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RESPONSE OF EARLY-CYCLE COMMON BEAN CULTIVARS WITH CARIOCA, BLACK AND SPECKLED GRAINS TO TOP-DRESSING NITROGEN FERTILIZATION

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Abstract
The aim was to evaluate the agronomic and qualitative attributes of early-cycle common bean cultivars with different grains types grains in response to top-dressing nitrogen (N) doses. The experiment was carried out using a randomized block design, in a split-plot scheme, with 4 replicates. The plots consisted of the cultivars IAC Nuance, IAC 1849 Polaco and IAC Veloz, with speckled, Carioca and black grains, respectively. The subplots were formed by N doses applied as top-dressing: 0 kg ha^{-1}, 60 kg ha^{-1} (applied in the stage of third trifoliate leaf), 120 kg ha^{-1} (1/2 applied at third trifoliate leaf stage + 1/2 applied at the floral bud stage) and 180 kg ha^{-1} (1/3 applied at the first trifoliate leaf stage + 1/3 applied at the third trifoliate leaf stage + 1/3 applied at the floral bud stage). IAC Veloz stood out for grain yield, showing the highest grain yield in the lowest N doses, being classified as efficient to the use of N. The cultivars IAC Nuance and IAC 1849 Polaco reached maximum yields with 155 and 163 kg ha^{-1} of N. The IAC Nuance was the most responsive, increasing grain yield by up to 25.3% due to nitrogen fertilization. Increasing N doses applied as top-dressing increased the sieve yield and crude protein content of the common bean cultivars, with IAC Nuance standing out. The cultivars showed good grain quality, and IAC 1849 Polaco and IAC Veloz had the shortest cooking time and IAC Veloz also had the fastest hydration.

Keywords: Commercial Group. Cooking Time. Export Beans. Genotypes. *Phaseolus vulgaris* L.

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is a crop of high food, social and economic importance. Brazil stands out as the world's largest producer and consumer of beans (FAO 2019). In 2020, Brazilian production reached 3.2 million tons, of which 0.5 million tons were black beans, 2.0 million tons were colored beans, which include Carioca and special beans, and 0.7 million tons were cowpea (*Vigna unguiculata* (L.) Walp) (Conab 2020). Nutritionally, beans are rich in crude protein, with levels in the grains that can range from 18 to 25%, and minerals such as phosphorus, calcium and magnesium, iron, zinc and copper (Klasener et al. 2020).

Brazil has a diversity of common bean cultivars from different commercial groups, such as Carioca, black and special. Carioca beans are the most cultivated in Brazil, with 70% of production, followed by black beans. However, Brazil is not self-sufficient in the production of black beans, so imports are necessary to supply the market. These two types of grains are also the most appreciated by consumers (Chiorato et al. 2020a, Chiorato et al. 2020b). Grains with white, red, cream and yellow seed coat, among others, with absence or presence of streaks or strips of other colors, are known as special grain beans. The production of this type of grain is still incipient in Brazil, but its cultivation can be an alternative for crop diversification and minimization of income fluctuation for producers; in addition, it can be marketed in the domestic and foreign markets, as it is a differentiated product with high added value (Ribeiro et al. 2014; Alves et al. 2020; Carbonell et al. 2020). Both black and special beans are little produced in the state of São Paulo, which can be a good alternative of niche market for producers.

When recommending a common bean cultivar to the producer, in addition to the commercial type of grains, other agronomic attributes are important, such as adaptability to the region of cultivation, production potential, plant size, cycle, resistance to pests and diseases, tolerance to abiotic factors such as drought and high temperatures, as well as efficiency and response to the use of nutrients (Lemos et al. 2015). As for the cycle, earliness is an attribute increasingly sought after by the producer, because it allows better adequacy of the crop within a system of crop rotation and intercropping, water and energy savings in irrigated systems, cultivation of the crop in a period of the year more favorable to the development of plants, and faster return on invested capital (Lemos et al. 2015; Bettiol et al. 2020).

Regarding the response of cultivars to the use of nutrients, it is necessary to evaluate the efficiency in the absorption and utilization of nitrogen (N), since it is the nutrient most extracted by common bean plants (Fageria et al. 2015; Leal et al. 2019). According to Soratto et al. (2013), for each ton of grain produced, common bean plants extract on average 40 kg ha^{-1} of N.

Although common bean plants perform symbiosis with bacteria of the genus *Rhizobium*, the biological fixation of N is insufficient to meet the requirements of this nutrient during their cycle, so N fertilizer needs to be applied via fertilization (Aragão et al. 2020; Bettiol et al. 2020; Dias et al. 2020). There are studies in the literature indicating the response of the crop to the top-dressing application of doses greater than 180 kg ha^{-1} (Farinelli and Lemos 2010; Soratto et al. 2017; Souza et al. 2019).

In view of the above, the aim of this study was to evaluate the agronomic and qualitative attributes of early-cycle common bean cultivars with different types of grains in response to the top-dressing application of N doses.

2. Material and Methods

The experiment was conducted at the Universidade Estadual Paulista (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal, São Paulo, Brazil, near the coordinates 21º 14’ 59” S and 48º 17’16” W, at an altitude of 570 m. In the spring-summer crop season of 2018/2019, the area was cultivated with soybean (*Glycine max* L.), under conventional soil tillage, using the cultivar Pioneer 95R95 IPRO, sown on November 22, 2018 and harvested on March 22, 2019, with an average yield of 4.5 t ha^{-1}.

According to Köppen’s classification, the climate of the region is characterized as Aw - humid tropical with rainy season in summer and dry season in winter, showing an average annual temperature of 22 ºC and average annual precipitation of 1,425 mm. The soil is classified as clay-textured *Latossolo Vermelho eutroférrico* (Oxisol). Its chemical analysis, in the 0-0.20 m layer, showed the following results: pH ($CaCl_2$) = 5.9, OM = 19 g dm^{-3}, P_{resin} = 52 mg dm^{-3}, K = 5.6 $mmol_c$ dm^{-3}, Ca = 41 $mmol_c$ dm^{-3}, Mg = 18 $mmol_c$ dm^{-3}, H+Al = 24 $mmol_c$ dm^{-3}, SB = 64.6 $mmol_c$ dm^{-3}, CEC = 89 $mmol_c$ dm^{-3}, V = 75%, B = 0.22 mg dm^{-3}, Cu = 0.6 mg dm^{-3}, Fe = 11 mg dm^{-3}, Mn = 61.3 mg dm^{-3} and Zn = 3.7 mg dm^{-3}. The results of the particle-size analysis showed: clay = 540 g kg^{-1}; silt = 230 g kg^{-1} and sand = 230 g kg^{-1}.

The design used was randomized blocks, in a split-plot scheme, with four replicates. The plots were composed of the common bean cultivars IAC Nuance, IAC 1849 Polaco and IAC Veloz. The cultivars have determinate growth habit, type I and early cycle with 75 days. IAC Nuance has special type grains of rounded shape, speckled in cream color with reddish streaks, Cranberry type, intended for export; IAC 1849 Polaco has Carioca type grains, of cream color with light brown streaks and tolerance to darkening; and IAC Veloz has black grains and produces a chocolate-colored broth (Carbonell et al. 2020; Chiorato et al. 2020a,b). The subplots were formed by N doses applied as top-dressing: 0 kg ha^{-1} (without application), 60 kg ha^{-1} (applied at phenological stage V_4 - third trifoliate leaf), 120 kg ha^{-1} (half of the dose applied at V_4 + half the dose at R_5 - floral bud), 180 kg ha^{-1} (one-third of the dose applied at V_3 - first trifoliate leaf + one-third of the dose applied at V_4 + one-third of the dose applied at R_5). Top-dressing N fertilization was applied along a continuous strip, at 0.10 m distance from the crop row, using as source polymer-coated controlled-release urea (Kimcoat® - 45% N), followed by irrigation with a 15 mm water depth. Each experimental subplot consisted of five 5.0-m long rows, spaced by 0.45 m, considering the three central rows as usable area.

The seeds of the common bean cultivars came from the Agronomic Institute of Campinas (IAC) and were treated with fungicide + insecticide (StandakTop®) at a dose of 2 mL per kg of seed. For inoculation with *Rhizobium*, the product StarFix Feijão was used at a dose of 4 mL per kg of seed. The common bean crop was grown in the 2019 autumn-winter season in a no-tillage system. Sowing was performed on July 05, 2019, with spacing of 0.45 m between rows, using 11 seeds per meter. The final population was 216,000 plants ha^{-1}. Sowing fertilization was carried out using 8 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 40 kg ha^{-1} of K_2O, following the recommendations of Ambrosano et al. (1997). For the control of weeds, the pre-emergence herbicide Dual Gold (1.25 L ha^{-1} c.p.) was applied 1 day after sowing (DAS) and the post-emergence herbicides Select (0.4 L c.p. ha^{-1}) and Flex (0.9 L c.p. ha^{-1}) were applied at 27 DAS. For the control of pest insects and diseases, the following products were sprayed: Benevia (750 mL c.p. ha^{-1}) at 23 DAS, Engeo Pleno (125 mL c.p. ha^{-1}) and Opera (0.5 L c.p. ha^{-1}) at 49 DAS. Irrigation was applied using a conventional sprinkler system, with variable interval and total water depth of 315 mm.

Agronomic attributes were evaluated when the plants reached R_6 stage (full flowering). Ten plants were randomly collected in the usable area of each subplot, washed with deionized water, dried in an oven at 65 ºC for 72 hours and then weighed to determine shoot dry matter (g plant^{-1}). To determine leaf N content, the third trifoliate leaf with petiole was collected from the middle third, in 20 plants, following the recommendations of Ambrosano et al. (1997). The leaves were washed in running water, deionized water with neutral detergent (0.1%) and deionized water and subsequently kept in an air circulation oven at temperature of 65 ºC until reaching constant weight. After drying, the material was ground and subjected to chemical analysis to determine leaf N content by sulfuric acid digestion, distillation in strongly alkaline medium and titration with sulfuric acid solution. Cultivars IAC Nuance, IAC Veloz and IAC 1849 Polaco flowered at 41, 50 and 51 DAS, with a total cycle of 66, 73 and 75 DAS, respectively. At harvest, ten plants were collected in each experimental unit in the central row of each subplot to determine the number of pods per plant and number of grains per pod. 100-grain weight (g) was determined by weighing four subsamples of 100 grains per subplot, correcting the data to moisture content of 0.13 g g^{-1}. For the evaluation of grain yield, the plants of the usable area of each subplot were harvested, sun-dried and mechanically threshed. Then, the grains were weighed and the data were corrected to moisture content of 0.13 g g^{-1}.

The qualitative attributes of the grains were evaluated 30 days after harvest. The grains were classified according to size and shape based on their passage through a set of sieves with oblong holes [11/64” × 3/4 (4.37 × 19.05 mm), 12/64” × 3/4 (4.76 × 19.05 mm), 13/64” × 3/4 (5.16 × 19.05 mm) and 14/64” × 3/4 (5.56 × 19.05 mm)] under shaking for one minute (Santis et al. 2019). The percentage of grains was calculated by the relationship between the weight of grains retained on each sieve and the total weight of the sample of each subplot. The relative grain production on sieves was also calculated, according to the methodology described by Carbonell et al. (2010), using equation 1.

$$\mathrm{RGPS} = \frac{(\mathrm{S10}\times 1)+(\mathrm{S11}\times 4)+(\mathrm{S12}\times 6)+(\mathrm{S13}\times 10)+(\mathrm{S14}\times 10)+(\mathrm{S15}\times 6)}{\mathrm{S10}+\mathrm{S11}+\mathrm{S12}+\mathrm{S13}+\mathrm{S14}+\mathrm{S15}} \quad (1)$$

Where: RGPS: relative grain production on sieves; S10: sieve 10; S11: sieve 11; S12: sieve 12; S13: sieve 13; S14: sieve 14; S15: sieve 15;

Crude protein content (CPC%) was determined by sulfuric digestion and the following equation was used for calculation: CPC = 6.25 x Total N, where CPC, in percentage, is the crude protein content, and total N is the N content in the grains. The other quality evaluations were performed with the grains retained on sieve 13. Cooking time (minutes) was determined using a Mattson cooker, according to the methodology described in Farinelli and Lemos (2010). Hydration capacity (hours:minutes) was determined by evaluating the volume of water not absorbed by the grains, at 1-h intervals, for 22 hours. Analysis of polynomial regression between time (hours) and hydration capacity (mL) was carried out to determine the time required for maximum hydration of common bean grains (Santis et al. 2019).

The data were subjected to analysis of variance using the F test ($p < 0.05$) and means were compared by Tukey test ($p < 0.05$). The effects of top-dressing N doses and the interaction between common bean cultivars and N doses were assessed by polynomial regression. Pearson's simple correlation analysis between agronomic and qualitative attributes was also performed. Due to the structure dependency of the original data set, multivariate statistical analysis by principal components (PCs) was used. The data were standardized with zero mean and unit variance. The number of PCs was selected based on the Kaiser criterion, using those with eigenvalues greater than 1 (Kaiser 1958). The statistical programs AgroEstat and Statistica v.7 were used for univariate statistics, multivariate statistics and Pearson's correlation.

3. Results

Regarding agronomic attributes, it can be verified that shoot dry matter was significantly influenced by cultivars, with IAC Veloz having the highest value (5.08 g plant^{-1}), while IAC Nuance and IAC 1849 Polaco showed no differences (Table 1). The N doses promoted a linear increase in dry matter for the three common bean cultivars (Figure 1A). The N dose of 180 kg ha^{-1}, compared to the absence of top-dressing application of N, enabled increments in shoot dry matter of 51%, 41% and 98% for the cultivars IAC Nuance, IAC 1849 Polaco and IAC Veloz, respectively.

Table 1. Agronomic attributes of early-cycle common bean cultivars fertilized with top-dressing nitrogen. Jaboticabal, São Paulo – 2019[1].

Cultivar	DM (g plant^{-1})	LNC (g kg^{-1})	NPP (nº)	NGP (nº)	100GW (g)	GY (kg ha^{-1})
IAC Nuance	3.88 b	31.50 c	8.34 b	3.63 c	35.52 a	1.342 b
IAC 1489 Polaco	4.01 b	39.20 b	10.60 b	4.00 b	22.92 b	1.672 b
IAC Veloz	5.08 a	45.37 a	15.96 a	4.81 a	21.25 c	2.603 a
F test						
Cultivar (C)	8.08*	45.67**	32.41**	55.42**	426.35**	38.81**
N doses (N)	13.16**	5.98**	1.56^{NS}	0.75^{NS}	2.18^{NS}	4.79**
C*N	1.55^{NS}	4.31**	0.43^{NS}	0.70^{NS}	0.58^{NS}	0.67^{NS}
CV for cultivar (%)	21.71	10.63	23.67	8.57	5.69	18.86
CV for doses (%)	19.55	7.28	12.61	7.78	5.28	14.37

[1] DM – shoot dry matter; LNC – leaf nitrogen content; NPP – number of pods per plant; NGP – number of grains per pod; 100GW – 100-grain weight; GY – grain yield. Means followed by different letters in the rows differ from each other by Tukey test at 5% probability level. ^{NS} Not significant by F test. ** Significant by F test ($p < 0.01$). * Significant by F test ($p < 0.05$).

Top-dressing N application promoted an increase in leaf N content, with a difference between cultivars and for the interaction between cultivars (C) and N doses (Tables 1 and 2). The cultivar IAC Nuance was inferior to the others and, at the N dose of 60 kg ha^{-1} and under no N application, it showed values below the range considered adequate or of sufficiency for common bean, from 30 to 50 g kg^{-1} (Ambrosano et al. 1997). The cultivar IAC Veloz was superior to the others, showing higher leaf N content at a N dose of 180 kg ha^{-1}, but with a value above the maximum recommended. It is worth pointing out that the cultivars IAC 1849 Polaco and IAC Veloz had high leaf N contents even where there was no fertilizer application. Negative and significant correlations were also observed between leaf N content and the qualitative attributes cooking time ($r = -0.42^{**}$) and sieve yield ≥11 ($r=-0.61^{**}$), ≥12 ($r=-0.72^{**}$), ≥13 ($r=-0.79^{**}$) and ≥14 ($r=-0.76^{**}$).

The number of pods per plant was influenced by the cultivar factor and the C x N interaction (Table 1 and Figure 1B). The cultivar IAC Veloz was superior to the others, with an average of 16 pods per plant, but without response to fertilizer application. The addition of N promoted quadratic effect on the cultivars IAC Nuance and IAC 1849 Polaco, with maximum number of pods per plant equal to 9 and 10, respectively, at doses of 145 and 122 kg ha^{-1}.

The number of grains per pod was higher in the cultivar IAC Veloz, which differed statistically from the others and was not influenced by N doses or C x N interaction (Table 1). 100-grain weight was significantly influenced by the cultivars, and IAC Nuance had higher average (35.52 g) compared to the others (Table 1). Also for the 100-grain weight, it was possible to observe the difference in the response of the cultivars to the N doses (Figure 1C). IAC Nuance showed a quadratic increment, with the highest value (36.14 g) promoted by the N dose of 102.3 kg ha^{-1}. For the cultivars IAC 1849 Polaco and IAC Veloz, the increments of N promoted a linear increase in the 100-grain weight. This response is related to the fact that N is associated with organic compounds after being absorbed by plants, originating proteins that increase grain weight (Amaral et al. 2016).

Table 2. Analysis of the cultivar x nitrogen doses interaction for leaf nitrogen content[1].

	Leaf N content (g kg^{-1})		
N doses (kg ha^{-1})	IAC Nuance	IAC 1849 Polaco	IAC Veloz
0	29.75 abB	39.20 aA	40.76 bA
60	28.70 bC	38.85 aB	45.50 bA
120	34.30 aB	40.25 aA	43.58 bA
180	33.25 abB	38.50 aB	51.63 aA
F test for C x N interaction		4.31**	
CV (%)		7.28	

[1] Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by Tukey test at 5% probability level. ** Significant by F test ($p < 0.01$).

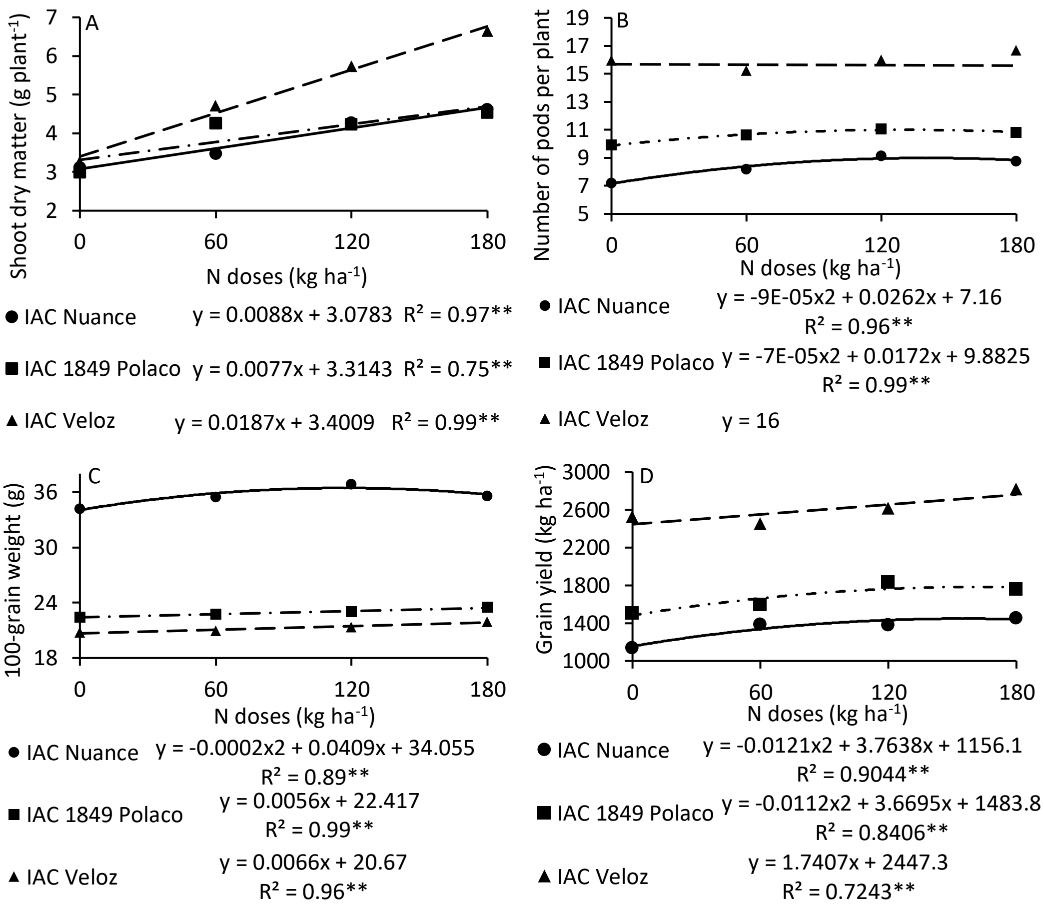

Figure 1. Analysis of the cultivar x nitrogen doses interaction for A - shoot dry matter, B - number of pods per plant, C - 100-grain weight and D - grain yield. *(p<0.05); **(p<0.01).

The cultivar IAC Veloz obtained higher grain yield than the others, and IAC Nuance and IAC 1849 Polaco showed statistically equal production performance (Table 1). For the interaction between C and N, it can be observed that the cultivar IAC Veloz showed increasing grain yield as a function of N doses, and it was not possible to find a maximum point, with increments of 17 kg ha^{-1} for every 10 kg ha^{-1} of N applied (Figure 1D). At a dose of 180 kg ha^{-1}, the IAC Veloz grain yield was 2.761 kg ha^{-1}. The cultivars IAC Nuance and IAC

1849 Polaco showed maximum grain yields of 1,449 and 1,784 kg ha^{-1}, at N doses of 155 and 163 kg ha^{-1}, respectively. The cultivar IAC Veloz obtained higher grain yield at all N doses applied as top-dressing. In the absence of top-dressing N application, the cultivars IAC Veloz, IAC 1849 Polaco and IAC Nuance obtained grain yields of 2,447 kg ha^{-1}, 1,484 kg ha^{-1} and 1,156 kg ha^{-1}, respectively. The differences between maximum and minimum grain yield of cultivars IAC Nuance, IAC 1849 Polaco and IAC Veloz as a function of N doses were 12.8, 25.3 and 20.2%, respectively. Furthermore, it was observed that grain yield was positively and significantly correlated with the number of pods per plant (r=0.90**) and the number of grains per pod (r=0.80**).

Regarding the qualitative attributes of the grains, it was found that the sieve yields ≥11, ≥12, ≥13 and ≥14 were influenced by the cultivars and N doses (Table 3 and Figure 2). The cultivar IAC Nuance showed higher yield in all sieves, with values ranging from 84 to 97%. The cultivar IAC 1849 Polaco did not differ from IAC Nuance in the amount of grains retained on the sieve ≥11, and IAC Veloz had the lowest values due to its lower 100-grain weight (Table 1), but obtained an outstanding value, close to 90%. For sieve yield ≥11 and ≥12, the N doses promoted a quadratic increase, with maximum values of 95 and 86%, respectively, for the N doses of 111 and 150 kg ha^{-1}. The sieve yields ≥13 and ≥14 increased linearly, and it was not possible to find a maximum point. The relative grain production on sieves (RGPS) was significantly affected only by the cultivar factor, with IAC Nuance and IAC 1849 Polaco being superior to IAC Veloz (Table 3).

Table 3. Sieve yields greater than or equal to 11, 12, 13 and 14, and relative grain production on sieves for early-cycle common bean cultivars fertilized with top-dressing nitrogen. Jaboticabal, São Paulo – 2019[1].

Cultivar	SY ≥ 11 (%)	SY ≥ 12 (%)	SY ≥ 13 (%)	SY ≥ 14 (%)	RGPS
IAC Nuance	97.37 a	97.37 a	94.83 a	84.00 a	7.95 a
IAC 1849 Polaco	97.37 a	88.12 b	62.62 b	12.43 b	8.25 a
IAC Veloz	89.12 b	71.37 c	23.56 c	1.81 c	6.26 b
F test					
Cultivar (C)	10.84^{*}	40.12^{**}	449.94^{**}	1007.2^{**}	18.49^{**}
N doses (N)	0.70^{NS}	0.49^{NS}	1.36^{NS}	3.61^{NS}	1.06^{NS}
C*N	0.99^{NS}	2.07^{NS}	0.81^{NS}	1.36^{NS}	2.03^{NS}
CV for cultivar (%)	17.1	25.18	9.41	15.99	13.33
CV for doses (%)	5.05	12.1	9.03	14.75	5.35

[1] SY≥ 11 - sieve yield greater than or equal to 11; SY≥ 12 - sieve yield greater than or equal to 12; SY≥ 13 - sieve yield greater than or equal to 13; SY≥ 14 - sieve yield greater than or equal to 14; RGPS - relative grain production on sieves. Means followed by different letters in the rows differ from each other by Tukey test at 5% probability level. ^{NS} Not significant by F test. ** Significant by F test ($p < 0.01$). * Significant by F test ($p < 0.05$).

The cultivars IAC Nuance and IAC 1849 Polaco did not differ in relation to crude protein content and were superior to IAC Veloz (Table 4), obtaining values close to those observed by Santis et al. (2019) in a study with 13 common bean cultivars. Regarding the C x N interaction, all cultivars showed linear increase in crude protein content with increasing N doses (Figure 3), which is consistent with the results obtained by Farinelli and Lemos (2010) and Amaral et al. (2016). For the cultivar IAC Nuance, the increments were 1.56, 3.12 and 4.68% for N doses of 60, 120 and 180 kg ha^{-1}, in comparison to the absence of top-dressing N application. These increments were equal to 1.38, 2.76 and 4.14% for IAC 1849 Polaco and 2.41, 4.83 and 7.25% for IAC Veloz. It is worth pointing out that a negative and significant correlation was observed between crude protein content and grain yield ($r=-0.41^{**}$).

The cultivars IAC 1849 Polaco and IAC Veloz had shorter cooking time, differing statistically from IAC Nuance (Table 4). IAC 1849 Polaco and IAC Veloz showed normal resistance to cooking, and IAC Nuance showed medium resistance to cooking, according to the scale proposed by Proctor and Watts (1987). Regarding the C x N interaction, the cultivar IAC Nuance obtained the longest cooking time at all doses applied (Table 5).

Regarding the hydration capacity of the grains, there were differences between the cultivars in relation to the time necessary for maximum hydration (Table 4). The cultivar IAC Veloz required 12h05min to reach maximum grain hydration, differing from IAC Nuance and IAC 1849 Polaco, which had values of 14h27min and 19h41min, respectively.

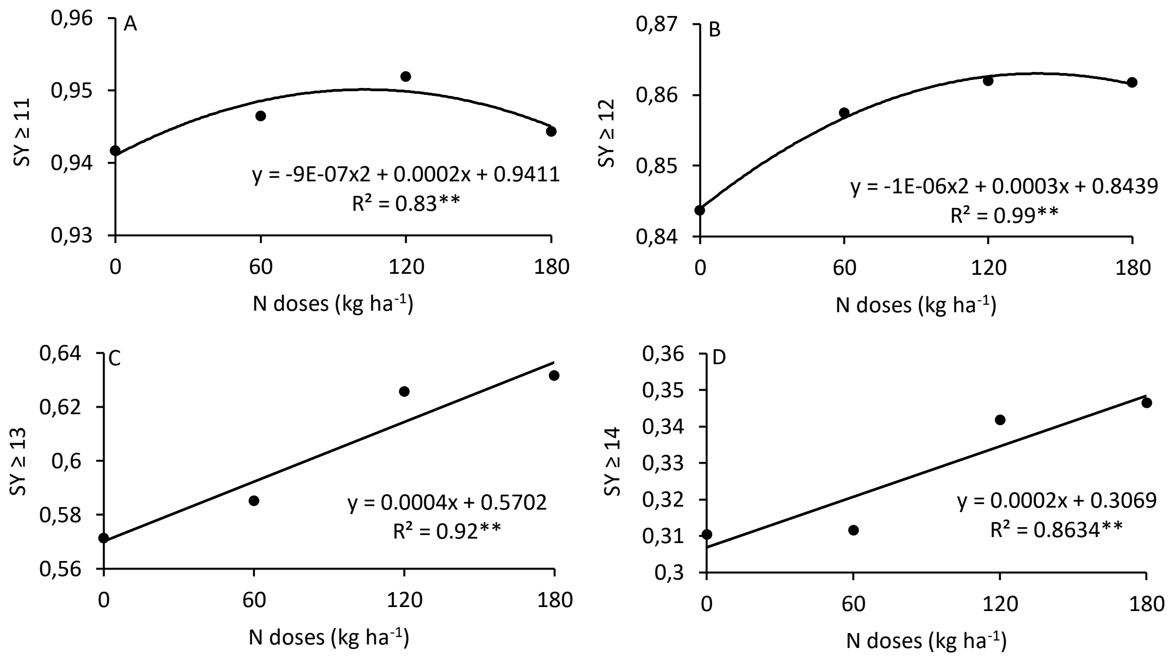

Figure 2. Sieve yield A - ≥11, B - ≥ 12, C - ≥ 13 and D - ≥ 14 in early-cycle common bean cultivars fertilized with top-dressing nitrogen. *(p<0.05); **(p<0.01).

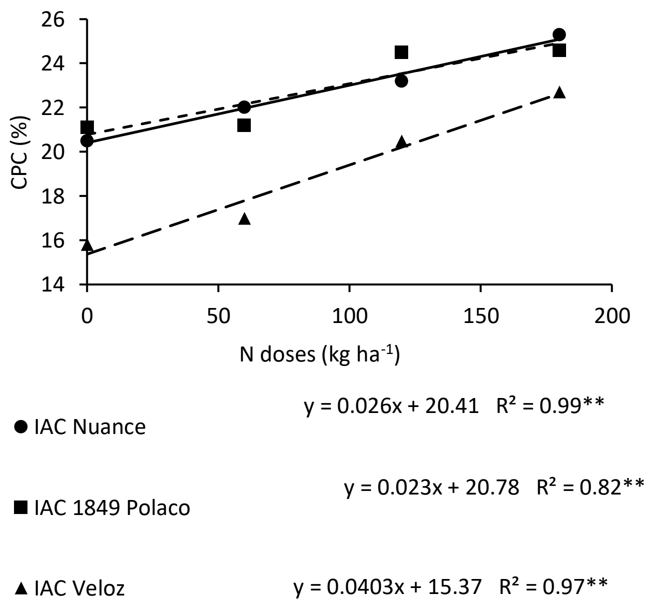

Figure 3. Analysis of the cultivar x nitrogen doses interaction for crude protein content. *(p<0.05); **(p<0.01)

Table 4. Crude protein content, cooking time and time for maximum hydration in early-cycle common bean cultivars fertilized with top-dressing nitrogen. Jaboticabal, São Paulo – 2019[1].

Cultivar	Crude protein content (%)	Cooking time (minutes)	Time for maximum hydration (hours:minutes)
IAC Nuance	22.8 a	31 a	14:27 b
IAC 1849 Polaco	22.9 a	21 b	19:41 a
IAC Veloz	19.0 b	23 b	12:05 c
F test			
Cultivar (C)	33.04^{*}	95.38^{**}	103.82^{**}
N doses (N)	24.37^{**}	2.75^{NS}	2.67^{NS}
C*N	1.09^{NS}	4.37^{**}	0.86^{NS}
CV for cultivar (%)	7.61	8.99	11.14
CV for doses (%)	7.04	8.90	9.72

[1] Means followed by different letters in the rows differ from each other by Tukey test at 5% probability level. ^{NS} Not significant by F test. ** Significant by F test (p < 0.01). * Significant by F test (p < 0.05).

Regarding the multivariate analysis of principal components (PCs), it was possible to verify that the first two PCs were responsible for explaining 88.77% of the total variability of the data (Figure 4). The variables that most discriminated PC1 were those related to the distribution of grains on the sieves: sieve yield ≥11, sieve yield ≥12, sieve yield ≥13, sieve yield ≥14, with factor scores of 0.88, 0.97, 0.99 and 0.88, respectively, in addition to crude protein, 100-grain weight and cooking time, with factor scores of 0.55, 0.87 and 0.63. The variable most related to PC2 was the time for maximum grain hydration, with a factor score of 0.95.

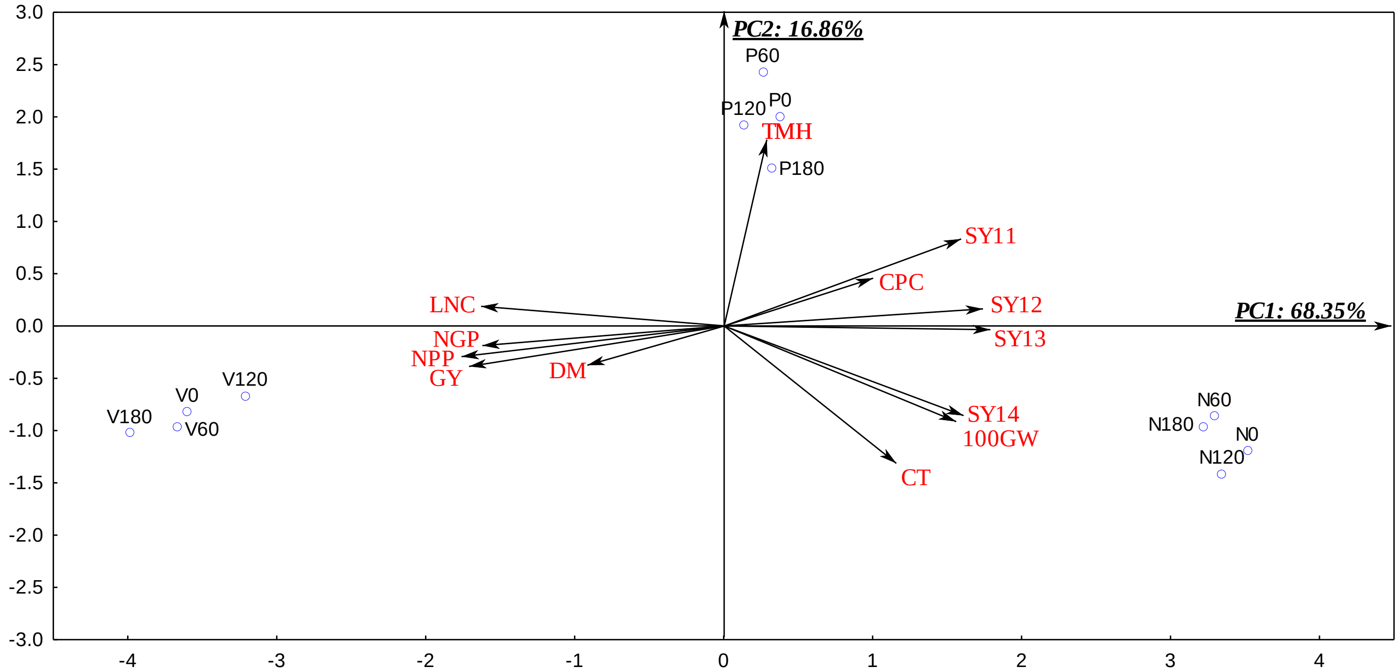

Figure 4. Biplot of principal components (PC) for common bean cultivars under nitrogen doses as a function of agronomic attributes (DM: shoot dry matter, LNC: leaf nitrogen content, NPP: number of pods per plant, NGP: number of grains per pod, 100GW: 100-grain weight and GY: grain yield) and grain quality attributes (SY11: sieve yield greater than or equal to 11, SY12: sieve yield greater than or equal to 12, SY13: sieve yield greater than or equal to 13, SY14: sieve yield greater than or equal to 14, CPC: crude protein content, CT: cooking time and TMH: time for maximum hydration). Letters indicate the common bean cultivars and numbers indicate nitrogen doses (N: IAC Nuance, P: IAC 1849 Polaco, V: IAC Veloz - 0, 60, 120 and 180: 0, 60, 120 and 180 kg ha^{-1} of nitrogen).

4. Discussion

Studies in the literature have reported a linear increase in the dry matter content of common bean with the addition of N. Soratto et al. (2017), studying N fertilization in common bean, concluded that the use of top-dressing N fertilizer increased shoot dry matter production in the cultivars IPR 139 and BRS Pérola, both of indeterminate growth habit, normal cycle and Carioca grains. The same performance was observed by Bettiol et al. (2020) using the cultivars IAC Imperador and IPR Curió, both of determinate growth habit, early cycle and Carioca grains. This occurs because N is directly related to the increase of net photosynthesis (Taiz and Zeiger 2017), positively affecting the absorption and accumulation of nutrients and increase of yield (Fageria et al. 2015).

All in all, the cultivars presented leaf N contents within the range considered adequate for common bean (Ambrosano et al., 1997). This may have occurred due to the presence of residual N from the soybean crop previously cultivated in the area (Ambrosano et al. 1997), due to the plant's ability to perform biological N fixation (Aragão et al. 2019; Bettiol et al. 2020, Dias et al. 2020) and due to the fertility of the soil in the experimental area.

Souza et al. (2019), using the cultivar IAC Alvorada, verified that there was a linear increase in the number of pods per plant with the increase of N doses applied as top-dressing up to 200 kg ha^{-1}, and it was not possible to find a maximum point. This demonstrates that this agronomic attribute can be influenced by the addition of top-dressing N differently among cultivars. The number of grains per pod was not influenced by N doses since this attribute has high genetic heritability, hence being little affected by the environment and crop management, such as N fertilization (Nascente et al. 2017).

The cultivar IAC Nuance showing the higher 100-grain weight value. This result occurred because this cultivar belongs to the group of speckled grains intended for export (special type), which are larger and heavier, as described by Carbonell et al. (2020). For IAC 1849 Polaco and IAC Veloz, this attribute showed a different response compared to the other production components, being lower, because these cultivars had a higher number of pods per plant and grains per pod. Due to the adjustment in the balance of photoassimilates sent to the different production components, the increase in the number of pods per plant and grains per pod reduces the amount of photoassimilates distributed to each grain, reducing the 100-grain weight (Fageria et al. 2015). Thus, plants with a high number of pods per plant and grains per pod may have lower values of 100-grain weight.

The linear increase in the yield of cultivar IAC Veloz as a function of N doses corroborates those of other studies, in which the common bean did not reach its maximum grain yield with the top-dressing application of N doses until 180 kg ha^{-1} (Farinelli and Lemos 2010; Soratto et al. 2017; Souza et al. 2019). Although the yield variation of IAC Veloz as a function of N doses was linear, the yield increments were small. This result characterizes that IAC Veloz is an efficient N use cultivar, that is, it produces satisfactorily well under low N availability conditions, and has a low N response, as it increases its productivity little due to the greater availability of N in the soil (Fageria et al. 2015).

Based on the principles of efficiency and responsiveness in the use of nutrients reported by Fageria et al. (2015), the cultivar IAC Veloz proved to be the most efficient in the N use, because it presented the highest grain yield in low N doses, while the cultivar IAC Nuance was the most responsive, being the cultivar with the highest relative increase in grain yield as a function of N doses. These results corroborate those reported by Leal et al. (2019), who observed differences in the efficiency and response of 16 common bean cultivars of the Carioca commercial group.

The higher sieves yield for IAC Nuance occurred because this cultivar has rounded grains intended for export (Carbonell et al. 2020), as well as a higher 100-grain weight (Table 1). For sieve yield ≥11 and ≥12, the cultivars IAC 1849 Polaco and IAC Veloz had values higher than 70%, which is used as a reference by packing industries to pay a bonus to the producer because the grains are large and with good acceptance in the market (Carbonell et al. 2010). The linear increase of sieve yields ≥13 and ≥14 can be explained by the fact that the increase in N doses applied as top-dressing, associated with soil fertility and appropriate crop management practices, promoted an increase in shoot dry matter, positively affecting leaf N content and yield, leading to larger grains from the moment when there was greater availability of the nutrient in the soil-plant system (Fageria et al. 2015).

The values of RGPS for all cultivars were above or close to 7, which is proposed by Carbonell et al. (2010) as indicative of grains with good acceptance by the market and packing industries. Bettiol et al. (2020) also verified that there was no effect of the forms of N supply on this qualitative attribute, obtaining values of 6.78 and 6.83 for the cultivars IPR Curió and IAC Imperador, respectively.

For the cultivar IAC Veloz, due to the higher number of pods per plant, grains per pod and grain yield (Table 1), there may have been an effect of dilution in the crude protein content due to the lower amount of N in the grains, and the same performance was observed by Farinelli and Lemos (2010) and Amaral et al. (2016).

The values for the cooking time of the IAC Nuance cultivar are close to those verified by Carbonell et al. (2020), of 33 minutes, in a study with cultivars of special bean for export (IAC Nuance, IAC Tigre, IAC Boreal and IAC Harmonia), in 18 environments in the rainy, dry and winter seasons. Alves et al. (2020), using special grain cultivars and top-dressing N application of 90 kg ha^{-1}, in the winter season, found an average value of 28 minutes. Ribeiro et al. (2014) evaluated 29 special grain bean strains in the state of Rio Grande do Sul and verified that the cooking time ranged from 14 to 36 minutes. The cultivar IAC 1849 Polaco, of Carioca grain, was the only one for which the cooking time did not differ statistically with the increase in top-dressing N doses, obtaining values between 20 and 22 minutes, which are below the cooking time of 30 minutes observed by Chiorato et al. (2020a). The cultivar IAC Veloz, of black grains, had the longest cooking time at the N dose of 180 kg ha^{-1}, with a value of 27 minutes, which is below the cooking time of 32 minutes verified by Chiorato et al. (2020b).

The results to maximum hydration time demonstrate the superiority of IAC Veloz in terms of this qualitative attribute, since in Brazilian cookery, during the process of food preparation, bean grains are soaked for approximately 12 h (Santis et al. 2019). Alves et al. (2020), working with five common bean cultivars with Carioca grain (BRS Estilo, BRS MG Majestoso, BRS Ametista, BRS Cometa and BRS Notável) and five cultivars with special grain for export (BRS MG Realce, BRS Embaixador, BRS FS 305, BRS Executivo and BRS Garça), verified on average for each group values of 13h18min and 14h16min, respectively. Although there was no effect of N doses and C x N interaction on this qualitative attribute, it can be verified that the cultivar IAC Veloz also stood out, obtaining the shortest times for maximum grain hydration at each top-dressing N dose (Table 6). However, Farinelli and Lemos (2010) verified that there was an increase in the time for maximum grain hydration with N doses of 0, 40, 80 and 120 kg ha^{-1} applied as top-dressing. The authors also reported that the hydration capacity of common bean grains is dependent on the cultivar, storage conditions and environment, emphasizing the need for scientific studies about the influence of N fertilization on this qualitative characteristic.

Analysis of the biplot showed a positive correlation between the variables crude protein, 100-grain weight, cooking time and sieve yield greater than or equal to 11, 12, 13 and 14 and negative correlation of these variables with leaf N content, number of grains per pod, number of pods per plant, grain yield and dry matter. This indicates the dilution effect discussed earlier, in which higher grain yields are inversely correlated with the protein content of the grains. In addition, there is a direct correlation between protein content, 100-grain weight and cooking time, i.e., the larger the size and protein content of the grains, the longer the cooking time. This can be justified by the greater difficulty of water in breaking down the molecules of carbohydrates and proteins of the grains and promoting their ideal cooking. It was verified that the time for maximum hydration was not correlated with any other variable, being the only one discriminated by PC2, that is, the variation in the time for maximum hydration of common bean grains is independent of the other variables analyzed.

5. Conclusions

Early-cycle common bean cultivars with different types of grains respond differently to N doses applied as top-dressing regarding agronomic and qualitative attributes. The cultivar IAC Veloz stood out in terms of shoot dry matter production, leaf N content, number of pods per plant and number of grains per pod, and the use of increasing N doses up to 180 kg ha^{-1} applied as top-dressing increased grain yield linearly, so it was classified as efficient to the N use. The cultivars IAC Nuance and IAC 1849 Polaco reached maximum grain yields of 1,741 and 1,784 kg ha^{-1} with 155 and 163 kg ha^{-1} of N applied as top-dressing, with increases in grain yield due to the N application of up to 25.3 and 20.2%, respectively. This demonstrates that, among the evaluated cultivars, the IAC Nuance is the one with the greatest response to nitrogen fertilization. Increasing doses of top-dressing N increase the sieve yield and crude protein content of common bean, with the cultivar IAC Nuance standing out for the amount of grains retained on all sieves. The cultivars have good grain quality, and IAC 1849 Polaco and IAC Veloz stood out with the shortest cooking time and IAC Veloz also with the fastest hydration.

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