http://journal.unoeste.br/index.php/ca/index
DOI: 10.5747/ca.2024.v20.h529
ISSN on-line 1809-8215

Colloquium Agrariae

Submetido: 13/12/2023 Revisado: 28/02/2024 Aceito: 12/06/2024

PERFORMANCE OF COMMON BEAN CULTIVARS IN DIFFERENT ENVIRONMENTS AND PLANT POPULATIONS

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Abstract

This study aimed to identify the most suitable plant populations, considering different environmental conditions (locations, growing seasons, and sowing dates), to express the yield potential of common bean cultivars released or in the process of releasing for regions not included in the initial release. Forty-four experiments were carried out from November 2016 to March 2019, encompassing wet, dry, and winter seasons, across the states of Goiás, Minas Gerais and Paraná. Five plant populations established at sowing (12, 18, 24, 30, and 36 plants m^{-2}) were compared in a randomized block design with four replications, using the cultivars BRS FC310, BRS FC409, and BRSMG Uai. Across winter season experiments, the BRS FC310 cultivar consistently displayed higher yield than the others at all plant populations. In contrast, the BRSMG Uai cultivar exhibited the highest yield during the wet season. The maximum grain yields of the three cultivars were higher in the wet than in the winter season and obtained with higher plant populations. Cultivars BRS FC310, BRS FC409, and BRSMG Uai maximized grain yield with, respectively, 28.4, 25.4, and 26.2 plants m^{-2} at harvest time in the wet season, and 20.4, 14.0, and 15.2 plants m^{-2} in the winter season.

Keywords: *Phaseolus vulgaris* L.; plasticity; sowing date; yield potential.

PERFORMANCE DE CULTIVARES DE FEIJÃO-COMUM EM DIFERENTES AMBIENTES E POPULAÇÕES DE PLANTAS

Resumo

O estudo teve como objetivo identificar populações de plantas mais adequadas, frente a diferentes condições ambientais (locais, épocas de cultivo e safras), para expressar o potencial produtivo de cultivares de feijoeiro recentemente lançadas ou em processo de extensão de lançamento para outras regiões não contempladas no lançamento inicial. Foram conduzidos 44 experimentos, entre novembro de 2016 e março de 2019, nas épocas das águas, da seca e de inverno, em Goiás, Minas Gerais e Paraná. Foram comparadas, no delineamento de blocos ao acaso, com quatro repetições, cinco populações de plantas estabelecidas na semeadura, 12; 18; 24; 30 e 36 plantas m^{-2}, usando as cultivares BRS FC310, BRS FC409 e BRSMG Uai. A cultivar BRS FC310 foi mais produtiva que as demais em todas as populações de plantas nos experimentos conduzidos durante a época de inverno e a cultivar BRSMG Uai foi a mais produtiva na época das águas. As produtividades máximas das três cultivares na época das águas foram superiores às observadas na época de inverno e foram obtidas com maiores populações finais de plantas. As cultivares BRS FC310, BRS FC409 e BRSMG Uai maximizaram a produtividade com, respectivamente, 28,4; 25,4 e 26,2 plantas m^{-2} por ocasião da colheita, na época das águas, e 20,4; 14,0 e 15,2 plantas m^{-2}, na época de inverno.

Palavras-chave: *Phaseolus vulgaris* L.; plasticidade; época de semeadura; potencial produtivo.

Introduction

Common bean (*Phaseolus vulgaris* L.) is cultivated in a large part of the Brazilian states, in different sowing seasons (wet, dry, and winter), cropping systems and technological levels, subjecting the crop to diverse edaphoclimatic conditions (Barili *et al.*, 2015; Tavares *et al.*, 2017).

Due to environmental variability, the performance of common bean cultivars varies substantially with sowing seasons, with average yields in 2019, in the states where the experiments were conducted, of 1,969; 1,580 and 2,886 kg ha^{-1} for the wet and dry seasons (average of GO, MG and PR) and winter (average of GO and MG), respectively (IBGE, 2020). In the seasons when the common bean crop depends on rainfall (wet and dry seasons), it is subjected to greater abiotic and biotic limitations than in the winter season, when the crop is irrigated (Justino *et al.*, 2022; Teixeira *et al.*, 2017).

In the continuous search for new common bean cultivars, which are more productive, less sensitive to biotic and abiotic stresses and with characteristics that meet the needs of the consumer market, it is essential to know the performance of cultivars in different environments (Barili *et al.*, 2015; Kavalco *et al.*, 2018; Tavares *et al.*, 2017). This is especially true in the case of common bean cultivars in the release phase and the extension of recommendation to regions not included in the initial release.

To efficiently utilize production factors and maximize the yield potential of cultivars, it is crucial to determine the most suitable spatial arrangement for each cultivar and environment (Guimarães; Stone; Melo, 2020). Proper plant distribution affects weed control and can represent an important strategy for the more efficient use of production factors such as light, water, and nutrients, especially when these resources are in quantities lower than plant needs (Guimarães *et al.*, 2019).

Generally, the most recommended spacing for common beans is from 40 to 50 cm between rows, with 10 to 15 seeds per meter (Araújo; Camelo, 2015). However, the growing season can influence how the crop responds to sowing density. If environmental conditions favor more vegetative growth, a lower sowing density is recommended. However, it's important to consider the specific growth habit of the common bean variety and its yield component plasticity (Santos *et al.*, 2014).

The adequate plant population per unit area maximizes productivity and its agronomic components. The number of pods per plant is the first yield component defined in the reproductive phase and the most easily affected by the increase in plant population due to the competitive environment. In turn, environmental conditions influence the number of grains per pod more than the plant population. However, the competition for light and photoassimilates provided by the increase in the plant population can cause flower and grain abortion in the pods, reducing the number of grains produced. The 100-grain weight (GW) is the yield component least influenced by the plant population, as it is a character of qualitative inheritance, little influenced by the environment (Santos *et al.*, 2014).

Edaphoclimatic conditions and plant population affect the leaf area of plants, interfering with the amount of photosynthetically active radiation intercepted and absorbed by the leaves, which has a straight influence on the growth and development of common beans, as it directly relates to the plant's photosynthetic rate (Teixeira; Stone; Heinemann, 2015).

This study aimed to identify the most suitable plant populations, considering different environmental conditions (locations, growing seasons, and harvests), to express the yield potential of common bean cultivars released or in the process of releasing for regions not included in the initial release.

Material and Methods

Forty-four experiments were conducted with common bean (Table 1**)** from November 2016 to March 2019, encompassing wet, dry, and winter seasons, across the states of Goiás (Cristalina, Formosa, Rio Verde, São João da Aliança, and Santo Antônio de Goiás), Minas Gerais (Patos de Minas and Uberlândia) and Paraná (Ponta Grossa). In all locations, during wet and dry seasons, the crop was grown in a rainfed regime, while in winter it was irrigated by sprinkling, with a central pivot system. The soils of the experimental areas were classified as Red Latosol (Oxisol).

Some experiments were conducted at the experimental areas of partner institutions and others directly on producer farms. At the partner institutions, researchers were able to collect more detailed data, including productivity and its various components. On the farms, data collection was limited to productivity and final plant population. In almost all of these farms, the experiments were conducted for just one season. Irrigation equipment was not available at all locations, so experiments were primarily conducted during the wet season. Ponta Grossa, in the southern region, was the only location where experiments were carried out during the dry season. Due to the high risk of golden mosaic virus in the central region, no experiments were conducted there at that time.

Five plant populations were established at sowing (12, 18, 24, 30, and 36 plants m²), with a row spacing of 0.50 m. This corresponds to 6, 9, 12, 15, and 18 plants m^{-1}, respectively. The populations were compared in a randomized block design with four replications, using the cultivars BRS FC310, BRS FC409, and BRSMG Uai, all from the carioca group, with similar phenology and architecture.

Table 1. Locations, common bean cultivars, sowing and harvesting seasons and dates, and geographic coordinates of the experiments.

Nº	Location	Cultivar	Season	Sowing date	Harvest date	Geographic coordinates
1	Patos de Minas, MG	BRS FC310	Wet	11/23/17	2/21/18	18°31'0.93"S, 46°26'19.98"W
2	Patos de Minas, MG	BRS FC409	Wet	11/23/17	2/21/18	18°31'0.93"S, 46°26'19.98"W
3	Patos de Minas, MG	BRSMG Uai	Wet	11/23/17	2/21/18	18°31'0.93"S, 46°26'19.98"W
4	Uberlândia, MG	BRS FC310	Winter	6/19/17	9/27/17	19º06'09.00"S, 48º21'04.00"W
5	Uberlândia, MG	BRS FC409	Winter	6/19/17	9/27/17	19º06'09.00"S, 48º21'04.00"W
6	Uberlândia, MG	BRSMG Uai	Winter	6/19/17	9/27/17	19º06'09.00"S, 48º21'04.00"W
7	Sto. Antônio de Goiás, GO	BRS FC409	Wet	11/09/16	2/07/17	16º29'22.87"S, 49º18'00.40"W
8	Sto. Antônio de Goiás, GO	BRS FC310	Wet	11/09/16	2/07/17	16º29'22.87"S, 49º18'00.40"W
9	Sto. Antônio de Goiás, GO	BRS FC409	Winter	6/08/17	9/05/17	16º29'15.01"S, 49º17'58.33"W
10	Sto. Antônio de	BRS	Winter	6/08/17	9/05/17	16º29'15.01"S,

	Goiás, GO	FC310				49º17'58.33"W
11	Formosa, GO	BRS FC310	Winter	5/05/17	8/23/17	15º42'27.82"S, 47º19'22.75"W
12	Cristalina, GO	BRS FC310	Wet	11/23/17	2/21/18	17º03'58.72"S, 47º45'55.86"W
13	Cristalina, GO	BRS FC409	Wet	11/23/17	2/21/18	17º03'58.72"S, 47º45'55.86"W
14	Cristalina, GO	BRSMG Uai	Wet	11/23/17	2/21/18	17º03'58.72"S, 47º45'55.86"W
15	Sto. Antônio de Goiás, GO	BRS FC310	Wet	12/19/17	3/17/18	16º29'57.34"S, 49º17'35.63"W
16	Sto. Antônio de Goiás, GO	BRS FC409	Wet	12/19/17	3/17/18	16º29'57.34"S, 49º17'35.63"W
17	Sto. Antônio de Goiás, GO	BRSMG Uai	Wet	12/19/17	3/17/18	16º29'57.34"S, 49º17'35.63"W
18	São João D'Aliança, GO	BRS FC310	Wet	11/25/17	2/21/18	14º23'51.35"S, 47º26'07.25"W
19	São João D'Aliança, GO	BRS FC409	Wet	11/25/17	2/21/18	14º23'51.35"S, 47º26'07.25"W
20	São João D'Aliança, GO	BRSMG Uai	Wet	11/25/17	2/21/18	14º23'51.35"S, 47º26'07.25"W
21	Rio Verde, GO	BRS FC310	Wet	12/12/17	3/07/18	17º48'00.00"S, 50º55'00.00"W
22	Rio Verde, GO	BRS FC409	Wet	12/12/17	3/07/18	17º48'00.00"S, 50º55'00.00"W
23	Rio Verde, GO	BRSMG Uai	Wet	12/12/17	3/07/18	17º48'00.00"S, 50º55'00.00"W
24	Ponta Grossa, PR	BRS FC310	Dry	1/25/18	5/02/18	25°08'21.00"S, 50°04'41.00"W
25	Ponta Grossa, PR	BRS FC409	Dry	1/25/18	5/02/18	25°08'21.00"S, 50°04'41.00"W
26	Ponta Grossa, PR	BRSMG Uai	Dry	1/25/18	5/02/18	25°08'21.00"S, 50°04'41.00"W
27	Sto. Antônio de Goiás, GO	BRS FC310	Winter	6/07/18	9/07/18	16º29'24.05"S, 49º17'53.24"W

28	Sto. Antônio de Goiás, GO	BRS FC409	Winter	6/07/18	9/07/18	16º29'24.05"S, 49º17'53.24"W
29	Sto. Antônio de Goiás, GO	BRSMG Uai	Winter	6/07/18	9/07/18	16º29'24.05"S, 49º17'53.24"W
30	Uberlândia, MG	BRS FC310	Winter	5/16/18	8/27/18	19º06'09.00"S, 48º21'04.00"W
31	Uberlândia, MG	BRS FC409	Winter	5/16/18	8/27/18	19º06'09.00"S, 48º21'04.00"W
32	Uberlândia, MG	BRSMG Uai	Winter	5/16/18	8/27/18	19º06'09.00"S, 48º21'04.00"W
33	Formosa, GO	BRS FC310	Wet	10/26/18	1/23/19	15°44'05.75"S, 47º26'09.25"W
34	Formosa, GO	BRS FC409	Wet	10/26/18	1/23/19	15°44'05.75"S, 47º26'09.25"W
35	Formosa, GO	BRSMG Uai	Wet	10/26/18	1/23/19	15°44'05.75"S, 47º26'09.25"W
36	Sto. Antônio de Goiás, GO	BRS FC310	Wet	12/06/18	3/04/19	16º30'01.78"S, 49º17'28.92"W
37	Sto. Antônio de Goiás, GO	BRS FC409	Wet	12/06/18	3/04/19	16º30'01.78"S, 49º17'28.92"W
38	Sto. Antônio de Goiás, GO	BRSMG Uai	Wet	12/06/18	3/04/19	16º30'01.78"S, 49º17'28.92"W
39	Rio Verde, GO	BRS FC310	Wet	12/05/18	2/28/19	17º48'00.00"S, 50º55'00.00"W
49	Rio Verde, GO	BRS FC409	Wet	12/05/18	2/28/19	17º48'00.00"S, 50º55'00.00"W
41	Rio Verde, GO	BRSMG Uai	Wet	12/05/18	2/28/19	17º48'00.00"S, 50º55'00.00"W
42	Patos de Minas, MG	BRS FC310	Wet	12/05/18	2/25/19	18°31'0.93"S, 46°26'19.98"W
43	Patos de Minas, MG	BRS FC409	Wet	12/05/18	2/25/19	18°31'0.93"S, 46°26'19.98"W
44	Patos de Minas, MG	BRSMG Uai	Wet	12/05/18	2/25/19	18°31'0.93"S, 46°26'19.98"W

Fertilization was carried out according to soil chemical analysis and crop recommendations. Agronomic management practices, such as weed, insect pest and disease control, followed the recommendations for the crop (Carneiro; Paula Júnior; Borém, 2015). Grain yield and final plant population were determined in a useful area of 4 m^2 and, in some experiments; the 100 GW and the number of pods per plant and of grains per pod were also evaluated.

Joint analyses were performed considering all locations and growing seasons (environments) as main plot and plant population as subplot, and individual analyses by environment. Data were subjected to analysis of variance using the GLM procedure of the SAS statistical program (SAS Institute, 1985) and means were compared by Tukey's test at a probability of 0.05. In addition, whenever pertinent, regression analyses between the final plant population and other variables were performed.

Results and Discussion

There was a significant effect of environment on grain yield and its components for all cultivars (Tables 2 and 3). This is due to the different edaphoclimatic conditions of the locations and sowing seasons. Barili et al. (2015), Tavares et al. (2017), and Kavalco et al. (2018) also observed a differentiated response in the grain yield of common bean genotypes when grown in different environments.

Table 2. Summary of the analysis of variance of grain yield of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai grown in different environments (location x season) and plant populations.

Cause of variation	BRS FC310		BRS FC409		BRSMG Uai	
	DF	MSE	DF	MSE	DF	MSE
Environment (E)	15	16330980.9**	14	15962520.9**	12	19345895.4**
Error a	48	451361.2	45	211395.1	39	491178.9
Population (P)	4	1442124.3**	4	297669.0ns	4	1055327.4**
E x P	60	438356.3**	56	170656.9ns	48	317038.7**
Error b	192	202424.4	180	157614.6	156	150998.5
CV (%)	20.7		20.0		17.7	

DF = degrees of freedom; MSE = mean square error; CV = coefficient of variation; ns = F not significant; ** = F significant, $p \leq 0.01$.

The plant population had a significant effect on the grain yield of the cultivars BRS FC310 and BRSMG Uai and, among the yield components, only on the number of pods per plant of all cultivars

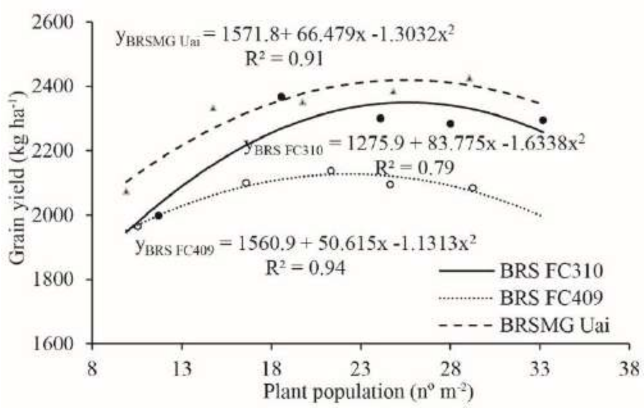
(Tables 2 and 3). The yield response of the BRSMG Uai and BRS FC310 cultivars to the final plant population was quadratic, with maximums of 2,420 and 2,350 kg ha^{-1}, with 25.5 and 25.6 plants m^{-2}, respectively, that is, between 12 and 13 plants per meter. Although the plant population did not significantly affect the grain yield of the BRS FC409 cultivar, it showed a quadratic response trend, with a maximum of 2127 kg ha^{-1}, with 22.4 plants m^{-2}, or 11 plants per meter (Figure 1).

Table 3. Summary of the analysis of variance of number of pods per plant (NPP), number of grains per pod (NGP) and 100 GW of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai grown in different environments (location x season) and plant populations.

Cause of variation		**NPP**	**NGP**	**100 GW**
	DF	**MSE**	**MSE**	**MSE**
			BRS FC310	
Environment (E)	12	220.6**	11.0**	154.3**
Error a	39	11.1	0.2	7.2
Population (P)	4	714.8**	0.3ns	3.1ns
E x P	48	15.9**	0.3ns	6.6ns
Error b	156	10.0	0.3	5.3
CV (%)		21.4	12.6	9.8
			BRS FC409	
Environment (E)	11	316.0**	10.2**	172.6**
Error a	36	14.7	0.4	3.6
Population (P)	4	432.5**	0.6ns	0.5ns
E x P	44	12.3ns	0.4ns	4.4ns
Error b	144	12.7	0.4	5.5
CV (%)		24.7	14.8	9.0
			BRSMG Uai	
Environment (E)	9	245.1**	16.6**	89.2**
Error a	30	17.9	0.7	6.8
Population (P)	4	666.1**	0.6ns	3.3ns
E x P	36	17.7ns	0.6ns	3.7ns
Error b	120	14.1	0.6	3.6
CV (%)		24.3	17.4	7.8

DF = degrees of freedom; MSE = mean square error; CV = coefficient of variation; ns = F not significant; ** = F significant, $p \leq 0.01$.

Figure 1. Grain yield of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai as a function of final plant population in experiments conducted at various sowing seasons and locations.



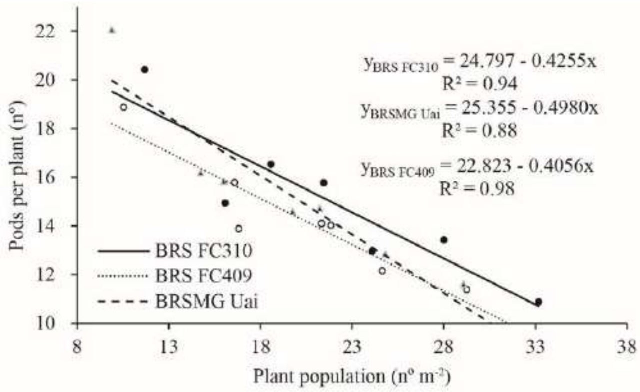
According to the literature, the effect of increasing plant population on common bean yield is variable: Silveira and Stone (2019) observed a decrease in yield, Masa, Tana and Ahmed (2017) reported an increase and Silva et al. (2012), Santos et al. (2014) and Guimarães et al. (2019) found that plant population did not affect yield.

The number of pods per plant decreased linearly with increasing final plant population in all cultivars, ranging from 19.7 to 7.4 pods per plant. The pod reduction rates in the plants with increasing plant population, inferred by the angular coefficient of the linear model fitted to the data, were 0.40, 0.42, and 0.50 pods per plant for each increase of 1 plant m^{-2}, respectively for cultivars BRS FC409, BRS FC310 and BRSMG Uai (Figure 2).

The environment x plant population interaction was significant for the grain yield of the BRS FC310 and BRSMG Uai cultivars and, among the yield components, for the number of pods per plant of the BRS FC310 cultivar (Tables 2 and 3). Therefore, the results were discussed separately by environment.

Of the 16 experiments with the BRS FC310 cultivar, in 11 the plant population significantly affected productivity (Table 4). For the BRS FC409 cultivar, this occurred in 11 of the 15 experiments and for the BRSMG Uai, in 10 of the 13 experiments.

Figure 2. Pods per plant of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai as a function of final plant population in experiments conducted at various sowing seasons and locations.



The response of BRS FC310, BRS FC409, and BRSMG Uai cultivars' yield to the final plant population was quadratic in five, eight, and five environments, respectively, with maximum yields achieved with populations of 23.6 to 29.0, 23.3 to 32.5, and 21.8 to 30.8 plants m^{-2}. For these same cultivars, the response was linear and increasing in six, three, and five environments, respectively.

The lack of yield response to the final plant population in some of the experiments is due to the plasticity of the common bean crop. This plasticity causes grain yield to remain stable over a wide range of plant populations. Stone and Silveira (2008) observed common bean yield stability between 18.5 and 40 plants m^{-2}, Silva *et al*. (2012) between 20 and 40 plants m^{-2}, and Silva *et al*. (2018) between 10 and 30 plants m^{-2}.

Table 4. Common bean cultivars, locations, seasons and grain yield response to final plant population.

Nº	Cultivar	Location	Season	Equation	R	Xmax	Ymax
1	BRS FC310	Patos de Minas, MG	Wet	$y = 1486.9 + 112.92x - 1.9493x^2$	0.91*	29.0	3,122
2	BRS FC409	Patos de Minas, MG	Wet	$y = 677.52 + 113.84x - 1.8975x^2$	0.93*	30.0	2,385
3	BRSMG Uai	Patos de Minas, MG	Wet	$y = 1337.8 + 40.369x$	0.91*	-	-
4	BRS FC310	Uberlândia, MG	Winter	$y = 2108.1 - 36.156x$	0.99**	-	-
5	BRS FC409	Uberlândia, MG	Winter	$y = -58.062 + 83.469x -1.7877x^2$	0.88*	23.3	1,032
7	BRS	Sto. Antônio de	Wet	$y = 1720.4 - 21.219x$	0.91*	-	-

	FC409	Goiás, GO					
10	BRS FC310	Sto. Antônio de Goiás, GO	Winter	y = 2730.1 + 16.863x	0.95**	-	-
12	BRS FC310	Cristalina, GO	Wet	y = 3544.2 + 5.9429x	0.83*	-	-
13	BRS FC409	Cristalina, GO	Wet	y = 1214.6 + 149.54x - 2.3008x^2	0.96**	32.5	3,644
14	BRSMG Uai	Cristalina, GO	Wet	y = 1031.5 + 222.64x - 3.8916x^2	0.94*	28.6	4,216
15	BRS FC310	Sto. Antônio de Goiás, GO	Wet	y = 984.75 + 211.44x - 4.2786x^2	1.00**	24.7	3,597
16	BRS FC409	Sto. Antônio de Goiás, GO	Wet	y = 458.09 + 139.09x - 2.239x^2	0.97**	31.1	2,618
17	BRSMG Uai	Sto. Antônio de Goiás, GO	Wet	y = 3102.2 + 7.9826x	0.86*	-	-
18	BRS FC310	São João D'Aliança, GO	Wet	y = -3065.2 + 531.66x - 9.4885x^2	0.98**	28.0	4,382
19	BRS FC409	São João D'Aliança, GO	Wet	y = 1255.5 + 147.33x - 3.0042x^2	0.97**	24.0	3,061
20	BRSMG Uai	São João D'Aliança, GO	Wet	y = 2528.1 + 24.324x	0.87*	-	-
23	BRSMG Uai	Rio Verde, GO	Wet	y = 541.75 + 90.312x - 1.684x^2	0.98**	26.8	1,753
24	BRS FC310	Ponta Grossa, PR	Dry	y = 719.17 + 41.389x	0.95**	-	-
25	BRS FC409	Ponta Grossa, PR	Dry	y = 475 + 47.202x - 0.7606x^2	0.94*	31.0	1,207
26	BRSMG Uai	Ponta Grossa, PR	Dry	y = -511.74 + 172.14x - 3.0645x^2	0.95**	28.1	1,906
29	BRSMG Uai	Sto. Antônio de Goiás, GO	Winter	y = 1150.8 + 142.38x - 3.2618x^2	0.97**	21.8	2,705
30	BRS FC310	Uberlândia, MG	Winter	y = -661.57 + 225.9x - 4.7853x^2	0.89*	23.6	2,004
31	BRS FC409	Uberlândia, MG	Winter	y = 1650.2 - 6.5234x	0.96**	-	-

33	BRS FC310	Formosa, GO	Wet	$y = 400.99 + 217.34x - 4.1734x^2$	0.97**	26.0	3,231
34	BRS FC409	Formosa, GO	Wet	$y = 818.54 + 163.69x - 3.1833x^2$	0.99**	25.7	2,923
35	BRSMG Uai	Formosa, GO	Wet	$y = 1704.5 + 91.862x - 1.4906x^2$	0.96**	30.8	3,120
36	BRS FC310	Sto. Antônio de Goiás, GO	Wet	$y = 1051.5 - 15.538x$	0.83*	-	-
37	BRS FC409	Sto. Antônio de Goiás, GO	Wet	$y = 383.73 + 15.779x - 0.2923x^2$	0.98**	27.0	597
38	BRSMG Uai	Sto. Antônio de Goiás, GO	Wet	$y = 772.96 -17.755x$	0.99**	-	-
40	BRS FC409	Rio Verde, GO	Wet	$y = 1218.9 + 20.783x$	0.83*	-	-
42	BRS FC310	Patos de Minas, MG	Wet	$y = 1522 + 47.628x$	0.95**	-	-
44	BRSMG Uai	Patos de Minas, MG	Wet	$y = 3184.8 - 19.939x$	0.84*	-	-

*Significant, p≤0,05, **significant, p≤0,01

The plasticity of yield components face to different environmental conditions, due to variations in plant population, is a genetic factor, therefore subject to differentiation between cultivars. This characteristic of cultivars is desirable when plantability is poor. Increased emission of lateral branches induced by the greater availability of solar radiation compensates, at least partially, seed distribution failure. On the other hand, it limits the increase in productivity, because when the plant population increases, there is a lower emission of lateral branches, therefore a lower number of nodes and a lower capacity of the plant to produce grains.

The dry season has the lowest production potential due to the reduction in rainfall and accumulated radiation, in addition to the high frequency of minimum temperatures below the optimum during the reproductive phase (Heinemann; Stone, 2015). Thus, as only one experiment with each of the cultivars was conducted in the dry season, it was disregarded and the experiments were grouped by wet and winter growing season and the variance analyzes were conducted separately (Tables 5 and 6).

Table 5. Summary of the analysis of variance of grain yield of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai grown in different locations and plant populations, in wet and winter seasons.

Causa da variação	DF	MSE	DF	MSE	DF	MSE
	BRS FC310		**BRS FC409**		**BRSMG Uai**	
			Wet			
Location (L)	8	16330549.1**	8	10128125.9**	7	13494460.7**
Error a	27	219379.2	27	164837.5	24	261285.6
Population (P)	4	1479594.0**	4	328556.6ns	4	908374.2**
L x P	32	512276. 7**	32	243714.3ns	28	221085.9*
Error b	108	195862.4	108	175394.9	96	133117.9
CV (%)		17.6		18.2		13.7
			Winter			
Location (L)	4	9789420.6**	3	22833690.3**	2	7542361.2*
Error a	15	928358.9	12	357396.7	9	1418345.7
Population (P)	4	153764.9ns	4	114742.2ns	4	463860.8ns
L x P	16	369902.4ns	12	77744.4ns	8	743326.1**
Error b	60	268094.5	48	173635.4	36	245674.9
CV (%)		26.7		22.3		28.7

DF = degrees of freedom; MSE = mean square error; CV = coefficient of variation; ns = F not significant; * = F significant, $p \leq 0.05$; ** = F significant, $p \leq 0.01$.

There was a significant effect of location on grain yield and its components, in both winter and wet seasons, except for the 100-grain weight of the BRS FC409 cultivar in the winter season. Additionally, the final population of plants had a significant effect on the grain yield of the BRS FC310 and BRSMG Uai cultivars in the wet season, with no effect on this variable in the winter season (Table 5). Among the yield components, the final plant population only significantly affected the number of pods per plant of all cultivars (Table 6).

During the wet season, the yield response of BRS FC310 and BRSMG Uai cultivars to the final plant population was quadratic (Figure 3A), with respectively maximum yields of 2,782 and 2,986 kg ha^{-1} being reached with 28.4 and 26.2 plants m^{-2}. The BRSMG Uai cultivar was more productive than BRS FC310 in all populations and the BRS FC409 cultivar, in addition to being less productive, did not show a significant response to the plant population.

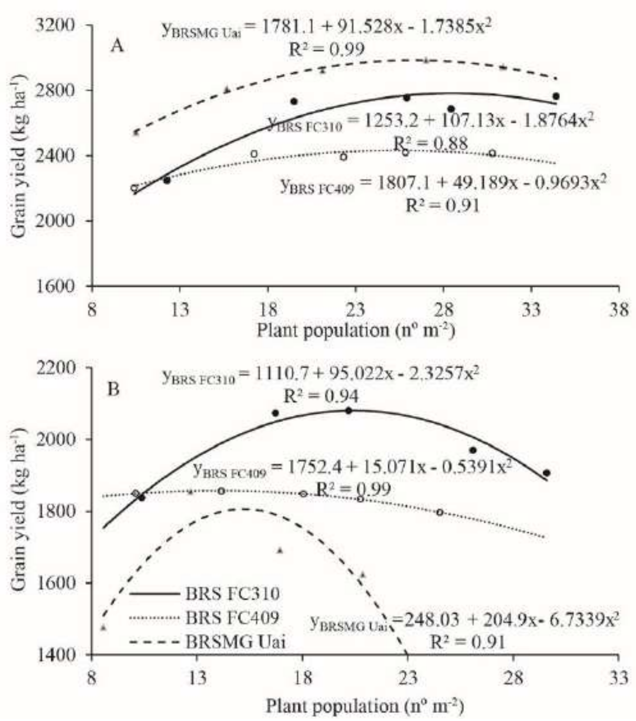
Table 6. Summary of NPP, NGP and 100 GW of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai grown in different locations and plant populations, in wet and winter seasons.

Cause of variation	Wet				Winter			
	DF	NPP	NGP	100 GW	DF	NPP	NGP	100 GW
				BRS FC310				
Location (L)	7	187.6**	5.8**	81.0**	3	133.8**	13.9**	292.8**
Error a	24	11.3	0.2	8.2	12	10.7	0.4	6.6
Population (P)	4	390.9**	0.3ns	5.1ns	4	317.3**	0.3ns	3.6ns
L x P	28	13.4ns	0.3ns	8.6ns	12	23.0**	0.2ns	3.2ns
Error b	96	10.8	0.3	6.6	48	9.3	0.1	3.6
CV(%)		22.2	13.2	10.6		18.6	9.7	8.2
				BRS FC409				
Location (L)	7	172.6**	2.8**	114.9**	2	605.0**	12.9**	142.5ns
Error a	24	15.8	0.4	2.4	9	13.1	0.1	6.4
Population (P)	4	361.8**	0.4ns	2.2ns	4	83.2**	0.3ns	10.6ns
L x P	28	11.3ns	0.4ns	2.4ns	8	18.4ns	0.4ns	8.2ns
Error b	96	10.0	0.4	3.0	36	22.3	0.2	13.5
CV (%)		21.6	15.6	6.6		29.5	11.3	13.4
				BRSMG Uai				
Location (L)	6	157.6**	5.0**	27.2*	1	108.2*	2.5*	26.5**
Error a	21	17.6	0.8	8.8	6	14.9	0.4	1.9
Population (P)	4	636.1**	0.3ns	1.4ns	4	36.4*	0.4ns	2.8ns
L x P	24	14.4ns	0.8ns	4.6	4	13.6ns	0.3ns	0.1ns
Error b	84	13.9	0.8	3.6	24	11.0	0.2	1.1
CV (%)		22.6	18.6	7.8		21.5	8.6	4.2

DF = degrees of freedom; MSE = mean square error; CV = coefficient of variation; ns = F not significant; * = F significant, $p \leq 0.05$; ** = F significant, $p \leq 0.01$.

Ramalho *et al*. (2016), comparing the three sowing seasons, observed that the advantage of the BRSMG Uai cultivar over the control was more prominent in the wet season. Combined with the higher yield at this time, BRSMG Uai has the advantage of having upright plants. When sowing takes place in November, harvesting occurs in January, a time when rainfall is usually intense. In prostrate plants, the pods can contact with the wet soil and, thus, affect grain yield and quality, which does not occur with BRSMG Uai. The BRS FC310 cultivar, in turn, has broad adaptability and stability (Corrêa *et al.*, 2016) and the BRS FC409 cultivar is specifically adapted to favorable environments (Melo *et al.*, 2022).

Figure 3. Grain yield of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai as a function of final plant population in experiments conducted at wet (A) and winter (B) seasons, in different locations.



The effect of plant population on the grain yield of all cultivars, in the winter season, was not significant (Table 5), probably due to irrigation minimizing the effects of competition between plants. The BRS FC310 cultivar showed higher yield than the other cultivars in all plant populations and its maximum productivity, 2,081 kg ha^{-1}, occurred with 20.4 plants m^{-2} (Figure 3B). The cultivar BRS FC409 reached its maximum yield, 1,858 kg ha^{-1}, with 14 plants m^{-2}, and the cultivar BRSMG Uai was the one that presented the worst productive behavior, with a maximum yield of 1,807 kg ha^{-1} obtained with 15.2 plants m^{-2}.

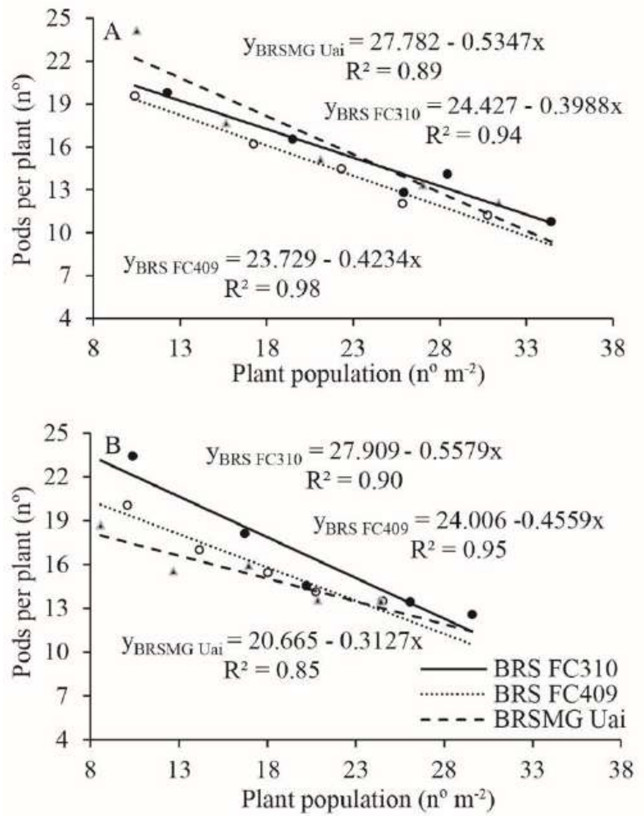
Maximum grain yields were higher in the wet season than in the winter season for all three cultivars. The maximum yields observed were 2,782; 2,431; and 2,986 kg ha^{-1} in the wet season and 2,081; 1,858; and 1,807 kg ha^{-1} in the winter season for the BRS FC310, BRS FC409, and BRSMG Uai cultivars, respectively. These maximum yields were obtained with higher plant populations in the wet regarding to the winter season. In the wet season, the plant populations resulting in maximum yields were 28.4; 25.4; and 26.2 plants m^{-2}, and in the winter season, they were 20.4; 14.0; and 15.2 plants m^{-2}, respectively.

The greater availability of solar radiation in the wet season, which contributes to increased light penetration into the plant canopy, even in environments with higher plant populations, explains this result. Greater light interception allows for higher yield, especially in cultivars with a more upright plant architecture, such as the BRSMG Uai cultivar (Figure 3B).

Justino *et al.* (2022) also observed higher common bean yields during the wet season compared to the dry and winter seasons. Teixeira *et al.* (2017) related that the upright BRS Radiante cultivar reduced yield as sowing dates shifted every 10 days from March 1st to June 20th, and attributed this result to the reduction in solar radiation from March onwards. Similar results were also observed by Vieira, Araújo and Chagas (1991), who observed a decrease in common bean yield in the fall and winter the later the sowing was carried out from April onwards.

The number of pods per plant, in both the wet and winter seasons, showed a linear decreasing response to increasing plant population (Figures 4A and 4B). The reduction rates, inferred from the angular coefficient of the linear model adjusted to BRS FC310, BRS FC409 and BRSMG Uai cultivars, were 0.40, 0.42 and 0.53 pods per plant, respectively, in the wet season (Figure 4A), and 0.56, 0.46 and 0.31, in the winter season (Figure 4B), for each increase of one plant per m^2.

Figure 4. Pods per plant of common bean cultivars BRS FC310, BRS FC409, and BRSMG Uai as a function of final plant population in experiments conducted at wet (A) and winter (B) seasons, in different locations.



These rates were higher in the winter season for BRS FC310 and BRS FC409 cultivars, possibly due to the greater competition for solar radiation, since it is lower at this time (Teixeira *et al.*, 2017). Didonet and Silva (2004) observed more production of pods when plants receive high solar radiation between emergence and the beginning of flowering. The BRSMG Uai cultivar, on the other hand, showed a smaller decrease in the number of pods per plant in the winter season, perhaps because it started from a lower value. As previously discussed, this cultivar was the least productive at this time.

Conclusions

The common bean cultivar BRS FC310 outyielded all other cultivars in all plant populations in the experiments conducted during the winter season, while the cultivar BRSMG Uai was the most productive in wet season. The maximum grain yields of the three cultivars were higher in the wet than in the winter season and obtained with higher plant populations. Cultivars BRS FC310, BRS FC409 and BRSMG Uai maximized grain yield with, respectively, 28.4, 25.4 and 26.2 plants m^{-2} at harvest time in the wet season, and 20.4, 14.0 and 15.2 plants m^{-2} in the winter.

References

ARAÚJO, G. A. A.; CAMELO, G. N. Preparo do solo e plantio. *In*: CARNEIRO, J. E.; PAULA JÚNIOR, T. J.; BORÉM, A. **Feijão:** do plantio à colheita. 1. ed. Viçosa: UFV, 2015. p. 115-144.

BARILI, L. D.; VALE, N. M.; AMARAL, R. C.; CARNEIRO, J. E. S.; SILVA, F. F.; CARNEIRO, P. C. S. Adaptabilidade e estabilidade e a produtividade de grãos em cultivares de feijão preto recomendadas no Brasil nas últimas cinco décadas. **Ciência Rural**, v. 45, n. 11, p. 1980-1986, 2015. https://doi.org/10.1590/0103-8478cr20141383

CARNEIRO, J. E. S.; PAULA JÚNIOR, T. J.; BORÉM, A. **Feijão:** do plantio à colheita. 1. ed. Viçosa: UFV, 2015.

CORRÊA, A. M.; PEREIRA, M. I. S.; ABREU, H. K. A.; SHARON, T.; MELO, C. L. P.; ITO, M A.; TEODORO, P. E.; BHERING, L. L. Selection of common bean genotypes for the Cerrado/Pantanal ecotone via mixed models and multivariate analysis. **Genetics and Molecular Research**, v. 15, n. 4, gmr15048888, 2016. https://doi.org/10.4238/gmr15048888

DIDONET, A. D.; SILVA, S. C. Elementos climáticos e produtividade do feijoeiro. **Informe Agropecuário**, v. 25, n. 223, p. 13-19, 2004.

GUIMARÃES, C. M.; STONE, L. F.; MELO, M. F. Management of plant architecture, spacing and population on the yield of super early common bean. **Científica,** v. 48, n. 3, p. 206-211, 2020. https://doi.org/10.15361/1984-5529.2020v48n3p206-211

GUIMARÃES, C. M.; STONE, L. F.; SILVEIRA, P. M.; SARMENTO, P. H. L. Componentes agronômicos do feijoeiro superprecoce BRS FC104 em diferentes arranjos espaciais e adubações fosfatadas. **Colloquium Agrariae**, v. 15 n. 3, p. 40-48, 2019. https://doi.org/10.5747/ca.2019.v15.n3.a297

HEINEMANN, A. B.; STONE, L. F. Requirement of supplemental irrigation for dry season common bean in Goiás. **Irriga**, p. 57-66, 2015. **https://doi.org/10.15809/irriga.2015v1n2p57**

IBGE. **Produção Agrícola Municipal**. 2020. Disponível em: https://sidra.ibge.gov.br/pesquisa/pam/tabelas. Acesso em: 22 abr. 2022.

JUSTINO, L. F.; BATTISTI, R.; STONE, L. F.; HEINEMANN, A. B. *In silico* assessment of sowing dates and nitrogen management in common bean crops. **European Journal of Agronomy**, v. 133, n. 2, p. 126-434, 2022. https://doi.org/10.15809/irriga.2015v1n2p57

KAVALCO, S. A. F.; NICKNICH, W.; VIEIRA NETO, J.; CRISPIM, J. E.; VOGT, G.A.; COIMBRA, J. L. M. Adaptabilidade e estabilidade de cultivares e linhagens de feijão no estado de Santa Catarina. **Agropecuária Catarinense**, v. 31, n. 3, p. 62-66, 2018. https://doi.org/10.22491/RAC.2018.v31n3.8

MASA, M.; TANA, T.; AHMED, A. Effect of plant spacing on yield and yield related traits of common bean (*Phaseolus vulgaris* L.) varieties at Areka, Southern Ethiopia. **Journal of Plant Biology & Soil Health**, v. 4, n. 2, p. 1-13, 2017. https://doi.org/10.13188/2331-8996.1000020

MELO, G. G.; SANTOS, P. R.; GONÇALVES, R. J. S.; NASCIMENTO, M. R.; COSTA, A. F.; SILVA, J. W. da. Adaptability and stability of carioca bean pre-cultivars in Agreste-Sertão Pernambucano. **Revista Brasileira de Ciências Agrárias**, v. 17, n. 3, e1697, 2022. https://doi.org/10.5039/agraria.v17i3a1697

RAMALHO, M. A. P.; ABREU, A. F. B.; CARNEIRO, J. E. S.; MELO, L. C.; PAULA JÚNIOR, T. J.; PEREIRA, H. S.; DEL PELOSO, M. J.; PEREIRA FILHO, I. A.; MARTINS, M. BRSMG Uai: common bean cultivar with carioca grain type and upright plant architecture. **Crop Breeding and Applied Biotechnology**, v. 16, n. 3, p. 261-264, 2016. https://doi.org/10.1590/1984-70332016v16n3c40

SANTOS, M. G. P.; CARVALHO, A. J.; DAVID, A. M. S. S.; AMARO, H. T. R.; VIEIRA, N. M. B.; SOUZA, V. B.; CARNEIRO, J. E. S. Densidades de semeadura e safras de cultivo no desempenho produtivo de cultivares de feijoeiro-comum. **Semina: Ciências Agrárias,** v. 35, n. 5, p. 2309-2324, 2014. https://doi.org/10.5433/1679-0359.2014v35n5p2309

SAS INSTITUTE. Statistical Analysis System Institute. **SAS/STAT Procedure guide for personal computers**. Version 6. 2. ed. Cary, NC: SAS Institute, 1985. 378 p.

SILVA, L. O.; OLIVEIRA, D. P.; MARTINS, F. A. D.; MORAIS, A. R.; GONÇALVES, A. H.; ANDRADE, M. J. B. de. Doses de fomesafen no feijoeiro-comum cultivado em diferentes densidades de semeadura. **Revista Agrogeoambiental**, v. 10, n. 1, p. 57-66, 2018. https://doi.org/10.18406/2316-1817v10n120181001

SILVA, R. R.; SCARIOTTO, S.; MALAGI, G.; MARCHESE, J. A. Análise de crescimento em feijoeiro cultivado sob diferentes densidades de semeadura. **Scientia Agraria**, v. 13, n. 2, p. 41-51, 2012. https://doi.org/10.5380/rsa.v13i2.40883

SILVEIRA, P. M.; STONE, L. F. Competition limits of the yield components of the common bean 'BRS Ártico' with white grains. **Científica**, v. 47, n. 1, p. 46–51, 2019. https://doi.org/10.15361/1984-5529.2019v47n1p46-51

STONE, L. F.; SILVEIRA, P. M. Limites de competição dos componentes da produtividade de grãos do feijoeiro-comum cv. Pérola. **Bioscience Journal**, v. 24, n. 2, p. 83-88, 2008.

TAVARES, T.; SOUSA, S.; SALGADOS, F.; SANTOS, G.; LOPES, M.; FIDELIS, R. Adaptabilidade e estabilidade da produção de grão em feijão comum (*Phaseolus vulgaris*). **Revista de Ciências Agrárias**, v. 40, n. 2, p. 411-418, 2017. https://doi.org/10.19084/RCA16058

TEIXEIRA, G. C. S.; STONE, L. F.; HEINEMANN, A. B. Eficiência do uso da radiação solar e índices morfofisiológicos em cultivares de feijoeiro. **Pesquisa Agropecuária Tropical**, v. 45, n. 1, p. 9-17, 2015. https://doi.org/10.1590/1983-40632015v4528297

TEIXEIRA, G. C. S.; STONE, L. F.; SANTOS, A. B.; SILVA, S. C.; HEINEMANN, A. B. Early sowing can improve irrigation water use efficiency and yield of common bean. **Pesquisa Agropecuária Tropical**, v. 47, n. 1, p. 118-126, 2017. https://doi.org/10.1590/1983-40632016v4743193

VIEIRA, C.; ARAÚJO, G. A. A.; CHAGAS, J. M. Efeitos das datas de plantio sobre o feijão cultivado no outono-inverno. **Pesquisa Agropecuária Brasileira**, v. 26, n. 6, p. 863-873, 1991.