Morphological traits and yield in common bean

Características morfológicas e produtividade do feijão-comum

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Abstract

It is necessary to explore the relationship between yield-related traits to define the appropriate selection procedures to improve bean yield. The relationships between yield and its components have been extensively investigated by common bean breeding programs. However, less attention has been given to morphological and physiological traits. This study evaluates the effects of morphological traits of bean plants on their yield. Forty-one carioca genotypes were evaluated in a randomized block design with three replicates. The abscission of flowers, flower buds, and newly formed pods was monitored and specific leaf mass, leaflet area, average length and thickness of racemes and peduncles, 100-grain weight, number of pods per plant, and yield were determined. Yield responded negatively to increases in raceme and peduncle length and number of pods per plant and positively to increases in peduncle thickness and grain weight. Genotypes differed regarding yield and grain weight and were divided into two groups by the Scott-Knott's test considering yield. The most productive group showed increased abscission of flowers and newly formed pods, decreased number of pods, and increased grain weight. The most productive genotypes were those that remobilized photoassimilates more easily for having shorter racemes and peduncles, thicker peduncles, and decreased expenditure of structural carbohydrates with malformed pods and other structures required for conditioning grains in the plant, compensating with greater grain weight.

Additional keywords: abscission of flowers and pods; leaf area; raceme and peduncle length; specific leaf mass; *Phaseolus vulgaris L.*

Resumo

É necessário explorar a relação entre produtividade e características relacionadas, para definir os procedimentos de seleção adequados para melhorar a produtividade do feijoeiro. As relações da produtividade com seus componentes produtivos têm sido amplamente investigadas por programas de melhoramento de feijão-comum, contudo menor atenção tem sido dada às características morfológicas e fisiológicas. O trabalho objetivou avaliar os efeitos de características morfológicas das plantas de feijoeiro sobre sua produtividade. Foram avaliados 41 genótipos do tipo carioca, no delineamento experimental de blocos casualizados, com três repetições. Monitorou-se a abscisão de flores, de botões florais e de vagens recém-formadas e determinou-se a massa foliar específica, área foliar dos folíolos, comprimento e espessura média dos racemos e pedúnculos, massa de 100 grãos, número de vagens por planta e produtividade. A produtividade respondeu negativamente ao aumento no comprimento dos racemos e dos pedúnculos e ao número de vagens por planta, e positivamente ao aumento na espessura dos pedúnculos e massa dos grãos. Os genótipos diferiram quanto à produtividade e massa dos grãos e foram divididos em dois grupos pelo teste de Scott-Knott, considerando-se a produtividade. O grupo mais produtivo apresentou maior abscisão de flores e de vagens recém-formadas, menor número de vagens e maior massa de grãos. Os genótipos mais produtivos são aqueles que remobilizam fotoassimilados mais facilmente por apresentarem racemos e pedúnculos mais curtos, pedúnculos mais espessos e menor gasto de carboidratos estruturais com vagens malformadas e outras estruturas demandadas para o acondicionamento dos grãos na planta, compensando com maior massa dos grãos.

Palavras-chave adicionais: abscisão de flores e vagens; área foliar; comprimento de racemo e pedúnculo; massa foliar específica; *Phaseolus vulgaris* L.

Introduction

Increasing bean yield is important for millions of people in developing and developed countries worldwide. Understanding the production physiology of this crop is one of the most important aspects to achieve this objective. Higher yields are only possible when various physiological processes or yield components are appropriately balanced (Fageria & Santos, 2008). Yield improvement is an objective of most crop improvement programs. As in other crops, the grain yield of the common bean is a complex characteristic, consisting of many morphological and physiological traits (Negahi et al., 2014). It has a quantitative nature, being ruled by several major and minor genes, and being affected by variations in environmental factors, hampering direct selection for yield, which may not be successful. Direct selection of another simply inherited trait strongly correlated with yield facilitates selection procedures and lead to the desired progress in breeding programs. Therefore, it is necessary to explore the relationship between yield-related traits to define the appropriate selection procedures to improve bean yield (Al-Ballat & Al-Araby, 2019), which requires good knowledge of the associations of different traits with yield and among traits (Negahi et al., 2014).

Yield traits (number of pods per plant, number of grains per plant, number of grains per pod, 100-grain weight, and grain yield) have been extensively investigated by common bean breeding programs (Ribeiro et al., 2018). However less attention has been given to morphological and physiological traits.

Checa & Blair (2012) found that traits such as raceme length, number of pods per raceme, and pod length are of great importance to improve common beans for high yield. Okii et al. (2014) and Ejara et al. (2017) recommended to consider the number of nodes on the main stem in improvement programs. According to White & Izquierdo (1989), flowers with short peduncles, large cross section, and large leaves, close to storage sites, can increase bean yield by increasing the volume of photoassimilates produced and by reducing the flow resistance of assimilates to storage sites.

Therefore, this study evaluates the effects of morphological traits of the bean plant on its yield.

Material and methods

The experiment was conducted from July to October 2018 in the municipality of Santo Antônio de Goiás, Goiás state, Brazil (16º 30' 13.23" S and 49º 16' 54.73" W). The climate, according to the Köppen's classification system, is Aw, savanna tropical, megathermal.

The randomized block experimental design was used, with three replicates. In the plots, 41 genotypes of the Embrapa common bean breeding program, adapted to the climate and soil conditions of the study site, were evaluated. Sowing was conducted on 7/4/2018 in plots with three rows 3-m long, spaced 0.50 m apart. The usable area consisted of a 2-m long row. The soil of the experimental area is an Acric Red Latosol whose chemical analysis showed the following results: pH (H_2O) = 5.5; Ca = 18.6 mmol$_c$ dm^{-3}; Mg = = 10.4 mmol$_c$ dm^{-3}; Al = 1 mmol$_c$ dm^{-3}; P = 13.4 mg dm^{-3}; K = 48 mg dm^{-3}; Cu = 1.0 mg dm^{-3}, Zn = 11.8 mg dm^{-3}, Fe = 27.8 mg dm^{-3}, Mn = 6.8 mg dm^{-3}. Fertilization was performed with application of 250 kg ha^{-1} of monoammonium phosphate at sowing and topdressing of 80 kg ha^{-1} of N in the V4 stage (third trifoliate leaf open). The other agronomic managements were those recommended for the crop (Carneiro et al., 2015).

The abscission of flowers, flower buds, pods at the beginning of development, and leaf area and mass were monitored. To quantify the abscission of flowers, flower buds, and pods at the beginning of development, 82 collecting nets of 1 x 0.50 m were made with plastic net, string, and iron bar. The collection nets were distributed on 08/09/2018, R5 development stage (pre-flowering), between the rows with plants evenly distributed. The earliest genotypes, 54% of the total, showed the beginning of R6 (flowering) at 32 DAE (days after emergence) and the remainder up to 36 DAE. Collections were conducted every two days from 08/10/2018 until the end of flowering of all plants in the experiment, on 09/14/2018. In order to determine the specific leaf mass (leaf dry matter/leaf area) used to infer carbohydrate accumulation in the leaf, five trifoliates were collected per plot weekly. Trifoliates of the apex of plants that were undamaged and in full development were selected. Trifoliate leaf areas were determined with the aid of the leaf area meter LI 3100. After drying in a forced air circulation oven at 80 ºC for 48 hours, trifoliates were weighed on an analytical balance to determine dry matter.

At the maturation stage, five plants were collected to determine the average length and thickness of racemes and peduncles and the number of pods per plant. In the evaluation of average thickness of racemes and peduncles, the individual average of the largest and the shortest length of the cross section of the center of these plant components was considered. Grain yield and 100-grain weight were also evaluated. The 100-grain weight was determined by the average weight of two samples of 100 grains per plot. Grain yield was determined from the grain mass of the usable area corrected to 13% moisture and expressed in kg ha^{-1}.

Yield and 100-grain weight data were submitted to analysis of variance by F test using the GLM procedure of the SAS statistical program (SAS Institute, 1999). Means were compared by Scott-Knott's test at 0.05 probability level. Regression analyzes were also performed between the variables evaluated.

Results and discussion

The number of grains per raceme increased linearly with raceme length (Figure 1A), which explained 11% of the variability of that number. The greater number of pods in the longest racemes increased the number of grains. Checa & Blair (2012) also found significant and positive correlation between raceme length and number of pods per raceme of common bean. Yamaguchi et al. (2014) found that soybean cultivars with longer racemes had a greater number of pods per raceme. Common bean flowers originate from raceme nodes. Therefore, the longer the raceme length, the greater the number of nodes and consequently the greater the number of flowers, pods, and grains per raceme.

Increase in the number of grains in the raceme and raceme length decreased 100-grain weight (Figure 1B) probably due to decreased photoassimilate availability associated with increased resistance of its flow, which is caused by the longer phloem path of longer racemes. Raceme length explained 16% of the variability of 100-grain weight in the raceme. White & Izquierdo (1989) postulated that long racemes with smaller phloem section increased the flow resistance of photoassimilates to the storage sites, decreasing their availability for accumulation in the grains.

Grain mass decrease in each raceme caused by its increased length decreased 100-grain weight in the plant as a whole (Figure 2A), probably due to the greater number of grains per plant caused by the increased number of pods per plant. Checa & Blair (2012) also observed that the number of pods per plant was positively correlated with the number of pods per raceme. Mismatch was observed between the increase of sites of carbohydrate storage and carbohydrate availability for its fulfillment. As the number of pods per plant and grains per pod increased, grain mass decreased due to limited carbohydrate availability to form the grains present in greater numbers in the plants.
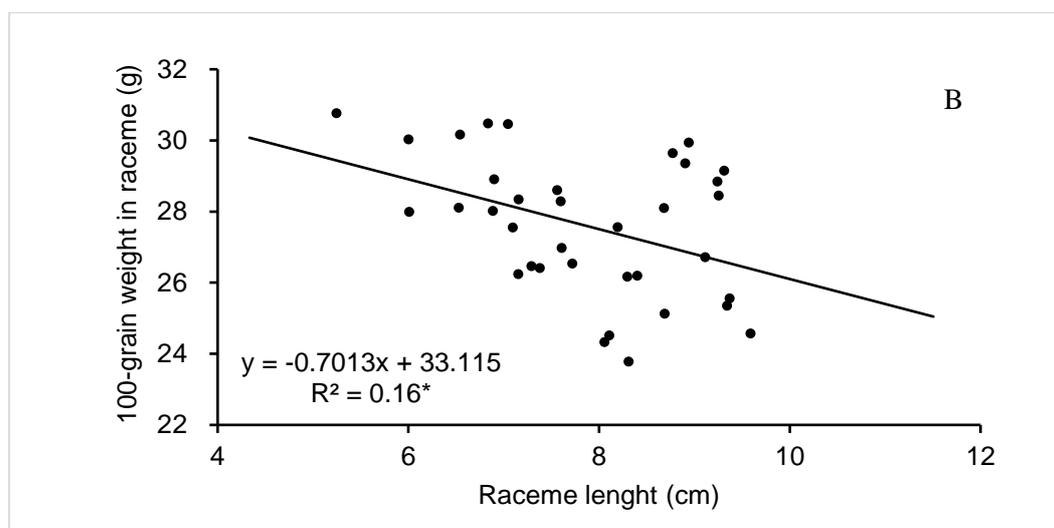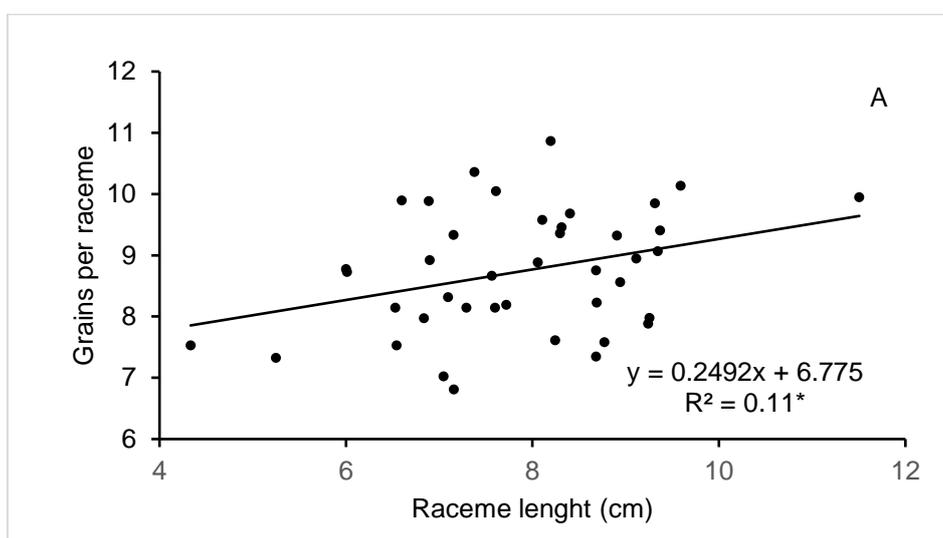

Figure 1 – Effect of raceme length on the number of grains per raceme (A) and on 100-grain weight in raceme (B) of 41 common bean genotypes.

Rana et al. (2015) observed negative correlation between 100-grain weight of beans and number of pods per plant and grains per pod. Okii et al. (2014) observed that the 100-grain weight of beans was negatively correlated with the number of locules formed per pod, while Loko et al. (2018) observed negative correlation of 100-grain weight with the number of grains per pod.

Yield increased linearly as raceme length decreased, explaining 23% of the yield variation of bean

genotypes (Figure 2B). Each decrease of one unit in raceme length resulted in a yield increase of 260 kg ha^{-1}. In contrast to this result, Checa & Blair (2012) observed positive correlation between yield and raceme length, probably for being a study of recombinant lines that had a creole and climbing variety, adapted to high altitude, that has a shoot architecture atypical to that of the commercial bean genotypes evaluated in the present study, which prioritized the remobilization of pho-toassimilates for grain production.
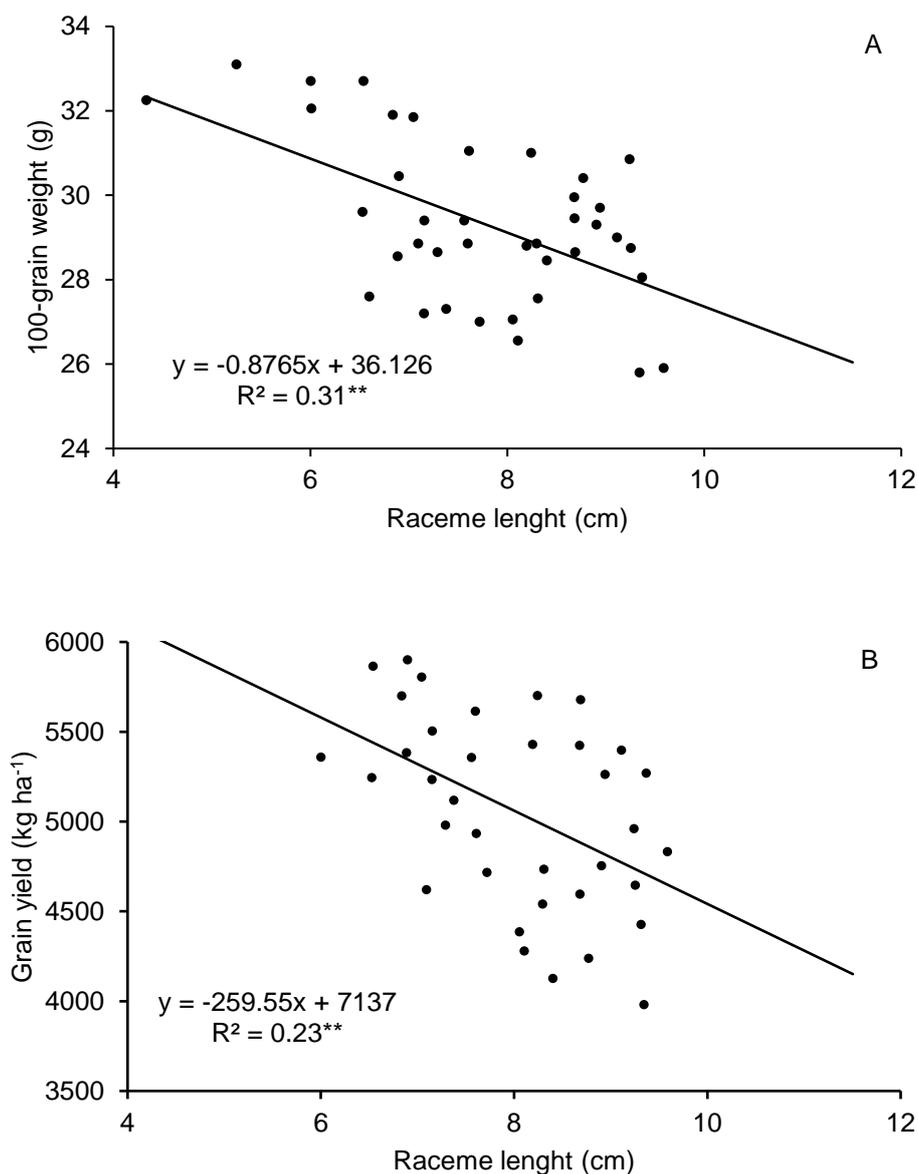

Figure 2 - Effect of raceme length on grain weight (A) and on grain yield (B) of 41 common bean genotypes.

In the present study, yield increase along with raceme length decrease can be explained by its nega-tive relationship with the number of pods per plant (Figure 3) and positive relationship with grain mass (Figure 4), considering the 41 genotypes evaluated. Önder et al. (2013) and Ejara et al. (2017) also observed

negative relationship between yield and number of pods per plant and postulated that this may be caused by negative indirect effects of this trait on the number of grains per pod and per plant and on 100-grain weight. Depending on environmental conditions and genotypes, some yield components may increase and others may

decrease. This effect is attributed to compensatory growth, as the distribution of yield-limiting resources is affected by genetic and environmental factors. The main implication of this process is that the increase of one component may not result in yield increases (White & Izquierdo, 1989), as verified with the number of pods per plant.
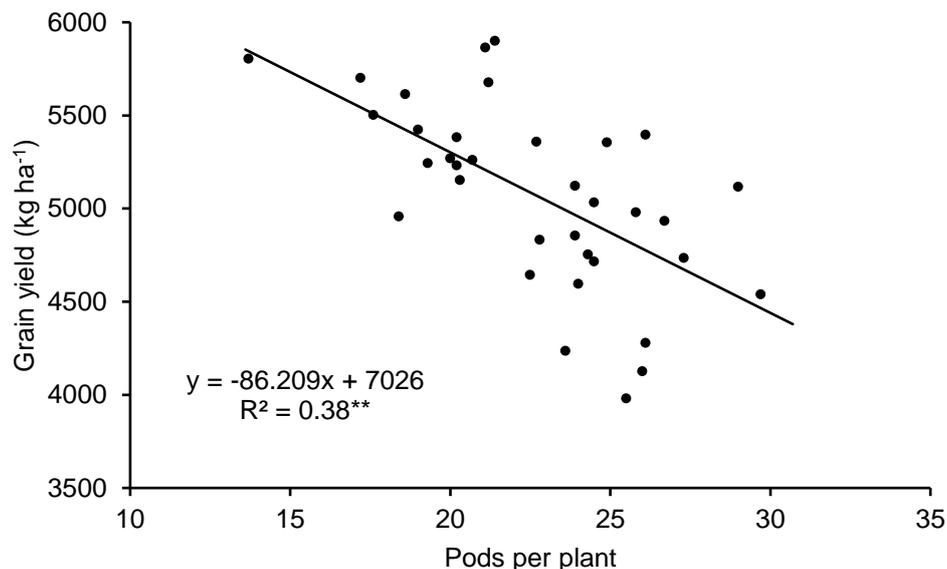

Figure 3 - Effect of number of pods per plant on grain yield of 41 common bean genotypes.
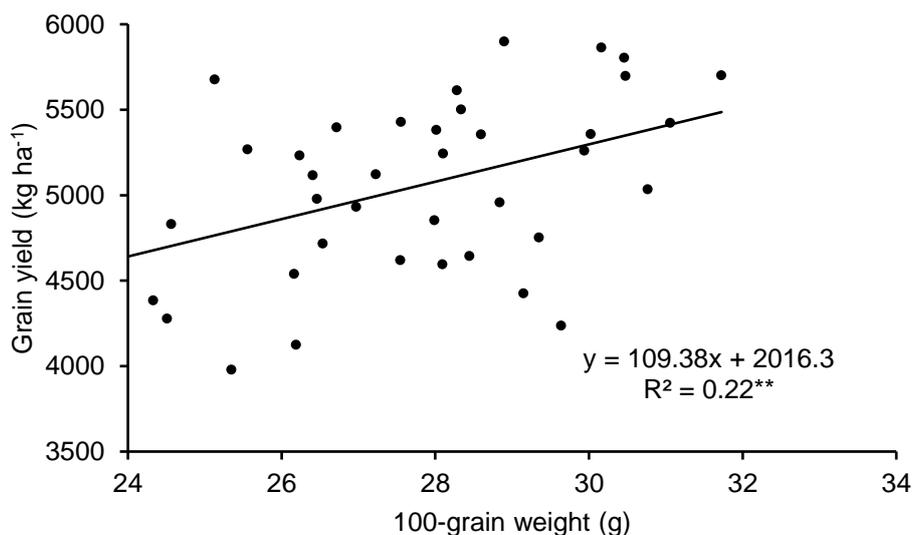

Figure 4 - Effect of 100-grain weight on grain yield of 41 common bean genotypes.

Fageria & Santos (2008), Negahi et al. (2014), Ejara et al. (2017), and Ribeiro et al. (2018) observed positive correlation between 100-grain weight and bean yield. The latter authors found no correlation between yield and the number of pods and grains per plant. On the other hand, Fageria & Santos (2008), Negahi et al. (2014), and Al-Ballat & Al-Araby (2019) observed positive correlation between yield and number of pods per plant. Negahi et al. (2014) also observed a positive correlation between yield and number of grains per plant.

Peduncle length also affected grain formation. Shorter peduncles resulted in grains with greater mass accumulation, being heavier. The variability of peduncle length explained 16% of variability in grain mass (Figure 5A). Each decrease of one unit in peduncle length increased 100-grain weight by 5.9 g. Yield was also influenced by peduncle length, increasing linearly with its decrease (Figure 5B). Peduncle length explained 13% of variation in the yield of the common bean and each unit of reduction in its length resulted in a yield increase of 1210 kg ha^{-1}.
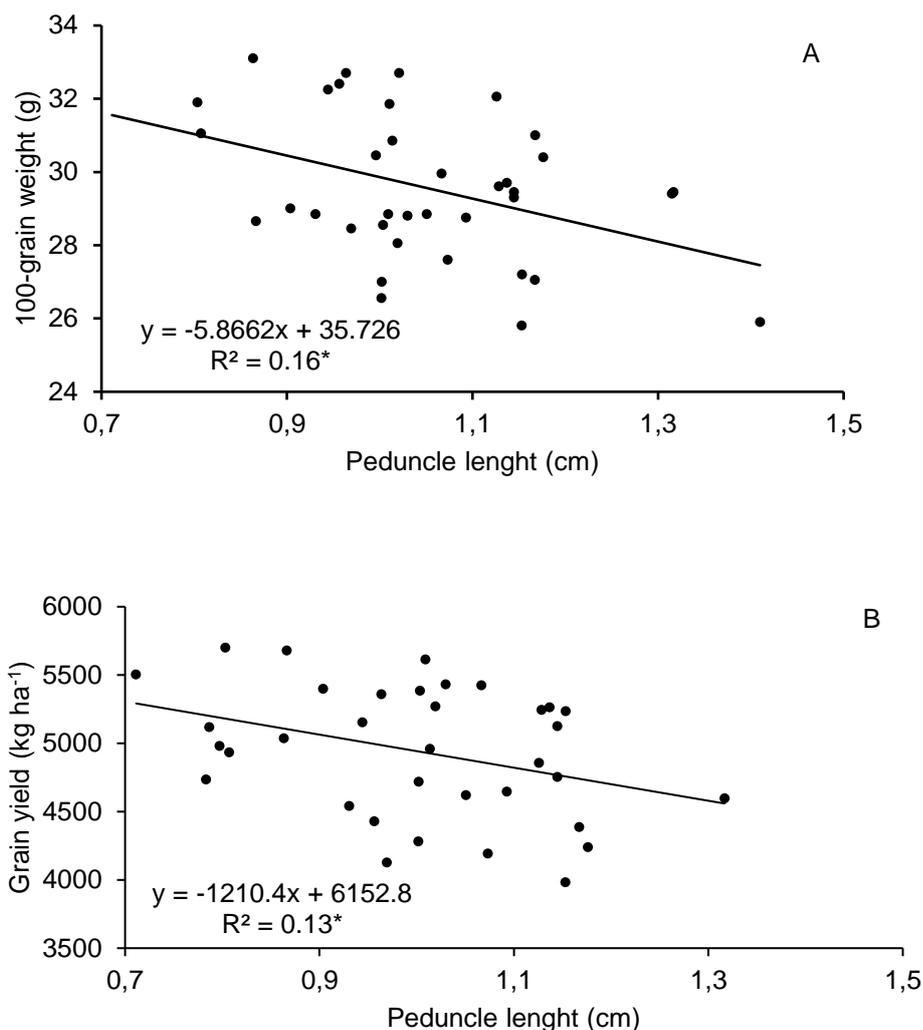
Figure 5 - Effect of peduncle length on 100-grain weight (A) and on grain yield (B) of common bean.

Significant effect of raceme thickness on 100-grain weight and yield of beans was not observed. However, yield responded positively to peduncle thickness (Figure 6). Its variability explained 15% of the variability of yield in the genotypes evaluated in the experiment. Each unit of variation in peduncle thickness resulted in an average increase of 390 kg ha^{-1} in the grain yield of bean genotypes.
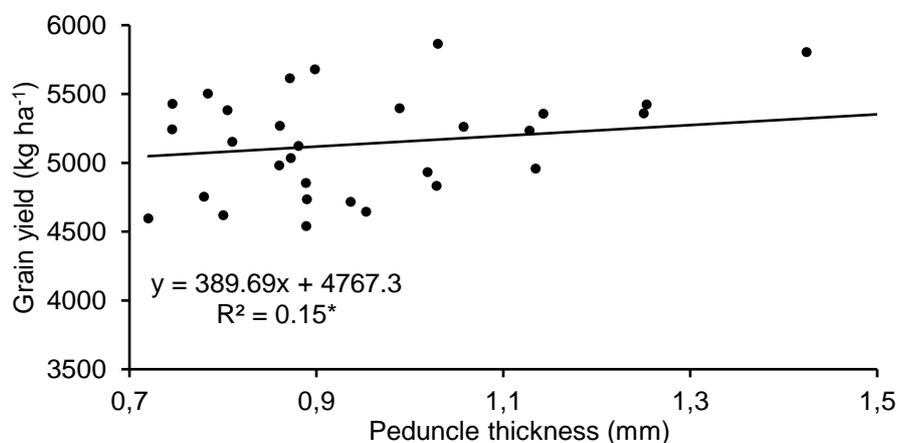

Figure 6 - Effect of peduncle thickness on grain yield of 41 common bean genotypes.

According to White & Izquierdo (1989), flowers with short peduncles, large cross section, and large leaves, close to storage sites, can increase yield by increasing the volume of photoassimilates produced and by reducing the flow resistance of assimilates to storage sites.

Phloem translocation is ruled by a pressure gradient generated osmotically between source and drain, which is affected both by the cross section of the sieved elements and by the distance to be covered (Taiz & Zeiger, 2010). The length of racemes and peduncles determine the distance of the path to be crossed by photoassimilates towards the drain, and the diameter of the translocation path in the phloem can be inferred by the thickness of racemes and peduncles.

Response of yield to carbohydrate accumulation in the leaves, inferred by the specific leaf mass evaluated in the early hours of the morning, was not observed. Response of yield to trifoliate area was also not observed possibly due to the large leaf areas of the genotypes evaluated. Yield increases with increasing leaf area up to a limit, above which there is no further increase. Mutual shading of leaves can decrease their photosynthetic efficiency. In addition, the respiration rate increases almost proportionally to the increase in leaf area as it is not affected by mutual shading (Fageria & Santos, 2008).

The genotypes evaluated differed significantly regarding yield and 100-grain weight (Table 1). Considering yield, genotypes were divided into two groups by Scott-Knott's test. The first group was formed by 22 genotypes that produced between 5756 kg ha^{-1} and 4853 kg ha^{-1} and the second group by 19 genotypes that produced between 4782 kg ha^{-1} and 3848 kg ha^{-1}.

Table 1 - Grain yield and 100-grain weight of common bean genotypes.

Genotype	Grain yield (kg ha^{-1})	100-grain weight (g)
Pérola	5756a	30.7b
CNFC 17271	5611a	28.5c
CNFC 17275	5603a	31.2b
CNFC 17304	5535a	33.1a
CNFC 17305	5476a	32.5a
CNFC 17170	5327a	29.2c
CNFC 17303	5327a	31.3b
CNFC 17259	5299a	29.3c
CNFC 17273	5231a	31.9a
CNFC 17260	5191a	29.4c
CNFC 17182	5186a	27.3d
CNFC 17264	5170a	30.1b
IPR Campos Gerais	5066a	27.3d
CNFC 17172	5062a	28.8c
CNFC 17302	5058a	32.5a
ANFC 09	5054a	29.9b
CNFC 17330	5023a	29.7c
CNFC 17236	5005a	28.8c
BRS Estilo	4982a	28.6c
CNFC 17265	4902a	28.1c
CNFC 17301	4874a	32.4a
CNFC 17318	4853a	32.6a
CNFC 17411	4782b	28.6c
CNFC 17328	4769b	28.8c
CNFC 17347	4764b	30.2b
CNFC 17278	4756b	27.8d
CNFC 17309	4636b	30.9b
CNFC 17268	4616b	29.4c
CNFC 17180	4606b	32.4a
CNFC 17324	4546b	28.0d
CNFC 17270	4492b	30.0b
CNFC 17310	4442b	27.4d
CNFC 17308	4392b	26.5e
CNFC 17238	4370b	29.0c
CNFC 17279	4353b	29.3c
CNFC 17314	4282b	27.9d
BRS FC402	4183b	25.8e
CNFC 17335	4140b	28.4c
CNFC 17164	4099b	29.3c
CNFC 17257	4035b	30.6b
BRS Notável	3848b	26.2e

Means followed by the same letter in the column did not differ significantly at the level of 5% by the Scott-Knott's test.

The averages of the accumulated abscission of flowers and new pods of the two groups that showed similar yields by Scott-Knott's test are shown in Figure 7. The most productive group presented the greatest accumulated abscission of flowers and newly formed pods throughout evaluation, 96 and 93, respectively (Figure 7A). The least productive group presented abscission of 75 flowers and 85 newly formed pods during the same period (Figure 7B). The data suggested that the most productive genotypes are those with the greatest abscission of these reproductive organs, resulting in a decreased number of pods per plant,

which is supported by the negative response of yield to the increase in the number of pods per plant (Figure 3). On the other hand, it was observed that the most productive genotypes were those that presented better formed grains and with less expenditure of structural carbohydrates for the formation of pods and other structures required for conditioning grains in the plant, as observed in Figure 4. The group with the most productive genotypes presented a 100-grain weight of 30.1 g, while the least productive group presented 28.6g.
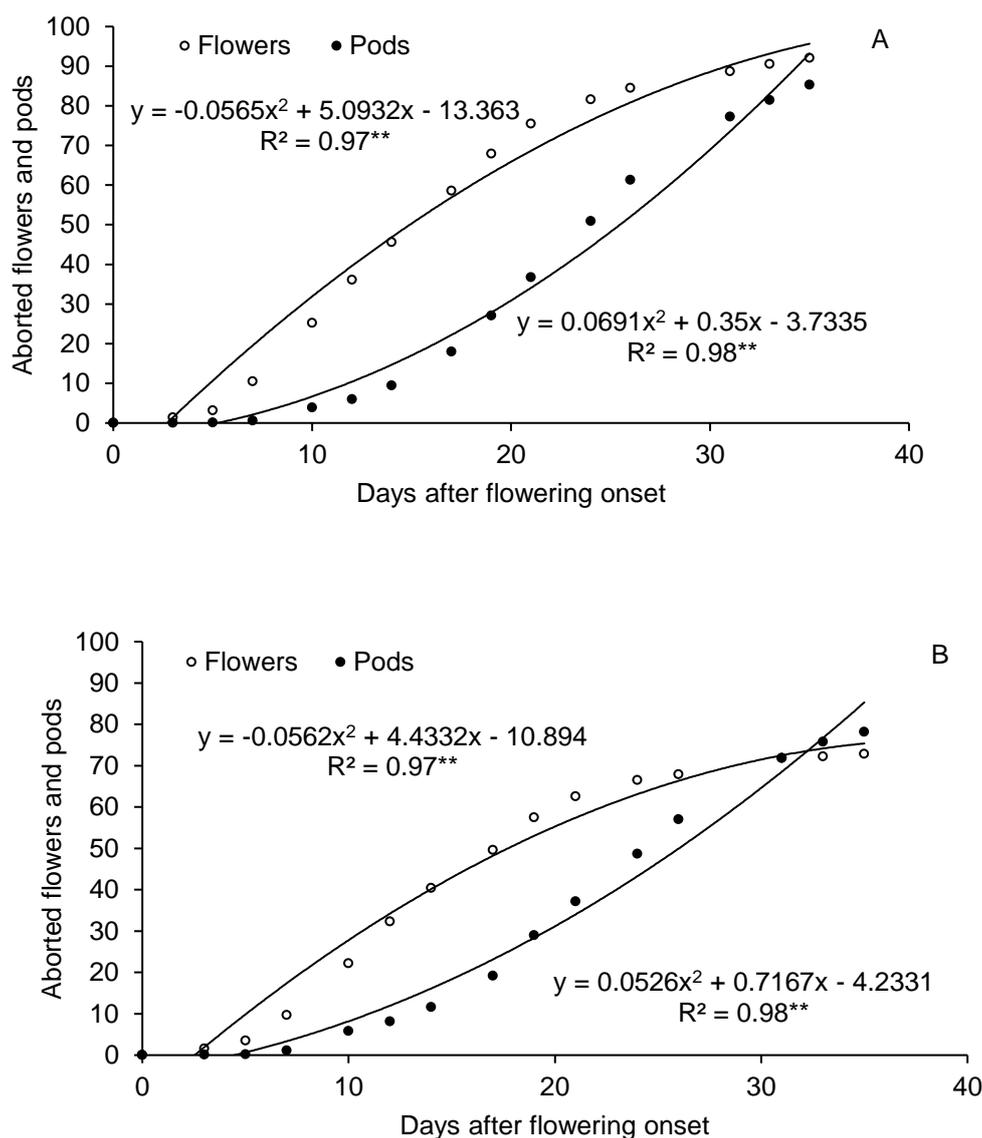

Figure 7 - Cumulative abscission of flowers and newly formed pods from the most productive (A) and least productive (B) groups according to the grouping test of means.

Carbohydrate supply by the source may not adequately supply pods during grain formation, as the carbohydrate content in the pod wall decreases intensely during this stage, suggesting that the remobilization of carbohydrates in the pod wall occurs without

limitations, although it is not verified regarding its replacement from the temporary storage in the culms (Tanaka & Fujita, 1979). Inadequate supply of carbohydrates establishes competitiveness in favor of other organs and older pods, causing the abscission of

younger pods and poor formation of grains (White & Izquierdo, 1989).

The negative effects of increasing the length of racemes and peduncles on grain yield and mass, caused by increasing the flow resistance of photoassimilates and by unnecessary expenditures of structural carbohydrates caused by the increase of malformed pods, suggest the introduction of these traits in the selection of common bean lines for high yield.

Conclusions

The most productive genotypes were those that remobilized photoassimilates more easily for having shorter racemes and peduncles, thicker peduncles, and decreased expenditure of structural carbohydrates with malformed pods and other structures required for conditioning grains in the plant, compensating with greater grain weight.

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