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Variability among common bean lines for maximum dry matter accumulation in the grains

Abstract – The objective of this work was to verify if there is variability in the dry matter accumulation rate of grains of the carioca-type common bean, as well as to identify the success of selection for this trait and the best time for harvest. Sixteen lines with carioca-type grains were evaluated in three sowing seasons through samples of five plants obtained at regular intervals. A quadratic equation was used to estimate the number of days to obtain the maximum dry matter in the grains. A low variability was observed among the lines, discouraging selection for this trait. The ideal moment for harvesting is when 100% of the grains present the typical stripes of carioca common bean, which may vary among and within pods of the same plant. If the harvest is carried out before complete physiological maturation is reached, the dry matter in the grains decreases, on average, 2.75% per day.

Index terms: *Phaseolus vulgaris*, grain yield, harvest, physiological maturation.

Variabilidade entre linhagens de feijão comum para máximo acúmulo de matéria seca nos grãos

Resumo – O objetivo deste trabalho foi verificar se há variabilidade na taxa de acúmulo de matéria seca nos grãos de feijão comum do tipo carioca, bem como identificar o sucesso na seleção para este caráter e a melhor época para colheita. Dezesseis linhagens com grãos do tipo carioca foram avaliadas em três *épocas de semeadura*, por meio de amostras de cinco plantas, obtidas em intervalos regulares. Utilizou-se equação quadrática para estimar o número de dias para obtenção do máximo de matéria seca nos grãos. Observou-se baixa variabilidade entre as linhagens, o que desestimula a seleção para esse caráter. O momento ideal para a colheita é quando 100% dos grãos apresentam as listras típicas do feijão carioca, o que pode variar entre e dentro das vagens da mesma planta. Se a colheita for realizada antes da maturação fisiológica completa ser atingida, a matéria seca nos grãos é reduzida, em média, 2,75% por dia.

Termos para indexação: *Phaseolus vulgaris*, produtividade de grãos, colheita, maturação fisiológica.

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Introduction

One of the alternatives to increase common bean (*Phaseolus vulgaris* L.) grain yield is to extend the grain-filling period, mainly at the end of the cycle when there is a higher dry matter (DM) accumulation in the grains (Guilherme et al., 2021). The association between grain filling and grain yield was previously reported by Gasura et al. (2013) for corn

(*Zea mays* L.) and by Aude et al. (1994) and Wu et al. (2018) for wheat (*Triticum aestivum* L.). Guilherme et al. (2021) related other traits to grain filling, including grain DM, number of days for physiological maturation, and rate of DM accumulation.

In addition to increasing grain yield, it is also important to avoid grain losses by carrying out harvesting at the right time, i.e., when all pods are dry. However, this is not always possible, as observed in Brazil despite the technological advances in the cultivation of the common bean crop. In the country, bean harvest often coincides with the period of precipitation, characterized by intermittent rains that can damage the grains and the success of the crop, leading most farmers to bring forward the harvest or use desiccant herbicides to accelerate the process (Carneiro et al., 2015). However, there are no known researches on the effects of early harvesting on grain quality and yield.

The carioca-type market class of common bean, which has a cream-colored seed coat with brown stripes, represents approximately 70% of Brazil's production (Melo et al., 2017; Lemos et al., 2020; Pereira et al., 2021). Although there are several cultivars of this species on the market, there is little information about DM accumulation in the grains up to physiological maturation when all stripes appear (Vieira & Vieira, 1997). There are also no known studies about the variability of this trait among cultivars.

The objective of this work was to verify if there is variability in the DM accumulation rate of grains of the carioca-type common bean, as well as to identify the success of selection for this trait and the best time for harvest.

Materials and Methods

The experiment was conducted during three sowing seasons in the experimental area of Centro de Desenvolvimento e Transferência de Tecnologia of Universidade Federal de Lavras (UFLA), located in the southern region of the state of Minas Gerais, Brazil (21º14'S, 45"W, at 919 m of altitude). The soil of the experimental area is classified as a Latossolo Vermelho-Amarelo (Santos et al., 2018), i.e., an Oxisol. According to Köppen-Geiger's classification, the climate of the region is of the Cwa type, mesothermic with mild summers and dry winters. The annual mean temperature and precipitation were 20.2°C and 1,237 mm, respectively.

For the study, 16 lines with carioca-type grains were evaluated (Table 1). Of these, 7 belong to the breeding program of UFLA and 9 are cultivars already recommended for cultivation.

Common bean was sown in July and November 2016 and February 2017, representing the three seasons. The experimental design was a randomized complete block, with five replicates. The plot consisted of four lines with 4.0 m each. The cultural practices were those usually adopted for the crop in the region (Carneiro et al., 2015).

The following traits were evaluated: number of days to the beginning of flowering (NDF), grain DM, and grain yield.

NDF was considered the number of days from sowing until 50% of the plants in the two central lines of the plot had at least one open flower. The duration of flowering was considered the number of days until the pods of all evaluated plants were completely formed.

To obtain the grain DM of the plants sown in July 2016, samples were taken from five contiguous plants from one of the central lines of the plot at 35 days after flowering (DAF) and, subsequently, at three-day intervals until the appearance of the typical grain stripes. This number of plants was chosen to mitigate the effect of sampling on the performance of the other plants in the plot. For the plants sown in November and February, sampling started at 26 DAF, with a subsequent sampling at two-day intervals of seven samples in each season. The grains of each sample obtained from the five plants were removed from their pods in a laboratory, where the number of grains was counted. A sample of 100 grains was then taken and placed in an oven, at 65°C, for 72 hours for DM determination. In addition, the DM of a sample containing 50 grains with stripes was compared with that of another sample with 50 grains without stripes. Grain yield (kg ha^{-1}) was obtained using the plot's central line.

Grain DM data in each sampling period was subjected to the analysis of variance, using the following model:

$$Y_{ijk} = m + L_i + B_j + LB_{ij} + A_k + AB_{kj} + AL_{ki} + \varepsilon_{ijk}$$

where Y_{ijk} is the observed value in the plot that received line i in sampling period k on block j; m is the constant associated to all observations; L_i is the effect of line i

(i = 1, 2, ...,16); B_j is the effect of block j (j =1, 2, ..., 5); LB_{ij} is the effect of the interaction between line i and block j; A_k is the effect of sampling period k (k =1, 2, ..., 8); AB_{kj} is the effect of the interaction between sampling period k and block j; AL_{ki} is the effect of the interaction between sampling period k and line i; and ε_{ijk} is the experimental error ($\varepsilon_{ijk} \sim N(0 \text{ and } \sigma^2)$).

The data for DM in the grains per plot per sampling period was used in the quadratic regression equation to obtain the number of sampling days, considering flowering as an independent variable (X) and DM in the grains as a dependent variable (Y). The maximum values of DM accumulation in the grains (Ymax) were estimated through the derivative of the quadratic regression equation. The number of days for maximum accumulation of DM (Xmax) were also counted (Steel et al., 1997).

From the data per plot, the percentage of DM accumulation in the grains was estimated considering the DM sampled on day X and the Ymax. For this, a linear regression equation was used, with number of sampling days as the independent variable (X) and percentage of DM in relation to the maximum value as the dependent variable (Y). Through the b-estimate of the linear regression, the mean percentage of DM accumulation per day, i.e., the rate of DM accumulation per day in percentage, was estimated. These data were subjected to the analysis of variance by season and, then, to a joint analysis of variance, as was grain yield.

Pearson's correlation was estimated between the following variables: Xmax, Ymax, percentage of the rate of DM accumulation in the grains per day (b), and grain yield. The statistical analysis was performed with the R software (R Core Team, 2020).

Table 1. Plant architecture, growth habit, and growth cycle of the common bean (*Phaseolus vulgaris*) lines and cultivars evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil.

Lines/Cultivars[(1)]	Plant architecture	Growth habit[(2)]	Growth cycle[(3)]
BRSMG Talismã	Prostrate	III	Semi-early
BRSMG Majestoso	Semi-erect	II/III	Regular
BRS Estilo	Erect	II	Regular
Pérola	Semi-erect	II/III	Regular
Carioca	Prostrate	II	Regular
Carioca MG	Erect	II	Regular
BRMG Uai	Erect	II	Regular
BRSMG Madrepérola	Prostrate	III	Semi-early
BRSMG Zape	Semi-prostrate	II/III	Regular
RPVIII-1	Erect	II	Regular
CXII-15	Prostrate	III	Regular
CXI-1	Prostrate	III	Regular
CXI-26	Prostrate	III	Regular
MAX-1	Prostrate	III	Regular
MAXII-7	Prostrate	III	Regular
RPXI-1	Erect	II	Regular

[(1)]Lines: RPVIII-1, CXII-15, CXI-1, CXI-26, MAX-1, MAXII-7, and RPXI-1; and cultivars: BRSMG Talismã, BRSMG Majestoso, BRS Estilo, Pérola, Carioca, Carioca MG, BRSMG Uai, BRSMG Madrepérola, and BRSMG Zape. [(2)]I, determinate growth; II, indeterminate growth with short vines; and III, indeterminate growth with long vines. [(3)]Semi-early, 75–85 days; and regular, 85–95 days.

Results and Discussion

Accuracy estimates were above 80% for the evaluated traits (data not shown), indicating good experimental precision according to Resende & Alves (2022). Specifically for grain yield, experimental precision was similar or even superior to that reported in the literature (Lima et al., 2014; Ribeiro et al., 2019).

There was a significant difference among the evaluated lines for grain yield and DM accumulation in the grains (Table 2), as well as for plant type, architecture, resistance to pathogens, and, to some extent, length of the crop cycle.

Regardless of the experimental season, it was possible to generalize the obtained results since sowing in February, July, and November is usual in the study region. The joint analysis of variance showed significant differences among seasons for all traits (Table 2). The highest average grain yield was obtained when sowing

Table 2. Summary of the joint analysis of variance for mean percentage of dry matter accumulation in the grains (PDMA) and grain yield of common bean (*Phaseolus vulgaris*) lines evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil.

Source of variation	DF[(1)]	Mean square	
		PDMA (g)	Grain yield (kg ha^{-1})
Season (S)	2	25.98**	30,758,084**
Lines (L)	15	2.44**	561,036**
Blocks/Season	12	0.26	113,402
L x S	30	0.98**	377,463**
Error	180	0.34	128,288
Mean		2.75	2,226.7

[(1)]Degrees of freedom. **Significant by the F-test, at 1% probability.

was carried out in July (Figure 1), which also resulted in a higher number of days for the beginning of flowering and harvesting, as well as in a lower average percentage of DM accumulation (Table 3). In July, the crop requires irrigation throughout its growth cycle and, due to the milder initial temperatures, shows a lower occurrence of pathogens and pests (Carneiro et al., 2015).

In November, according to the same authors, it is not necessary to irrigate the crop since precipitation is usually sufficient, although not always distributed uniformly. In this sowing season, daytime and nighttime temperatures are higher, contributing to a shorter cycle and lower yield, as observed in the present. In February, the crop needs to be irrigated for most of its cycle because rainfall is scarce, plant development coincides with the end of summer, and, after the flowering period, temperatures, especially at night, are usually milder. Although, in the literature, the effect of sowing date on the duration of the grain-filling period and the percentage of DM accumulation was not observed in the study region, similar results were reported for grain yield (Lima et al., 2014; Dias et al., 2021).

Regarding grain yield per area, the greatest discrimination among lines occurred when sowing was carried out in November (Figure 1). However, regardless of the sowing season, lines CXII-15 and 'Pérola' were always classified in the highest-yielding group, and 'Carioca', 'BRSMG Madrepérola', and 'BRSMG Majestoso' in the intermediate group.

The duration of the flowering period varied, on average, from seven to ten days. As to grain size, differences were observed due to the development of the pods of the five sampled plants. Furthermore, the number of grains between samples varied and DM of each grain has been determined.

The quadratic regression equation obtained between sampling date, as the independent variable, and DM in the grains, as the dependent variable, showed an excellent fit in the three seasons, with a coefficient of variation (R^2) higher than 96% (Figure 2). Although comparing the equations of each season was difficult due to the different dates in which sampling began,

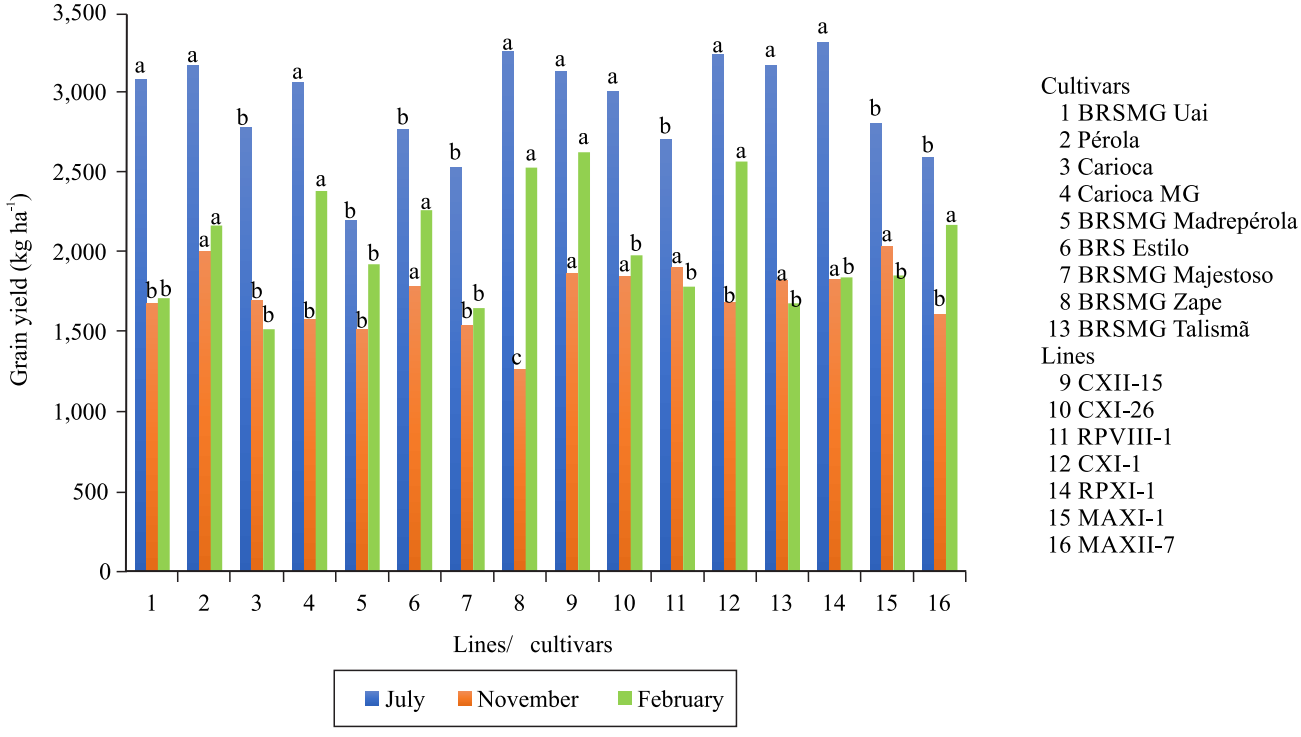

Figure 1. Grain yield of the sixteen common bean (*Phaseolus vulgaris*) lines and cultivars evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil. In the same experiment, lines with the same letter belong to the same group based on Scott-Knott's test, at 5% probability.

a similar trend was observed with the highest accumulation of DM in the grains sown in July.

Since the estimates of the R^2 of the linear equations were high, the percentage of DM accumulation to reach the maximum value at the end of the common bean cycle can also be considered linear, facilitating the following inferences. The highest average percentage of DM accumulation per day, starting at 30 days after flowering, varied between experiments (Table 3). Higher and lower values of 3.27 and 2.14% were obtained with sowing in February and July, respectively. The average DM accumulation rate was 2.75% per day. Despite the significant interaction between lines and sowing seasons for percentage of DM accumulation per day shown by the estimates of the linear regression coefficient, it was still possible to classify the lines. The 'BRSMG Madrepérola', 'BRSMG Talismã', and RPXI-1 lines were classified in the group with the lowest accumulation of DM in the grains.

There was no significant difference between the lines for the grain-filling period, indicating that the variation in number of days from the beginning of flowering to the point of maximum DM accumulation in the grains was low (Table 3). Considering the average of all seasons and lines, the duration of grain filling was 43 days, shorter than that found by Teófilo et al. (1999) of up to 63 days. These divergent results are possibly explained by the difference in the average temperature in the sowing months in the different study years. However, even at the same sowing time in July, the average number of days for the lines to reach the maximum point of DM accumulation was only 47 in the present work.

To significantly increase common bean yield, the lines should have a grain-filling period at least ten days longer than that observed in the present study. In addition, this increase should occur mainly in the period of maximum DM accumulation since, at the beginning of grain filling, cell multiplication occurs for seed development (Lee & Tollenaar, 2007). Therefore, the obtained results are an indicative that it is not feasible to select lines for the longest duration to reach the maximum DM accumulation in the grains at the end of the cycle, meaning that another strategy should be used to obtain carioca bean lines with a higher yield than the existing ones.

Table 3. Percentage of dry matter accumulation rate in the grains per day in relation to the maximum rate and number of days for the maximum accumulation of dry matter (Xmax) of common bean (*Phaseolus vulgaris*) lines and cultivars evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil[1].

Lines/Cultivars[2]	Sowing season in July		Sowing season in November		Sowing season in February		Mean
	Mean	Xmax	Mean	Xmax	Mean	Xmax	
BRSMG Uai	2.13a	47	2.55b	39	3.36b	42	2.68a
Pérola	2.26a	48	3.10b	40	3.78b	43	3.05b
Carioca	1.86a	46	2.56b	39	2.76a	41	2.39a
Carioca MG	2.57b	45	2.59b	39	3.06a	43	2.74a
BRSMG Madrepérola	1.69a	46	2.12a	40	3.25a	41	2.35a
BRS Estilo	3.11b	46	2.95b	40	3.18a	42	3.08b
BRSMG Majestoso	1.86a	45	2.89b	40	2.89a	43	2.55a
BRSMG Zape	2.96b	47	4.12c	39	3.78b	42	3.62c
CXII-15	2.06a	46	4.25c	40	3.38b	43	3.23b
CXI-26	1.83a	48	2.60b	39	3.10a	42	2.51a
RPVIII-1	1.68a	47	2.75b	40	2.59a	42	2.34a
CXI-1	1.90a	47	2.67b	39	3.66b	43	2.74a
BRSMG Talismã	2.07a	48	1.89a	40	2.92a	42	2.29a
RPXI-1	2.30a	47	1.59a	39	2.91a	42	2.27a
MAX-1	2.12a	47	3.29c	39	3.75b	42	3.05b
MAXII-7	1.83a	48	3.77c	40	3.87b	43	3.16b
Mean	2.14A	47	2.85B	40	3.27C	42	2.75

[1]Means followed by equal letters, in the same column, belong to the same group based on Scott-Knott's test, at 5% probability. [2]Lines: RPVIII-1, CXII-15, CXI-1, CXI-26, MAX-1, MAXII-7, and RPXI-1; and cultivars: BRSMG Talismã, BRSMG Majestoso, BRS Estilo, Pérola, Carioca, Carioca MG, BRSMG Uai, BRSMG Madrepérola, and BRSMG Zape.

As observed initially by Vieira & Vieira (1997), the occurrence of stripes in the grains indicate the physiological maturation of carioca common bean. In the present study, with advancing physiological maturation, the percentage of DM in the grains decreased (Table 4), showing that the presence of stripes in the grain is a suitable marker for harvest time and for estimating the risk of anticipating the application of desiccant herbicides. Regardless of seasons and lines, if the herbicide is sprayed before physiological maturation, there will average losses of 2.75% in the DM in the grains. This means that grains with all stripes can be harvested and receive desiccant herbicide application without negative effects on their yield or quality, whereas, grains that still do not have stripes will show a decreased yield due to herbicide use. In this case, the greatest challenge is the lack of homogeneity regarding the maturation of each grain even of those from the same pod.

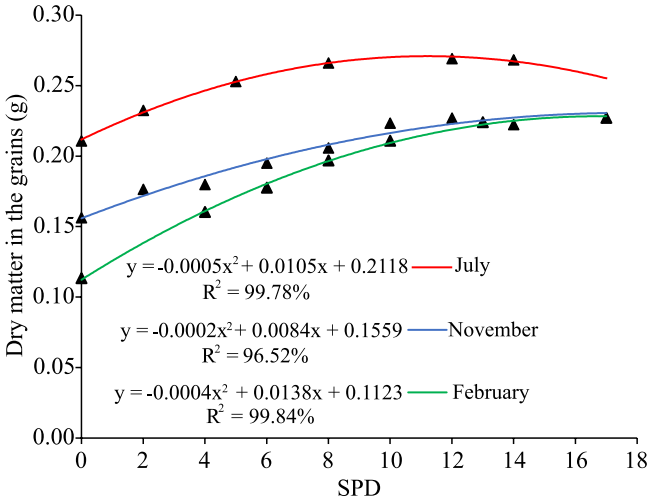

Figure 2. Dry matter in the grains of common bean (*Phaseolus vulgaris*) lines and cultivars throughout the sampling periods in days (SPD) in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil.

Other studies have evaluated the use of desiccant herbicides in the common bean crop (Castoldi et al., 2019; Rosado et al., 2019; Silva et al., 2021), but without estimating the percentage of DM accumulation per day until physiological maturation. Moreover, the results do not necessarily provide accurate information on physiological maturation, as the treatment that receives the desiccant herbicide is compared with the control, whose yield will not be affected by the herbicide if the plant has already reached physiological maturity.

The estimates of correlations (r) between the evaluated traits were of low magnitude and most were not significant (Table 5). As in the present work there was no expressive variation among the lines for the evaluated traits (Table 3), the estimates of r contributed

Table 4. Decrease in the percentage of dry matter in the grains with and without stripes of four common bean (*Phaseolus vulgaris*) lines evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil.

Lines/cultivars[(1)]	Days of harvest anticipation								
	17	14	13	12	10	9	8	6	4
					Sowing in July				
BRSM Madrepérola	-	36.47	-	30.00	-	28.50	-	0	-
BRS Estilo	-	28.04	-	27.41	-	26.30	-	0	-
CXI-26	-	24.59	-	24.37	-	22.17	-	0	-
CXI-1	-	31.56	-	30.36	-	30.19	-	0	-
					Sowing in November				
BRSM Madrepérola	-	26.54	-	22.63	21.97	-	18.83	0	0
BRS Estilo	-	27.13	-	27.10	26.68	-	24.55	24.24	0
CXI-26	-	42.51	-	35.44	27.64	-	27.11	16.31	0
CXI-1	-	29.60	-	14.57	12.58	-	2.120	0	0
					Sowing in February				
BRSM Madrepérola	15.06	-	13.78	-	12.60	-	6.87	0	0
BRS Estilo	30.66	-	30.66	-	30.44	-	23.65	0	0
CXI-26	26.89	-	16.93	-	13.53	-	11.41	0	0
CXI-1	22.93	-	21.25	-	20.12	-	19.63	0	0

[(1)]Lines: CXI-1 and CXI-26; and cultivars: BRS Estilo and BRSMG Madrepérola.

Table 5. Estimates of the coefficients of correlation between the traits number of days for the maximum accumulation of dry matter (Xmax), maximum dry matter in the grains (Ymax), accumulation rate of dry matter in the grains per day in relation to the maximum rate (b) and grain yield of common bean (*Phaseolus vulgaris*) lines evaluated in different sowing seasons in July and November 2016 and February 2017 in the municipality of Lavras, in the state of Minas Gerais, Brazil.

Trait	Sowing in July			Sowing in November			Sowing in February		
	Xmax	Ymax	b	Xmax	Ymax	b	Xmax	Ymax	b
Ymax	0.18			0.32*			0.30**		
b	0.13	-0.27*		0.04	-0.16		-0.39**	-0.22*	
Grain yield	0.09	0.0007	-0.28*	0.14	0.23**	0.14	-014	0.02	-0.02

* and **Significant by the t-test, at 5 and 1% probability, respectively.

little to possible inferences on the association between the studied variables.

Conclusions

1. The variability among carioca common bean (*Phaseolus vulgaris*) lines for number of days to reach the maximum dry matter in the grains is low, discouraging selection for this trait, which shows that it is not a feasible alternative to obtain carioca bean lines with a higher yield than the existing ones.

2. The ideal moment for harvesting is when 100% of the grains present the typical stripes of carioca bean, which is challenging due to the variation in the appearance of stripes among and within pods of the same plant.

3. The average loss in accumulated dry matter in the grains and, consequently, in yield in relation to the maximum dry matter accumulation is, on average, 2.75% per day.

4. If common bean grains are harvested before reaching complete physiological maturation, their dry matter is reduced, negatively affecting crop yield.

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