Original Article

CONTRIBUTION OF MORPHOLOGICAL TRAITS FOR GRAIN YIELD IN COMMON BEAN

CONTRIBUIÇÃO DE CARACTERES MORFOAGRONÔMICOS PARA PRODUTIVIDADE DE GRÃOS EM FEIJOEIRO COMUM

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ABSTRACT: In Brazil, the common bean crop has representative agricultural exploitation, not only because of its production economic value, but also because there is a large cultivation area. This research aimed to investigate the direct and indirect relationship of morphological components on grain yield in common bean plants. This study was carried out in a Quartzarenic Neosol in the municipality of Cassilândia, Mato Grosso do Sul State, Brazil, in the agricultural year of 2016/2017. The evaluated traits were: grains yield (GY) with its primary components; mass of one hundred grains (HG); number of grains per plant (GP); number of grains per pod (GPP); dry weight of aerial parts (DWA); number of pod per plant (PP); plant dry mass (DM); plant high (PH); and stem diameter (SD). Initially, the Pearson's correlation among these traits was estimated and the correlation network was used to graphically express the obtained results. Analysis of these data through the statistical techniques of multicollinearity diagnosis followed by path analysis enabled to verify that the number of pod per plant, the mass of one hundred grains, and the number of grains per plant, among the primary components of grain yield, are the traits of greater potential to select and identify superior genotypes for grain productivity yield, and that dry matter and stem diameter traits showed a negative correlation with grain yield in common bean grains.

KEYWORDS: Path analysis. Genetic improvement. *Phaseolus vulgaris* L.

INTRODUCTION

The common bean plant (*Phaseolus vulgaris* L.) is cultivated in practically whole Brazilian territory. It is recognized as excellent protein, vitamins, minerals, and fibers source that nourish and reduce diseases incidence, besides being a food component of the Brazilian diet. Considering the 2016/2017 harvest, it is estimated that the total area of common bean plant will be increased to 3,078 thousand hectares, 8.5% higher than the previous harvest. The common bean national production is expected to be 3,285.3 thousand tons, 30.7% higher than the last season with the average productivity of 1.07 tons per hectare (CONAB, 2017).

Currently, common bean breeding programs in Brazil have aimed to increase grain yield, in addition to other desirable characteristics such as shorter cooking time and resistance to pests and diseases. For this purpose, it is needed to use adequate breeding strategies, since many crosses are carried out per year in each breeding program. For each crossing, many plants are obtained and one of them may contain the desirable genetic constitution (TSUTSUMI et al., 2015).

Due to these objectives, some traits are evaluated on each plant. However, some traits are more difficult to measure than others, and among these traits, grain yield is highlighted. To evaluate them, it is needed that the plants are in generations with high homozygosis and have the possible largest number of replicates. Therefore, to define the success of an improvement program, it is important to find other traits that can be used indirectly to select more productive common bean genotypes (TSUTSUMI et al., 2015). Estimating correlations among traits is a technique widely used by breeders. However, the correlation between two variables can be influenced by a third variable or by a variables' group. To remove the effect of these other variables, path analysis is the most appropriate technique. It allows unfolding the correlation coefficient between two variables in direct and indirect effects. The variable to be used as indirect selection criterion should have high correlation with the main dependent variable, high direct effect, and the same correlation sense, besides being easier to measure (CRUZ et al., 2012).

The path analysis has been used by many authors in various crops of economic importance such as cotton (FARIAS et al., 2016), sorghum (SILVA et al., 2017a), sugarcane (SILVA et al., 2017b), soybean (TEODORO et al., 2015), and corn (TEODORO et al., 2014).

Therefore, the objective of this study was to evaluate a relationship between the morphological

Received: 31/07/17
Accepted: 05/12/17

traits and grain yield of the bean plant, in order to indicate criteria for direct selection.

MATERIAL AND METHODS

This work was developed in the irrigated area of a center pivot, at the vicinity of the 356,381.383 m and 7,893,667.280 m [Universal Transverse Mercator (UTM)] geographic coordinates, from Flor Jardim Farm, municipality of Cassilândia, Mato Grosso do Sul, Brazil. The average annual rainfall is 1,500 mm and the average temperature is 24.2°C. The climatic type is Aw, according to Köppen classification, characterized as humid tropical with rainy season in the summer, and dry season in the winter.

The x and y directions of the Cartesian coordinate system were defined and the experimental mesh was staked close to the common bean seed maturation, that is, in the first ten-day period of October/2016, spaced 6.0 m apart. Each experimental mesh was consisted of nine transects of 48.0 m x 48.0 m. Therefore, the transects had 6.0 m spacing with 6.0 m x 6.0 m squared sample points, containing 81 points. However, points with smaller spacings than those mentioned were spaced inside the large mesh, with 2.0 m spacing among them (mesh with higher density). As in this case it was 36 points, the total of sampling points in the data network was 117.

The soil in which the experimental meshes were installed was classified according to the Brazilian Soil Classification System. It is a Neosolo Quartzarenic orthic latosolic, very sandy texture. In the crop management area, with no-tillage system in irrigated area, only the weed desiccation prior to the common bean planting, with an application of 2.0 kg ha^{-1} of glyphosate herbicide, and the area was prepared on 8 and 9 July 2016. On 10 July 2016, the Elite common bean cultivar was sown at 0.45 m rows spacing, with density of 246,914 plants per hectare. For this procedure, 11 seeds on average were used per meter of sowing. Harvesting was performed after 100 days sowing.

The evaluated morphological traits were: grain yield (GY) obtained by the values transformed to the standardized conditions of 0.13 kg kg^{-1} humidity, represented in kg ha^{-1}; mass of hundred grains (HG) obtained by weighing one hundred random common bean grains of sample in g; number of grains per plant (GP); number of grains per pods (GPP); number of pods per plant (PP); dry weight of aerial parts (DWA), 100 grains in gram, determined by placing the plants at the sun for 10 days, and then removed to a greenhouse at 650°C for 48 h, when practically dry; plant height (PH), in centimeters, dimensioned by measuring the distance from the hypocotyl to the last growth point of the plant; and the stem diameter (SD) in millimeters, which was determined by measuring the hypocotyl diameter of the plant with a digital caliper.

The determined morphological traits were collected individually around each sampling point, which usually consisted of the data collection of the plant positioned in the center and of its surrounding areas. This collection representative area was 3.20 m^2 with 4 plant rows (1.80 m x 1.80 m). All the plants originated around the stained sampling point were collected.

To graphically express the functional relationship among the correlations estimates among the traits, a correlation network was used, in which the proximity among nodes (traces) was proportional to the absolute value among their correlation. The edges' thickness was controlled by applying a cut-off value of 0.50, which meant that only $|rij| \geq 0.50$ had their edges highlighted. Finally, the positive correlations were represented in green, whereas the negative correlations were represented in red.

Subsequently, two path analyses were carried out: (a) the first analyses considered YIE as the principal dependent variable (Y); and (b) the second analyses considered the model described in Equation 1 and Figure 1:

$$Y = p1X1 + p2X2 + ... + pnXn + p\varepsilon u \quad (1)$$

in which, Y is the principal dependent variable (YIE or FLO); X1, X2, ..., xn are the independent explanatory variables; and p1, p2, ..., pn are the path analysis coefficients, according Figure 1. The coefficient of determination (R2) was calculated by Equation 2:

$$R^2 = p1y2 + p2y2 + ... 2p2yp2nr2n \quad (2)$$

The multicollinearity degree of the X'X matrix was established on the basis of its number of conditions (NC), which is the ratio between the largest and the smallest eigenvalue of the matrix (MONTGOMERY et al., 2001). If NC <100, the multicollinearity is considered weak and it is not a problem for analysis; if 100 ≤NC ≤1,000, the multicollinearity is considered moderate to strong; and if NC >1,000, the multicollinearity is considered strong. All statistical analyses were carried out with the GENES software (CRUZ, 2013).

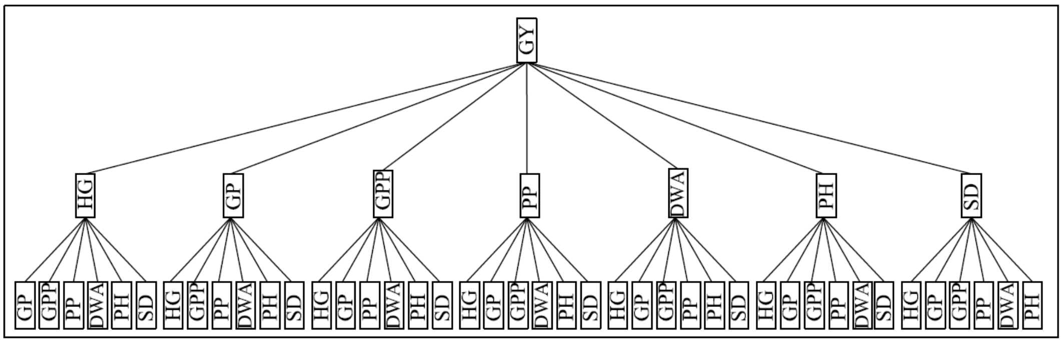

Figure 1. Causal chain diagram showing the relationship of morphological traits: (a) mass of hundred grains (HG); (b) number of grains per plant (GP); (c) number of grains per pods (GPP); (d) number of pods per plant (PP); (e) dry weight of aerial parts (DWA); (f) plant height (PH); (g) stem diameter (SD); and those traits on the grain yield (GY) variable of the performed trail analysis

RESULTS AND DISCUSSION

Figure 2 expresses Pearson's correlation network among morphological traits and grain yield. The efficiency of this innovative technique has already been verified by DiLeo et al. (2011) and Silva et al. (2017a, 2017b). The obtained estimates ranged from -0.0451 to 0.9497. There was a high and positive correlation between the number of pods per plant and the number of grains per plant. In addition, these traits showed high correlation with grain yield. Equivalent results were obtained in other works with the common bean crop. Montanari et al. (2013), studying the correlation between common bean production and plant attributes in an Oxisol soil in Mato Grosso do Sul, also found a high and positive correlation between the number of pods per plant (0.271) and the number of grains per plant (0.429).

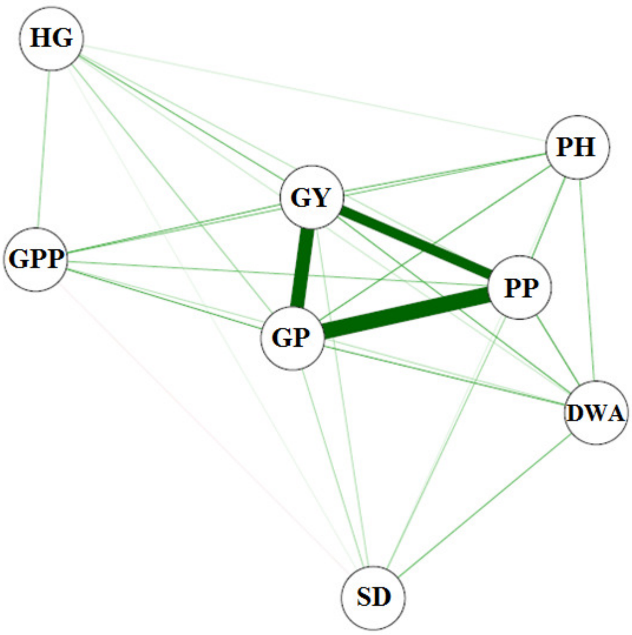

Figure 2. Correlations network of morphological traits: (a) grain yield (GY); (b) mass of hundred grains (HG); (c) number of grains per plant (GP); (d) number of grains per pods (GPP); (e) number of pods per plant (PP); (f) dry weight of aerial parts (DWA); (g) plant height (PH); and (h) stem diameter (SD).

The remaining traits had a low correlation with each other. In accordance with Coimbra et al. (1999), the correlations are generally explained by the additive effect of the genes, affecting two traits simultaneously, thus, showing to be important to know the association degree among agronomic traits, mainly because the selection on a certain trait can come to change the behavior of the other.

Thus, although important, the Pearson's correlation coefficient can produce wrong results about the relation between two traits, and it does not have to be a real measure of cause and effect. The strength of the correlation coefficient between two traits may be the result of an effect by a third trait or group of traits on the traits, not resulting in the exact relative importance of the direct and indirect effects by the factors being analyzed (CRUZ et al., 2012).

For these reasons, a path analysis is carried out, investigating the cause-effect relationship. Teodoro et al. (2014) state that this analysis provides a detailed knowledge of the traits' influence, and justify the existence of positive and negative correlations of high and low magnitude among the studied traits. However, for obtaining direct and indirect effects by path analysis, it is needed that the X'X matrix be well conditioned. In the presence of multicollinearity, the variances associated with the estimators of the path coefficients can become excessively high, making the analysis unreliable. In addition, the parameter estimates can accept absurd or nonsense values in relation to the studied biological phenomenon (CRUZ et al., 2012). According to the NC criterion presented by Montgomery and Peck (2001), the estimate matrix of the phenotypic correlations obtained here showed strong multicollinearity (NC=181). Thus, in the presence of multicollinearity, all the evaluated traits in the path analysis could be included, but a constant (k=0.05) should be added to the correlation matrix diagonal for solving the multicollinearity problem. This constant caused the correlation matrix determinant to be nonzero (Figure 3).

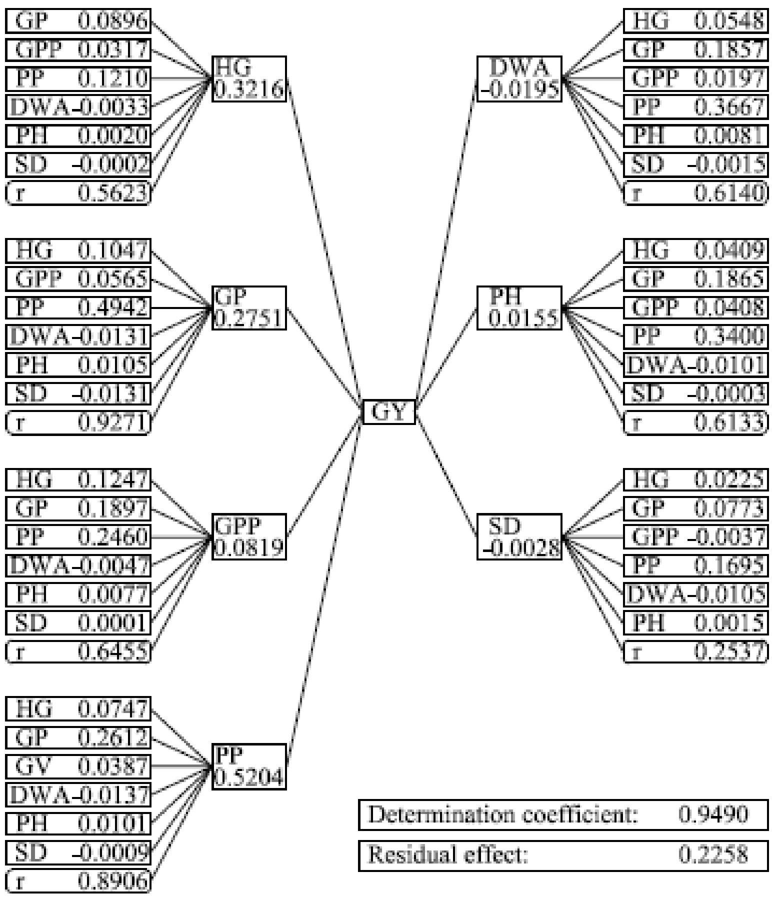

Figure 3. Path analysis among morphological traits: (a) mass of hundred grains (HG); (b) number of grains per plant (GP); (c) number of grains per pods (GPP); (d) number of pods per plant (PP); (e) dry weight of aerial parts (DWA); (f) plant height (PH); (g) stem diameter (SD); (h) and (i) those traits on the grain yield variable (GY)

In this work, a more didactic scheme was proposed for expressing the results of path analysis. In this scheme, it is possible to verify that the variable that had the greatest direct effect on productivity was the number of pods per plant, followed by the mass of one hundred grains and number of grains per plant. Considering the above criteria, for a variable to be useful for direct selection, it is needed that it has high correlation and direct effect in the same sense with grain yield. Therefore, the variables number of pods per plant and mass of one hundred grains are the most adequate for the indirect selection of more productive common bean plants, since they have a cause and effect relationship with grain yield.

A high determination coefficient (0.9490) was obtained, which was higher than that one obtained in other studies, employing path analysis in common bean plants. Cabral et al. (2011), studying path analysis of grain yield of common bean plants and its components, found 0.3752 determination coefficient. This result suggests that the genetic effects related to the main dependent variable (grain yield) are very well explained by the model.

CONCLUSION

The number of pod per plant, the mass of one hundred grains, and the number of grains per plant, among the primary components of grain yield, are the traits of greater potential to select and identify superior genotypes for grain yield in common bean, and that dry matter and stem diameter traits showed a negative correlation with grain yield in common bean grains.

RESUMO: No Brasil, a cultura do feijoeiro tem uma exploração agrícola representativa, não só por seu valor econômico de produção, mas também porque existe grande área de cultivo. Este trabalho teve como objetivo investigar a relação direta e indireta de componentes morfológicos no rendimento de grãos nas plantas de feijão comum. Este estudo foi realizado em Neossolo Quartzarênico no município de Cassilândia, Estado de Mato Grosso do Sul, no ano agrícola de 2016/2017. As características avaliadas foram: produtividade de grãos (GY) com seus componentes primários; massa de cem grãos (HG); número de grãos por planta (GP); número de grãos por vagem (GPP); massa seca da parte aérea (DWA); número de vagens por planta (PP); massa seca da planta (DM); altura de planta (PH); e diâmetro do caule (SD). Inicialmente, a correlação de Pearson entre esses caracteres foi estimada e a rede de correlação foi usada para expressar graficamente os resultados obtidos. A análise desses dados através do diagnóstico de multicolinearidade seguida de análise de trilha permitiu verificar que o número de vagens por planta, a massa de cem grãos e o número de grãos por planta, entre os principais componentes do rendimento de grãos, são os caracteres de maior potencial para selecionar e identificar genótipos superiores para a produtividade de grãos no feijoeiro e que a matéria seca e o diâmetro do caule mostraram uma correlação negativa com a produtividade de grãos em grãos.

PALAVRAS-CHAVE: Análise de trilha. Melhoramento genético. *Phaseolus vulgaris* L.

REFERENCES

CABRAL, P. D. S.; SOARES, T. C. B.; LIMA, A. B. P.; SOARES, Y. J. B.; SILVA, J. A. Análise de trilha do rendimento de grãos de feijoeiro (*Phaseolus vulgaris L.*) e seus componentes. **Revista Ciência Agronômica**, Fortaleza, v. 42, n. 1, p. 132-138, 2011.

CONAB – Companhia Nacional de Abastecimento**. Perspectivas para a agropecuária**. Safra 2016/2017; abril/2017. Brasília: CONAB, 2017. Disponível em: V. 4 - SAFRA 2016/17 - N.7 - Sétimo levantamento | ABRIL 2017

COIMBRA, J. L. M.; GUIDOLIN, A. F.; CARVALHO, F. I. F.; COIMBRA, S. M. M.; MARCHIORO, V. S. Análise de Trilha I: Análise do Rendimento de Grãos e seus Componentes. **Ciência Rural**, Santa Maria, v. 29, n. 02, p. 213-218, 1998.

CRUZ, C. D. GENES: A Software Package for Analysis in Experimental Statistics and Quantitative Genetics. **Acta Scientiarum: Agronomy**, Maringá, v. 35, p. 271-276, 2013. http://dx.doi.org/10.4025/actasciagron.v35i3.21251

CRUZ, C. D.; CARNEIRO, P. C. S.; REGAZZI, A. J. **Modelos biométricos aplicados ao Melhoramento Genético**. 3rd edn. Editora UFV, Viçosa, 2012.

DILEO, M. V., STRAHAN, G. D., BAKKER, M. HOEKENGA, O. A. Weighted correlation network analysis (WGCNA) applied to the tomato fruit metabolome. **PLoS One**, New York, v. 6, p. e26683, 2011. http://dx.doi.org/10.1371/journal.pone.0026683

FARIAS, F. J. C.; CARVALHO, L. P.; SILVA FILHO, J. L.; TEODORO, P. E. Correlations and path analysis among agronomic and technological traits of upland cotton. **Genetics and Molecular Research,** Ribeirão Preto, v. 15, p. 1-8, 2016.

MONTANARI, R.; PELLIN, D. M. P.; CARVALHO, M. P.; GIOIA, M. T.; DALCHIAVAN, F. C.; GONALEZ, A. P. Correlação entre produção de feijão e atributos físicos de um Latossolo em Mato Grosso do Sul. **Revista Ceres**, Viçosa, v. 60, n.6, p. 772-784, 2013.

MONTGOMERY, D. C.; PECK, E. A.; VINING, G. G. **Introduction to Linear Regression Analysis**. New York: wiley, 5th Edition, 2012. 672 p.

SILVA, K. J.; TEODORO, P. E.; MENEZES, C. B.; JULIO, M. P. M.; SOUZA, V. F.; SILVA, M. J.; PIMENTEL, L. D.; BOREM, A. Contribution of morphoagronomic traits to grain yield and earliness in grain sorghum. **Genetics and Molecular Research,** Ribeirão Preto, v. 2, p. 1-8, 2017a.

SILVA, L. A.; TEODORO, P. E.; PEIXOTO, L. A.; ASSIS, C.; GASPARINI, K.; BARBOSA, M. H. P. B. BHERING, L. L. Selecting sugarcane genotypes by the selection index reveals high gain for technological quality traits. **Genetics and Molecular Research,** Ribeirão Preto, v. 2, p. 1-8, 2017b.

TEODORO, P. E.; RIBEIRO, L. P.; CORREA, C. C. G.; LUZ JUNIOR, R. A. A.; ZANUNCIO, A.; CAPRISTO, D. P.; TORRES, F. E. Path analysis in soybean genotypes as function of growth habit. **Bioscience Journal (Online)**, Uberlândia, v. 31, p. 794-799, 2015.

TEODORO, P. E.; SILVA JUNIOR, C. A.; CORRÊA, C. C.; RIBEIRO, L. P.; OLIVEIRA, E.P.; TORRES, F.E. Path analysis and correlation of two genetic classes of maize (*Zea mays* L.). **Journal of Agronomy**, New York, v. 13, p. 23-28, 2014.

TSUTSUMI, C. Y.; BULEGON, L. G.; PIANO, J. T. Melhoramento genético do feijoeiro: avanços, perspectivas e novos estudos, no âmbito nacional. **Nativa**, Sinop, v. 03, n. 03, p. 217-223, 2015. http://dx.doi.org/10.3923/ja.2014.23.28.