Original Article

COMBINED SELECTION IN BEANS FOR CYCLE, PLANT ARCHITECTURE AND GRAIN YIELD

SELEÇÃO COMBINADA EM FEIJÃO PARA CICLO, ARQUITETURA DE PLANTA E PRODUTIVIDADE DE GRÃOS

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ABSTRACT: The selection of common bean cultivars for high agronomic performance can be difficulty by genotype x environment interaction. The objectives of this work were to evaluate if common bean cultivars differ for cycle, plant architecture and grain yield in different growing seasons, and to select early, upright and highly grain yield common bean cultivars, by the use of selection index. For this, five experiments were conducted in the randomized blocks design, with three replicates. A total of 26 common bean cultivars were evaluated and the multiplicative index was used to select superior cultivars. A significant cultivar x season interaction for flowering, cycle, insertion of the first pod, insertion of the last pod, number of pods per plant and grain yield was observed. The common bean cultivars have early or semi-early cycle in rainy season and upright plant architecture. The cultivars Macanudo, BRS Campeiro, IAPAR 81, and IPR Juriti presented high grain yield in most growing seasons. The four superior common bean cultivars selected by the multiplicative index were BRS Campeiro, Macanudo, IPR Juriti, and Guapo Brilhante. The cultivars BRS Campeiro, Macanudo, and IPR Juriti presents earliness, upright plant architecture, and high grain yield and will be selected for the breeding program.

KEYWORDS: *Phaseolus vulgaris*. Genotype x environment interaction. Genealogy. Selection index.

INTRODUCTION

The development process of a common bean cultivar (*Phaseolus vulgaris* L.) by classic breeding demands years of work and a lot of effort in the selection of cultivars with high agronomic performance. However, the breeder's job does not end when a new common bean cultivar is registered. They need to continue to assess the agronomic performance of these new cultivars in the region of adaptation. In addition, these cultivars can be used in controlled crossings for the introgression of favorable alleles in new cultivars.

The newly registered common bean cultivars present a genetic progress when comparing the older cultivars. The annual genetic gain observed for grain yield was from 0.72 to 1.10% in common bean grown in Brazil (RIBEIRO et al., 2008; FARIA et al., 2013, 2014). This increase in grain yield has been followed by phenological, plant architecture, and yield potential modifications. The new common bean cultivars development by different breeding programs have earlier flowering and cycle (RIBEIRO et al., 2008), present more resistance to lodging and upright plant architecture (FARIA et al., 2013, 2014), and greater number of pods per plant (RIBEIRO et al., 2008). It was also possible to verify that the common bean cultivars registered after 2005 presented higher grain yield, adaptation and production stability when comparing the older cultivars (BARILI et al., 2015a,b).

The traits that confer high agronomic performance in common bean cultivars are affected by genotype x environment interaction. A significant genotype x environment interaction was described previously for flowering and life cycle (RIBEIRO et al., 2004; PEREIRA et al., 2012; MOURA et al., 2013; ZILIO et al., 2013; RIBEIRO et al., 2014a; MAMBRIN et al., 2015), insertion of the first and last pod (MOURA et al., 2013; RIBEIRO et al., 2014a; MAMBRIN et al., 2015; MAZIERO et al., 2015), number of pods per plant and grain yield (PEREIRA et al., 2009, 2012, 2014; ZILIO et al., 2011, 2013; MOURA et al., 2013; TORGA et al., 2013; RIBEIRO et al., 2014a,b; BARILI et al., 2015a,b; MAMBRIN et al., 2015) in common bean cultivars. The dissimilarity in the performance of common bean lines can be explained by the different minimum and maximum air temperature, rainfall distribution, and air relative humidity recorded in each growing season (RIBEIRO et al., 2014a,b; BARILI et al., 2015a,b; MAMBRIN et al., 2015).

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If the agronomic performance of the common bean cultivars is not constant in the growing environment, this would difficult the selection of superior cultivars. In addition, it is necessary to see if the genealogy is related to the agronomic performance of common bean cultivars in different growing environments. No information was found in previous literature that consider the effects of genotype x environment interaction, genealogy analysis, and selection indices for the selection of common bean cultivars with high agronomic performance.

Therefore, the objectives of this study were to evaluate if common bean cultivars differ for cycle, plant architecture and grain yield in different growing seasons, and to select early, upright and highly grain yield common bean cultivars by the use of selection index.

MATERIAL AND METHODS

Five experiments were carried out on a field area of the Department of Plant Sciences of Federal University of Santa Maria, Santa Maria, located at the geographic coordinates of 29°42’ south latitude and 53°43’ longitude west of Greenwich, at an altitude of 95 m, in the Central Depression of State of Rio Grande do Sul (RS), Brazil. Sowing was done in October in the experiments of the rainy season 2010, 2011, 2012 and 2013 and in February for the 2011 dry season, which correspond to growing traditional seasons of common bean in RS (Table 1).

Table 1. Meteorological data collected in the 8th Meteorology District, in Santa Maria Meteorological Station, set at the Federal University of Santa Maria (29^{o}42´S lat, 53^{o}43´W long, 95 m asl), in the State of Rio Grande do Sul Brazil.

Growing season	Month	Rainfall	Maximum temperature	Minimum temperature	Relative humidity
		mm	^{o}C	^{o}C	%
2010 rainy season	Oct	49.30	24.42	12.65	71.33
	Nov	71.30	27.79	14.88	66.48
	Dec	157.90	30.39	18.32	67.12
	Jan	127.10	32.45	21.62	76.85
2011 dry season	Feb	165.80	30.02	20.77	78.60
	Mar	54.90	28.85	17.97	75.64
	Apr	164.90	26.58	14.71	79.93
	May	54.90	21.51	12.00	83.98
	Jun	99.00	19.21	9.09	80.99
2011 rainy season	Oct	184.80	25.17	14.37	75.91
	Nov	41.60	28.98	16.43	62.98
	Dec	13.40	30.29	17.37	60.82
	Jan	68.80	32.99	19.40	63.05
2012 rainy season	Oct	255.20	25.70	16.74	79.74
	Nov	72.80	30.39	17.48	70.49
	Dec	293.00	31.14	19.90	77.87
	Jan	145.30	30.27	18.17	75.81
2013 rainy season	Oct	108.70	26.19	14.22	73.99
	Nov	294.50	28.73	17.52	72.71
	Dec	92.80	32.12	19.70	70.11
	Jan	132.30	32.62	21.23	78.36

The climate of the region is classified as cfa — humid subtropical, according to the Köppen classification (KUINCHTNER; BURIOL, 2001). The soil of the experimental unit is classified as typicall alitic Argisol, Hapludalf, belonging to the Santa Maria mapping unit, and was prepared in the conventional manner. The fertilizers were applied according to the interpretation of the soil chemical analysis, aiming to provide the appropriate nutrients amounts for the development of the crop. At the base, 250 kg ha^{-1} of the 5-30-20 formula (nitrogen, phosphorus and potassium) was applied and 20 kg ha^{-1} of nitrogen as urea (45% nitrogen) was added as coverage at the growth stage of the first trifoliolate leaf (V3).

The experimental design used was randomized blocks with three repetitions. The treatments evaluated consisted of 26 common bean cultivars: 17 cultivars from the "black" commercial group and 9 cultivars from the "colors" commercial group. All these cultivars were registered on the National Register of Cultivars, in the Ministry of Agriculture, Livestock, and Supply for cultivation in Rio Grande do Sul between 1971 and 2010 (Table 2), and represent the commercial groups most consumed in Brazil. The experimental unit was composed of two 4.0 m-long rows, spaced in 0.50 m, and a useful area of 4 m^2.

Table 2. Genealogy, growth habit (GH), breeding program (program) and year of registered of 26 common bean cultivars evaluated in five experiments carried out from 2010 to 2014.

Cultivar	Genealogy	GH[1]	Program[2]	Year
	... "Black" commercial group...			
Rio Tibagi	S-89-N (introduction of Costa Rica)	II	FEPAGRO	1976
Guateian 6662	Introduction of Costa Rica	II	FEPAGRO	1979
Macanudo (BR IPAGRO 1)	A 358 [A 176 (G 4326 x BAC 40)]	III	EMBRAPA	1989
Minuano (BR IPAGRO 3)	A 358 [A 176 (G 4326 x XAN 40)]	III	EMBRAPA	1991
Diamante Negro	XAN 87 / A 367	II	EMBRAPA	1991
Macotaço (BR IPAGRO 35)	A 358 [A 176 (G 4326 x XAN 40)]	III	EMBRAPA	1994
Guapo Brilhante (BR FEPAGRO 44)	XAN 125 / [BAT 336 (A83 x ICA Pijao)]	II	EMBRAPA	1995
IPR Uirapurú	BAC29/PR 1711/3/NEP2/2/Puebla173ICapijao	II	IAPAR	2000
BRS Valente	(Emgopa 201-Ouro / Ônix) // AN 512586	II	EMBRAPA	2001
IPR Graúna	EP 173/2/Rio Iguaçu/ Great Northern Nebraska 1 sel #27/3/Rio Tibagi/ Cornell 49242/4/ IAPAR BAC 25/ 5/ IAPARBAC 26	II	IAPAR	2002
BRS Campeiro	Mutation induction program for the Corrente cultivar by gama radiation	II	EMBRAPA	2003
BRS 7762 Supremo	W22-34/ VAN163	II	EMBRAPA	2004
FEPAGRO 26	Selection in the BR FEPAGRO 44 cultivar (Guapo Brilhante)	II	FEPAGRO	2006
BRS Expedito	CNF 5491 / FT Tarumã	II	EMBRAPA	2006
IPR Tiziu	IAPAR LP91-117/ IAC Uma	II	IAPAR	2007
BRS Esplendor	CB911863 / AN9123293	II	EMBRAPA	2007
IPR Tuiuiú	LP96-72 / Xamego	II	IAPAR	2010
	..."Colors" commercial group...			
Carioca	Selection in producer's crops (Palmital, São Paulo)	III	IAC	1971
Iraí	Selection in producer's crops (Rio Grande do Sul)	I	FEPAGRO	1981
Pérola	Selection in the Aporé cultivar	III	EMBRAPA	1996
IAPAR 81	{BAT 93 x [(Carioca99 x Great Northen Nebraska 1#Sel27) x Sel Aroana] x (A 176 x A 259)}	II	IAPAR	1997
IPR Juriti	BAT93 /2/ Carioca Sel.99 / Great Northen Nebraska 1 sel#27 /3/ sel. Aroana /4/ A176 / A259 /5/ II 133 / XAN87	II	IAPAR	2002
BRSMG Pioneiro	Backcrossing Rudá (recorrente) / Ouro Negro	II	EMBRAPA	2005
BRS Estilo	EMP 250 / 4 / A 769 /// A 429 / XAN S52 // V 8025 / PINTO VI 114	II	EMBRAPA	2006
IPR Siriri	IAPAR 31/ IAC Akitã	II	IAPAR	2007
IPR Tangará	LP 95 -92/ Pérola	II	IAPAR	2008

[1]GH: growth habit - I: determinate; II: indeterminate with short guides; III: indeterminate with long guides. [2]Program: EMBRAPA: Brazilian Agricultural Research Corporation; FEPAGRO: Agricultural Research State Foundation; IAPAR - Paraná Agronomic Institute; IAC - Campinas Agronomic Institute.

The insects were controlled with the application of the insecticide Engeo Pleno (14.1% of thiamethoxam and 10.6% of lambda-cyhalothrin, Syngenta Brasil, São Paulo, SP, Brazil), at 125 mL ha^{-1}. The weeds were mechanically eliminated whenever necessary, in order to avoid competition with the crop. Diseases were not controled.

Flowering was evaluated in the period between the emergence (V1) and the opening of the first flower (R6), and the cycle in the interval between emergence (V1) and maturation (R9), that is, when pods dried and acquired the typical coloring of each cultivar. These traits were evaluated in the field, considering 51% of the plants in R6 and R9, respectively. When plants reach maturation, 10 plants were randomly collected from the useful area and the distance between the cotyledon node and the insertion of the first and last pod was measured. The number of pods per plant was also counted. The grain yield was determined by the extrapolation of the grains weight obtained from the useful area by hectare, at 13% average moisture.

The data were subjected to individual and joint analyses of variance. The F test ($p< 0.05$) was used to evaluate the main fixed effects (cultivar and season) and the cultivar x season interaction. Homogeneity of residual variance was tested using the Hartley's maximum F test (CRUZ; REGAZZI, 1997). The means for different cultivars and for growing seasons were compared using the Scott-Knott test ($p = 0.05$). The multiplicative index (SUBANDI et al., 1973) was used to obtain estimates of genetic gain in selection. The four superior cultivars were selected (15% of the cultivars evaluated) with the best results in the simultaneous selection were presented. Analyses were performed with the aid of Microsoft Office Excel, and Genes software (CRUZ, 2013).

RESULTS AND DISCUSSION

The variance of the experimental error was homogeneous for all traits ($p> 0.05$), enabling the joint analysis of variance. In the joint analysis of variance, a significant effect was observed for cultivar, season and cultivar x season interaction for all traits (Table 3). Therefore, the common bean cultivars differed for flowering, cycle, insertion of the first pod, insertion of the last pod, number of pods per plant and grain yield; the growing seasons were different for the meteorological conditions; and the agronomic performance of the common bean cultivars was variable in growing seasons. A significant cultivar x environment interaction has been described for phenological traits - flowering and cycle (RIBEIRO et al., 2004; PEREIRA et al., 2012; MOURA et al., 2013; ZILIO et al., 2013; RIBEIRO et al., 2014a; MAMBRIN et al., 2015); plant architecture - insertion of the first and last pod (MOURA et al., 2013; RIBEIRO et al., 2014a; MAMBRIN et al., 2015; MAZIERO et al., 2015); and production traits - number of pods per plant and grain yield (PEREIRA et al., 2009, 2012, 2014; ZILIO et al., 2011, 2013; MOURA et al., 2013; TORGA et al., 2013; RIBEIRO et al., 2014a,b; BARILI et al., 2015a,b; MAMBRIN et al., 2015) in experiments evaluating the performance of common bean cultivars. For these traits, the performance of common bean cultivars varied in function of the growing environment.

Table 3. Joint analysis of variance containing the degrees of freedom (DF), mean squares, mean and variation coefficient (VC, %) for the flowering (FLO), cycle, insertion of the first pod (IFP), insertion of the last pod (ILP), number of pods per plant (NPP) e grain yield (YIELD) of 26 common bean cultivars, assessed in five experiments carried out from 2010 to 2014.

Sources of variation	DF	Mean square[1]					
		FLO days	CYCLE days	IFP cm	ILP cm	NPP	YIELD kg ha^{-1}
Block/Season	10	5.71	93.41	29.19	87.88	17.73	295990.81
Cultivar (C)	25	12.39*	33.72*	46.68*	268.38*	54.59*	413532.67*
Season (S)	4	2754.39*	2975.45*	2857.13*	6452.39*	910.83*	31008044.84*
C x S	100	5.06*	14.01*	17.55*	73.41*	20.65*	256764.84*
Residue	250	2.44	5.74	7.48	31.29	9.64	42374.81
Mean		35.59	78.59	19.04	46.57	12.04	1,543.87
VC (%)		4.39	3.05	14.37	12.01	25.80	13.33

[1]*Significant by the F test (p= 0.05). [ns] = non-significant.

Flowering varied from 23.7 (Iraí, 2011 dry season) to 45.3 days (BRS Estilo, 2013 rainy season) (Table 4). Zilio et al. (2013) and Mambrin et al. (2015) also observed a similar range for the flowering of common bean genotypes evaluated in different growing seasons. In the present study, the cultivar effect affected flowering significantly (Table 3). However, the application of the Scott-Knott test did not result in stratification among the treatments in the 2010 rainy, 2011 dry, and 2011 rainy seasons (Table 4). On the 2012 and 2013 rainy seasons, two groups of cultivars were formed. In the 2012 rainy season, Iraí was the earliest cultivar for the flowering (27 days), differing significantly from the other cultivars evaluated. In the 2013 rainy season, the cultivars BRS Campeiro, BRS Expedito, BRS 7762 Supremo, BRS Valente, FEPAGRO 26, Guapo Brilhante, IPR Graúna, IPR Tuiuiú, Macanudo, Macotaço, Minuano, Rio Tibagi, IAPAR 81, IPR Juriti, and IPR Siriri had earlier flowering.

Table 4. Mean* number of days for flowering and cycle of 26 common bean cultivars assessed in the seasons 2010 rainy (2010 rs), 2011 dry (2011 ds), 2011 rainy (2011 rs), 2012 rainy (2012 rs), and 2013 rainy (2013 rs).

Cultivar	Flowering (days)					Cycle (days)				
	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs
BRS Campeiro	39.7 a A	28.7 a C	30.3 a C	35.0 a B	40.3 b A	75.0 b B	85.3 b A	76.0 a B	73.7 a B	74.0 a B
BRS Esplendor	41.0 a A	27.3 a D	30.3 a C	37.0 a B	43.3 a A	81.0 a B	89.0 a A	75.3 a C	74.3 a C	76.7 a C
BRS Estilo	41.3 a B	32.0 a D	30.3 a D	37.7 a C	45.3 a A	81.3 a B	91.7 a A	71.0 b D	76.3 a C	77.7 a C
BRS Expedito	40.3 a A	28.0 a D	30.7 a C	36.7 a B	42.3 b A	81.3 a B	90.0 a A	74.7 b C	74.3 a C	76.0 a C
BRS 7762 Supremo	41.0 a A	28.0 a D	30.7 a C	35.3 a B	41.3 b A	80.7 a B	90.3 a A	74.3 b C	78.7 a B	78.0 a B
BRS Valente	41.0 a A	28.0 a D	31.3 a C	37.3 a B	40.0 b A	81.3 a B	89.3 a A	71.3 b D	75.0 a C	77.7 a C
Diamante Negro	41.3 a A	28.7 a C	29.7 a C	36.7 a B	42.7 a A	82.0 a B	89.0 a A	73.0 b C	72.7 b C	76.7 a C
FEPAGRO 26	41.0 a A	28.7 a C	30.3 a C	35.7 a B	41.7 b A	79.7 a B	90.0 a A	75.3 a C	73.7 a C	76.7 a C
Guapo Brilhante	40.3 a A	28.0 a D	30.7 a C	34.7 a B	42.3 b A	80.3 a B	85.7 b A	73.0 b C	71.3 b C	75.3 a C
Guateian 6662	37.0 a B	28.7 a D	32.3 a C	36.3 a B	43.0 a A	78.7 a B	88.7 a A	74.3 b C	69.7 b D	78.3 a B
IPR Graúna	41.7 a A	29.3 a C	29.0 a C	36.3 a B	41.3 b A	79.0 a B	88.7 a A	72.7 b C	74.0 a C	74.0 a C
IPR Tiziu	41.0 a A	28.0 a D	31.3 a C	38.0 a B	43.0 a A	81.0 a B	87.7 b A	80.0 a B	74.0 a C	79.3 a B
IPR Tuiuiú	41.0 a A	29.7 a C	30.7 a C	37.3 a B	42.3 b A	81.7 a B	92.0 a A	79.3 a B	74.7 a C	77.7 a C
IPR Uirapurú	41.0 a B	29.3 a D	31.7 a D	36.0 a C	44.0 a A	81.0 a B	88.7 a A	77.3 a B	72.3 b C	78.0 a B
Macanudo	39.3 a A	27.0 a D	30.0 a C	35.7 a B	40.0 b A	76.0 b B	85.7 b A	75.0 b B	75.7 a B	73.7 a B
Macotaço	39.7 a A	28.7 a C	30.7 a C	37.3 a B	41.7 b A	78.0 b B	89.7 a A	73.3 b C	71.7 b C	75.3 a B
Minuano	41.0 a A	27.7 a D	31.3 a C	36.3 a B	40.7 b A	76.3 b B	86.7 b A	71.0 b C	71.7 b C	75.3 a B
Rio Tibagi	39.7 a A	29.0 a D	32.3 a C	37.3 a B	41.0 b A	80.7 a B	89.3 a A	77.7 a B	71.3 b C	78.0 a B
BRSMG Pioneiro	40.7 a B	29.3 a D	32.3 a C	34.7 a C	43.3 a A	80.0 a B	90.3 a A	76.3 a C	74.3 a C	79.7 a B
Carioca	40.0 a B	28.0 a E	30.7 a D	36.3 a C	43.7 a A	76.7 b B	85.7 b A	74.0 b C	71.0 b C	77.7 a B
IAPAR 81	41.0 a A	29.7 a C	32.0 a C	37.7 a B	41.7 b A	81.7 a B	91.7 a A	74.3 b C	72.0 b C	75.7 a C
IPR Juriti	41.0 a A	29.0 a C	29.3 a C	37.0 a B	42.0 b A	81.7 a B	90.3 a A	72.0 b C	72.7 b C	75.7 a C
IPR Siriri	39.3 a B	28.7 a D	30.0 a D	35.0 a C	42.0 b A	80.7 a B	88.3 a A	72.0 b C	74.7 a C	77.3 a B
IPR Tangará	38.7 a B	30.7 a C	31.7 a C	37.7 a B	43.7 a A	81.7 a B	94.3 a A	73.7 b C	73.0 b C	77.0 a C
Pérola	41.7 a A	29.7 a C	28.3 a C	36.3 a B	43.3 a A	81.3 a B	93.3 a A	71.3 b C	74.3 a C	78.0 a B
Iraí	37.7 a B	23.7 a D	28.7 a C	27.0 b C	44.0 a A	74.0 b A	75.7 c A	74.3 b A	70.7 b B	78.0 a A
Mean	40.3	28.6	30.6	36.1	42.3	79.7	88.7	74.3	73.4	76.8
VC (%)	4.5	5.2	5.2	3.7	3.6	2.0	2.6	3.4	3.8	3.3

*Means not followed by the same lower case letter in the column differ by the Scott-Knott test (p = 0.05), and uppercase letters on each row by the Scott-Knott test (p = 0.05).

The greatest means for the flowering was obtained in the 2013 rainy season (42.3 days), and an increase was seen in the number of days for flowering of most of the cultivars evaluated. In this growing season, the highest rainfall volume recorded in the vegetative period (Table 1) may have contributed for the delay in beginning of flowering in the cultivars. The higher rainfall amount may contribute to a higher duration of vegetative and reproductive periods in common beans, as reported previously by Zilio et al. (2013).

The cycle of the common bean cultivars varied greatly within and among the growing seasons, with a minimum value verified for Guateian 6662 cultivar in the 2012 rainy season (69.7 days), and a maximum value for IPR Tangará cultivar in the 2011 dry season (94.3 days) (Table 4). These values were similar to the ones previously observed in competition experiments of common bean genotypes carried out in different years, seasons and growing locations (RIBEIRO et al., 2004; PEREIRA et al., 2012; ZILIO et al., 2013).

Common bean cultivars were classified in two cycles in the 2011 dry season: early (Iraí cultivar, 75.7 days) and normal cycle (other cultivars, 85.3 to 94.3 days), according to the stratification proposed by Del Peloso et al. (2009). Iraí was the only cultivar that presented an early cycle in all environments evaluated. The cultivars BRS Campeiro, Macanudo, Macotaço, Minuano, and Carioca presented early cycle in the 2010, 2011, 2012, and 2013 rainy seasons, and a normal cycle in the 2011 dry season. For the other common bean cultivars, the cycle classification was altered in the growing season. Similarly, Ribeiro et al. (2004) observed that the cycle of common bean cultivars varied a lot in the growing seasons, so it was not possible to identify cultivars with cycle predictability.

Iraí was the only cultivar with determinate growth habit (type I) evaluated in this study. Type I common bean cultivars had a flowering period from five to six days (DAWO et al., 2007) and do not produce vegetative nodes after flowering (BURATTO et al., 2007). These traits contributed so that Iraí cultivar presented smaller variation in the cycle duration among the cultivars evaluated. The other common bean cultivars evaluated have indeterminate growth habit with short (type II) or long (type III) guides (Table 2). The common bean cultivars with indeterminate growth are characterized by the higher duration of flowering period, from 15 to 30 days (DAWO et al., 2007) and continue to produce vegetative nodes even after flowering (BURATTO et al., 2007). Therefore, these cultivars are exposed to the variations in the environmental conditions by greater number of days during the reproductive period. This contributed for the greater variation observed for the cycle duration in the cultivars with indeterminate growth habit.

Regarding the growing seasons, the highest means for the cycle (88.7 days) was observed in the 2011 dry season. The hypothesis is that the lowest minimum and maximum means temperatures values registered in the 2011 dry season, especially during the pod filling to plant maturation period (Table 1), justifies the longer cycle of the common bean cultivars. In this situation, the necessary thermal sum to reach the end of the cycle in the common bean cultivars took longer to be accumulated.

The identification of common bean cultivars of early or semi-early cycle enables less time of soil use for cultivation and early harvest, representing market advantages for the farmers that perform rotate crops and commercialize the grains in periods of lower product supply (BURATTO et al., 2007). In the present study, all common bean cultivars evaluated presented an early or semi-early cycle in the 2010, 2011, 2012, and 2013 rainy seasons. In the 2011 dry season, only the Iraí cultivar had an early cycle. These results indicate that the cycle of common bean cultivars may be different in growing seasons, and highlight the importance of its characterization in the evaluation process and indication of common bean cultivars for a particular cultivation region.

The application of the Scott-Knott test enabled the differentiation among the common bean cultivars for the insertion of the first pod only in the 2012 rainy season (Table 5). In this season, the cultivars BRS Esplendor, Guateian 6662, IPR Tiziu, IPR Uirapurú, and IPR Tangará showed higher insertion of the first pod values. It is important to identify the common bean cultivars with higher insertion of the first pod for the manual and mechanized harvest because it reduces the contact of the pods with the soil, which would imply better grain quality and smaller incidence of diseases in the pods and grains (COSTA et al., 2008). Therefore, common bean cultivars that present insertion of the first pod equal to or above 12 cm are associated to the plants with upright architecture (MELO, 2009). In the present study, all common bean cultivars evaluated attended this criterion, except Guapo Brilhante that presented insertion of the first pod of 11.8 cm in the 2011 dry season. Similarly, Ribeiro et al. (2014a), Mambrin et al. (2015), and Maziero et al. (2015) observed that the insertion of the first pod of common bean lines and cultivars in growing at Brazil was above 11.8 cm. These results show the effort of breeding programs in the development of common bean cultivars of upright architecture.

Table 5. Mean* insertion of the first pod and insertion of the last pod of 26 common bean cultivars assessed in the seasons 2010 rainy (2010 rs), 2011 dry (2011 ds), 2011 rainy (2011 rs), 2012 rainy (2012 rs), and 2013 rainy (2013 rs).

Cultivar	Insertion of the first pod (cm)					Insertion of the last pod (cm)				
	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs
BRS Campeiro	16.7 a B	15.8 a B	18.9 a B	27.9 c A	21.3 a B	37.5 c B	41.4 b B	43.5 b B	67.0 a A	47.5 a B
BRS Esplendor	18.3 a B	17.1 a B	20.1 a B	34.8 a A	18.0 a B	52.7 a B	51.7 a B	53.3 a B	63.7 a A	30.7 b C
BRS Estilo	20.8 a B	14.1 a B	17.2 a B	32.0 b A	17.1 a B	48.7 b B	41.1 b C	45.9 b B	62.3 a A	34.1 b C
BRS Expedito	18.7 a B	16.1 a B	16.4 a B	32.0 b A	17.1 a B	45.1 b B	46.7 a B	48.3 b B	60.4 a A	31.5 b C
BRS 7762 Supremo	14.6 a B	13.3 a B	16.3 a B	30.3 b A	18.1 a B	42.0 c B	39.0 b B	43.8 b B	56.8 a A	41.9 a B
BRS Valente	15.1 a B	12.8 a B	17.5 a B	30.5 b A	14.5 a B	46.6 b B	44.6 a B	47.5 b B	58.9 a A	36.4 b C
Diamante Negro	14.9 a B	15.2 a B	18.6 a B	26.5 c A	17.7 a B	45.0 b B	45.5 a B	49.1 b B	60.4 a A	36.6 b C
FEPAGRO 26	15.9 a B	16.4 a B	14.9 a B	27.9 c A	19.3 a B	42.2 c B	42.5 b B	43.0 b B	54.9 a A	38.2 a B
Guapo Brilhante	13.3 a C	11.8 a C	17.3 a B	24.2 c A	16.6 a B	36.7 c B	34.2 b B	41.6 b B	61.2 a A	34.6 b B
Guateian 6662	13.4 a B	15.4 a B	15.4 a B	35.5 a A	12.4 a B	37.7 c C	43.3 b B	43.7 b B	68.3 a A	31.8 b C
IPR Graúna	13.9 a B	14.0 a B	16.7 a B	28.4 c A	16.3 a B	55.9 a A	41.1 b B	50.6 a A	62.4 a A	41.3 a B
IPR Tiziu	16.6 a B	16.8 a B	18.6 a B	40.0 a A	17.0 a B	48.1 b C	43.6 b C	53.7 a B	67.9 a A	33.2 b D
IPR Tuiuiú	15.5 a B	12.7 a B	14.6 a B	30.0 b A	15.5 a B	45.8 b A	36.2 b B	48.0 b A	52.3 a A	32.5 b B
IPR Uirapurú	16.4 a B	15.3 a B	19.3 a B	35.5 a A	14.9 a B	49.6 b B	45.9 a B	47.5 b B	60.1 a A	29.0 b C
Macanudo	13.3 a A	15.3 a A	18.4 a A	19.2 d A	17.1 a A	35.0 c C	40.8 b C	48.3 b B	58.7 a A	46.6 a B
Macotaço	14.7 a B	14.9 a B	15.8 a B	30.2 b A	15.6 a B	40.1 c B	39.2 b B	54.9 a A	58.4 a A	29.7 b C
Minuano	13.0 a B	13.9 a B	15.9 a B	28.0 c A	13.1 a B	34.6 c C	38.6 b C	49.6 b B	62.1 a A	34.7 b C
Rio Tibagi	16.5 a B	14.9 a B	18.0 a B	29.4 b A	14.6 a B	47.4 b B	49.6 a B	48.0 b B	65.6 a A	36.1 b C
BRSMG Pioneiro	13.5 a B	15.5 a B	16.1 a B	27.2 c A	14.4 a B	46.3 b A	41.3 b B	51.0 a A	54.0 a A	30.2 b C
Carioca	14.1 a B	18.0 a B	20.1 a B	31.8 b A	15.9 a B	34.7 c C	47.0 a B	53.8 a B	61.4 a A	28.4 b C
IAPAR 81	13.4 a B	17.4 a B	20.5 a B	27.7 c A	16.6 a B	45.6 b B	40.9 b B	55.3 a A	61.8 a A	45.4 a B
IPR Juriti	15.7 a B	15.2 a B	19.0 a B	27.2 c A	19.5 a B	43.0 c B	39.3 b B	46.3 b B	59.1 a A	38.6 a B
IPR Siriri	17.2 a B	16.9 a B	18.7 a B	33.0 b A	14.8 a B	47.5 b B	48.6 a B	52.8 a B	66.1 a A	38.7 a C
IPR Tangará	20.8 a B	18.9 a B	21.4 a B	35.3 a A	20.1 a B	60.6 a A	57.2 a A	59.2 a A	66.6 a A	37.9 a B
Pérola	17.4 a B	16.0 a B	20.6 a B	30.3 b A	19.1 a B	53.9 a A	52.7 a A	61.3 a A	60.6 a A	35.3 b B
Iraí	14.6 a A	13.9 a A	16.1 a A	17.7 d A	17.0 a A	25.7 c B	29.7 b B	29.8 c B	45.3 a A	36.7 b A
Mean	15.7	15.3	17.8	29.7	16.7	44.1	43.2	48.8	60.6	36.1
VC (%)	11.1	13.4	15.9	13.3	15.4	10.7	10.2	10.4	11.4	17.7

*Means not followed by the same lower case letter in the column differ by the Scott-Knott test (p = 0.05), and uppercase letters on each row by the Scott-Knott test (p = 0.05).

The insertion of the last pod is also an important trait for the selection of common bean cultivars of upright architecture. In this study, there was no differentiation among the common bean cultivars for the insertion of the last pod in the 2012 rainy season (Table 5). However, the cultivars BRS Estilo, Guapo Brilhante, Guateian 6662, IPR Tuiuiú, Minuano, and Iraí presented smaller insertion of the last pod in the 2010, 2011, and 2013 rainy seasons, and in the 2011 dry season. Mambrin et al. (2015), also identified common bean lines with smaller insertion of the last pod in different growing seasons, and that was associated to plants that are more compact and resistant to lodging. Selection through the smaller insertion of the last pod is promising for the common bean breeding program, because these plants keep their development more uniform, although there are variations for the environmental conditions (Table 1).

Common bean cultivars presented a number of pods per plant, ranging from 3.7 (Carioca, 2013 rainy season) to 30.7 (IPR Graúna, 2010 rainy season) (Table 6). These values were above the ones observed in experiments of common bean cultivars competition carried out in different seasons, years, and growing locations (ZILIO et al., 2011;

RIBEIRO et al., 2014b; MAMBRIN et al., 2015). Therefore, the common bean cultivars present genetic variability for the number of pods per plant, which enables the selection of superior cultivars for this trait. However, superior cultivars for the number of pods per plant were not identified for all the growing seasons, suggesting that this is a quantitative character, and it is very influenced by the environment.

Table 6. Mean* number of pods per plant and grain yield of 26 common bean cultivars assessed in the seasons 2010 rainy (2010 rs), 2011 dry (2011 ds), 2011 rainy (2011 rs), 2012 rainy (2012 rs), and 2013 rainy (2013 rs).

Cultivar	Number of pods per plant					Grain yield (kg ha^{-1})				
	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs	2010 rs	2011 ds	2011 rs	2012 rs	2013 rs
BRS Campeiro	13.7 b A	11.7 b A	14.7 a A	11.7 a A	11.7 a A	2629 c A	1918 b B	1911 a B	1080 a C	1850 a B
BRS Esplendor	15.7 b A	13.3 b A	14.7 a A	9.0 a B	4.7 b B	2699 c A	2049 b B	1526 b C	811 a D	441 d E
BRS Estilo	9.3 b B	16.7 a A	15.3 a A	7.0 a B	9.7 a B	2764 c A	1734 c B	1719 a B	897 a C	750 c C
BRS Expedito	8.7 b B	13.3 b A	17.0 a A	6.0 a B	6.7 b B	2172 e A	2391 a A	1776 a B	766 b D	1217 b C
BRS 7762 Supremo	10.7 b A	11.7 b A	14.7 a A	7.7 a A	8.3 b A	2171 e A	1773 c B	2161 a A	997 a C	1139 b C
BRS Valente	13.0 b A	16.3 a A	17.0 a A	6.3 a B	11.7 a A	2319 d A	1606 c B	1429 b B	823 a C	1340 b B
Diamante Negro	12.7 b A	12.3 b A	14.3 a A	8.7 a A	9.0 b A	2047 e A	1750 c B	1538 b B	846 a D	1309 b C
FEPAGRO 26	11.3 b B	9.0 b B	18.3 a A	9.0 a B	6.3 b B	2454 d A	1617 c B	1549 b B	863 a C	868 c C
Guapo Brilhante	15.7 b A	15.3 a A	15.7 a A	11.3 a B	10.0 a B	2470 d A	1581 c C	2018 a B	1111 a D	1237 b D
Guateian 6662	16.3 b A	19.3 a A	19.3 a A	6.7 a B	11.7 a B	2266 d A	1424 c C	1859 a B	727 b D	926 c D
IPR Graúna	30.7 a A	13.7 b B	18.3 a B	9.0 a C	10.0 a C	1446 f B	1921 b A	1648 a A	816 a C	1360 b B
IPR Tiziu	12.0 b A	12.0 b A	13.7 a A	4.3 a B	7.0 b B	2584 c A	1717 c B	1450 b B	484 b D	964 c C
IPR Tuiuiú	8.7 b B	11.0 b A	15.0 a A	6.7 a B	5.7 b B	2528 c A	1949 b B	1786 a B	808 a C	779 c C
IPR Uirapurú	10.3 b A	12.0 b A	12.0 a A	6.3 a B	5.7 b B	2620 c A	1935 b B	1955 a B	937 a C	567 d D
Macanudo	14.7 b B	21.7 a A	15.7 a B	13.3 a B	11.3 a B	2382 d A	1729 c B	1705 a B	1177 a C	1676 a B
Macotaço	11.7 b B	16.7 a A	17.3 a A	8.3 a B	6.7 b B	1984 e A	1857 b A	1672 a A	897 a B	554 d C
Minuano	13.0 b A	15.3 a A	14.7 a A	8.0 a B	15.3 a A	2429 d A	1852 b B	1832 a B	855 a D	1384 b C
Rio Tibagi	15.3 b A	14.3 a A	17.3 a A	10.0 a B	8.7 b B	2138 e A	1561 c B	1655 a B	521 b C	820 c C
BRSMG Pioneiro	13.0 b B	14.3 a B	19.3 a A	7.0 a C	6.0 b C	3096 b A	1915 b B	1560 b C	562 b D	800 c D
Carioca	11.7 b B	10.3 b B	17.3 a A	6.0 a C	3.7 b C	2452 d A	1561 c B	1690 a B	658 b C	507 d C
IAPAR 81	14.0 b A	15.7 a A	17.3 a A	9.7 a A	13.7 a A	2614 c A	1535 c B	1734 a B	818 a C	1770 a B
IPR Juriti	14.3 b A	13.3 b A	14.0 a A	9.3 a A	9.7 a A	3464 a A	1342 c C	1914 a B	1219 a C	1733 a B
IPR Siriri	19.7 b A	15.7 a A	16.3 a A	7.7 a B	12.7 a B	2286 d A	1768 c B	1724 a B	1015 a C	1015 c C
IPR Tangará	11.3 b A	9.3 b B	14.7 a A	6.0 a B	8.3 b B	2844 c A	1629 c B	1039 c C	521 b D	584 d D
Pérola	12.3 b A	15.0 a A	15.3 a A	7.3 a B	6.3 b B	2388 d A	1695 c B	1164 c C	550 b D	901 c C
Iraí	9.0 b B	7.7 b B	19.0 a A	11.0 a B	7.0 b B	2042 e A	1212 c B	1297 c B	733 b C	1103 b B
Mean	13.3	13.7	16.1	8.1	8.6	2434	1731	1666	827	1061
VC (%)	16.0	30.6	22.6	21.7	34.9	8.9	11.3	12.0	18.8	23.5

*Means not followed by the same lower case letter in the column differ by the Scott-Knott test ($p = 0.05$), and uppercase letters on each row by the Scott-Knott test ($p = 0.05$).

Grain yield varied a lot among the common bean cultivars, from 441 kg ha^{-1} (BRS Esplendor, 2013 rainy season) to 3,464 kg ha^{-1} (IPR Juriti, 2010 rainy season) (Table 6). In the present study, the identification of common bean cultivars with high grain yield for all the growing seasons was difficult, because the ranking of the cultivars was modified in each environment. In the 2010 rainy season, the cultivar that showed the highest grain yield was the IPR Juriti (3,464 kg ha^{-1}), while in the 2011 dry season was the BRS Expedito (2,391 kg ha^{-1}). The cultivars BRS Campeiro, BRS Estilo, BRS 7762 Supremo, Guapo Brilhante, IPR Graúna, IPR Tuiuiú, IPR Uirapurú, Macanudo, Macotaço, Minuano, IAPAR 81, IPR Juriti, and IPR Siriri fit the group with higher grain yield in the 2011 and 2012 rainy seasons. In turn, in the 2013 rainy season, the cultivars that stood out were BRS Campeiro, Macanudo, IAPAR 81, and IPR Juriti.

The cultivars Macanudo, BRS Campeiro, IAPAR 81, and IPR Juriti were grouped by the Scott-Knott test in the group of high grain yield in most of the growing seasons evaluated, which suggests adaptation to the cultivation conditions. The cultivars Macanudo and BRS Campeiro are from "black" commercial group and were registered by Brazilian Agricultural Research Corporation (EMBRAPA) in 1989 and in 2003, respectively (Table 2). The cultivars IAPAR 81 and IPR Juriti are Carioca-type beans (beige seed coat with brown streaks), and they were developed by the Paraná Agronomic Institute (IAPAR) and registered in 1997 and 2002, respectively. Therefore, they are cultivars that are being cultivated in Brazil, for a period of 15 to 29 years, and still present high grain yield potential of the grown for the rainy season, i. e,, when the sowing is done between September and November. Common bean cultivars registered after 2005 in Brazil showed low grain yield or stood out in specific season, indicating little adaptation to the cultivation conditions. This result is different from the one observed by Barilli et al. (2015a,b) in the Minas Gerais state, Brazil. In these experiments, the black and Carioca common bean cultivars registered after 2005 presented high grain yield, higher adaptation and production stability.

The black grains cultivars (Macanudo and BRS Campeiro) present a very different genealogy (Table 2). However, the Carioca grains cultivars (IAPAR 81 e IPR Juriti) have several parental in common in their genealogy, indicating greater genetic similarity. Thus, in the present study we did not see a direct relation between the genealogy of common bean cultivars and grain yield. Silva et al. (2011) did not see any relation between the origin of common bean cultivars and grain yield.

High heritability estimates were obtained for the all traits evaluated, so greater selection gains are expected for these traits (Table 7). The multiplicative index showed negative genetic gain values for flowering, cycle, insertion of the first pod, and insertion of the last pod, and positive genetic gain values for number of pods per plant and grain yield. These estimates are favorable to selection of superior common bean cultivars for earliness, upright plant architecture and grain yield, except for the insertion of the first pod. A negative sign of genetic gain for the insertion of the first pod is unfavorable for the selection. However, the four superior cultivars selected by the multiplicative index have insertion of the first pod superior to 16 cm, which facilitates the manual and mechanized harvest of common bean plants according by Costa et al. (2008).

Table 7. Mean of the original population (Xo), mean of selected (Xs), heritability (h²), genetic gain (GG) and percentage genetic gain (GG %) with simultaneous selection by multiplicative index for the four superior cultivars assessed in five experiments carried out from 2010 to 2014.

Trait*	Xo	Xs	h²	GG	GG%	Selected cultivars			
						BRS Campeiro	Macanudo	IPR Juriti	G. Brilhante
FLO	35.59	35.02	80.32	-0.46	-1.29	34.80	34.40	35.67	35.20
CYCLE	78.59	77.40	82.97	-0.99	-1.26	76.80	77.20	78.47	77.13
IFP	19.03	18.18	83.96	-0.72	-3.77	20.11	16.66	19.32	16.63
ILP	46.57	45.04	88.34	-1.35	-2.89	47.38	45.86	45.25	41.68
NPP	11.98	13.39	82.64	1.17	9.74	12.61	15.24	12.15	13.56
YLD	1543.87	1807.28	89.75	236.41	15.31	1877.52	1733.68	1934.50	1683.41
Gain				234.06	15.84				

*Trait: FLO: flowering, days; CYCLE, days; IFP: insertion of the first pod, cm; LPH: insertion of the last pod, cm; NPP: number of pods per plant; YLD: grain yield, kg ha^{-1}.

The multiplicative index showed selection gains sum of 15.84%, which meets the objectives of this study by flowering (-1.29%), cycle (-1.26%), insertion of the last pod (-2.89%), number of pods per plant (+9.74%), and grain yield (+15.31%). The four superior cultivars selected by the multiplicative index were BRS Campeiro, Macanudo, IPR Juriti, and Guapo Brilhante. These cultivars present earliness, upright plant architecture and high grain yield. Preliminary results showed that the multiplicative index was the most efficient strategy of simultaneous selection for the upright architecture and grain yield in common bean lines (JOST et al., 2012; MAZIERO et al., 2015).

The cultivars BRS Campeiro, Macanudo, and IPR Juriti stood out due to their high grain yield in most of the growing seasons, have considering the effects of genotype x environment interaction. These common bean cultivars presented early or semi-early cycle in grown carried out in the rainy season, and normal cycle in the dry season, and the insertion of the first pod is above 12 cm. The three superior cultivars identified by the multiplicative index in present study were BRS Campeiro, Macanudo, and IPR Juriti. These cultivars present genealogy very different (Table 2), indicating lower genetic similarity. Therefore, the cultivars BRS Campeiro, Macanudo, and IPR Juriti cultivars presents earliness (flowering and cycle early), upright plant architecture (high insertion of the first pod and low insertion of the last pod) and high grain yield (higher values of number of pods per plant and grain yield), and so it will be selected for the breeding program.

CONCLUSIONS

The common bean cultivars differ for flowering, cycle, insertion of the first pod, insertion of the last pod, number of pods per plant, and grain yield in different growing seasons.

The cultivars BRS Campeiro, Macanudo, and IPR Juritipresents earliness, upright plant architecture and high grain yield, and so it will be selected for the breeding program.

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RESUMO: A seleção de cultivares de feijão com alto desempenho agronômico pode ser dificultada pela ocorrência de interação genótipo x ambiente. Os objetivos desse trabalho foram avaliar se cultivares de feijão diferem para ciclo, arquitetura de planta e produtividade de grãos em diferentes épocas de cultivo e selecionar cultivares de feijão precoces, eretas e altamente produtivas pelo uso de índice de seleção. Para tanto, cinco experimentos foram conduzidos em delineamento de blocos ao acaso, com três repetições. Um total de 26 cultivares de feijão foram avaliadas e o índice multiplicativo foi usado para selecionar cultivares superiores. Interação cultivar x época de cultivo significativa foi constatada para a floração, ciclo, inserção da primeira vagem, inserção da última vagem, número de vagens por planta e produtividade de grãos. As cultivares de feijão avaliadas possuem ciclo precoce ou semiprecoce no cultivo de safra e arquitetura de planta ereta. As cultivares Macanudo, BRS Campeiro, IAPAR 81 e IPR Juriti apresentaram alta produtividade de grãos na maioria das épocas avaliadas. As quatro melhores cultivares de feijão selecionadas pelo índice multiplicativo foram BRS Campeiro, Macanudo, IPR Juriti e Guapo Brilhante. As cultivares BRS Campeiro, Macanudo e IPR Juriti apresentam precocidade, arquitetura de planta ereta e alta produtividade de grãos, portanto serão selecionadas pelo programa de melhoramento.

PALAVRAS-CHAVE: *Phaseolus vulgaris.* Interação genótipo x ambiente. Genealogia. Índice de seleção.

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