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Selection of common bean cultivars for the irrigated production system[1]

Seleção de cultivares de feijão-comum em sistema de produção irrigado

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HIGHLIGHTS:
Suitable common bean cultivar choice promoted gains of up to 17% in grain yield.
The cultivars IAC Milênio and IAC Alvorada stood out for grain yield and its components.
Common bean grain yield increased by 86 kg ha^{-1} for each unitary increment in the number of pods per plant.

ABSTRACT: In irrigated production systems, the common bean grain yield must reach high levels to maintain economic viability. In this context, management, like the selection of the most adapted cultivars, may be effective in obtaining high yields. Through a three-year experiment, it was aimed to select the common bean cultivars with the highest agronomic and technological performance in an irrigated production system and to determine the yield component that most interfered with common bean yield. The treatments consisted of eight common bean cultivars with indeterminate growth habit and from the pinto bean variety (carioca): ANFc 9, BRS Estilo, BRSMG Madrepérola, Pérola, IAC Alvorada, IAC Milênio, TAA Bola Cheia, and TAA Dama. IAC Milênio and IAC Alvorada had the highest agronomic performance for irrigated production systems, with grain yields up to 17% higher than other cultivars. The cultivars show little variation in the grain technological quality, meeting the culinary and nutritional qualities recommended for common bean. The ANFc 9 cultivar showed the highest crude protein content in grains (19%). The number of pods per plant is the yield component that most interferes with common bean grain yield, generating 86 kg ha^{-1} increments for each unitary increase. Therefore, the common bean cultivars selection in the irrigated production system is an effective management practice to increase common bean agronomic and quality performance.

Key words: *Phaseolus vulgaris* L., cooking time, crude protein content, grain yield

RESUMO: Em sistemas de produção irrigados, a produtividade de grãos do feijão-comum deve atingir níveis elevados para manter a viabilidade econômica. Nesse contexto, manejos como a seleção de cultivares mais adaptadas podem ser eficazes na obtenção de altas produtividades. Através de um experimento de três anos, objetivou-se selecionar as cultivares de feijão-comum com maior desempenho agronômico e tecnológico em sistema de produção irrigado, além de determinar o componente de produção que mais interfere na produtividade de grãos. Os tratamentos consistiram de oito cultivares de feijão-comum de hábito de crescimento indeterminado e grupo comercial de grãos 'carioca': ANFc 9, BRS Estilo, BRSMG Madrepérola, Pérola, IAC Alvorada, IAC Milênio, TAA Bola Cheia e TAA Dama. As cultivares IAC Milênio e IAC Alvorada apresentam o maior desempenho agronômico para o sistema de produção irrigado, com produtividade de grãos até 17% superior em relação às demais cultivares. As cultivares apresentam pouca variação na qualidade tecnológica do grão, atendendo às qualidades culinárias e nutricionais recomendadas para o feijão-comum. A cultivar ANFc 9 apresentou o maior teor de proteína bruta nos grãos (19%). O número de vagens por planta foi o componente de produção que mais interferiu na produtividade de grãos do feijão-comum, gerando incrementos de 86 kg ha^{-1} para cada aumento unitário. Portanto, a seleção de cultivares de feijão em sistema de produção irrigado é uma prática de manejo eficaz para aumentar o desempenho agronômico e qualitativo do feijão-comum.

Palavras-chave: *Phaseolus vulgaris* L., tempo de cozimento, teor de proteína bruta, produtividade de grãos

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Introduction

Common bean is cultivated in several Brazilian states, in three seasons, and in different production systems (Leal et al., 2019). Present in family farming, aimed at subsistence, and farms with high technological levels, mainly characterized by irrigation and cultivars with high yield potential, correction of acidity, and soil chemical quality improvement. In addition to high yield gains, the aim is to produce grains with better technological quality (Carbonell et al., 2010).

Among the inputs used in common bean crops, seeds represent a small value in the farmer's effective operating cost, around 6.6% (IFAG, 2021). However, choosing the most suitable cultivar for the production system may guarantee the greatest return, resulting in better inputs use and high yield. In addition to cultivars' adaptability and stability (Pereira et al., 2021; Zeffa et al., 2021), the management practices may favor or limit the plant's genetic potential due to factors such as nutrient use efficiency (Leal et al., 2019; Zeffa et al., 2020; 2021) and water use efficiency (Fatumah et al., 2021).

The number of pods per plant, number of grains per pod, 100-grain weight, and plant population are the yield components that may affect grain yield. The genotype-environment interaction influences yield components (Philipo et al., 2021), interfering distinctly with the crop yield. The contribution of each component may help crop breeding programs to improve cultivars in irrigated production systems.

This present study was based on the following hypotheses: (i) common bean cultivars differ in agronomic performance and grain quality in the irrigated production system, and (ii) there is a yield component that most interferes with the common bean grain yield. Therefore, through a three-year experiment, it was aimed at selecting the common bean cultivars with the highest agronomic and technological performance in irrigated production systems and determining the yield component that most interferes with common bean yield.

Materials and Methods

The experiment was conducted in Jaboticabal, São Paulo, Brazil, for three consecutive years (2015, 2016, and 2017), in the fall/winter season (May/June) of common bean. The experimental area is located at 21° 14' 33" S, 48° 17' 10" W, and an altitude of 565 m. According to Köppen's classification, the climate of the region is Aw-type, humid tropical with a rainy season in the summer and a dry season in the winter. The soil in the experimental area is classified as Typic Eutrudox (Soil Survey Staff, 2014), corresponding to 'Latossolo Vermelho eutroférrico' in the Brazilian Soil Classification System (EMBRAPA, 2018). The soil had 540 g kg^{-1} of clay, 230 g kg^{-1} of silt, and 230 g kg^{-1} of sand. Soil sampling was conducted in the 0-0.20 m layer to determine the chemical attributes in each year (Table 1).

In 2015, the average maximum and minimum temperatures during the experimental period were 28.6 and 15.3 °C, respectively, with accumulated rainfall of 170 mm (Figure 1). In 2016, it was 29.1 and 13.9 °C, respectively, with accumulated rainfall of 93 mm, while in 2017, it was 28.0 and 13.4 °C and 21 mm, respectively.

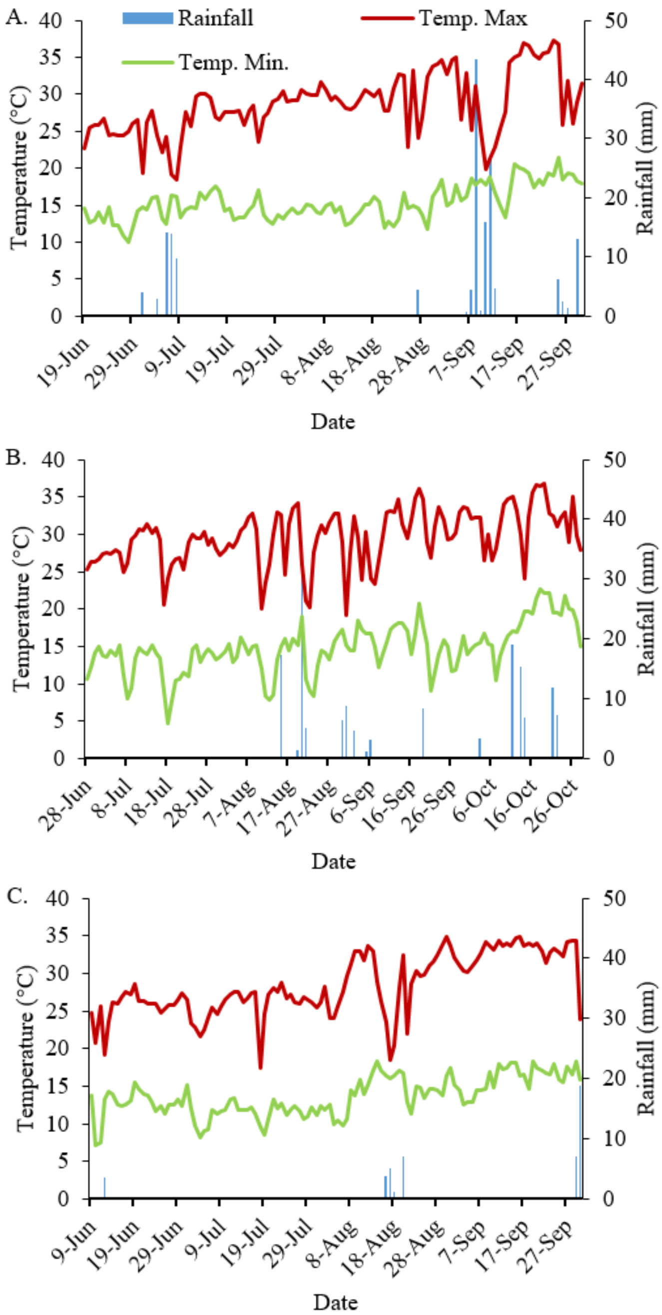


Figure 1. Maximum and minimum temperatures and daily rainfall during the experimental period in 2015 (A), 2016 (B), and 2017 (C)

Table 1. Characterization of soil fertility in the 0-0.20 m layer before the installation of the experiment in the three years

Year	OM (g dm^{-3})	pH$_{1:2}$ (CaCl$_2$)	P$_{resin}$ (mg dm^{-3})	H + Al	K	Ca	Mg	SB	T	V (%)
				(mmol$_c$ dm^{-3})						
2015	24	5.6	41	28	5.7	30	14	49.7	77.7	64
2016	24	5.6	41	25	5.8	34	13	52.8	77.8	68
2017	29	6.0	50	16	6.4	33	14	53.4	69.4	77

OM: organic matter; SB: sum of bases; T: cation exchange capacity; V: base saturation

The experimental design was a randomized block design with eight treatments and four replicates. The treatments consisted of eight common bean cultivars (*Phaseolus vulgaris* L.) from the pinto bean variety (carioca): ANFc 9, BRS Estilo, BRSMG Madrepérola, Pérola, IAC Alvorada, IAC Milênio, TAA Bola Cheia, and TAA Dama. These cultivars were chosen because they are the most cultivated by producers in Brazil. All cultivars show indeterminate growth, types II or III, with a normal cycle, except for BRSMG Madrepérola, which has a semi-early cycle. The experimental plots were composed of five rows 5 m long, spaced at 0.45 m, with the three central rows considered the observation area, except for 2015, when the plot consisted of four rows of common beans and the two central rows were considered as the observation area.

For the common bean sowing, in all years, a seed-cum-fertilizer drill without seeds in the box was used. With the help of this implement, sowing furrows were opened with a spacing of 0.45 m between rows, and the application of fertilizer in the sowing furrow was conducted. The sowing dates in 2015, 2016, and 2017 were June 19, June 28, and June 8, respectively. According to the germination variables, the seeds were manually distributed in the sowing furrows to obtain plant populations between 210 and 240 thousand plants ha^{-1} in the three years. As the experiments were conducted in the winter season, they were irrigated by a conventional sprinkler system. The irrigation depths were variable and performed to meet the water demands of each phenological phase.

Irrigation management was via climate, as defined by Coelho et al. (2023), using daily weather data to calculate reference evapotranspiration (ETo) using the FAO 56 method. Weather data were obtained at a station located 1,000 m from the experiment. Crop evapotranspiration (ETc) was calculated daily by the product of ETo with the tabled crop coefficient (Kc) values for common beans (Coelho et al., 2023). The initial, mid-season, and final Kc values were 0.40, 1.15, and 0.35, respectively. Irrigation showed a variable watering shift, applying 15 mm when the accumulated deficit reached this value.

In 2015, the sowing fertilization (basal dose) comprised 10, 50, and 50 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. In 2016, 3, 29, and 29 kg ha^{-1} of N, P_2O_5, and K_2O were applied, respectively. In 2017, 8, 42, and 42 kg ha^{-1} of N, P_2O_5, and K_2O were applied, respectively. Topdressing fertilization was carried out at the V_{4-4} stage, characterized by the fourth fully expanded trifoliate leaf of each cultivar. At that time, N rates of 90, 100, and 120 kg ha^{-1} were applied in 2015, 2016, and 2017, respectively, using urea coated with the polymer Kimcoat® as the source. Fertilization was carried out in a continuous line 10 cm away from the row, followed by a 20 mm irrigation depth.

At the time of harvest of each cultivar, ten consecutive plants were collected in one of the observation rows of each plot. In these plants, the following yield components were determined: number of pods per plant (NPP), number of grains per pod (NGP), and 100-grain weight (100GW). For the determination of 100GW, four subsamples of 100 grains were used in each plot, standardizing the moisture in 0.13 kg kg^{-1}. To estimate grain yield (GY), the rest of the plants in the observation area in each plot were manually harvested and dried in the sun. After one day, the plants of each plot were mechanically threshed, at 1400 rpm, to determine the grain mass, standardizing the moisture (0.13 kg kg^{-1}).

After estimating the GY, the grains from each plot were placed in a paper bag at room temperature. Between 30 and 60 days after harvest, evaluations were carried out regarding the grain technological quality, determining the grain yield in sieves greater than or equal to 12 (SY≥12), crude protein content (CPC) of the grains, and the cooking time (CT). In determining the SY≥12, the grains of each plot were submitted to a set of sieves with openings of 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), 14/64 × 3/4 (5.56 × 19.05 mm), and 15/64 × 3/4 (5.96 × 19.05 mm) and stirred for one minute. The SY≥12 was calculated by the ratio between the mass of grains retained up to sieve 12 by the total grain mass in each plot, multiplied by 100.

The grains retained in sieves 12 and 13 were used for CPC and CT determination. For the CPC determination, the grains were dried in an air-forced air circulation oven between 65-70 °C until constant weight. After drying, the grains were ground in a Willey-type mill and then submitted to sulfuric acid digestion to determine the N content. CPC was estimated by the equation: CPC = N content x 6.25 (AOAC, 1995). The CT was determined with a Mattson cooker, according to Nunes et al. (2021). The scale proposed by Proctor & Watts (1987) was adopted to assess the degree of resistance of the beans to cooking.

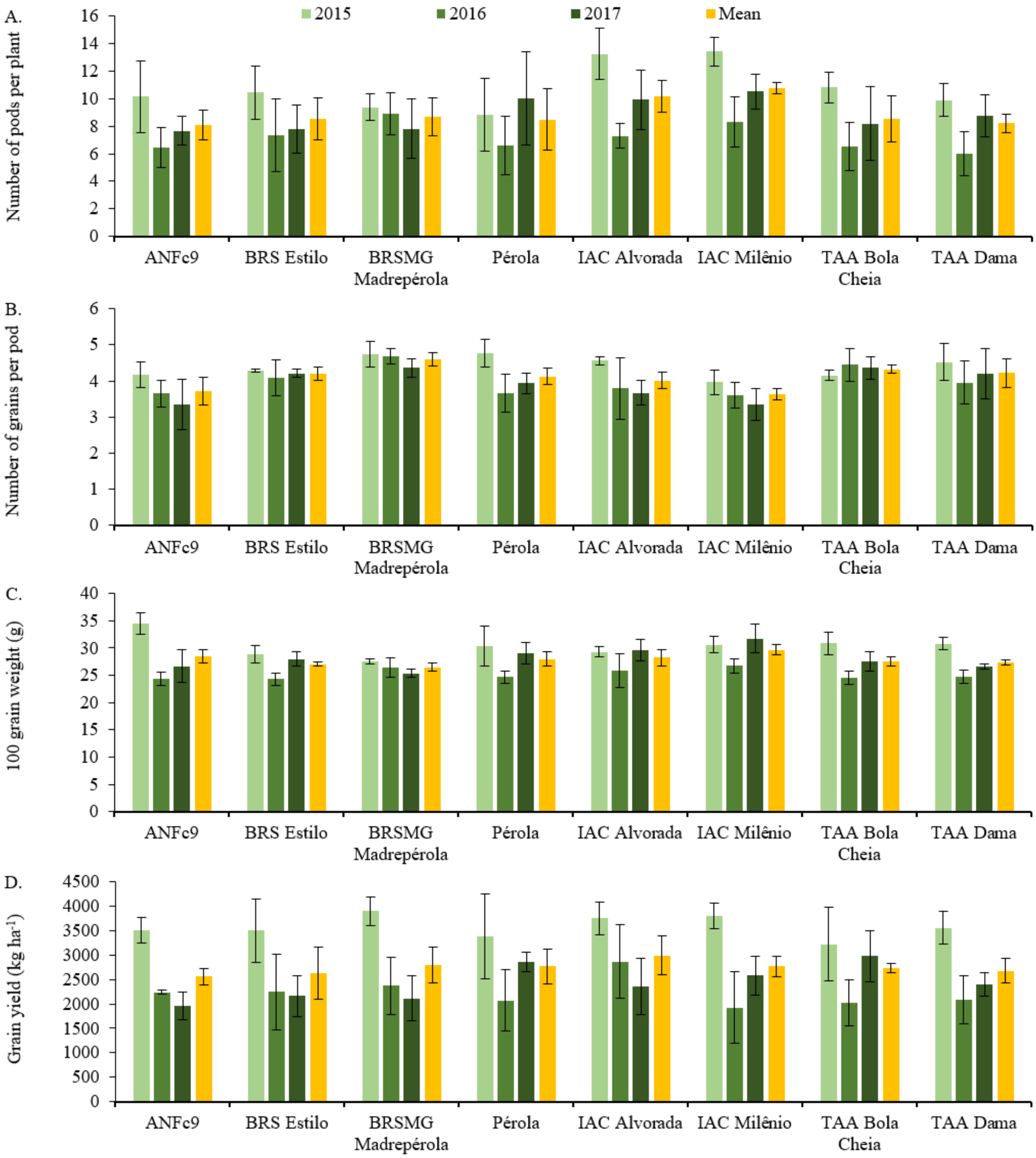
First, descriptive statistics of the variables related to agronomic performance (NPP, NGP, 100GW, and GY) and grain technological quality (SY≥12, CPC, and CT) were performed using the mean and standard deviation. Due to the dependency structure contained in the original set of variables, the data were subjected to principal component analysis. In this analysis, the means of the variables for each cultivar in each year were used, in addition to the analysis of the means of the variables in the three years.

Data were standardized, aiming for all variables to have the same weight in the analysis, generating null mean and unit variance. The number of principal components was selected based on the Kaiser criterion (Kaiser, 1958). Variables with scores above 0.500 were considered relevant to explain each principal component. This analysis made it possible to make a biplot of the spatialization of variables and cultivars in two dimensions. The graphs plotted ellipses covering the values of the X and Y axes, ranging from -1.96 to 1.96. These values refer to the Z value of the normal distribution, where values less than -1.96 and greater than 1.96 indicate points with specific characteristics ($p \leq 0.05$) (Romano et al., 2022). Thus, it was possible to identify cultivars with specific characteristics for each year, as performed by Bertasello et al. (2021). Statistical analyzes were performed using the Statistica® version 7.0 software.

To verify the effect of the yield components on GY, polynomial regression analysis was performed ($p \leq 0.05$).

Results and Discussion

Among the yield components, number of pods per plant (NPP), number of grains per pod (NGP), and 100-grain weight (100GW), NPP showed the greatest variation between cultivars and years (Figure 2).



Bars indicate the standard deviation (n=4)

Figure 2. Mean values of number of pods per plant (A), number of grains per pod (B), 100-grain weight (C), and grain yield (D) of common bean cultivars in 2015, 2016, and 2017 and the three-year mean

The NPP was higher in the first year, except for the Pérola cultivar, in which the values for the first and third years were similar. Among the cultivars, IAC Alvorada and IAC Milênio had the highest values of the three years.

Cultivars showed similar values between years for NGP, except for Pérola and IAC Alvorada, which showed higher means in the first year. In the mean among cultivars, the BRSMG Madrepérola genotype stood out for the highest value for the NGP. As for 100GW, the lowest values were obtained in the second year (2016), except for the cultivar BRSMG Madrepérola, which presented similar values of 100GW between the three years evaluated. Overall, the cultivars IAC Milênio, IAC Alvorada, Pérola, and ANFc9 had the highest means of 100GW (Figure 2).

For grain yield (GY), the highest means were obtained in the first year, while in the second and third years, the GY was similar for each cultivar. An exception happened for the cultivar TAA Bola Cheia, which showed a similar GY between the first and third years. In the three-year mean, GY was similar among the eight cultivars evaluated, with means ranging from 2400 to 3000 kg ha^{-1}.

As for the technological attributes (Figure 3), there was greater variation between years and cultivars for cooking time (CT). For the sieves yield greater than or equal to 12 (SY≥12), the Pérola cultivar presented the lowest value in the three-year mean, with similar values among the other genotypes. On average, the cultivar with the highest crude protein content (CPC) values was ANFc9, while BRS Estilo and TAA Bola Cheia presented the lowest mean values. The other cultivars showed similar values for CPC. For cooking time (CT), the highest values were obtained in 2015, except for the cultivars BRS Estilo, Pérola, and IAC Alvorada, which presented similar values. The CT in the third year was lower than the first two years for all cultivars. On average, between years, the cultivars that presented the lowest CT were BRS Estilo, IAC Alvorada, and TAA Bola Cheia.

Compared to other yield components, the greater variation in NPP between years and cultivars allowed it to be the most important yield component to explain the differences in GY between cultivars. The only variable that showed a correlation with GY ($p \leq 0.01$) in the three years was the NPP.

In the first, second, and third years, for each increase of one pod per plant, there were increases in GY of 79, 195, and 91 kg ha^{-1}, respectively. NGP showed a positive correlation ($p \leq 0.01$) with GY only in the second year, with an increase of 812 kg ha^{-1} for each unit increase in NGP. 100GW showed a positive correlation with GY only in the third year ($p \leq 0.05$), with an increase of 75 kg ha^{-1} in GY for each increment of one g. In the three-year mean, only the NPP presented a positive correlation with GY ($p \leq 0.01$), observing a GY increase of 86 kg ha^{-1} for each unit increase of the NPP.

In the principal components analysis (PCs) for all years and the mean between them, there were two relevant PCs to explain the data variability (Table 2). In 2015, 2016, and 2017 (Figure 5) and the mean among the years (Figure 6), data variability explanation by the first two PCs was 59.47, 58.90, 71.49, and 67.68%, respectively.

In 2015, NGP, 100GW, and CPC were relevant to PC1, with 100GW and CPC being directly correlated with each other and indirectly correlated with NGP, given the negative

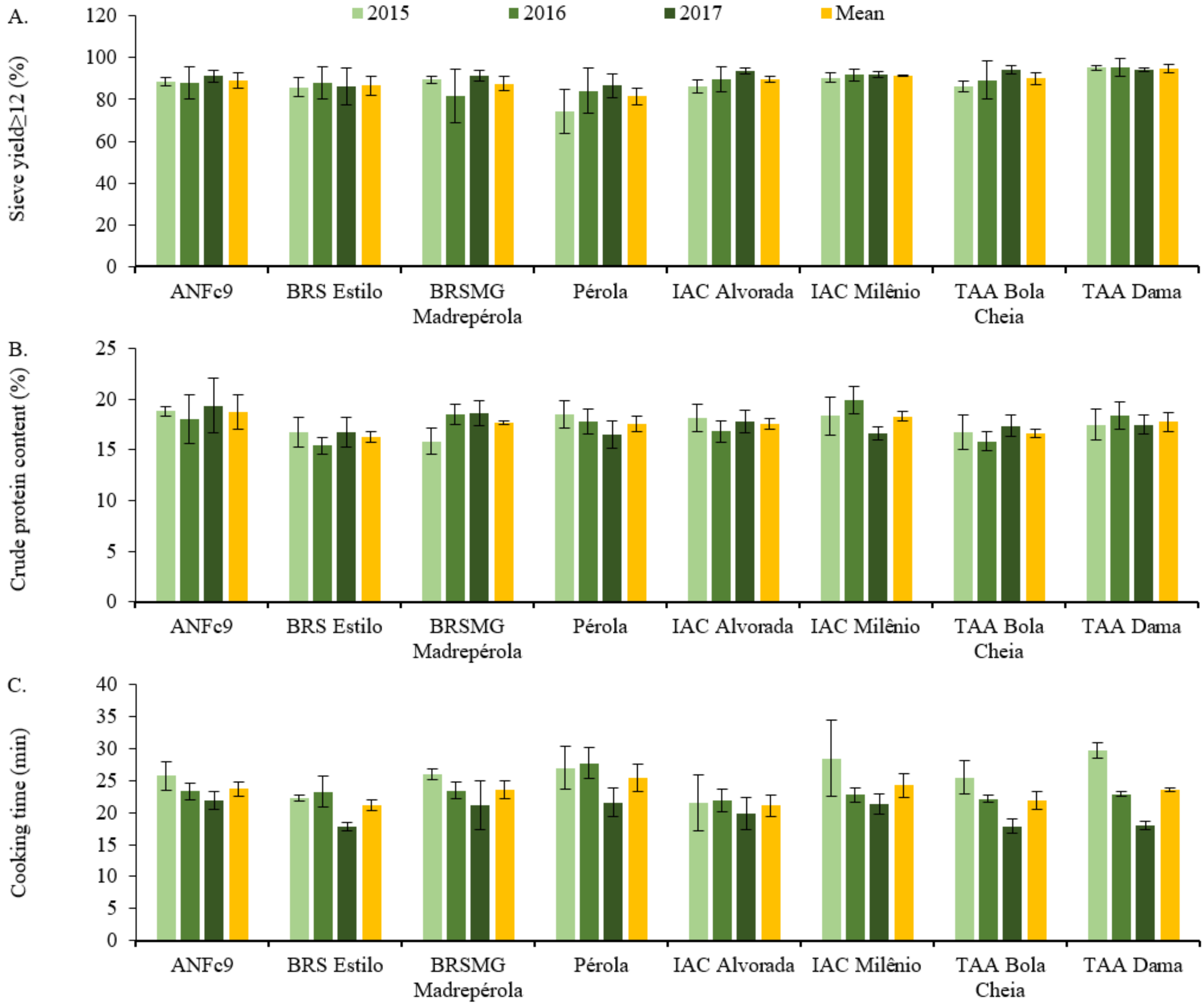
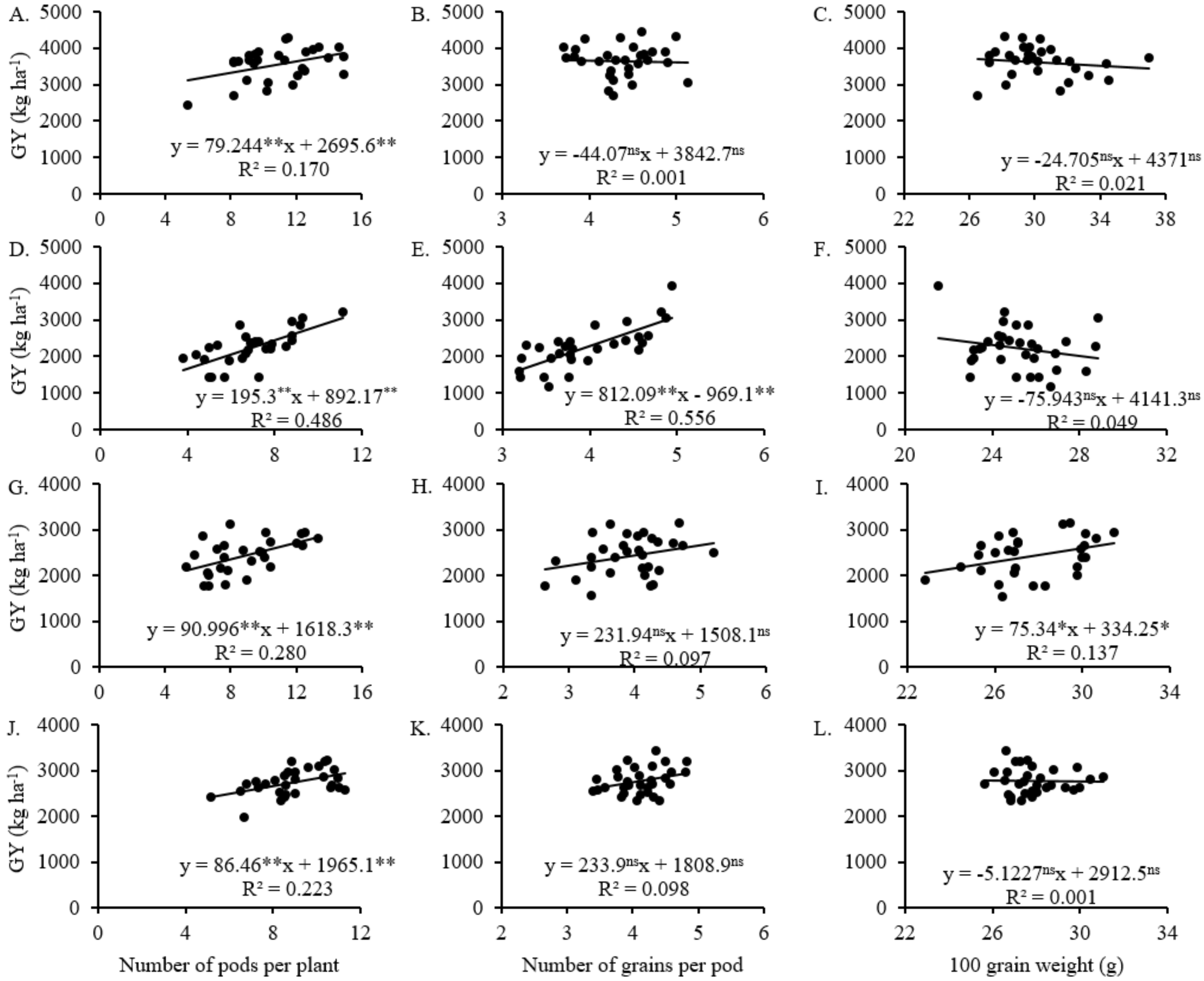


Figure 3. Mean values of sieves yield greater than or equal to 12 (A), crude protein content (B), and cooking time (C) of common bean cultivars in 2015, 2016, and 2017 and the three-year mean



n = 32; *p ≤ 0.05; **p ≤ 0.01 by t-test; [ns]not significant

Figure 4. Relationship of number of pods per plant (NPP), number of grains per pod (NGP), and 100-grain weight (100GW) with grain yield (GY) of common bean cultivars in 2015 (A, E, I), 2016 (B, F, J), 2017 (C, G, K), and the three-year mean (D, H, L)

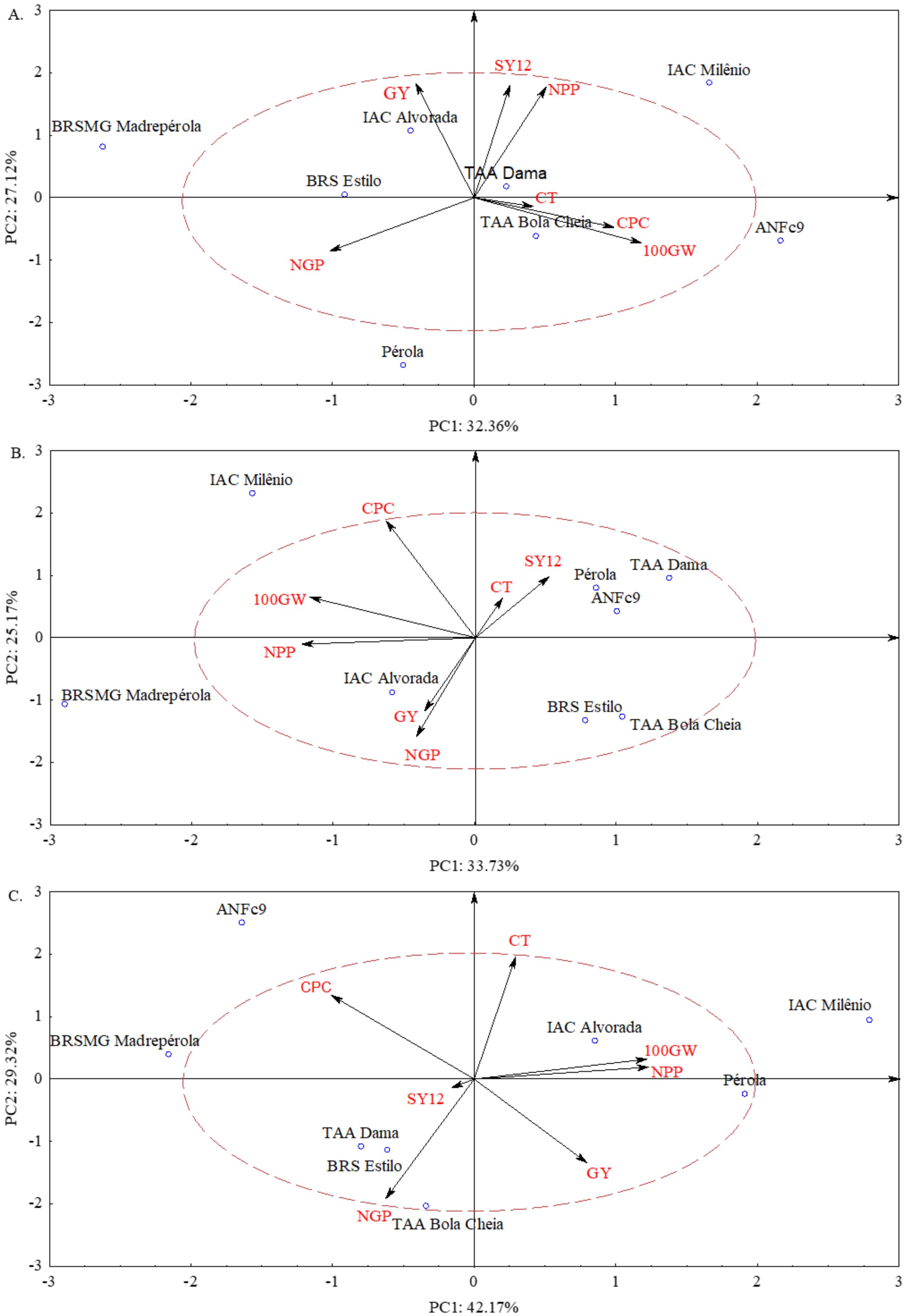
Table 2. Correlation of variables with the principal components for each year and the three-year mean

Attributes	2015		2016		2017		Mean	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
NPP	0.376	0.720	-0.953	-0.062	0.929	0.109	0.646	-0.693
NGP	-0.760	-0.357	-0.327	-0.701	-0.453	-0.819	-0.895	-0.099
100GW	0.885	-0.310	-0.922	0.276	0.943	0.125	0.948	-0.054
GY	-0.294	0.753	-0.266	-0.520	0.609	-0.577	0.117	-0.798
SY≥12	0.182	0.734	0.416	0.419	-0.136	-0.035	0.258	-0.231
CPC	0.740	-0.213	-0.475	0.820	-0.747	0.571	0.771	0.380
CT	0.310	-0.071	0.164	0.270	0.218	0.833	0.397	0.679

NPP: number of pods per plant; NGP: number of grains per pod; 100GW: 100-grain weight; GY: grain yield; SY≥12: sieve yield greater than or equal to 12; CPC: crude protein content; CT: cooking time; PC: principal component

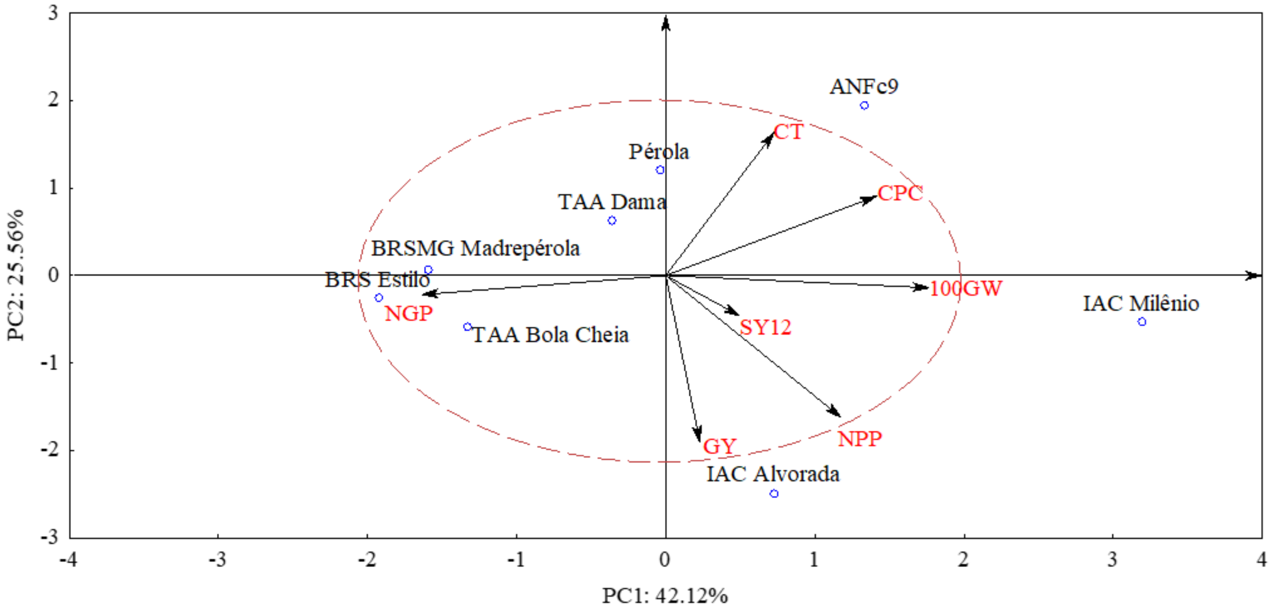
and positive values of the factor loadings. Variables NPP, GY, and SY≥12 were relevant to explain PC2, and all variables were directly correlated. In 2016, PC1 was explained by the variables NPP and 100GW, which are directly correlated. The variables NPP, GY, and CPC were relevant for PC2, showing a direct correlation between NGP and GY, and these showed an indirect correlation with CPC. In 2017, the variables NPP, 100GW, GY, and CPC were relevant to the PC1 explanation, with the variables NPP, 100GW, and GY showing a direct correlation with each other and these variables being indirectly correlated with CPC. For PC2, the variables NGP, GY, CPC, and CT were relevant to explain the variability. The variable NGP with GY and CPC with CT was directly correlated. The variables NGP and GY showed an indirect correlation with CPC and CT.

In the three-year mean, the NPP, NGP, 100GW, and CPC were relevant within PC1, with the NPP, 100GW, and CPC being directly correlated to each other and indirectly with NGP (Table 2). In PC2, the variables NPP, GY, and CT were relevant, with the variables NPP and GY showing a direct



NPP: number of pods per plant; NGP: number of grains per pod; 100GW: 100 grain-weight; GY: grain yield; SY12: Sieve yield ≥12; CPC: crude protein content; CT: cooking time

Figure 5. Principal components (PC) biplot graph of the variables dispersion and common bean cultivars for 2015 (A), 2016 (B), and 2017 (C)



NPP: number of pods per plant; NGP: number of grains per pod; 100GW: 100 grain weight; GY: grain yield; SY12: Sieve yield ≥12; CPC: crude protein content; CT: cooking time

Figure 6. Principal components (PC) biplot graph of the variables dispersion and common bean cultivars for the three-year mean

correlation with each other, and these showed an indirect correlation with CT.

By the biplot graph, some genotypes had specific characteristics distributed outside the ellipse constructed according to the normal distribution at 0.05 probability (Z = -1.96 to 1.96). In the three years evaluated, only the cultivars IAC Milênio and BRSMG Madrepérola were the ones that showed distribution outside the ellipse in the three years. For the biplot graph of the three-year mean (Figure 6), the cultivar IAC Milênio had specific characteristics, as well as the cultivars IAC Alvorada and ANFc9. However, in the three-year mean, the cultivar BRSMG Madrepérola followed the standard of the other cultivars.

The PCA multivariate analysis is a technique that identifies genotypes with specific characteristics, helping producers and breeders make decisions. For coffee, Romano et al. (2022) used the PCA to select the yellow Bourbon genotypes that presented the best agronomic performance, helping breeding programs to select the genetic materials of interest. In maize, Bertasello et al. (2021) verified the most responsive genotypes to the application of *Azospirillum brasilense*, contributing to selecting the genotypes with the highest yield and reducing the use of mineral N.

The distribution of the cultivar IAC Milênio in the four biplot graphs indicates the highest agronomic performance for this cultivar in all cases, as the cultivar was always located close to the variables corresponding to the yield components and GY of the common bean. This pattern was not observed in the cultivar BRSMG Madrepérola, even though it was individually located outside the ellipse for the three years analyzed. For the latter cultivar, the location outside the ellipse was in an inverse quadrant to the variables NPP, 100GW, and GY, which indicates the common bean agronomic performance. In addition, the cultivar did not present specific characteristics for the mean data for the three years. This indicates that, although the cultivar may present high agronomic performance under the conditions studied, its response has high variability.

Another cultivar with specific characteristics for agronomic performance was IAC Alvorada. In the biplot graph with the three-year mean, this cultivar was located outside the ellipse and close to the GY and NPP variables (Figure 6). Even though in the annual multivariate analyses, this cultivar did not show specific characteristics, the three-year mean analysis showed the high agronomic performance of this genotype and its yield stability over the years.

In addition to the cultivars IAC Milênio and IAC Alvorada, it is worth highlighting the results observed for ANFc9. This cultivar had specific characteristics for 2015 and 2017 and the three-year mean analysis. The cultivar was always close to the CPC variable, indicating specific characteristics. The data of descriptive statistics can confirm this fact, as the genotype presented the highest protein content in the general mean. Thus, the cultivar IAC Milênio can be highlighted regarding its agronomic performance, while the cultivar ANFc9 is for the grain quality.

Overall, the appropriate cultivar choice promoted gains of up to 17% in common bean GY in the irrigated production system. The cultivars that stood out regarding agronomic performance were IAC Milênio and IAC Alvorada, with the highest GY values. This demonstrates the benefits of breeding programs in the search for more productive genotypes regionally (IAC). Thus, studies conducted for releasing these genotypes were carried out in edaphoclimatic conditions more similar to the conditions of the present study compared to the other cultivars, which come from breeding programs of other regions.

It is noteworthy that the present study was conducted in the soil of high natural fertility (eutrophic), with high concentrations of P, K, Ca, and Mg (Table 1) and medium organic matter concentration (Fernandes et al., 2019) and in a production system with a high technological level, that is, with adequate irrigation and fertilization management. Thus, under these conditions, responsive cultivars should be prioritized, whose yield increases with the increased availability of the applied resource. Evaluating the use efficiency and response to N of 16 common bean cultivars, Leal et al. (2019) reported that the cultivars IAC Milênio and IAC Alvorada are responsive to N, that is, the increment of this nutrient in the soil increases the GY of these genotypes. The same was concluded by Nunes et al. (2021), where the authors found that the cultivars IAC Alvorada and IAC Milênio are N-use responsive.

However, Leal et al. (2019) and Nunes et al. (2021) related that IAC Alvorada and IAC Milênio are not N-use efficient; that is, under conditions of low availability of N in the soil, these two genotypes produce less than the others. This indicates that these two cultivars can be recommended for irrigated production systems. In the present study, these two genotypes had the highest GY under a high nitrogen fertilizer rate (close to 100 kg ha^{-1} of N). These results demonstrate the adaptability of these cultivars in high-fertility soils, given their responsiveness to nutrient application, such as N.

As for the technological attributes, the cultivars had little variation among themselves. This is because these are already commercial genotypes, improved to present good culinary and nutritional characteristics (Pereira et al., 2021). All cultivars presented SY≥12 above 70%, characterizing large grains with good market acceptability and potential for receiving financial gratification from packers (Carbonell et al., 2010). Regarding the CT, the cultivars were classified as having normal resistance to cooking (Proctor & Watts, 1987), with values ranging from 21 to 28 minutes (three-year mean).

About CPC, the cultivar ANFc 9 showed the highest values, generating a product with higher nutritional quality and biological food value. The highest CPC values for the cultivar ANFc 9 are explained by the lower GY mean of this genotype concerning the others, with protein concentration in the grains. According to Zeffa et al. (2020), in common beans, there is a dilution effect; that is, the higher the GY, the lower the CPC. This same process was reported by Nunes et al. (2021), in which for each increment of 100 kg ha^{-1} in GY, the CPC was reduced by 0.37%. In addition, the common bean has low heritability for CPC (Buratto et al., 2009; Dias et al., 2021), being more easily influenced by environmental and management variations, which makes it difficult to select cultivars for this trait. In this sense, D'Amico-Damião et al. (2020) reported that the CPC was influenced by the straw type on the soil and by the topdressing nitrogen fertilization. Perina et al. (2014) reported that grain technological quality changes depending on the environment.

Among the yield components, NPP was the one that most interfered in the common bean GY, in which the GY increased by 86 kg ha^{-1} (1.43 bags ha^{-1}) for each unitary increment. NPP has been cited as the common bean yield component that most interferes with GY, with the highest phenotypic, genotypic, and environmental correlation coefficients with GY (Philipo et al., 2021). However, Assefa et al. (2015) reported that different yield components might have the highest phenotypic correlations with GY depending on the region and year. This also occurs in the present study, in which in some years, NGP and 100GW presented positive correlations with GY, but in general, in all three years and three-year mean analysis, NPP and GY showed a positive correlation, which can be considered a more stable yield component for more productive cultivars selection.

The NGP is a yield component with the highest genotypic variation (>70%) (Philipo et al., 2021). However, it has low interference due to the environment and management; the production system practically does not act on this component. This fact makes it difficult to use only NGP for the selection of more productive genotypes, as observed in the present study, in which NGP had little interference in the GY. According to Leal et al. (2015), the interaction between yield components composes the common bean grain yield. Among these components, there is an adjustment in the balance for photoassimilates, in which 100GW is the most affected, as higher or lower values of NPP and NGP directly affect the grain mass. This fact explains the little effect of 100GW on common bean GY, as obtained in the present study. This adjustment in the balance between source and drain for the yield components also justifies the differences in the relationship between them verified in the principal components analysis, in which, depending on the year, the correlations between the three yield components are not the same.

Notably, knowledge of the yield component that most interferes with common bean GY is essential for breeding programs and producers. Through this definition, breeding programs can carry out the indirect selection of the best genotypes through NPP for irrigated production systems. At the same time, producers can use management that favors an NPP increase.

Conclusions

1. Cultivars IAC Milênio and IAC Alvorada have the highest agronomic performance for irrigated production systems, with grain yield up to 17% higher than other cultivars.

2. The cultivars show little variation in the grain technological quality, meeting the culinary and nutritional qualities recommended for common bean.

3. The ANFc 9 cultivar showed the highest crude protein content in grains (19%).

4. The number of pods per plant is the yield component that most interferes with common bean grain yield, generating 86 kg ha^{-1} increments for each unitary increase.

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