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Development and grain yield of common bean cultivars according to sowing season

Desenvolvimento e produtividade de grãos de cultivares de feijão-comum em função da época de semeadura

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Abstract

The cycle and grain yield of bean crops can be influenced by several factors, among them sowing season and bean cultivar. The objective of this work is to evaluate the development, production components, and grain yield of common bean cultivars in function of sowing seasons. The experiment was conducted at the Experimental Farm of Universidade do Oeste Paulista in the municipality of Presidente Bernardes, São Paulo state, in 2016. The experimental design was randomized blocks in a 4 x 4 factorial design with four replications. The treatments were four sowing seasons (SS1 - April 12; SS2 - May 14; SS3 - June 11; and SS4 - July 14), and four common bean cultivars (BRS Estilo, BRS Pérola, BRS Requinte, and IPR Campos Gerais). The phenological stages V4, R6 and R9, plant height, plant population, number of pods per plant, mass of 100 grains, and grain yield were influenced by sowing seasons and bean cultivars. The highest grain yields for the cv. BRS Estilo, BRS Requinte and IPR Campos Gerais were obtained at SS2. However, for the cv. BRS Pérola, it occurred at SS4. At SS1, the highest grain yield was obtained by the cv. BRS Estilo, and other sowing seasons by the cv. BRS Pérola.

Additional keywords: cultivars; grain yield; *Phaseolus vulgaris*; sowing seasons.

Resumo

O ciclo e a produtividade de grãos da cultura do feijão podem ser influenciados por diversos fatores, dentro dos quais se situam a época de semeadura e a cultivar de feijão. Assim, o objetivo deste trabalho foi avaliar o desenvolvimento, os componentes de produção e a produtividade de grãos de cultivares de feijão-comum em função da época de semeadura. O experimento foi conduzido na Fazenda Experimental da Universidade do Oeste Paulista, no município de Presidente Bernardes – SP, no ano de 2016. O delineamento experimental foi em blocos casualizados, em esquema fatorial 4 × 4, com quatro repetições. Os tratamentos foram compostos por quatro épocas de semeadura (E1 - 12 de abril; E2 - 14 de maio; E3 - 11 de junho e E4 - 14 de julho) e quatro cultivares de feijão-comum (BRS Estilo, BRS Pérola, BRS Requinte e IPR Campos Gerais). Os estádios fenológicos V4, R6 e R9, a altura de plantas, a população de plantas, o número de vagens por planta, a massa de 100 grãos e a produtividade de grãos foram influenciados pelas épocas de semeadura e cultivares de feijão. As maiores produtividades de grãos para as cvs. BRS Estilo, BRS Requinte e IPR Campos Gerais foram obtidas na E2; entretanto, para a cv. BRS Pérola, ocorreu na E4. Na E1, a maior produtividade de grãos foi obtida com a cv. BRS Estilo, e nas demais épocas de semeadura com a cv. BRS Pérola.

Palavras-chave adicionais: cultivares; épocas de semeadura; *Phaseolus vulgaris*; produtividade de grãos.

Introduction

The bean crop has a great importance for agriculture and for food for the Brazilian population as it is an excellent source of protein. The total area cultivated with beans in Brazil is approximately 3.2 million ha, with a production of 3.4 million tons of grains. Common bean (*Phaseolus vulgaris* L.) is the main cultivated species (CONAB, 2018). According to a survey conducted by FAOSTAT (2018), Brazil is one of the largest producers of beans in the world.

Bean cultivation in Brazil is carried out throughout the year. The sowing periods are between August and December (commonly known as "harvesting of the waters"), January and March ("dry season"), and April and June ("winter harvest") (Arf et al., 2015). The sowing of beans throughout the year occurs mainly because the bean plant does not have sensitivity to photoperiods. Thus, rainfall and temperature are the climatic factors that influence the development and grain yield of common bean grains the most. Water supply by rainfalls, when not sufficient to supply the water demand of the bean crop, can be provided by irrigation. However, temperature control for a proper development of bean culture is very difficult to obtain.

The choice of the sowing season is important to cultivate beans in environments that present adequate temperatures for its development and consequently grain yield. The bean is a C3-cycle plant. Therefore, when cultivated in high temperature environments, its photosynthesis can decrease mainly due to increased respiration and photorespiration (Taiz et al., 2017). According to Fancelli & Dourado Neto (2007), the average optimal temperature for bean crop development is 21 ºC. Night and/or day temperatures above 25 and 30 ºC, respectively, may adversely affect flower buds and pod formation (Barbosa & Gonzaga, 2012), decreasing the number of pods per plant and, consequently, grain yield. Arf et al. (2015) have pointed out that high temperatures at the initial stages of development may cause death of bean seedlings.

Due to the influence of temperature on bean grain development and yield, studies should be carried out to evaluate the best sowing season for bean cultivars. There may be an interaction between environments × bean cultivars (Cunha, 2005). Thus, a specific sowing season provides the highest grain yield for each common bean cultivar.

The objective of this work is to evaluate the development, production components, and grain yield of common bean cultivars in function of sowing seasons.

Materials and methods

The experiment was conducted in 2016 at the Experimental Farm of the Universidade do Oeste Paulista, located in Presidente Bernardes, state of São Paulo (22º17'05.04" S, 51º40'40.22" W, and 396 m of altitude). The climate of the region, according to the Köppen classification, is Aw. It has a rainfall regime characterized by two distinct periods, one rainy from October to March and another with low rainfalls from April to September (Figure 1).

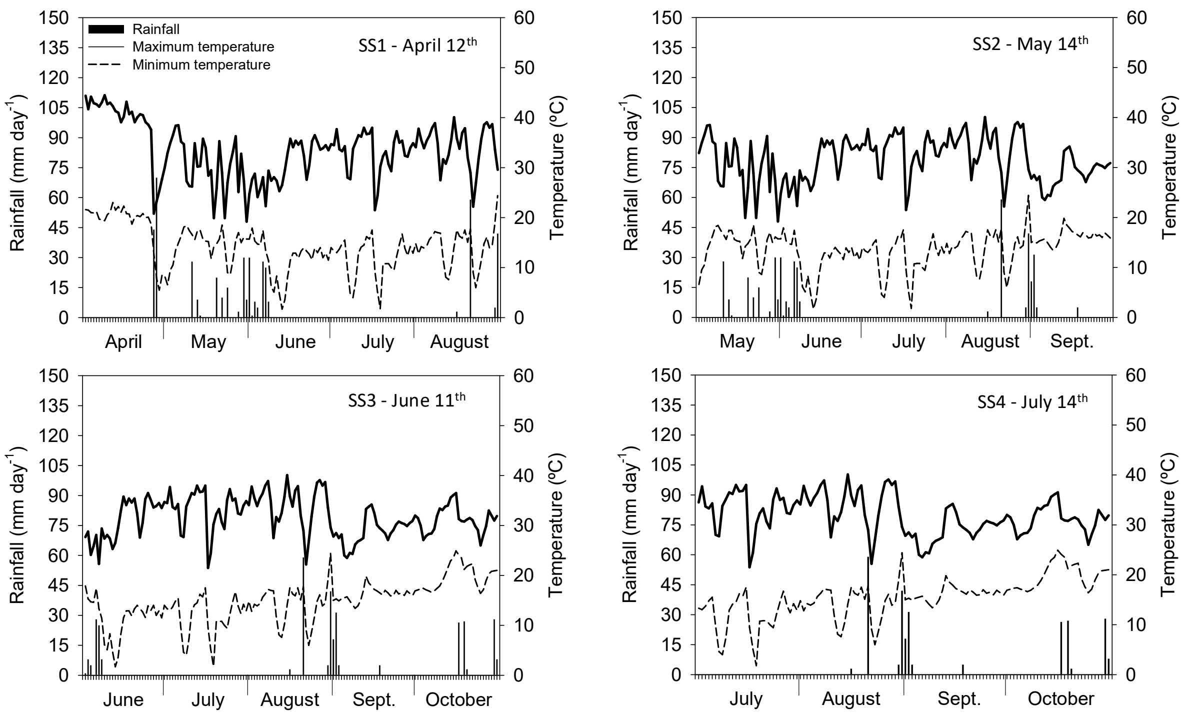

Figure 1 – Rainfall, maximum and minimum air temperature registered in the sowing seasons of the common bean, in 2016.

The area used to install the experiments was cultivated with maize between January and June 2015 (winter harvest), and soybean between October and February 2015/16 (summer harvest). The soil of the experimental area was classified as a dystrophic red Argisol (Santos et al., 2013), with 730, 110 and 160 g kg^{-1} of sand, silt and clay at the 0-20 cm depth layer, respectively. At the same depth, the chemical characteristics of the soil are pH ($CaCl_2$) 5.5, OM 17.3 g dm^{-3}; P_{resin} 10.7 mg dm^{-3}; K, Ca, Mg and H+Al 2.7, 14.5, 8.0 and 15.1 $mmol_c$ dm^{-3}, respectively; and base saturation of 62%.

The experimental design was randomized blocks in a 4 x 4 factorial design with four replications. The treatments were four sowing seasons (SS1 - April 12; SS2 - May 14; SS3 - June 11; and SS4 - July 14), and four common bean cultivars (BRS Estilo, BRS Pérola, BRS Requinte, and IPR Campos Gerais). Each experimental unit consisted of seven rows of 6 m in length, with a spacing of 0.45 m between rows. For the evaluations, the two central rows were considered, excluding 0.5 m at the ends of each evaluation row.

The studied cultivars present beans of the Carioca type, indeterminate growth, and cycle between emergence and maturation of approximately 90 days after emergence (DAE). The cv. BRS Estilo has a type II size (erect), while the cv. BRS Pérola, BRS Requinte and IPR Campos Gerais have a type III size (prostrate and branching) (MAPA, 2018).

Three weeks before each sowing season of bean cultivars, the area was desiccated with glyphosate (1.08 kg ha^{-1} of a.i.). Moments before sowing, the seeds of both bean cultivars were treated with the fungicide carboxin + thiram (60 + 60 g a.i. per 100 kg of seeds) and with the insecticide fludioxonil + metalaxyl-M (7.55 ± 3 g per 100 kg of seeds). The bean cultivars were sown in a soil planted using direct planting system and a seed fertilizer (Semeato, model SHM 15/17), which was regulated to distribute 15 bean seeds per meter of furrow. For seeding fertilization, 70 kg ha^{-1} of P_2O_5 (triple superphosphate) were applied.

The crop was irrigated throughout the cycle. The irrigation depths were between 7 and 10 mm. The irrigation was performed every four days using sprinklers (conventional system), according to crop requirements, when rainfall was not sufficient to meet the crop water requirement. Top dressing fertilization was performed when the cultivars were at the V4 development stage (third trifoliate leaf). 90 kg ha^{-1} of K_2O (potassium chloride) and 80 kg ha^{-1} of N (ammonium sulfate) were applied (Ambrosano et al., 1997). When the cultivars were at the development stage R5 (pre-flowering), 180 g ha^{-1} Zn (zinc sulfate), 260 g ha^{-1} Mn (manganese sulphate) and 31 g ha^{-1} Mo (sodium molybdate) were applied in a 200 L ha^{-1} volume broth.

At the V3 stage (first trifoliate leaf), weed control was performed between the lines of bean plants with the application of the herbicide fluazifop-p-butyl (187.5 g ha^{-1} of a.i.). For pest and disease control, thiamethoxam + lambda-cyhalothrin (17.6 ± 13.5 g ha^{-1} of a.i.) and chlorpyrifos (480 g ha^{-1} of a.i.) were sprayed. The fungicides azoxystrobin + diphenoconazole (80 + 50 g ha^{-1} of a.i.) and carbendazim (250 g ha^{-1} of a.i.) were applied at the V4 and R5 stages.

From the emergence (V1) of beans, the number of days required for bean cultivars to reach the development stages V4 (third trifoliate leaf), R6 (flowering) and R9 (maturation) was evaluated. The stages of development were defined when 50% or more of plants in each experimental unit had the characteristics described as specific to each phenological stage (Oliveira et al., 2018). The data are presented in days after emergence (DAE).

When bean cultivars reached the R6 development stage, ten plants per experimental unit were evaluated as for plant height (PHe) and first pod insertion height (FPIH). For quantification of PHe, the length between the base and the apex of the stem (considering the branching) was considered. For the quantification of FPIH, the length between the base of the stem and the insertion of the first pod was considered. Both results are given in cm.

At the R9 development stage, ten plants per experimental unit were collected for the quantification of production components (final population of plants, number of pods per plant, number of grains per pod, and mass of 100 grains). To determine grain yield, the plants contained in three rows of 3 m in length were harvested manually. Afterwards, these grains were submitted to mechanical tracing, cleaning and weighing in a semi-analytical scale for grain yield quantification, which is presented in kg ha^{-1} (13% moisture).

The data were submitted to analysis of variance. The means of the treatments were compared by Tukey test at 5% probability using the statistical software SISVAR (Ferreira, 2011). The figures were prepared using the software SIGMAPLOT.

Results and discussion

According to Figure 1, rainfalls of 344, 355, 168 and 224 mm were recorded between sowing and harvesting on SS1, SS2, SS3 and SS4, respectively. The mean maximum and minimum air temperatures recorded between sowing and harvesting of bean cultivars were 33 and 13, 31 and 13, 32 and 13, and 31 and 14 ºC on SS1, SS2, SS3 and SS4, respectively. The SS2, because it presented the highest rainfall and an average temperature (maximum and minimum) lower than the other sowing seasons, provided the best climatic conditions for the development of the bean crop. According to Fancelli & Dourado Neto (2007), the average optimal temperature for the bean crop development is 21 ºC.

The number of days required for common bean cultivars to reach the developmental stages V4, R6 and R9 were influenced by sowing seasons and common bean cultivars (Table 1). There was a significant interaction between sowing seasons × bean cultivars as for the number of days required for common bean cultivars to reach the V4 and R9 stages. In general, the low number of days required for the cv. BRS Estilo, BRS Pérola and IPR Campos Gerais to reach the V4 stage were obtained on SS4, while for the cv. BRS Requinte, it occurred on SS2 (Figure 2 A and B). The lowest number of days required to reach the R6 development stage was obtained on SS4 independently of the bean cultivars (Table 1). The cv. IPR Campos Gerais presented the shortest period to reach the R6 development stage, at which it differed statistically from the cv. BRS Estilo and BRS Pérola (Table 1). To reach the R9 stage, the shortest periods were observed when the bean cultivars were sown on SS4 (Figure 2 C and D). On SS1, the period in which the cv. BRS Estilo and BRS Pérola reached the R9 development stage was higher than the period for the cv. BRS Requinte and IPR Campos Gerais. These results may have occurred mainly due to climatic conditions (rainfall and temperature), which were different, and, consequently, influenced the development of bean cultivars. According to Fernández et al. (1986), factors such as growth habits (indeterminate and determined), climatic conditions (temperature) and soil types may influence the phenological stages of common bean crops. Miranda & Campelo Júnior (2010) also observed that sowing seasons might influence the development of common bean crops.

Table 1 – Number of days after emergence (DAE) to reach the phenological stages of third trifoliated leaf (V4), flowering (R6) e maturation (R9), and plant height (PHe) e first pod insertion height (FPIH) of commom bean cultivars in sowing seasons

Treatments	V4	R6	R9	PHe	FPIH
Sowing season (SS)[2]	------------------ DAE ------------------			-------- (cm) --------	
SS1	23.06a[1]	56.13ab	106.88a	63.98a	11.92a
SS2	20.44b	54.44b	103.44b	55.81a	9.42ba
SS3	23.38a	57.19a	104.63b	60.27a	11.56a
SS4	19.38b	51.38b	87.44c	56.35a	13.04a
Cultivars (C)					
BRS Estilo	22.00a	55.25a	102.25a	51.98ab	11.79a
BRS Pérola	22.31a	56.06a	103.63a	81.54a	12.38a
BRS Requinte	20.50b	54.63ab	98.19b	46.44c	10.81a
IPR Campos Gerais	21.44ab	53.19b	98.31b	56.46b	10.96a
	------------------------- F test (probability - p) -------------------------				
SS	<0.001	<0.001	<0.001	0.037	0.051
C	<0.001	<0.001	<0.001	<0.001	0.076
SS × C	0.016	0.060	<0.001	<0.001	0.228
CV (%)	6.64	3.28	1.74	14.74	15.04

(1) Means followed by different letters in the column differ from other by Tukey test ($p < 0.05$). (2)SS1 - April 12; SS2 – May 14; SS3 – June 11, and SS4 – July 14.

Plant height (PHe) was influenced by sowing seasons and bean cultivars, with a significant interaction between these factors (Table 1 and Figure 2 E and F). The cv. BRS Pérola, when cultivated on SS1, presented a higher PHe than the other bean cultivars (Figure 2). In general, at all sowing seasons, the highest PHe was obtained by the cv. Pérola (81 cm) (Figure 2 E and F). Branches in type III bean cultivars (BRS Pérola) are larger than in cultivars with type II size (BRS Estilo, BRS Requinte, IPR Campos Gerais) (Fancelli & Dourado Netto, 2007). Abrantes et al. (2011) evaluated PHe in common bean cultivars (IAC Apuã, type II, and Carioca Precoce, type I), and observed a higher plant height for the cv. IAC Apuã, which has an indeterminate growth habit and a type II size.

The first pod insertion height (FPIH) was not influenced by sowing seasons and bean cultivars (Table 1). Plant population (PP), number of pods per plant (NPP) and mass of 100 grains (M100) were influenced by sowing seasons and bean cultivars (Table 2). The highest PP values were obtained at sowing seasons SS2 and SS3, with 234 and 231 thousand plants ha^{-1}, respectively. This response probably occurred due to the lower temperatures recorded between germination (V0) and emergence (V1), with average temperatures of 21 and 20ºC on SS2 and SS3, compared to SS1, which, between the stages V0 and V1, presented a mean temperature of 30ºC, reflecting a lower plant population (93,957 plant ha^{-1}) (Figure 1). The occurrence of high temperatures between the V0 and V1 stages of development may decrease seed germination, cause seedling death, consequently reducing bean grain yield in function of plant population decrease (Arf et al. 2015; Ecco et al. 2017). The cv. BRS Requinte presented the highest PP, with an average of 240 thousand plants ha^{-1}.

The highest NPP was obtained on SS1, differing statistically from SS2 and SS3 (Table 2). This higher NPP obtained on SS1 (13 pods $plant^{-1}$) can be attributed mainly to the lower PP obtained during that same sowing season (93,957 plant ha^{-1}). According to Fancelli & Dourado Neto (2007), common bean cultivars, which have an indeterminate growth habit (type II and III), have the capacity to compensate the production components when there is a lower plant density.

Soratto et al. (2017) evaluated the NPP in the cv. BRS Pérola and observed that the decrease in the population of 199,990 plants ha^{-1} to 111,110 plants ha^{-1} resulted in an increase in the number of pods per plant and consequently an increase in grain yield. Among the cultivars, the BRS Estilo presented the highest NPP, but differed statistically only from the cv. BRS Requinte, which presented the lowest NPP.

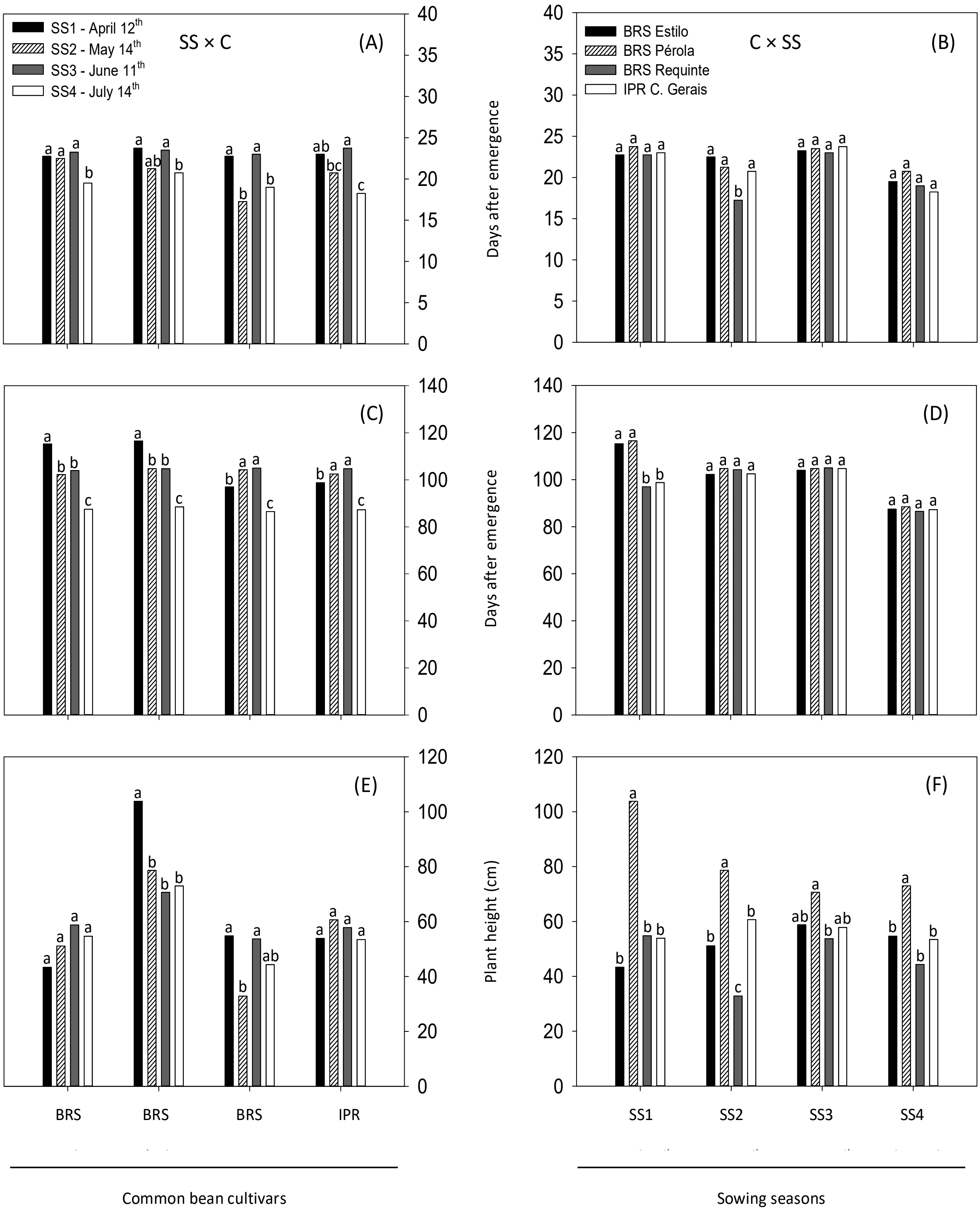

Figure 2 – Interaction between sowing seasons and commom bean cultivars upon the number of the days to reach the phenological stages V4 (A and B) and R9 (C and D), and for plant height (E and F). Means followed by different letters for each combination of the factors differ from other by Tukey test ($p < 0.05$).

Table 2 – Plant population (PP), number of pods per plant (NPP), number of grains per pod (NGP), mass of 100 grains (M100), and grain yield (GY) of commom bean cultivars in sowing seasons.

Treatments	PP (plants ha^{-1})	NPP	NGP	M100 (g)	GY (kg ha^{-1})
Sowing season (SS)[2]					
SS1	93,957c[1]	13.0a	3.9	29.4a	1762b
SS2	234,719a	10.6b	4.2	24.7b	2340a
SS3	231,247a	10.2b	3.7	30.4a	2051ab
SS4	172,915b	12.8ab	4.2	23.8b	1970ab
Cultivars (C)					
BRS Estilo	159,836b	14.0a	4.1	28.2ab	1955b
BRS Pérola	157,104b	12.5a	3.9	31.7a	2624a
BRS Requinte	240,391a	8.5b	4.2	23.2c	1867b
IPR Campos Gerais	175,507b	11.6a	3.7	25.2bc	1678b
	------------------------- F test (probability - p) -------------------------				
SS	<0.001	0.017	0.147	<0.001	0.023
C	<0.001	<0.001	0.229	<0.001	<0.001
SS × C	0.589	0.381	0.867	0.960	0.026
CV (%)	27.72	25.82	18.6	17.27	25.22

[(1)] Means followed by different letters in the column differ from other by Tukey test ($p < 0.05$). [(2)]SS1 - April 12; SS2 – May 14; SS3 – June 11, and SS4 – July 14.

The sowing of bean cultivars on SS1 and SS3 resulted in the highest M100 grains, with a mean of 29.2 and 30.4 g, respectively (Table 2). These results may have occurred due to the lower number of grains per pod (3.9 grains pods^{-1}) and plant population (93,957 plants ha^{-1}) on SS1, and fewer grains per pod (3.7 grains pod^{-1}) and pods per plant (10.2 pods plant^{-1}) on SS1. Thus, there is a lower division of photoassimilates redistributed by grain per unit area, resulting in a higher M100. Almeida et al. (2017) also observed that sowing seasons influenced the M100 grain of the bean crop (*Vigna unguiculata* (L.) Walp). The cv. BRS Pérola presented a higher M100 grains (31.7 g) than the other bean cultivars, which is related to the morphological characteristic of the grain of this cultivar in presenting a greater M100 in relation to the other cultivars studied in the present study. According to Lemos et al. (2015), the average M100 is 26, 27, 24 and 24 g, respectively, for the cv. BRS Estilo, BRS Pérola, BRS Requinte, and IPR Campos Gerais. In addition to the characteristic of the cultivar, the smaller redistribution of photoassimilates between grains, a result from the lower number of grains per pod (3.9 grains pod^{-1}) and lower plant population (157,104 plants ha^{-1}), which decreases competition between plants for water, light and nutrients, is another factor that may also explain the higher M100 for the cv. Pérola.

Grain yield (GY) was influenced by sowing seasons and bean cultivars, with a significant interaction between these factors (Table 2 and Figure 3). The sowing season that provided the highest GYs varied according to the bean cultivars. In general, the highest GY were obtained by the cv. BRS Estilo (2,402.36 kg ha^{-1}), BRS Pérola (2,748.97 kg ha^{-1}) and BRS Requinte (2,225.53 kg ha^{-1}) on SS2 (Figure 3B). These results can be attributed mainly to climatic conditions and to the larger plant population (234,719 kg ha^{-1}) observed during SS2 (Figure 1 and Table 2). Regarding the climatic conditions on SS2, the determining factor was the average temperature during the entire crop cycle and at the emergence stage, which was 22 ºC, close to the average optimum temperature for the development of bean crops (21 ºC) (Fancelli & Dourado Neto, 2007).

When cultivars were sown on SS1, the bean plants were exposed to higher average temperatures (23 ºC) during the total cycle of plants and average temperatures of 30 ºC at germination (V0) and emergence (VE), which resulted in a decrease in plant population (Figure 1 and Table 2). Another important factor is the effect of high temperatures on decreasing net photosynthesis as a result of an increased respiration and photorespiration, reflecting a higher mean GY (1,762 kg ha^{-1}) (Table 2) (Hoffmann Júnior et al. 2007; Taiz et al. 2017).

Among the cultivars, the highest GY was obtained by the cv. BRS Pérola (3,081.83 kg ha^{-1}) on SS4 (Figure 3A). During the sowing seasons SS3 and SS4, the cv. Pérola presented the highest GY, but differed only from the cv. BRS Requinte and IPR Campos Gerais on SS3 and from the cv. BRS Estilo and BRS Requinte on SS4. The highest grain yield obtained by the cv. BRS Pérola can be explained by its characteristic growth habit: type III indeterminate, with a long flowering period, generally of 15 to 20 days (Lemos et al., 2015). This confers a greater productive flexibility when cultivated under adverse conditions, such as on SS3, in which the flowering period of the cv. BRS Pérola (first half of August) occurs at high temperatures (25 ºC) (Figure 1). However, because it has a longer flowering period, the plant is able to obtain a higher index of pod ripening, since there is a probability of part of the period of flowering occurring under favorable climatic conditions, with an average temperature close to 21 ºC.

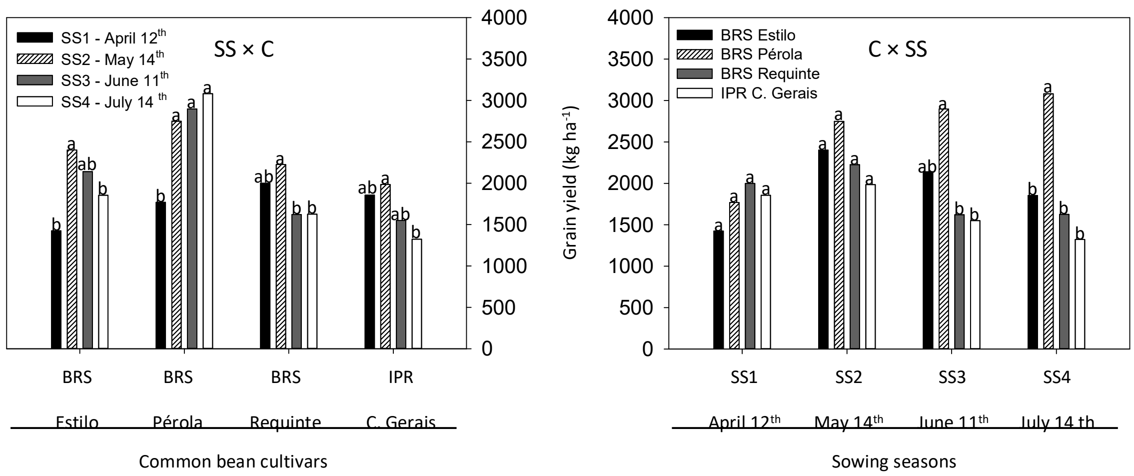

Figure 3 – Interaction between sowing seasons and common bean cultivars upon grain yield. Means followed by different letters for each combination of the factors differ from other by Tukey test ($p < 0.05$).

Conclusions

The phenological stages V4, R6 and R9, plant height, plant population, number of pods per plant, mass of 100 grains, and grain yield were influenced by sowing seasons and common bean cultivars.

There is an interaction between sowing seasons × common bean cultivars regarding the phenological stages V4 and R9, plant height, and grain yield.

The cultivars BRS Estilo, BRS Requinte and IPR Campos Gerais, in the Oeste Paulista region, should be sown in the first half of May. The cultivar BRS Pérola has a greater flexibility, with a good grain yield performance of sowing between May and July.

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