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The study of morpho-agronomic traits relationship in common bean (*Phaseolus vulgaris* L.)

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Abstract. The study of the associations between morpho-agronomic traits of common bean (*Phaseolus vulgaris* L.) was based on different statistical methods. Seventy two recombinant inbred lines and twenty cultivars of common bean were used to record data on seed yield and 21 morpho-agronomic characters. Correlation analysis demonstrated that seed yield is highly correlated with harvest index, seed number per plant, seed number per pod, pod number per plant, seed length, straw weight, 50% flowering, 50% poding, pod length and 100 seed weight. Path coefficients' analysis was applied to the data within the primary, secondary, and tertiary yield levels to work out the direct and indirect effects of 21 characters on the seed yield. Path analysis indicated that among primary traits, seed number per plant and harvest index had high positive direct effect on the seed yield. According to the obtained results, in the secondary level of seed yield characters such as length seed, pod number per plant and straw weight can be considered. Factor analysis revealed that five factors explain almost 75% of the total variance. The factors could explain 22.42, 14.59, 14.36, 13.76 and 9.94% of total variation, respectively. Cluster analysis separated the characters to four distinct groups. Hence, the study results proved that seed number per plant, pod number per plant, harvest index, seed number per pod, pod weight and pod length were the variables most closely related to seed yield. There was a harmony between results of path analysis, factor analysis and cluster analysis.

Keywords: yield, common bean, path analysis, factor analysis, cluster analysis.

Introduction

The legume family (Leguminosae) is the third largest family of flowering plants and includes about 750 genera and over 19,000 distinct species (Lewis et al. 2005). The common bean as a food legume has been domesticated by evolution from a wild plant in the highlands of Middle America and the Andes into a major leguminous food crop, grown world wide in a broad range of environments and cropping systems (Gepts & Debouck 1991). The cultivated bean as an annual species with typical outcrossing rates less than 5% (Graham & Ranalli 1997) is a morphologically diverse crop with large variation in growth (Singh et al. 1991). The protein-rich seeds of bean are an important food source worldwide (Salehi et al. 2008). Bean is the most important grain legumes producing almost twice that of chickpea, which is the second most important grain legume (Broughton et al. 2003).

The genetic diversity of crop species is the result of natural selection on the wild parents and human intervention. The extent and distribution of the genetic diversity in a crop depends on its breeding system, geographical, ecological and human factors. Conservation of genetic variability is essential for present and future human wellbeing (Tiranti 2006). Study of genetic diversity is essential for conservation, management and to identify the hybrids (Franklin 2009). The genetic diversity among and within landraces makes them a valuable resource as potential donors of genes for breeding purposes, diversification of production, developing new farming systems and new quality products (Soleri & Smith 1995, Jing et al. 2010). To develop crop varieties and attain significant progress in breeding programs, it is essential to know the relationship between seed yield and its component (Assady et al. 2005).

Some of the characters are highly associated among themselves and with seed yield. Strategies to increase yield of common bean would be improved by an understanding of how morpho-agronomic characters interact with one another in affecting yield (Board et al. 1999). In order to establish selection criteria, the analysis of these relationships is essential. The correlation coefficient (r) indicates the measure of the association between two variables that have been measured on interval or ratio scales, such as the relationship between diameter of plant stem in millimeters and straw weight in grams. When more characters are involved in correlation study it becomes difficult to find out the characters which really contribute toward yield. Path coefficient analysis under such situations could help determine the direct and indirect contributions of these characters via other characters (Singh et al. 1990).

Path analysis is a standardized partial regression coefficient measuring the direct influence of one variable upon the other and permits separation of correlation coefficients into components of direct and indirect effects (Muhammad et al. 1999). As reported by others earlier, 100 seed weight is correlated negatively with seed yield, although its path coefficient was positive, thus suggesting that it should be considered in breeding studies to increase grain yield (Goncalves et al. 2003). White & Gonzalez 1990 and Singh et al. 1995 reported that positive relationships between seed size and yield were found in certain environments. Ozdemir 1996 indicated that pod number per plant had direct positive effect on grain yield in chickpea.

Factor analysis is a multivariate statistical method which can reduce a large number of correlated variables in small number of uncorrelated factors. Castineiras et al. 1991 used factor analysis to compare common bean accessions in Cuba. Using cluster analysis, you can also form groups of related variables, similar to what you do in factor analysis. Stoilova et al. 2005 showed that the evaluation of phenotypic variability by cluster analysis enables to identify the suitable resources and characters to be included in breeding activities. Hornakova et al. 2003 grouped common bean genotypes into two main branches with cluster analysis, reflecting the growth type, seed size parameters, and thousand-seed weight.

The objectives of the present study were to characterize relationships among the important morpho-agronomic characters with themselves and seed yield, to extract factors comprising important traits for improving seed yield of common bean in breeding programs and to group the different traits into groups with similar specification.

Materials and Methods

Plant material for the present study consisted of seventy two recombinant inbred lines (RILs) derived from the crosses of Goli/AND1007, G14088/talash, Dehghan/Wa2662, AND1007/D81083 and twenty cultivars of common bean obtained from National Bean Research Station in Khomein town, center of Iran (Table 1). The genotypes and recombinant inbred lines were planted into a randomized complete block design (RCBD) with two replications in the research field of Razi University, Kermanshah, Iran (latitude 34° 19´ N, longitude 47° 7´E, and altitude 1322 m) in 2009. Each plant sample was sown in 3 rows, 2 m long with 50 cm wide before sowing, 50 Kg ha^{-1} N fertilizer was applied. The field was irrigated every five to seven days.

Table 1. List of Crosses with number of inbred lines and genotypes with their origin.

Name of crosses		Number of inbred lines	
Goli/AND1007		23	
G14088/talash		20	
Dehghan/Wa2662		15	
AND1007/D81083		14	
Genotypes	Origin	Genotypes	Origin
Goli	IRAN	Sayad	CIAT
AND1007	CIAT	Cifem Cave	CIAT
G14088	CIAT	74-Emersun	CIAT
Talash	IRAN	Wa2662	CIAT
COS16	CIAT	Jules	CIAT
Araucano	CIAT	G11867	CIAT
Naz	IRAN	Wa4531	CIAT
Akhtar	CIAT	Daneshkade	IRAN
D81083	CIAT	Derakhshan	CIAT
Taylor	CIAT	Dehghan	IRAN

At maturity five guarded plants per replication were randomly selected to record data on seed yield and 21 morphological characters. Measurements were done according to the IPGRI descriptor list for *P. vulgaris* L. traits such as seed yield, seed number per plant, pod number per plant, pod weight, seed number per pod, harvest index, 50% poding, 50% flowering, days to maturity, node number of main stem, node number of lateral branches, height, seed width, seed diameter, seed length, pod tail length, 100 seed weight, biologic yield, straw weight, pod length, internode length and internode diameter. The mean values were used for statistical analysis. In order to determine the relationships between examined traits and seed yield per plant, Pearson's correlation coefficients were computed among phenotypic traits by using the MSTATC statistic program. In the present study, path analysis was applied to the data within the primary, secondary, and tertiary yield levels to work out the direct and indirect effects of 21 characters on the seed yield (Fig. 1). Path analysis was performed for seed yield and its components using the methodology proposed by Dewey and Lu (1959).

Factor analysis with varimax rotation was performed for the 22 characters in common bean. Ward's method was used to form hierarchical clustering (Ward 1963). The factor analysis, path coefficient analysis and clustering of traits were carried out by using SPSS software (version 16).

Figure 1. Scheme of path coefficient analysis of seed yield in common bean.

Results and Discussion

Correlation coefficient analysis

The correlation coefficients between seed yield and some measured traits (selected pairs of traits) are presented in Table 2. The seed yield had highly significant correlations with harvest index (0.833), seed number per plant (0.768), seed number per pod (0.729), pod number per plant (0.638), seed length (0.397), straw weight (-0.377), 50% flowering (-0.369), 50% poding (-0.362), pod length (0.361) and 100 seed weight (0.295). 50% poding displayed positive and highly significant correlation with 50% flowering (0.976). In some cases, compensation of characters related to yield was indicated by the presence of negative correlations among these characters with yield. Plant height, node number of main stem and pod tail length had low and negative non-significant correlations with seed yield, while positive non-significant correlations were observed between the seed yield and internode diameter, biological yield, seed width, node number of laternal branches and seed diameter. Among these traits, harvest index had the strongest association with the seed yield, suggesting that this trait may be important yield predictors and perhaps it is the most important for yield improvement in common bean. The similar results were also found by Salehi et al. (2008), Assady et al. (2005), Kumar et al. (2002) and Singh et al. (1995) in common bean. Our result showed that seed yield to seed number per plant and seed number per pod had strong positive correlations, too. It seems that these were useful characters to select for high yield in common bean breeding programs. Thus selection of variety with high number seed can be used in common bean breeding program.

Path coefficient analysis

Sometimes, correlation coefficients give misleading results because the correlation between two variables may be due to a third factor. It is therefore necessary to analyze the cause

Table 2. Correlation coefficients between different traits and seed yield in common bean.

	50% flowering	50% poding	Days to maturity	height	Node number of Main stem	Node number of lateral branches	Internode diameter	pod length	pod tail length	seed number per pod	seed length	Seed width	Seed diameter	straw weight	pod weight	Harvest Index	seed number per plant	Pod number per plant	Internode length	Biologic yield	100 seed weight	Seed yield
50% flowering	1																					
50% poding	0.976**	1																				
Days to maturity	0.715**	0.700**	1																			
height	0.080	0.083	0.053	1																		
Node number of Main stem	0.203	0.225*	0.073	0.838**	1																	
Node number of lateral branches	0.109	0.144	-0.042	0.721**	0.875**	1																
Internode diameter	0.117	0.153	0.085	-0.103	-0.126	-0.052	1															
pod length	-0.226*	-0.195	0.011	-0.211*	-0.231*	-0.170	0.257*	1														
pod tail length	-0.207*	-0.231*	-0.118	-0.261*	-0.285**	-0.205*	0.246*	0.249*	1													
seed number per pod	-0.457**	-0.425**	-0.337**	-0.202	-0.293**	-0.172	-0.035	0.407**	-0.067	1												
seed length	-0.589**	-0.570**	-0.409**	-0.088	-0.154	-0.056	0.081	0.427**	0.245*	0.386**	1											
Seed width	-0.307**	-0.309**	-0.260*	0.202	0.204	0.157	0.128	0.152	0.288**	-0.049	0.542**	1										
Seed diameter	-0.374**	-0.370**	-0.242*	0.177	0.148	0.148	0.251*	0.242*	0.279**	0.100	0.467**	0.797**	1									
straw weight	0.485**	0.466**	0.510**	0.276**	0.202	0.114	0.203	-0.044	0.050	-0.355**	-0.331**	-0.030	0.070	1								
pod weight	-0.308**	-0.293**	-0.184	-0.028	-0.056	0.027	0.098	0.475**	0.004	0.653**	0.432**	0.123	0.235*	-0.342**	1							
Harvest Index	-0.550**	-0.514**	-0.448**	-0.182	-0.178	-0.041	-0.025	0.333**	-0.026	0.759**	0.527**	0.117	0.174	-0.596**	0.623**	1						
seed number per plant	-0.227*	-0.184	-0.102	-0.037	-0.046	0.027	0.042	0.220*	-0.098	0.616**	0.231*	-0.128	0.012	-0.192	0.593**	0.467**	1					
Pod number per plant	-0.418**	-0.314**	-0.203	-0.141	-0.179	-0.082	0.003	0.339**	-0.049	0.690**	0.360**	-0.129	0.049	-0.285**	0.585**	-0.355**	0.766**	1				
Internode length	0.152	0.106	0.115	-0.053	-0.368**	-0.342**	0.151	-0.045	0.182	-0.174	-0.283**	-0.211*	-0.162	0.283**	-0.190	-0.349**	-0.213*	-0.285**	1			
Biologic yield	0.373**	0.351**	0.442**	0.288**	0.186	0.139	0.243*	0.180	0.047	-0.064	-0.146	0.020	0.180	0.812**	0.208*	0.664**	0.091	-0.021	0.216*	*1*		
100 seed weight	-0.462**	-0.449**	-0.425**	-0.074	-0.123	-0.054	0.111	0.283**	0.265*	0.261*	0.527**	0.407**	0.330**	-0.394**	0.346**	0.632**	0.071	0.148	-0.135	-0.258*	1	
Seed yield	**-0.369****	**-0.362****	**-0.263***	**-0.015**	**-0.036**	**0.097**	**0.016**	**0.361****	**-0.072**	**0.729****	**0.397****	**0.055**	**0.180**	**-0.377****	**0.831****	**0.833****	**0.768****	**0.638****	**-0.225***	**0.054**	**0.295****	1

*' ** indicate significant correlation at the 0.05 and 0.01 probability levels, respectively

and effect relationship between dependent and independent variables to entangle the nature of relationship between the variables (Sidramappa et al. 2008). Path coefficient analysis (Dewey & Lu 1959) was therefore used to elicit the nature of relationship of dependent variable (yield) with closely associated independent variables. The traits which not only have high positive correlation but also have high direct effects are expected to be useful as selection criteria in selection program. Considering this point, among primary traits, seed number per plant and harvest index had high positive direct effect on the seed yield (Table 3).

In the secondary level of seed yield through 100 seed weight, seed length had highest direct effect and seed width via seed length showed maximum indirect effect (Table 4). According to the result of Table 4, in order to obtain an increase of seed yield through 100 seed weight, characters such as width and length seed can be considered. In the secondary level of seed yield through seed number per plant, maximum and minimum direct effects belonged to pod number per plant and height, respectively (Table 5). Indeed high seed yield is associated with a large number of pods per plant. The results revealed that the most indirect effects on seed number per plant belonged to characters of seed number per pod (0.418) and pod weight (0.354) via pod number per plant. According to the obtained results selection can be carried out based on pod number per plant. Greater seed production from increased pod production was resulted among genetic materials in the current study. In the secondary level of seed yield through harvest index, straw weight showed greater importance in affecting harvest index than did other traits by both negative greater correlation coefficient and direct path coefficient (Table 6). The obtained results showed that days to maturity via straw weight had negative maximum indirect effect on harvest index.

In tertiary level of seed yield through days to maturity (Table 7), 50% flowering showed highest direct effect (0.647) and 50% poding via 50% flowering revealed maximum indirect effect (0.659). Maximum direct effect belonged to pod length on seed number per pod and pod tail length via pod length had highest indirect effect (Table 8). In tertiary level of seed yield by height, node number of main stem had highest direct effect and node number of lateral branches through node number of main stem had maximum indirect effect (Table 9). The results agree with results obtained by Rao & Kumar (2000) for days to 50 percent flowering, Reddy & Rao (1988) for 100 seed weight and Arora & Jeena (1999)

Table 3. Direct and indirect effects in the primary level of seed yield.

Traits in primary level seed yield	Correlation coefficients with seed yield	Direct effect trait on seed yield	Indirect effects primary trait on seed yield		
			seed number per plant	100 seed weight	Harvest index
Seed number per plant	0.768**	0.4010	-	-0.0003	**0.368**
100 seed weight	0.295**	-0.005	0.028	-	0.272
Harvest index	0.833**	**0.582**	0.253	-0.0023	-

** indicates significant at the 0.01 level of significance. (R^2= 0.761)

Table 4. Direct and indirect effects in the secondary level of seed yield by 100 seed weight.

Traits in secondary level seed yield by 100 seed weight	Correlation coefficients with 100 seed weight	Direct effect trait on 100 seed weight	Indirect effects secondary trait of seed yield by		
			Seed diameter	Seed wide	seed length
Seed diameter	0.330**	-0.027	-	0.153	0.204
Seed wide	0.407**	0.192	-0.215	-	**0.236**
seed length	0.527**	**0.436**	-0.126	0.104	-

** indicates significant at the 0.01 level of significance. (R^2= 0.299)

Table 5. Direct and indirect effects in the secondary level of seed yield by seed number per plant.

Traits in secondary level seed yield by seed number per plant	Correlation coefficients with seed number per plant	Direct effect trait on seed number per plant	Indirect effects secondary trait of seed yield by			
			Pod number per plant	pod weight	seed number per pod	height
Pod number per plant	0.766**	**0.606**	-	0.103	0.0662	-0.010
pod weight	0.593**	0.177	0.354	-	0.0627	-0.002
seed number per pod	0.616**	0.096	**0.418**	0.116	-	-0.015
height	-0.037	0.073	-0.085	-0.005	-0.0194	-

** indicates significant at the 0.01 level of significance. (R^2= 0.626)

Table 6. Direct and indirect effects in the secondary level of seed yield by Harvest index.

Traits in secondary level seed yield by Harvest index	Correlation coefficients with Harvest index	Direct effect trait on Harvest index	Indirect effects secondary trait of seed yield by		
			Biologic yield	straw weight	Days to maturity
Biologic yield	-0.355**	0.394	-	0.319	0.089
straw weight	-0.596**	**-0.809**	-0.155	-	-0.106
Days to maturity	-0.448**	-0.206	-0.167	**-0.413**	-

** indicates significant at the 0.01 level of significance. (R^2= 0.436)

Table 7. Direct and indirect effects in the tertiary level of seed yield by days to maturity.

Traits in tertiary level seed yield by days to maturity	Correlation coefficients with days to maturity	Direct effect trait on days to days to maturity	Indirect effects tertiary trait of seed yield by	
			50% flowering	50% poding
50% flowering	0.715**	**0.674**	-	0.041
50% poding	0.700**	0.042	**0.659**	-

** indicates significant at the 0.01 level of significance. (R^2= 0.511)

Table 8. Direct and indirect effects in the tertiary level of seed yield by seed number per pod.

Traits in tertiary level seed yield by seed number per pod	Correlation coefficients with seed number per pod	Direct effect trait on seed number per pod	Indirect effects tertiary trait of seed yield by	
			pod length	pod tail length
pod length	0.407**	**0.452**	-	-0.046
pod tail length	-0.067	-0.179	**0.112**	-

** indicates significant at the 0.01 level of significance. (R^2= 0.196)

Table 9. Direct and indirect effects in the tertiary level of seed yield by height.

Traits in tertiary level seed yield by height	Correlation coefficients with height	Direct effect trait on height	Indirect effects tertiary trait of seed yield by			
			Node number of Main stem	Node number of lateral branches	Internode length	Internode diameter
Node number of Main stem	0.838**	**0.963**	-	-0.019	-0.110	0.003
Node number of lateral branches	0.721**	-0.022	**0.843**	-	-0.102	0.001
Internode length	-0.053	0.298	-0.354	0.007	-	-0.004
Internode diameter	-0.103	-0.027	-0.121	0.001	0.045	-

** indicates significant at the 0.01 level of significance. (R^2= 0.779)

Table 10. Factor analysis with varimax rotation for 21 characters and seed yield in common bean.

Variables	Factors				
	1	2	3	4	5
Seed yield	**0.901**	-0.149	0.088	0.093	-0.086
Seed number per plant	**0.863**	-0.017	0.046	-0.107	0.017
Pod number per plant	**0.834**	-0.136	-0.083	-0.047	-0.068
Pod weight	**0.829**	-0.044	0.035	0.250	-0.020
Seed number per pod	**0.820**	-0.260	-0.174	0.007	-0.067
Harvest Index	**0.761**	-0.316	-0.069	0.131	-0.408
50% poding	-0.245	**0.877**	0.104	-0.250	0.080
50% flowering	-0.292	**0.856**	0.085	-0.256	0.118
Days to maturity	-0.121	**0.791**	-0.015	-0.135	0.233
Node number of Main stem	-0.107	0.121	**0.954**	-0.006	-0.031
Node number of lateral branches	0.003	0.063	**0.893**	0.023	-0.062
Height	-0.073	-0.072	**0.872**	-0.014	0.257
Seed wide	-0.121	-0.225	0.274	**0.803**	-0.090
Seed diameter	0.063	-0.232	0.246	**0.786**	0.119
Seed length	0.350	-0.353	-0.049	**0.617**	-0.236
Pod tail length	-0.140	-0.140	-0.364	**0.544**	0.178
100 seed weight	0.173	-0.319	-0.090	**0.539**	-0.340
Pod length	0.469	0.130	-0.266	0.497	0.060
Internode diameter	0.062	0.358	-0.188	0.492	0.167
Biologic yield	0.164	0.416	0.212	0.180	**0.787**
Straw weight	-0.250	0.413	0.176	0.067	**0.752**
Internode length	-0.248	-0.103	-0.398	-0.145	**0.644**
Eigenvalue	**4.933**	**3.21**	**3.159**	**3.027**	**2.186**
% of Variance explained	**22.420**	**14.59**	**14.36**	**13.76**	**9.94**
% of Cumulative	**22.420**	**37.013**	**51.371**	**65.129**	**75.065**

for pod number and plant height.

Finally, path analysis is most likely to be useful when we already have primary and clear information to test relationships between variables, or a little knowledge of hypotheses all of which can be represented within a path diagram. Therefore, it has little use at the exploratory stage of research. So obviously, path analysis can evaluate causal hypotheses, but it cannot establish the direction of causality. Path analysis can be used to solve problem of multicollinearity (when the independent variables are collinear and the results show multicollinearity).

Factor analysis

Factor analysis combined variables that were correlated into five factors in order of the amount of variance explained (Table 10). In order to select the appropriate number of factors, only specified factors with eigenvalues greater than 1 were used. Five factors explain almost 75% of the total variance.

The first factor could explain 22.42% of total variation.

The most important coefficients in this factor were related to seed yield, seed number per plant, pod number per plant, pod weight, seed number per pod and harvest index. For the purposes of interpretation only those factor loadings greater than 0.50 were considered important, these values are highlighted in bold in Table 10. The values in the Table, or loadings, indicate the contribution of each variable to the factors. The significant correlations were previously observed for all these traits. Therefore this factor can be called the detector yield factor. Salehi et al. (2008) also showed that the traits of pod number per plant, seed yield and seed number per plant were the important variables in the first factor in relation to seed yield in common bean.

The second factor contained 14.59% of total variation, where 50% flowering, days to maturity and 50% poding were the most important variables. Also, there were the significant positive correlations between these traits. Thus, this factor was named the phenologic factor. The third factor accounted for 14.36% of the total variation. The most important variables in this factor were node number of main stem, node number of lateral branches and height. Therefore this factor may be called the vegetation factor. The fourth factor could explain 13.76% of total variation. The most important coefficients in this factor were related to seed wide, seed diameter, seed length, pod tail length, 100 seed weight. The significant correlations were observed for all these traits. This factor can be named the seed factor. The fifth factor contained 9.94% of total variation, where biological yield, straw weight and internode length were the most important variables. Also, there were the significant positive correlations between these traits. Therefore this factor was called the biomass factor.

Cluster analysis

Cluster analysis is a data reduction/classification method and a similar technique with factor analysis, but it is used to discover similar groups. Hierarchical cluster analysis with common bean variables was used and resulted in a dendrogram (Fig. 2). In this method the distance of each variable in relation to other variables was calculated. For quantitative characters, number of clusters was chosen from the hierarchical analysis. As shown in Figure 2, the similarity level increased as the number of clusters increased.

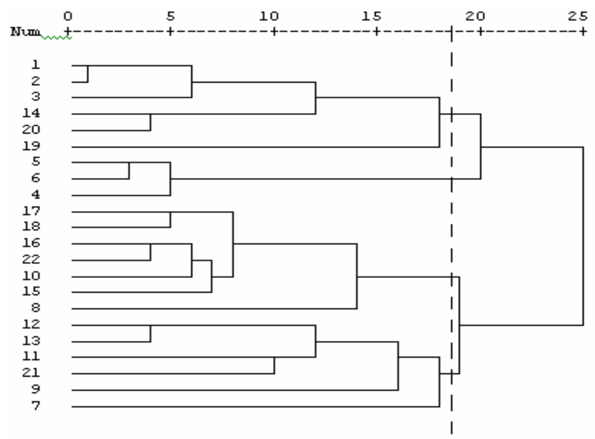

Figure 2. Dendrogram of the hierarchical cluster analysis for showing similarity value between 22 common bean characters (variables).

There were about 82% similarity levels, the tested twenty two variables could be collected into four clusters. Cluster 1 included 50% flowering (1), 50% poding (2), days to maturity (3), straw weight (14), biologic yield (20) and internode length (19), while cluster 2 includes node number of main stem (5), node number of lateral branches (6) and plant height (4). Cluster 3 includes seed number per plant (17), pod number per plant (18), seed yield (16), harvest Index (22), seed number per pod (10), pod weight (15), pod length (8). Cluster 4 includes seed wide (12), seed diameter (13), seed length (11), 100 seed weight (21), pod tail length (9) and internode diameter (7). Our data reflected the leaning of each grouped variables in one cluster to narrate closely to each other. Hence, the study results proved that seed number per plant, pod number per plant, harvest index, seed number per pod, pod weight and pod length were the variables most closely related to seed yield. There was a harmony between results of path analysis, factor analysis and cluster analysis. Overall, reduction of yield of common bean on the studied samples could be affected by traits such as seed number per plant, harvest index, 100 seed weight, pod weight and days to maturity.

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