pod width with the pod weight and firmness were significant, in the case of these snap bean varieties the selection for pod width assure a positive change of both pod weight and firmness. Also, given the very low values of the correlation coefficient it was noted that the pod thickness has no influence on the pod weight and the pod width and thickness does not affect their length.

Based on the path coefficient analysis for all studied varieties (Table 1), it has been seen that the direct effects of length, width and firmness of pod were positive, while the pod thickness has had a negative effect on the pod weight. Like that, the highest direct effect was shown by pod width and the lowest by pod thickness. Pod width also exhibited a high positive indirect effect on pod weight through pod firmness (59.25%) and a high negative indirect effect on pod thickness (57.51%). Also, the association between pod firmness and weight was negative indirect affected (24.21%) by pod length.

Table 1. Path coefficients for pod traits in snap bean (*Phaseolus vulgaris* L.) varieties

Traits	Value	%	Traits	Value	%
Pod length vs pod weight	**0.413**	***100***	**Pod thickness vs pod weight**	**-0.087**	***100***
Direct effect	0.539	*80.81*	Direct effect	0.168	*38.80*
Indirect effect via pod width	-0.083	*12.44*	Indirect effect via pod length	0.005	*1.15*
Indirect effect via pod thickness	0.001	*0.15*	Indirect effect via pod width	-0.249	*57.51*

Indirect effect via pod firmness	-0.044	*6.60*	Indirect effect via pod firmness	-0.011	*2.54*
Pod width vs pod weight	**0.794**	***100***	**Pod firmness vs pod weight**	**0.392**	***100***
Direct effect	0.828	*82.47*	Direct effect	0.12	*14.60*
Indirect effect via pod length	-0.054	*5.38*	Indirect effect via pod length	-0.199	*24.21*
Indirect effect via pod thickness	-0.051	*5.08*	Indirect effect via pod width	0.487	*59.25*
Indirect effect via pod firmness	0.071	*7.07*	Indirect effect via pod thickness	-0.016	*1.95*
Residual effects 0.088					

Analysis of variance for the multiple regressions related to the effect of different traits on pod weight, shows that 91.23% of the variability for dependent variable is due to the influence of the four pod traits (Table 2). Of these characters, it was seen that the pod width has the highest and significant contribution (70.52 %) to the variability of pod weight, followed by the pod length which affects the level of this trait to an extent of 17.03 %, while the thickness and firmness of pod had lower influence of 0.8-2.9%.

Table 2. Variance components of multiple regressions between pod weight and other related traits in snap bean (*Phaseolus vulgaris* L.) varieties

Source of variation	SS	DF	MS	F test
Regression	37.02	4	9.25	38.99**
Pod length (x_1)	6.91	1	6.91	29.12**
Pod width (x_2)	28.62	1	28.62	120.57**
Pod thickness (x_3)	1.17	1	1.17	4.93*
Pod firmness (x_4)	0.32	1	0.32	1.36
Residual	3.56	15	0.24	
Total	40.58	19	2.14	
$\mathbf{y = -10.33 + 0.66x_1 + 4.22x_2 + 3.22x_3 + 0.91x_4}$ $R^2 = 0.9123$; $R^2_a = 0.8889$; SEE = 0.49 g; DW=2.13				

The regression model with four independent variables used for the analysis of the relationship between pod traits has a high statistical assurance, evaluating the pods weight/spike with an error of 0.49 g. Given that the Durbin-Watson index is greater than 1.4 it follows that possible errors that accompany the experimental results are not self correlated, and the order of variables in the regression equation does not influence the estimated values of pod weight.

According to Figure 2 it was noted that the highest representativeness of this regression model for pod weight can be observed for varieties: 'Roquencourt', 'Aurie de Turda', 'Meraviglia di Venezia', 'Dodge', 'Super Nano Yellow'. Also, 'Sondella', 'Minidor', 'Berggold' and 'Marconi' varieties express values of pod weight significantly higher than those estimated from the regression model with four independent variables. Furthermore, in the case of varieties 'Brittle Wax', 'Voletta', 'Contender' and 'Tytania', the estimates of pod weight are significantly lower compared to those experimentally observed. Considering the deviations of the two groups of varieties from the regression model, the relations between the pod traits will be analyzed separately for each group.

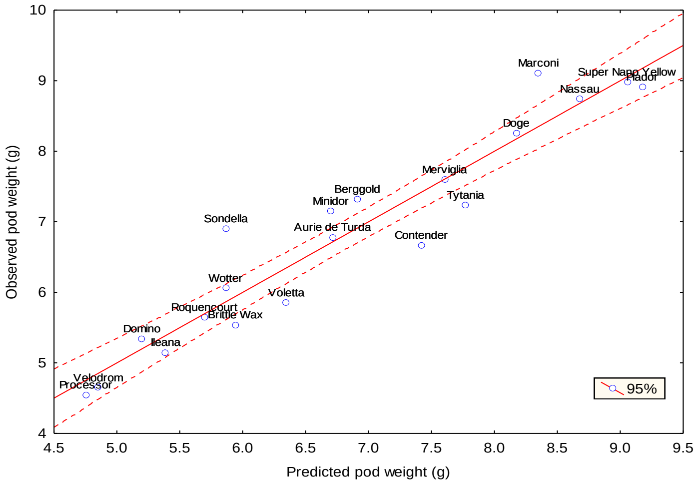
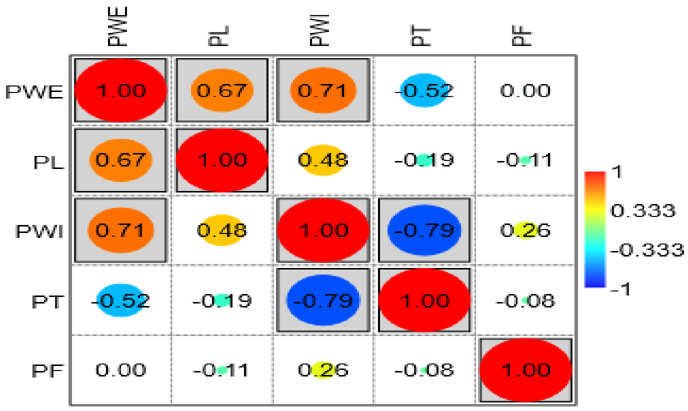


Figure 2. Observed and predicted values of pod weight based on multiple regression model for the snap bean varieties

The analysis of correlations between pod traits in the group of 'Sondella', 'Minido'r, 'Berggold' and 'Marconi' varieties indicates a significantly positive relationship between pod weights and their length and width, against a negative influence of pod thickness (Figure 3). It is also observed that the width of the pods shows a significantly negative correlation with their thickness. As such, in the case of these varieties, the selection of wide pods ensures an increase in their weight and a reduction in their thickness.



PWE-Pod weight; PL-Pod length; PWI-pod width; PT-Pod thickness; PF-pod firmness.

Figure 3. Correlations between pod traits in Sondella, Minidor, Berggold and Marconi varieties of snap bean (*Phaseolus vulgaris* L.)

The analysis of the path coefficients confirms that the relationships between pod weight and their length and width exhibit the highest stability (62.43-64.05%), and can be used in selection activities (Table 3). The width of the pod also has a high indirect influence on its weight through the width (72.08%) and firmness of the pod (49.03%). The length and width of the pod also exhibit reciprocal indirect influences on the weight of the pod. The correlations of pod weight with their thickness and firmness are due to a small extent of 11.89-31.91% % to their direct effect, given the low and negative values of the associated path coefficient.

Table 3. Path coefficients for pod traits in Sondella, Minidor, Berggold and Marconi varieties of snap bean (*Phaseolus vulgaris* L.)

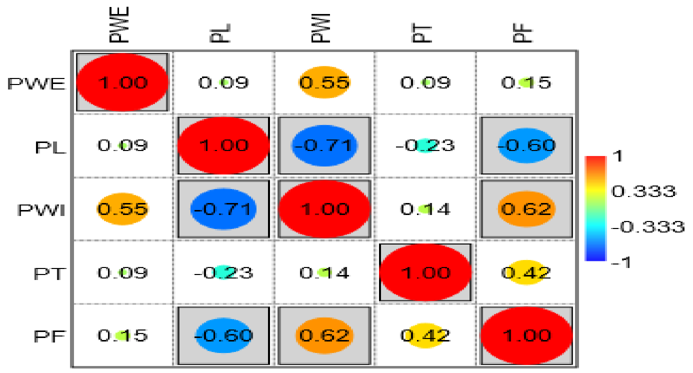
Traits	Value	%	Traits	Value	%
Pod length vs pod weight	**0.668**	***100***	**Pod thickness vs pod weight**	**-0.516**	***100***
Direct effect	0.417	*62.43*	Direct effect	-0.063	*11.89*
Indirect effect via pod width	0.23	*34.43*	Indirect effect via pod length	-0.078	*14.72*
Indirect effect via pod thickness	0.012	*1.80*	Indirect effect via pod width	-0.382	*72.08*
Indirect effect via pod firmness	0.009	*1.35*	Indirect effect via pod firmness	0.007	*1.32*
Pod width vs pod weight	**0.709**	***100***	**Pod firmness vs pod weight**	**0.003**	***100***
Direct effect	0.481	*64.05*	Direct effect	-0.082	*31.91*
Indirect effect via pod length	0.199	*26.50*	Indirect effect via pod length	-0.045	*17.51*
Indirect effect via pod thickness	0.05	*6.66*	Indirect effect via pod width	0.126	*49.03*
Indirect effect via pod firmness	-0.021	*2.80*	Indirect effect via pod thickness	0.004	*1.56*
Residual effects: 0.348					

Considering the data in Table 4, it is observed that in the case of 'Sondella', 'Minidor', 'Berggold' and 'Marconi' varieties, a considerable part (81.02%) of the variability of pod weight can be explained as the result of the influence of the four traits included in this regression model. Pod length has a major and significant influence of approximately 55.41% on pod weight, followed by pod thickness which influences this trait to a degree of 24.49% it is also observed that changes in the thickness and firmness of the pod have very little influence (0.49-0.63%) on its weight.

Table 4. Variance components of multiple regressions between pod weight and other related traits in Sondella, Minidor, Berggold and Marconi varieties of snap bean (*Phaseolus vulgaris* L.)

Source of variation	SS	DF	MS	F test
Regression	16.67	4	4.17	7.47*
Pod length (x_1)	11.40	1	11.40	20.44**
Pod width (x_2)	5.04	1	5.04	9.03*
Pod thickness (x_3)	0.10	1	0.10	0.18
Pod firmness (x_4)	0.13	1	0.13	0.23
Residual	3.90	7	0.56	
Total	20.57	11	1.87	
$y = -3.19 + 0.73x_1 + 3.47x_2 - 1.19x_3 - 0.6x_4$				
$R^2 = 0.8102$; $R^2_a = 0.6631$; SEE = 0.91 g; DW=3.12				

The regression model adopted for the analysis of the relationships between the weight of the pod and the other traits presents a strong statistical assurance, evaluating this trait with an error of 0.91 g. The values of the DW coefficient indicate that the errors related to the obtained results are independent, provided that the order of the four variables does not affect the estimated results of pod weight.



PWE-Pod weight; PL-Pod length; PWI-pod width; PT-Pod thickness; PF-pod firmness.

Figure 4. Correlations between pod traits in Brittle Wax, Voletta, Contender and Tytania varieties of snap bean (*Phaseolus vulgaris* L.)

In the case of 'Brittle Wax', 'Voletta', 'Contender' and 'Tytania' varieties, the pod weight showed a significant positive correlation only with pod width, while for the rest of the traits the coefficient values were very low (Figure 4). The pod length showed negative correlations with the other traits, significant in the case of width and firmness which were significantly positively correlated with each other. Therefore, in the case of these varieties, the selection of wider pods can ensure an increase in their weight and firmness.

Given on the path coefficient values for 'Brittle Wax', 'Voletta', 'Contender' and 'Tytania' varieties (Table 5), it has been seen that the direct effects of length, width and thickness of the pod were positive, while the pod firmness has had a negative effect on the pod weight. Like that, the highest direct effect was shown by pod width and the lowest by pod firmness. Pod width also exhibited a high negative indirect effect on pod weight through pod length (45.58%) and a high positive indirect effect on pod firmness (49.75%). Also, the association between pod thickness, firmness and weight was negative indirect affected (33.48-35.55%) by pod length.

Table 5. Path coefficients for pod traits in Brittle Wax, Voletta, Contender and Tytania varieties of snap bean (*Phaseolus vulgaris* L.)

Traits	Value	%	Traits	Value	%
Pod length vs pod weight	**0.089**	***100***	**Pod thickness vs pod weight**	**0.087**	***100***
Direct effect	0.953	*47.58*	Direct effect	0.191	*28.81*
Indirect effect via pod width	-0.913	*45.58*	Indirect effect via pod length	-0.222	*33.48*
Indirect effect via pod thickness	-0.044	*2.20*	Indirect effect via pod width	0.184	*27.75*
Indirect effect via pod firmness	0.093	*4.64*	Indirect effect via pod firmness	-0.066	*9.95*
Pod width vs pod weight	**0.547**	***100***	**Pod firmness vs pod weight**	**0.154**	***100***
Direct effect	1.29	*61.81*	Direct effect	-0.155	*9.65*

Indirect effect via pod length	-0.674	*32.30*	Indirect effect via pod length	-0.571	*35.55*
Indirect effect via pod thickness	0.027	*1.29*	Indirect effect via pod width	0.799	*49.75*
Indirect effect via pod firmness	-0.096	*4.60*	Indirect effect via pod thickness	0.081	*5.04*
Residual effects: 0.216					

Regarding the analysis of variance for the multiple regressions related to the effect of different traits on pod weight, shows that 88.09% of the variability for dependent variable in Brittle Wax, Voletta, Contender and Tytania varieties is due to the influence of the four pod traits (Table 6). Of these characters, it was seen that the pod width has the highest and significant contribution (83.75 %) to the variability of pod weight, while the length, firmness and thickness of pod had lower influence of 0.89-2.17%.

Table 6. Variance components of multiple regressions between pod weight and other related traits in Brittle Wax, Voletta, Contender and Tytania varieties of snap bean (*Phaseolus vulgaris* L.)

Source of variation	SS	DF	MS	F test
Regression	10.63	4	2.66	12.94**
Pod length (x_1)	0.11	1	0.11	0.52
Pod width (x_2)	10.11	1	10.11	49.23**
Pod thickness (x_3)	0.26	1	0.26	1.28
Pod firmness (x_4)	0.15	1	0.15	0.75
Residual	1.44	7	0.21	
Total	12.07	11	1.10	
$\mathbf{y = -6.77 + 0.53x_1 + 4.63x_2 - 3.72x_3 - 0.54x_4}$				
$R^2 = 0.8809$; $R^2_a = 0.7418$; SEE = 0.581 g; DW=2.82				

For the group of 'Brittle Wax', 'Voletta', 'Contender' and 'Tytania' varieties, the regression model with four independent variables used for the analysis of the relationship between pod traits has a high statistical assurance, evaluating the pods weight/spike with an error of 0.49 g. Given that the Durbin-Watson index is greater than 1.4 it follows that possible errors that accompany the experimental results are not self correlated, and the order of variables in the regression equation does not influence the estimated values of pod weight.

Pod width had negative and correlation with pod thickness, in conformity with present findings of other studies [11, 17, 22]. Given that pod weight is one of the major contributing traits towards plant pod yield [1, 11, 12, 15, 18, 20, 22] the selection on correlated traits can be effective for developing new high yielding snap bean varieties [13]. The estimated residual effect for path analysis was relatively low in accordance with other studies [1, 13, 18], which indicated that about 65.2-78.4% of the pod weight variability was due to the contribution of the other pod traits.

Conclusions

For this set of 20 bushing snap bean varieties, the width of pod has the highest contribution to the achievement of pod mass, followed by the pod length, while the pod firmness had the lowest influence. Given that only the relationships of pod width with the pod weight and firmness were significant, in the case of this bushing snap bean varieties the selection for width of the pod bring a positive change of the pod weight and firmness. The relationship between the width and weight of pod was affected in a small and lesser extent by the other pod traits. As such, the width of pod can be used as indirect selection criteria for the increase of pod weight. This set of varieties presents different associations between the pod traits and as such can be used as selection material for the improvement of those characters.

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