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Correlation and Path Coefficient Analysis for Seed Yield and some of its Traits in Common Bean (*Phaseolus vulgaris* L.)

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COMMON bean (*Phaseolus vulgaris* L.) is one of the most important vegetable crops grown in Egypt. This study was conducted to determine the phenotypic, genotypic, and environmental correlations between seed yield and some of its traits, and to perform path analysis to assess the direct and indirect effects between seed yield per plant as dependent variable and the other traits as explanatory variables.Twenty-seven accessions of common bean were evaluated at El-Dalgamon village, El-Gharbia Governorate, Egypt during the two successive summer seasons of 2016 and 2017 using a randomized complete block design with three replications.The results revealed the importance of genotypic correlations coefficients compared to the corresponding values of phenotypic ones. The genotypic correlations were positive ranging from 0.60 to 0.99 for the correlation between seed yield per plant and each of plant height, number of leaves per plant, number of days to flowering, number of racemes per plant, number of days to maturity, number of pods per plant, and number of seeds per pod. Genotypic path analysis indicated the importance of positive direct effects of plant height, number of pods per plant, number of days to maturity, and number of seeds per pod, suggesting the direct selection of these traits to improve seed yield. Whereas, number of leaves per plant, number of days to flowering, or number of racemes per plant should be selected simultaneously with plant height or number of pods per plant since they had high positive indirect effects on seed yield through these two traits.

Keywords: Common bean, *Phaseolus vulgaris*, Seed yield, Correlation, Path analysis, Direct effects, Indirect effects.

Introduction

Common bean (*Phaseolus vulgaris* L.) is a leguminous self-pollinated crop (2n= 2x= 22). It is one of the most important vegetable crops grown in the world as well as in Egypt to produce immature tender pods and/or dry seeds. According to FAOSTAT (2016), the cultivated area of dry bean in Egypt was 34.08 thousand hectares with a total production of 112.9 thousand tonnes. Egypt exportation of dry beans was 34.4 thousand tonnes, and it was ranked sixteenth among the largest exporters of dry bean in the world.

Seed yield in common bean is a quantitative trait which is influenced by several genes and environmental factors, in addition, it depends on other related traits (Ejara et al., 2017). The direct selection of complex traits such as seed yield may not be effective, thus, it is suitable to study the association between seed yield and its components to perform the indirect selection of traits related to seed yield (Ahmed and Kamaluddin, 2013).

Correlation and path analysis will clarify the relationship between various traits with seed yield, which will be important for effective selection procedures designed to improve seed yield. Although, the correlation coefficient is valuable to determine the relationship between traits, it does not provide the direct and indirect effects of different seed yield components. Path analysis gives information about the direct effect of a certain trait on another one and the indirect effects of such certain trait through the other studied traits. Correlation and path coefficient analysis could be used together to understand the cause and effects relationship between seed yield and its components to identify the traits which maybe considered as indirect selection criteria.

Many researchers studied the correlation and path coefficient analyses of seed yield and its components in common bean (Gonçalves et al., 2003, Karasu & Oz, 2010, Ahmed & Kamaluddin, 2013, Singh & Singh, 2013, Akhshi et al., 2015, Ambachew et al., 2015, Ejara et al., 2017,

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Gonçalves et al., 2017, and Panchbhaiya et al., 2017). However, there are few reports (Mohamed, 1997) on this subject in common bean under Egyptian conditions.

Therefore, this study was conducted to determine the phenotypic, genotypic, and environmental correlations between seed yield and some of its related traits in twenty-seven accessions of common bean and to perform path analysis to estimate the direct and indirect effects of such traits on seed yield.

Materials and Methods

The present study was carried out during the two successive summer seasons of 2016 and 2017, at El-Dalgamon village, Kafr El-Zayat, El-Gharbia Governorate, Egypt. The genetic materials comprised twenty-six common bean accessions obtained from the Nordic Genetic Resource Center (NordGen) in addition to Giza 6, the commercial cultivar widely grown in Egypt (Table 1). The accessions were cultivated for two generations for seed multiplication and disease-infected plants were discarded, then each accession was sown manually in four rows of 4 m long and 70 cm wide. Plants were spaced 10 cm within rows. The planting date was 4th march in each year. The experiment was arranged in a randomized complete block design with three replications.

TABLE 1. List of evaluated 27 common bean accessions including 26 accessions from the Nordic Genetic Resource Center (NordGen) and Giza 6, the Egyptian local commercial cultivar

Number	Accession	Name	Type	Origin
1	NGB 9300	ØIJORD	Advanced cultivar	Norway
2	NGB 17801	HALLANDSBONA	Primitive	Sweden
3	NGB 17803	SLOALYCKE	Primitive	Sweden
4	NGB 17805	MOR KRISTIN	Primitive	Sweden
5	NGB 17806	SARDAL	Primitive	Sweden
6	NGB 17807	HARPLINGE	Landrace	Sweden
7	NGB 17808	RYSK KEJSARBONA	Primitive	Sweden
8	NGB 17809	BERNADINA	Primitive	Sweden
9	NGB 17810	PETTERSONS BONA	Landrace	Sweden
10	NGB 17812	STÅSHULT	Primitive	Sweden
11	NGB 17813	HANNAS STRIMMIGA	Primitive	Sweden
12	NGB 17814	SVEA	Landrace	Sweden
13	NGB 17815	SANDA	Primitive	Sweden
14	NGB 17816	GULLSPANG	Landrace	Sweden
15	NGB 17817	MORBRORS GRONA	Landrace	Sweden
16	NGB 17821	FISKEBY	Advanced cultivar	Sweden
17	NGB 17823	SIGRID	Landrace	Sweden
18	NGB 17824	KULLA	Landrace	Sweden
19	NGB 17825	SIGNE	Landrace	Sweden
20	NGB 17826	PERSSON	landrace	Sweden
21	NGB 17827	EXTRA-HATIF DE JUILLAT	Advanced cultivar	France
22	NGB 18054	GULBONA FRAN OSTERGARN	Landrace	Sweden
23	NGB 20198	DAGMAR	Landrace	Sweden
24	NGB 20200	ELNA	Landrace	Sweden
25	NGB 21935	LAU	Primitive	Sweden
26	NGB 24332	THORNGRENS BONA	Primitive	Sweden
27	-----------	Giza 6	Commercial cultivar	Egypt

Ten competitive plants from the two middle rows of each plot were randomly taken and labeled, discarding 0.5 m on each side of the rows. Based on the descriptors for *Phaseolus vulgaris* L. (IPGR,1982), eleven agronomic traits were evaluated as follows:

- Plant height in cm, was obtained as an average at maturity measured from the cotyledon scar to the plant tip.
- Number of leaves per plant,was calculated as an average number of leaves of 10 plants.
- Number of days to flowering, was estimated as the number of days from emergence until 50% of the plants set flowers.
- Number of racemes per plant, was calculated as an average from 10 plants.
- Number of days to maturity, was estimated as the number of days from emergence until 90% of pods are mature.
- Number of mature pods per plant, was recorded as an average of 10 plants at harvest time.
- Pod width in cm,was measured from the middle of the pod for an average of 10 randomly taken mature pods.
- Pod length in cm, was measured from the exterior distance from the pod tip to the peduncle for 10 randomly taken mature pods.
- Number of seeds per pod, was calculated as an average number of seeds from 10 randomly taken mature pods.
- 100-seed weight in g, was recorded as weight of 100 dry seeds at a moisture content of 12-14% from10 plants.
- Seed weight per plant in g, was estimated as the total weight of seeds from 10 plants divided by 10.

Data analysis

The mean values were used for statistical analysis. The analyses of phenotypic, genotypic and environmental correlations were estimated according to Miller et al. (1958) as follows:

$$rP_{xy} = \frac{covp_{xy}}{\sqrt{\mathbf{vp_x} \cdot \mathbf{vp_y}}}$$

$$rg_{xy} = \frac{covg_{xy}}{\sqrt{\mathbf{vg_x} \cdot \mathbf{vg_y}}}$$

Wherer p_{xy} = phenotypic correlation coefficient between traits x and y.

$covp_{xy}$ = phenotypic covariance between traits x and y.

$\mathbf{vp_x}, \mathbf{vp_y}$ = phenotypic variance of trait x and trait y, respectively.

rg_{xy} = genotypic correlation coefficient between traits x and y.

$covg_{xy}$= genotypic covariance between traits x and y.

$\mathbf{vg_x}, \mathbf{vg_y}$ = genotypic variance of trait x and trait y, respectively.

The phenotypic correlation coefficients were tested for their significance at the probability levels of 0.05 and 0.01 by comparing the value of correlation coefficient with tabulated Pearson's-r value at n-2 degree of freedom where "n" is the number of accessions,while the significance of genotypic and environmental correlations was evaluated by the bootstrap method (Efron, 1979) with 1000 simulations.

Path coefficient analysis was done based on the genotypic correlation coefficient. Dry seed weight per plant (seed yield) was considered as the dependent variable and the other traits as explanatory independent ones. The path analysis was carried out as given by Wright (1921) and the method of Dewey and Lu (1959) as follows:

$r_{ij} = p_{ij} + \Sigma r_{ik} p_{kj}$

where, r_{ij} is the mutual association between the independent trait (i) and the dependent trait (j) as measured by the correlation coefficient, P_{ij} is the component of direct effects of the independent trait (i) on the dependent trait (j) and $\Sigma r_{ik} p_{kj}$ is the summation of components of the indirect effects of an independent trait (i) on the dependent trait (j) through all other independent traits (k).

The residual effect, which refers to the contribution of the remaining unknown factors and determines how best the independent factors stand for the variability of the dependent factor was calculated using the following formula:

Residual effect = $\sqrt{1 - \Sigma\, \mathbf{p_{ij} r_{ij}}}$

where, $\Sigma\ p_{ij} r_{ij}$ is a summation of the product of direct effect of a variable and its correlation coefficient with the dependent variable.

All statistical analyses were performed using GENES software (Cruz, 2016).

Results and Discussion

Correlation

Seed yield in common bean (*Phaseolus vulgaris* L.) is a complex trait with a quantitative nature, which is governed by several major and minor genes and is affected by variations in the environmental factors, making the direct selection of seed yield is a complicated process and may not be successful. The direct selection of another simply inherited trait which is strongly correlated with the seed yield, will facilitate the selection procedures and lead to desired progress in selection programs. Therefore, it is necessary to exploit the relationship between seed yield and its related traits, to define the suitable selection procedures designated to improve seed yield production in common bean.

The pleiotropism or "gene binding imbalance" can result in a genotypic correlation between two traits. Pleiotropism means that one gene can affect several traits at the same time, leading to strong correlation and gives the possibility for simultaneous selection of many traits together when one of them is selected (Falconer, 1960). Plant breeders can use the genetic correlations, because they are heritable. As suggested by Lopes et al. (2002), the indirect selection for traits can be performed when their correlation coefficient values with the desired trait are higher than 0.50. Accordingly, in the present study, the correlation coefficient is considered as weak when is less than 0.50, moderate when varies from ± 0.50 to ± 0.69, strong when varies from ± 0.70 to ± 0.89 and very strong when is higher than ± 0.90.

Data in Table 2 show the phenotypic, genotypic and environmental correlation coefficients among studied traits, which reveal that, for most traits at both years of study, the genotypic correlations were equal to or higher than the corresponding phenotypic ones, and they had the same signal, and both outperformed the environmental correlations. According to Ambachew et al. (2015), these results show a minor environmental effect and greater importance of the genotypic factor to the trait expression, suggesting the possibility of success in indirect selection for such trait. These results agree with those obtained by Ambachew et al. (2015) and Gonçalves et al. (2017). In several traits, environmental correlations presented difference in value and sign, in relation to phenotypic and genotypic correlations, which indicate that different physiological processes affect the genetic and environmental variations for these traits and the environment may restrict the direct selection (Falconer, 1960). Similar results were reported by Gonçalves et al. (2017).

The environmental correlation coefficient was equal to zero for the combination of 100-seed weight with number of racemes per plant in the second year, suggesting that the random factors affecting 100-seed weight are not related to the random ones affecting the number of racemes per plant.

There were highly significant (P < 0.01) positive phenotypic (rf) and genotypic (rg) correlations with very strong values in both years for the correlation of seed yield per plant with each of plant height (rf_{y1}= 0.979**, rg_{y1}=0.983**, rf_{y2}=0.969**, and rg_{y2}=0.972**) and number of pods per plant (rf_{y1}=0.986**, rg_{y1}=0.988**, rf_{y2}=0.983**, and rg_{y2}=0.985**), where y1 and y2 refer to the years of 2016 and 2017 respectively. The correlations were highly significant with strong positive values between seed yield per plant and each of number of leaves per plant (rf_{y1}=0.835**, rg_{y1}=0.840**, rf_{y2}=0.772**, and rg_{y2}=0.776**), number of racemes per plant (rf_{y1}=0.852**, rg_{y1}=0.864**, rf_{y2}=0.862**, and rg_{y2}=0.867**), and number of days to maturity (rf_{y1}=0.748**, rg_{y1}=0.755**, rf_{y2}=0.737**, and rg_{y2}=0.744**). While, moderate positive correlations (P < 0.01) were found for seed yield per plant and each of number of days to flowering (rf_{y1}= 0.597**, rg_{y1}= 0.601**, rf_{y2} = 0.553**, and rg_{y2}= 0.558**) and number of seeds per pod (rf_{y1}=0.657**, rg_{y1}=0.663**, rf_{y2}=0.641**, and rg_{y2}=0.648**). These results suggest that the selection for higher levels of such traits is expected to improve seed yield in common bean accessions. Among these traits, plant height and number of pods per plant have correlation values close to "1" with seed yield per plant, which propose, the true relationship of these traits with seed yield and their importance as seed yield predictors, accordingly, the direct selection of taller plants and plants with greater number of pods can be performed to indirectly increase seed yield per plant. In this regard, Gonçalves et al. (2017) stated that the traits which have moderate to strong correlations with the desired trait, are important for successful indirect selection in initial stages of plant breeding.

Our results support those obtained by many researchers who found positive correlations

TABLE 2. Estimates of phenotypic (rf), genotypic (rg) and environmental (re) correlation coefficients among 11 traits evaluated in 27 common bean accessions during the summer seasons of 2016 (upper diagonal) and 2017 (lower diagonal)

Traits	r	Plant height	Number of leaves/ plant	Number of days to flowering	Number of racemes/ plant	Number of days to maturity	Number of pods/plant	Pod width	Pod length	Number of seeds/pod	100-seed weight	Seed weight/ plant
Plant height	r f		0.880**	0.576**	0.791**	0.704**	0.961**	-0.355	-0.103	0.571**	-0.494**	0.979**
	r g		0.882^{++}	0.580^{++}	0.805^{++}	0.712^{++}	0.966^{++}	-0.355^{+}	-0.104	0.577^{++}	-0.498^{++}	0.983^{++}
	r e		0.339^{+}	0.015	-0.398^{+}	-0.261^{+}	-0.636^{+}	-0.421^{+}	-0.054	-0.019	-0.022	-0.680^{++}
Number of leaves/ plant	r f	0.831**		0.543**	0.679**	0.713**	0.827**	-0.164	0.0151	0.455*	-0.337	0.835**
	r g	0.832^{++}		0.547^{++}	0.693^{++}	0.721^{++}	0.833^{++}	-0.163	0.015	0.462^{+}	-0.341^{+}	0.840^{++}
	r e	0.619^{++}		0.053	-0.198	0.049	-0.192	-0.393^{+}	0.031	-0.246	-0.022	-0.070
Number of days to flowering	r f	0.561**	0.552**		0.529**	0.799**	0.601**	-0.3587	0.042	0.422*	-0.314	0.597**
	r g	0.565^{++}	0.559^{++}		0.541^{++}	0.814^{++}	0.606^{++}	-0.3622^{+}	0.042	0.426^{++}	-0.317	0.601^{++}
	r e	0.206^{+}	-0.026		0.020	-0.114	0.178	0.053	0.120	0.049	-0.140	0.085
Number of racemes/ plant	r f	0.811**	0.685**	0.519**		0.623**	0.913**	-0.4585*	-0.139	0.572**	-0.635**	0.852**
	r g	0.815^{++}	0.689^{++}	0.525^{++}		0.632^{++}	0.919^{++}	-0.468^{+}	-0.145	0.590^{++}	-0.656^{++}	0.864^{++}
	r e	0.266	0.159	0.018		0.298^{+}	0.779^{+}	0.103	0.311	-0.136	0.245	0.256
Number of days to maturity	r f	0.707**	0.784**	0.796**	0.620**		0.733**	-0.3313	0.187	0.576**	-0.415*	0.748**
	r g	0.714^{++}	0.793^{++}	0.810^{++}	0.630^{++}		0.740^{++}	-0.3341^{+}	0.190	0.586^{++}	-0.42^{++}	0.755^{++}
	r e	0.109	0.177	0.021	0.006		0.285	-0.159	-0.083	0.098	-0.158	0.291^{+}
Number of pods/plant	r f	0.962**	0.782**	0.562**	0.897**	0.722**		-0.4167*	-0.096	0.609**	-0.598**	0.986**
	r g	0.964^{++}	0.785^{++}	0.568^{++}	0.902^{++}	0.730^{++}		-0.4209^{+}	-0.099	0.618^{++}	-0.607^{++}	0.988^{++}
	r e	0.111	0.135	-0.040	0.222	0.050		0.268	0.358	-0.073	0.181	0.553^{++}
Pod width	r f	-0.298	-0.055	-0.341	-0.445*	-0.230	-0.352		-0.114	-0.416*	0.398*	-0.436*
	r g	-0.299	-0.054	-0.343^{+}	-0.447^{+}	-0.233	-0.354^{+}		-0.114	-0.421^{++}	0.402^{+}	-0.440^{++}
	r e	-0.020	-0.083	-0.161	-0.094	0.032	0.129		-0.109	0.033	-0.004	0.294
Pod length	r f	-0.064	0.118	0.054	-0.058	0.178	-0.043	-0.129		0.355	0.266	-0.064
	r g	-0.065	0.118	0.055	-0.062	0.180	-0.044	-0.130		0.362*	0.266	-0.063
	r e	0.362	0.282	0.001	0.579^{++}	0.028	0.547^{+}	0.094		-0.353^{+}	0.353^{+}	-0.241
Number of seeds/pod	r f	0.507**	0.386*	0.276	0.649**	0.490**	0.596**	-0.439*	0.352		-0.378	0.657**
	r g	0.512^{++}	0.391^{+}	0.286	0.656^{++}	0.499^{+}	0.603^{++}	-0.445^{+}	0.355^{+}		-0.381^{+}	0.663^{++}
	r e	-0.102	0.005	-0.306^{+}	0.120	-0.026	-0.178	0.086	0.103		-0.182	0.201
100-seed weight	r f	-0.441*	-0.195	-0.289	-0.616**	-0.330	-0.556**	0.378	0.266	-0.441*		-0.585**
	r g	-0.448^{++}	-0.196	-0.295	-0.629^{++}	-0.337^{+}	-0.566^{++}	0.388^{+}	0.271	-0.454^{+}		-0.589^{++}
	r e	-0.056	-0.171	-0.051	0.000	-0.056	0.002	-0.293	-0.046	0.075		-0.249
Seed weight/ plant	r f	0.969**	0.772**	0.553**	0.862**	0.737**	0.983**	-0.370	-0.029	0.641**	-0.557**	
	r g	0.972^{++}	0.776^{++}	0.558^{++}	0.867^{++}	0.744^{++}	0.985^{++}	-0.372^{+}	-0.030	0.648^{++}	-0.563^{++}	
	r e	-0.066	0.193	0.023	0.193	0.256^{+}	0.526^{++}	0.087	0.306^{+}	0.090	-0.386^{++}	

** and *significant at 1 and 5% probability level against tabulated Pearson's-r value, ++ and +significant at 1 and 5% by the bootstrap method with 1000 simulations.

between seed yield and plant height (Karasu & Oz, 2010, Ahmed & Kamaluddin, 2013, Akhshi et al., 2015, Gonçalves et al., 2017 and Panchbhaiya et al., 2017), number of pods per plant (Karasu & Oz, 2010, Sadeghi et al., 2011, Ahmed & Kamaluddin, 2013, Cokkizgin et al., 2013, Akhshi et al., 2015, Panchbhaiya et al., 2017, and Razvi et al., 2018), number of seeds per pod (Karasu & Oz, 2010, Sadeghi et al., 2011, Ahmed & Kamaluddin, 2013, Cokkizgin et al., 2013, Akhshi et al., 2015, Ejara et al., 2017, Panchbhaiya et al., 2017, and Razvi et al., 2018), number of days to flowering (Ahmed & Kamaluddin, 2013, Akhshi et al., 2015, and Panchbhaiya et al., 2017), number of days to maturity (Akhshi et al., 2015 and Panchbhaiya et al., 2017), and number of racemes per plant (Panchbhaiya et al., 2017).

In contrast to our findings, negative correlations have been reported between seed yield and plant height (Sadeghi et al., 2011, Kulaz & Ciftci, 2013, Önder et al., 2013, and Ejara et al., 2017), number of pods per plant (Önder et al. 2013 and Ejara et al., 2017), and both of number of days to flowering and number of days to maturity (Sadeghi et al., 2011 and Razvi et al., 2018).

Pod width had negative correlations with all traits except with 100-seed weight in both years, also pod length showed negative correlations with plant height, number of racemes per plant, number of pods per plant, pod width and seed yield per plant while it had positive correlations with the remaining traits. In addition, 100-seed weight had negative correlations with all traits except that with pod width and pod length, while all remaining correlation coefficients either phenotypic or genotypic among the other traits, were positive in both years.These results suggest that the selection for longer pods, wider pods, or greater weight of 100 seeds, will lead to a decrease in seed yield per plant.

In this respect, Panchbhaiya et al. (2017) found negative correlation between seed yield and pod length. Also, Gonçalves et al. (2003), Singh and Singh (2013) and Akhshi et al. (2015) reported negative correlations between 100-seed weight and seed yield. On the contrary, positive correlations have been found between seed yield and each of pod width (Karasu & Oz, 2010 and Panchbhaiya et al., 2017), pod length (Karasu & Oz, 2010, Sadeghi et al., 2011, Ahmed & Kamaluddin, 2013, Cokkizgin et al., 2013, Akhshi et al., 2015, Gonçalves et al., 2017, and Razvi et al., 2018), 100-seed weight (Sadeghi et al., 2011, Cokkizgin et al., 2013, Gonçalves et al., 2017 and Razvi et al., 2018), and 1000-seed weight (Karasu & Oz, 2010, Önder et al., 2013, Ejara et al., 2017 and Panchbhaiya et al., 2017).

The results demonstrated that the traits which had the highest correlations with seed yield per plant were plant height and number of pods per plant, which exhibited both phenotypic and genotypic correlations coefficients higher than 0.90. Also, number of leaves per plant, number of racemes per plant and number of mature pods per plant showed strong positive correlation coefficients higher than 0.70 with seed yield, suggesting the possibility to increase seed yield by indirect selection of such traits.

Path analysis

The correlation coefficient is useful for measuring the degree and direction of association between traits. However, it can generate deceptive results because the high degree of correlation between two traits may happen due to the indirect effect of a third one (Cruz et al., 2012) (as cited in Machado et al., 2017). Consequently, it is necessary to examine the cause and effect relationship between variables. Path analysis splits the correlation coefficient between traits into direct and indirect effects using main and explanatory variables (Ahmed and Kamaluddin, 2013). In our study, we considered seed yield per plant as the dependent variable and the other traits as independent ones.

Data in Table 3 illustrate the results of the path coefficients of direct and indirect effects at the genotypic level of studied traits on seed yield per plant. In the first year, number of pods per plant had maximum positive direct effect (0.6224) followed by plant height (0.4012), number of seeds per pod (0.0895) and number of days to maturity (0.0629) with a contribution of 62.97%, 40.81%, 13.5% and 8.33 % of the genotypic correlation of each trait respectively with seed yield per plant.While, in the second year, the maximum positive direct effects were obtained by plant height (0.5778), number of pods per plant (0.3731), number of days to maturity (0.1582) and number of seeds per pod (0.1203), with a contribution of 59.43%, 37.89%, 21.27% and 18.58% respectively, which suggest the importance of these traits as selection criteria for high seed yield in common bean. On the contrary, number of leaves per plant, number of days to flowering and number of racemes per

TABLE 3. Genotypic path coefficient analysis of seed yield and related traits in 27 common bean accessions evaluated in 2016 (Y1) and 2017 (Y2) summer seasons, Diagonal (bold) values indicate direct effects whereas values of upper and lower diagonal indicate indirect effects

Traits	year	Plant height	Number of leaves/plant	Number of days to flowering	Number of racemes/ plant	Number of days to maturity	Number of pods/plant	Pod width	Pod length	Number of seeds/pod	100-seed weight	Genotypic correlation with seed yield/plant
Plant height	Y1	**0.4012**	-0.0249	-0.0227	-0.1024	0.0448	0.6011	0.0151	0.0017	0.0516	0.0175	0.9830
	Y2	**0.5778**	-0.0886	-0.0442	-0.0310	0.1130	0.3596	0.0042	0.0016	0.0616	0.0181	0.9721
Number of leaves/ plant	Y1	0.3537	**-0.0283**	-0.0215	-0.0882	0.0454	0.5185	0.0069	-0.0002	0.0414	0.0120	0.8396
	Y2	0.4809	**-0.1065**	-0.0437	-0.0262	0.1254	0.2929	0.0008	-0.0028	0.0470	0.0079	0.7757
Number of days to flowering	Y1	0.2326	-0.0155	**-0.0392**	-0.0688	0.0512	0.3770	0.0154	-0.0007	0.0383	0.0111	0.6014
	Y2	0.3262	-0.0595	**-0.0783**	-0.0200	0.1282	0.2117	0.0049	-0.0013	0.0344	0.0119	0.5582
Number of racemes/plant	Y1	0.3228	-0.0196	-0.0212	**-0.1273**	0.0397	0.5717	0.0199	0.0024	0.0528	0.0231	0.8643
	Y2	0.4708	-0.0734	-0.0411	**-0.0380**	0.0996	0.3364	0.0063	0.0015	0.0789	0.0254	0.8666
Numberof days to maturity	Y1	0.2857	-0.0204	-0.0319	-0.0805	**0.0629**	0.4607	0.0142	-0.0031	0.0524	0.0148	0.7548
	Y2	0.4125	-0.0844	-0.0634	-0.0239	**0.1582**	0.2722	0.0033	-0.0043	0.0601	0.0136	0.7438
Number of pods/ plant	Y1	0.3876	-0.0236	-0.0238	-0.1169	0.0465	**0.6224**	0.0179	0.0016	0.0553	0.0213	0.9884
	Y2	0.5570	-0.0836	-0.0444	-0.0343	0.1154	**0.3731**	0.0050	0.0011	0.0726	0.0229	0.9847
Pod width	Y1	-0.1426	0.0046	0.0142	0.0596	-0.0210	-0.2620	**-0.0425**	0.0019	-0.0377	-0.0141	-0.4396
	Y2	-0.1727	0.0058	0.0269	0.0170	-0.0368	-0.1321	**-0.0142**	0.0031	-0.0535	-0.0157	-0.3723
Pod length	Y1	-0.0415	-0.0004	-0.0016	0.0184	0.0119	-0.0614	0.0048	**-0.0164**	0.0323	-0.0093	-0.0631
	Y2	-0.0376	-0.0125	-0.0043	0.0024	0.0285	-0.0165	0.0018	**-0.0239**	0.0427	-0.0109	-0.0304
Number of seeds/ pod	Y1	0.2314	-0.0131	-0.0168	-0.0751	0.0368	0.3847	0.0179	-0.0059	**0.0895**	0.0134	0.6629
	Y2	0.2959	-0.0416	-0.0224	-0.0250	0.0790	0.2251	0.0063	-0.0085	**0.1203**	0.0184	0.6475
100-seed weight	Y1	-0.1999	0.0096	0.0124	0.0836	-0.0264	-0.3780	-0.0171	-0.0044	-0.0341	**-0.0351**	-0.5894
	Y2	-0.2590	0.0209	0.0231	0.0239	-0.0533	-0.2112	-0.0055	-0.0065	-0.0546	**-0.0404**	-0.5627

The residual effect in 2016 = 0.02 and in 2017 = 0.07

plant had negative direct effects, which indicate that the selection based only on these traits, will decrease the seed yield per plant.

Plant height and number of pods per plant had the largest positive direct effect on seed yield per plant along with the largest genotypic correlations. The traits which have high positive correlation and high positive direct effects are expected to be useful selection criteria in selection programs. Thus, the higher seed yield may be obtained from the direct selection of such traits.

All traits had high positive indirect effects through plant height and number of pods per plant in the two years of study except pod width, pod length and 100-seed weight which had negative indirect effects. Although, number of leaves per plant, number of days to flowering and number of racemes per plant had negative direct effects on seed yield per plant, they had high positive indirect effects through plant height and number of pods per plant which nullifies their negative effects, so, they were related to the seed yield mostly by their positive indirect effects resulting in high positive genotypic correlations. In case of negative direct effect along with positive correlation coefficient, it means that the indirect effects are the cause of positive correlation and the simultaneous selection should be considered (Singh and Chaudhary, 1985). As a consequence, the selection based only on number of leaves per plant, number of days to flowering or number of racemes per plant will not be useful, as it will lead to the selection of accessions with lower seed yield and hence, the simultaneous selection of these traits accompanied by plant height or number of pods per plant is recommended.

Overall, to improve seed yield in common bean, the path analysis suggests the direct selection of plant height, number of days to maturity, number of pods per plant, or number of seeds per pod. Whereas, simultaneous selection with either plant height or number of pods per plant, should be considered for number of leaves per plant, number of days to flowering, or number of racemes per plant.

In this respect, many researchers found positive direct effects on seed yield for plant height (Karasu & Oz, 2010, Kulaz & Ciftci, 2013, Önder et al., 2013, Ejara et al., 2017, and Gonçalves et al., 2017), number of days to flowering (Raffi and Nath, 2004), number of days to maturity (Kulaz and Ciftci, 2013), number of pods per plant (Gonçalves et al., 2003, Raffi & Nath, 2004, Karasu & Oz, 2010, Ahmed & Kamaluddin, 2013, Kulaz & Ciftci, 2013, Ambachew et al., 2015, and Ejara et al., 2017), number of seeds per pod (Gonçalves et al., 2003, Karasu & Oz, 2010, Salehi et al., 2010, Ahmed & Kamaluddin, 2013, Önder et al., 2013, Akhshi et al., 2015, Ambachew et al., 2015, and Ejara et al., 2017), and 100 or 1000 seed weight (Karasu & Oz, 2010, Kulaz & Ciftci, 2013, Akhshi et al., 2015, Ejara et al., 2017 and Gonçalves et al., 2017).

On the contrary, negative direct effects on seed yield have been reported for plant height (Raffi & Nath, 2004 and Ahmed & Kamaluddin, 2013), number of leaves per plant (Önder et al., 2013), number of days to flowering (Önder et al., 2013 and Gonçalves et al., 2017), number of days to maturity (Raffi and Nath, 2004), number of pods per plant (Önder et al., 2013 and Gonçalves et al., 2017), number of seeds per pod (Kulaz & Ciftci, 2013 and Gonçalves et al., 2017), pod width (Karasu and Oz, 2010), pod length (Ejara et al., 2017), and 100 or 1000 seed weight (Önder et al., 2013 and Ahmed & Kamaluddin, 2013). The likely causes of contradictory results might due to different accessions involved in each study, different environmental conditions and the difference of the studied parameters.

The residual effect shows how much the explanatory variables represent the variability of the dependent variable (Singh and Chaudhary, 1985). The residual effect in our study at the genotypic path coefficient was 0.02 and 0.07 in the first and the second year, respectively, so the effects of studied traits explain 98 % and 93% of the variability in the seed yield in both years respectively and show that we did not consider few traits which are related to seed yield. In this regard, Ejara et al. (2017) found high residual effects both at phenotypic (45.82%) and genotypic (51.3%) levels.

Conclusion

This study suggested the indirect selection for plant height, number of pods per plant, number of seeds per pod, and number of days to maturity. Whereas, simultaneous selection with plant height or number of pods per plant will be suitable for number of leaves per plant, number of days to flowering and number of racemes per plant to select accessions with high seed yield potential in common bean.

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Conflicts of interest

The authors declare that there are no conflicts of interest related to the publication of this study.

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الارتباط ومعامل تحليل المسار لمحصول البذور وبعض الصفات المتعلقة به في الفاصوليا العادية

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تعد الفاصوليا واحدة من أهم محاصيل الخضر المنزرعة في مصر. أجريت هذه الدراسة لقياس معاملات الارتباط المظهرى والوراثي والبيئى بين محصول البذور وبعض الصفات المتعلقه به وكذلك لعمل تحليل المسار لتقدير التأثيرات المباشرة وغير المباشرة بين محصول البذور للنبات كمتغير تابع وباقي الصفات كمتغيرات مستقلة. لذلك تم تقييم سبعة وعشرين تركيبا وراثيا من الفاصوليا العادية في قرية الدلجمون بمحافظة الغربيه بمصر خلال الموسمين الصيفيين لعامى ٢٠١٦ و٢٠١٧ باستخدام تصميم القطاعات كامله العشوائية فى ثلاثة مكررات. أوضحت النتائج أهمية معاملات الارتباط الوراثي مقارنة بنظيرتها من معاملات الارتباط المظهري. كانت معاملات الارتباط الوراثى موجبة وتراوحت من ٠,٦٠ إلى ٠,٩٩ فيمايخص الارتباط بين محصول البذور للنبات وكل من طول النبات، عدد الأوراق/النبات، عدد الأيام حتى التزهير، عدد النورات للنبات، عدد الأيام حتى النضج، عدد القرون/نبات، وعدد البذور في القرن.

أثبت معامل تحليل المسار على المستوى الوراثي أهمية التأثيرات المباشرة الموجبة لكل من طول النبات، عدد القرون/نبات، عدد الأيام حتى النضج، وعدد البذور في القرن مما يقترح معه الانتخاب المباشر لهذه الصفات لتحسين محصول البذور وعلى الجانب الآخر فإن صفات عدد الأوراق/نبات، عدد الأيام حتى التزهير، أو عدد النورات/نبات يجب أن يتضمنهم انتخاب متزامن مع صفتى طول النبات أوعدد القرون/نبات، لما لهذه الصفات من تأثيرات غير مباشرة عالية وموجبة على محصول البذور من خلال هاتين الصفتين.