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Cycle, canopy architecture and yield of common bean genotypes (*Phaseolus vulgaris*) in Santa Catarina State

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ABSTRACT. The objective of this study was to identify the phenotypic and genotypic correlations between the plant cycle and plant habit and the effect on yield in landrace bean genotypes. The experiment was conducted in Joaçaba and Lages, Santa Catarina State for the 2008/2009 crop using 26 bean genotypes: 22 landrace and 4 commercial genotypes obtained from the UDESC. We evaluated the number of days from emergence to flowering, number of days from flowering to physiological maturity and number of days from emergence to physiological maturity in relation to the genotypes' cycle. The aerial plant architecture characteristics evaluated were the growth habit, plant habit, plant height, stem diameter, height of the first pod insertion and number of nodes on the main stem. Trail analysis showed that there was a positive correlation between the emergence-to-flowering period and yield and that the emergence-physiological maturity; flowering-physiological maturity showed a negative correlation to the yield in both locations. Therefore, short-cycle genotypes, especially those with a reduced post-flowering period, produced increased yields. The aerial plant architecture characteristics showed phenotypic and genotypic positive correlations with the yield in both environments. To increase yield, the reproductive period needs to coincide with periods of the greatest photosynthetically active radiation.

Keywords: trail analysis, genetic variability, short cycle, upright habit.

Ciclo, arquitetura de parte aérea e produtividade de genótipos de feijão (*Phaseolus vulgaris*), no Estado de Santa Catarina

RESUMO. O trabalho objetivou obter a correlação fenotípica e genotípica entre o ciclo e porte de planta para produtividade de genótipos crioulos de feijão. O experimento foi conduzido nos municípios de Joaçaba e Lages, Estado de Santa Catarina na safra 2008/2009, com 26 genótipos de feijão: 22 genótipos crioulos e 4 genótipos comerciais, provenientes da UDESC. Em relação ao ciclo os genótipos foram avaliados quanto: número de dias da emergência a floração, número de dias da floração a maturação fisiológica e número de dias da emergência a maturação fisiológica. As características de parte aérea avaliadas foram: hábito de crescimento, porte, estatura de planta, diâmetro da haste, altura de inserção da primeira vagem e número de nós na haste principal. A análise de trilha demonstrou que o período emergência–floração apresentou correlação positiva com a produtividade e o período emergência–maturação fisiológica; floração–maturação fisiológica apresentou correlação negativa com a produtividade para os dois locais. Portanto, genótipos mais precoces, principalmente a redução do ciclo após o período de floração, propiciou aumento na produtividade. Os caracteres de arquitetura de parte aérea mostraram correlação fenotípica e genotípica positiva com a produtividade nos dois locais. Para aumentos de produtividade é necessário coincidir o período reprodutivo com os momentos de maior incidência de radiação.

Palavras-chave: análise de trilha, variabilidade genética, precocidade, porte ereto.

Introduction

The planting of short-cycle bean genotypes presents various advantages: making better use of the cultivation area; allowing for a more favorable period for sowing and harvesting; reducing climatic stress, disease occurrence and harvest losses; lowering water consumption and the soil 'use' time under intensive and irrigated cultivation; and facilitating crop rotation. Furthermore, due to the early harvest, early-maturing beans can provide a better profit for the farmer (DALLA CORTE et al., 2003).

The number of days from emergence to flowering has been used by researchers to define early-maturing characteristics (RAMALHO et al., 2005; SILVA et al., 2007). The flowering initiation characteristic shows a high heritability and a high and positive correlation with physiological maturity (SILVA et al., 2007). However, genotypes with the shortest emergence-flowering period may not be the earliest to mature, suggesting that it is not always the early-flowering genotypes that will have the shortest cycles (RIBEIRO et al., 2004).

Early maturity can be related to bean yield. It has been reported that a reduction of one day of the cycle caused a 33 kg ha^{-1} increase in yield during the dry season in Minas Gerais State (RAMALHO et al., 1993) and that the yield of black and carioca bean genotypes increase with a reduction in the cycle in the central basin region of Rio Grande do Sul (RIBEIRO et al., 2004). Traka-Mavrona et al. (2002) showed that advanced families had a high degree and stability of early bean cultivars, a high yield, and normal seeds and pods of high quality. Therefore, the use of short-cycle genotypes can lead to increased yields.

The use of more productive cultivars, which have a plant architecture that facilitates cultural operations and mechanical harvest, has increased recently (SILVA et al., 2009): the modern cultivars tend to have a type-II growth habit, grow more upright, resist lodging and mature uniformly. However, Alves et al. (2001) argued that there is a negative correlation between more upright plant crops and yield, which is likely to be a problem for the modern cultivars.

According to Souza et al. (2010a and b), plants with greater hypocotyl and epicotyl diameters and a greater average plant height at harvest have better architecture. However, a negative linear association between the hypocotyl and epicotyl diameters and grain yield has been observed, indicating that plants with a more upright architecture demonstrate lower yields. In addition, it must be considered that there is a high negative genotypic correlation between the epicotyl diameter and the number of pods and branch internodes, indicating that plants with greater epicotyl diameters have fewer branches.

The cycle and aerial plant architecture (growth habit) are highly influenced by the environment, however the choice of a short-cycle genotype with ideal architecture is possible, especially if various genotypes are tested in diverse environments (SILVA et al., 2009; DAWO et al., 2007). Therefore, studies concerned with plant architecture, bean genotype diversity and growth cycle should address the effect of the environment on these characteristics and also concentrate on identifying productive plants with early maturity; a large, upright habit; and a higher point of first pod insertion, traits that are of great importance to meet new market demands.

The objective of this work was to determine the effect of the direct and indirect relationships between the cycle and aerial plant architecture on the bean grain yield through genotypic and phenotypic correlations.

Material and methods

The experiment was conducted under field conditions in Joaçaba, Santa Catarina State (27°10' S, 51°30' W, 522 meters above sea level) and Lages, Santa Catarina State (27°52' S, 50°18' W, 930 meters above sea level) for the 2008/2009 crop using 26 genotypes, including 22 landrace genotypes and 4 commercial genotypes, obtained from the common bean germplasm bank, named 'Banco Ativo de Feijão' (BAF) of the 'State University Santa Catarina' (UDESC). The following BAF genotypes used were used: 3; 4; 7; 13; 23; 36; 42; 44; 46; 47; 50; 55; 57; 60; 68; 75; 81; 84; 97; 102; 108; 112; 115; 120; 121 and 192. The 4 commercial cultivars were BAF 112 (IPR88-Uirapurú), BAF 115 (BRS-Valente), BAF 121 (Iapar-81) and BAF 192 (BRS-Radiante).

A random experimental block layout was used, comprising three repetitions in plots with four 3 meter-long lines, with 0.5 m between the lines. Fifteen seeds were sown per meter, with the two external lines being considered as border strips, thus making the two internal lines the useful area but excluding 0.5 m from the extremities of each.

Base fertilizer was applied next to the lines before sowing and in accordance with a soil analysis and the recommendations of the 'Comissão de Química e Fertilidade do Solo' - CQFS-RS/SC (2004). Top dressing was applied twice, at the three-lobed-leaf stage and at the start of flowering (V4 and R5) using 30 kg ha^{-1} of N for each application. Weed, disease and pest control was performed according to necessity using chemical products recommended for this culture.

The grain yield was estimated in kg ha^{-1}, corrected to a 13% moisture content (fresh weight), based on the grain yield obtained from the useful area of each plot. As for the cycle, the genotypes were evaluated during the emergence-flowering (number of days from emergence to flowering), flowering-physiological maturity (number of days from flowering to physiological maturity), and emergence-physiological maturity (number of days from emergence to physiological maturity) periods. In each plot, the phenological stage was considered as follows: emergence - 50% plus one seedling emergence; flowering - 50% plus one plant with an open flower; physiological maturity - 50% plus one plant with yellow pods (CIAT, 1983).

The following aerial plant architecture characteristics were evaluated: growth habit (type I, type II, type III and type IV); plant habit (upright, semi-upright, and prostrate); plant height (cm); stem diameter (cm); height of the first pod insertion (cm); and number of nodes on the main stem. The growth habit, plant habit, plant height and stem diameter were determined in R6, and the height of the first pod insertion and number of nodes were determined in R8. The determination of these characteristics was made for 10 plants, randomly selected from the useful area in each plot (IPGRI, 2001). The field genotype germination percentage was also estimated by counting the number of emerged plants in the useful area of each plot.

All of the variables studied were subjected to univariate variance analysis according to the fixed-effects linear model (LITTEL et al., 2006; ZILIO et al., 2011) for the components, location, genotype, and genotype response to the cultivation environment. The comparison between the average values of each variable analyzed for the different genotypes in each location was performed using the Scott-Knott test and for each genotype between locations using the Tukey test. The association between the characteristics was estimated through phenotypic and genotypic trail analysis. Trail analysis consists of a study of the direct and indirect effects of independent explanatory characteristics on a principal, basic dependent variable for which the estimates are obtained using regression equations using previously standardized variables (CABRAL et al., 2011). The minimum level of significance for all of the tests was 5%.

Results and discussion

The variance analysis indicated a genotype x environment interaction for the plant height characteristic only. For the other characteristics, the effect of genotype was only observed between the locations, suggesting that the genotypes do not respond differently to environmental influences in terms of the stem diameter, height of the first pod insertion and number of nodes. However, a significant difference was observed between the genotypes for all of the characteristics evaluated within the two locations, except for the height of the first pod insertion in the Lages environment. These results indicate the presence of variability for the majority of the characteristics in the two locations, thus facilitating the identification of the genotypes with ideal architecture.

Different genotype responses to cultivation environments were observed in terms of the cycle and yield, proving the existence of genetic diversity over the duration of the cycle and the effect of the location on each genotype. For this reason, the data obtained for the different genotypes are presented by the cultivation location.

After the phenotypic trail analysis (Table 1), it was revealed that the emergence-flowering period showed a positive correlation with the yield for both locations, i.e., the greater the number of days between emergence and flowering, the greater was the yield. According to Fageria et al. (2006), the pre-flowering period is necessary for the adequate development of the leaves to supply photosynthate to the grains during the grain-filling stage.

However, the emergence-physiological maturity and flowering-physiological maturity periods showed negative correlations in both of the environments, indicating that grain yield increases were obtained when the number of days between emergence and physiological maturity was reduced. Therefore, short-cycle genotypes, especially those with a reduced cycle post-flowering, give greater yields.

Similar results were found by Ramalho et al. (1993) in Minas Gerais State and by Ribeiro et al. (2004) in Rio Grande do Sul State in that reductions in the cycle led to yield increases. In a study conducted by Ribeiro et al. (2001), carioca bean genotypes showed a negative genetic correlation between the cycle and grain yield, weight of 100 grains, number of pods and grains per plant, and number of grains per legume. Cabral et al. (2011) also observed a negative correlation between the yield and emergence-flowering and emergence-harvest periods.

Table 1. Estimate of the phenotypic and genotypic correlation coefficients and their direct and indirect effects on the yield characteristics and cycle in common beans.

Characteristics	Estimate of correlation			
	Phenotypic		Genotypic	
Emergence – Flowering	Joaçaba	Lages	Joaçaba	Lages
Direct effect on yield	-2.79	8.88	-2.32	-26.1
Indirect effect via emergence-physiological maturity	2.57	-4.01	2.51	11.25
Indirect effect via flowering-physiological maturity	-0.24	-5.16	-0.24	14.02
Indirect effect via plant height	0.26	-0.05	0.41	-0.37
Indirect effect via stem diameter	0.17	0.05	0.28	-0.01
Indirect effect via first pod height	0.05	0.30	-0.05	0.82
Indirect effect via internodes number	0.17	0.24	-0.31	0.66
Indirect effect via emergence	-0.04	0.01	-0.12	0.01
Total	0.14	0.25	0.16	0.29
Emergence - Physiological Maturity				
Direct effect on yield	3.10	-15.28	3.02	36.44
Indirect effect via emergence- physiological maturity	-2.31	2.33	-1.93	-8.06
Indirect effect via flowering-physiological maturity	-1.42	12.76	-1.40	-28.56
Indirect effect via plant height	0.20	-0.01	0.32	-0.01
Indirect effect via stem diameter	0.13	-0.04	0.21	0.02
Indirect effect via first pod height	0.05	0.07	-0.05	0.31
Indirect effect via internodes number	0.11	-0.11	-0.21	-0.41
Indirect effect via emergence	-0.07	0.02	-0.19	0.03
Total	-0.20	-0.24	-0.24	-0.24
Flowering - Physiologic Maturity				
Direct effect on yield	-2.19	15.52	-2.18	-37.31
Indirect effect via emergence-physiological maturity	-0.30	-2.95	-0.26	9.81
Indirect effect via flowering-physiological maturity	2.00	-12.56	1.94	27.89
Indirect effect via plant height	0.01	0.03	0.01	0.25
Indirect effect via stem diameter	-0.01	-0.07	0.01	0.03
Indirect effect via first pod height	0.03	-0.11	-0.02	-0.27
Indirect effect via internodes number	-0.03	-0.25	0.05	-0.84
Indirect effect via emergence	-0.07	0.02	-0.18	0.02
Total	-0.55	-0.38	-0.64	-0.42
Plant Height				
Direct effect on yield	0.37	-0.14	0.57	-0.93
Indirect effect via emergence-physiological maturity	-1.98	3.53	-1.69	-10.42
Indirect effect via flowering-physiological maturity	1.69	-0.02	1.71	0.44
Indirect effect via plant height	-0.02	-3.66	-0.03	9.89
Indirect effect via stem diameter	0.12	0.07	0.20	-0.02
Indirect effect via first pod height	0.03	0.37	-0.03	0.91
Indirect effect via internodes number	0.13	0.22	-0.25	0.65
Indirect effect via emergence	-0.02	-0.01	-0.06	0.01
Total	0.34	0.36	0.41	0.51
Stem Diameter				
Direct effect on yield	0.33	0.14	0.50	-0.04
Indirect effect via emergence-physiological maturity	-1.45	2.81	-1.30	-10.30
Indirect effect via flowering-physiological maturity	1.22	4.69	1.29	-13.94
Indirect effect via plant height	0.01	-7.56	-0.01	23.75
Indirect effect via stem diameter	0.14	-0.06	0.23	-0.60
Indirect effect via first pod height	0.04	0.20	-0.05	0.81
Indirect effect via internodes number	0.07	0.27	-0.14	1.03
Indirect effect via emergence	-0.02	-0.01	-0.08	-0.03
Total	0.34	0.48	0.45	0.68
First Pod Height				
Direct effect on yield	0.13	0.50	-0.11	1.02
Indirect effect via emergence- physiological maturity	-1.02	5.43	-1.00	-21.21
Indirect effect via flowering- physiological maturity	1.25	-2.27	1.44	11.29
Indirect effect via plant height	-0.49	-3.41	-0.57	9.81
Indirect effect via stem diameter	0.10	-0.10	0.14	-0.84
Indirect effect via first pod height	0.11	0.06	0.22	-0.03
Indirect effect via internodes number	-0.01	0.12	0.01	0.35
Indirect effect via emergence	0.01	0.01	-0.02	0.01
Total	0.09	0.33	0.10	0.40
Internodes Number				
Direct effect on yield	0.21	0.59	-0.32	1.49
Indirect effect via emergence-physiologic maturity	-2.26	3.64	-2.21	-11.58
Indirect effect via flowering-physiologic maturity	1.69	2.87	1.96	-9.93
Indirect effect via plant height	0.30	-6.56	0.35	21.06
Indirect effect via stem diameter	0.24	-0.05	0.45	-0.40
Indirect effect via first pod height	0.12	0.07	0.22	-0.03
Indirect effect via internodes number	-0.01	0.10	0.01	0.24
Indirect effect via emergence	-0.02	-0.01	-0.10	-0.01
Total	0.27	0.64	0.34	0.84

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Characteristics	Estimate of correlation			
	Phenotypic		Genotypic	
Emergence	Joaçaba	Lages	Joaçaba	Lages
Direct effect on yield	0.16	-0.03	0.38	-0.02
Indirect effect via emergence-physiologic maturity	0.75	-1.76	0.74	12.87
Indirect effect via flowering-physiologic maturity	-1.35	8.84	-1.53	-53.11
Indirect effect via plant height	0.91	-6.90	1.02	40.6
Indirect effect via stem diameter	-0.04	-0.01	-0.09	0.01
Indirect effect via first pod height	-0.05	0.07	-0.10	-0.06
Indirect effect via internodes number	0.01	-0.02	0.01	-0.35
Indirect effect via emergence	-0.03	0.21	0.09	1.00
Total	0.35	0.39	0.52	0.94

According to Rocha and Vello (1999), soybean grain yield varied with maturity cycle and cultivation location: short-cycle, semi-short-cycle and medium-cycle genotypes demonstrated greater grain yields than late-cycle varieties. These authors also reported that late-cycle genotypes were more susceptible to fungal diseases due to their longer exposure to field conditions than short-cycle genotypes; the latter were exposed to field conditions for less time and were, thus, less affected or not affected at all by phytopathogenic fungi. The authors further indicated that medium-cycle genotypes demonstrated a greater stability to environmental factors compared to late-maturing genotypes due to their greater chance of not being adversely affected by fungi.

Other authors have found a relationship between the cycle and bean yield components. According to Cabral et al. (2011), plants with a lower number of days between emergence and flowering and between flowering and physiological maturity produce a greater number of pods per plant, seeds per pod and weight of 100 seeds.

In the present study, the aerial plant architecture characteristics showed a positive phenotypic correlation with the yield for both of the locations. The characteristic that contributed most to the increased grain yield in beans was the plant height (+0.34) and stem diameter (+0.34) in Joaçaba and the number of nodes (+0.64) and stem diameter (+0.48) in Lages. Similar results were found by Vale et al. (2009) who also found a positive correlation between the yield, plant height and height of the first pod insertion. In contrast, Cabral et al. (2011) found that the plant height and height of the first pod insertion did not present a correlation with the yield.

According to this, environmental conditions drastically affect the degree of association between cycle and yield. In general, the yield, rate of maturity, greater plant height, stem diameter and number of nodes were efficient for the selection of high-yielding genotypes by the cultivation location.

Our genotypic trail analysis results showed that the aerial plant architecture characteristics presented positive correlation coefficients with the yield for both of the locations (Table 1). Most notable were the stem diameter (+0.45) and plant height (+0.41) in Joaçaba and the number of nodes (+0.84) and stem diameter (+0.68) in Lages. These results indicate that elevated yields can be achieved when genotypes with greater aerial structure, number of nodes, height of first pod insertion and, especially, stem diameter are used.

The genotype correlation coefficient estimates show a positive association between the emergence-flowering period and yield for both of the locations, whereas the emergence-physiological maturity and flowering-physiological maturity periods show negative correlation coefficients for the environments (Table 1).

When the phenotypic and genotypic correlation coefficient values are compared, in general, the genotypic correlations are superior to the corresponding phenotypic values; when the correlation magnitudes are not similar, the genotypic correlations are more useful than the phenotypic correlations for selection strategies. However, genotypically correlated characteristics that are not phenotypically correlated may not be of practical use in selection, as selection is generally based on phenotype (CARVALHO et al., 2002). Thus, both types of correlation were considered in this study to facilitate the decision about the efficiency of these indirect selection criteria.

For characteristics related to the aerial plant architecture, the genotypes studied showed different behavior between the two locations in terms of the plant height only. However, there was variability within each location for the characteristics, with the exception of the height of the first pod insertion in Lages, Santa Catarina State (Table 2).

The height of the genotypes in Joaçaba varied between 100.5 cm (BAF 108) and 45.8 cm (BAF 4), with an average of 70.6 cm. Despite BAF 108 presenting an elevated height, this genotype exhibited a prostrate undetermined climber growth habit, which does not permit mechanical harvest. BAF 4 presented an upright determined growth habit. In Lages, the tallest genotype was BAF 7 (90.1 cm), which displayed a prostrate undetermined growth habit and was semi-upright, and the shortest was BAF 120 (35.5 cm), with a determined, upright growth habit. The genotypes with determined growth habits presented shorter plants in Joaçaba (60.0 cm) and Lages (42.9 cm), compared to the undetermined-habit genotypes (77.8 cm to 64.8 cm in Joaçaba and Lages, respectively) (Table 2).

The stem diameter of the genotypes cultivated in Joaçaba varied from 0.8 cm (BAF 7) to 0.6 cm (BAF 47), with an average of 0.7 cm. BAF 7 presented a type III growth habit, and BAF 47 showed a type II habit and an upright growth habit. In Lages, the genotypes varied from 0.7 cm (BAF 121) to 0.5 cm (BAF 47), with an average of 0.6 cm. BAF 121 (Iapar-81) was upright with a type II growth habit (Table 2).

The height of the first pod insertion for the Joaçaba genotypes was from 35.5 cm (BAF 13) to 14.0 cm (BAF 47), with an average of 20.7 cm. In Lages, the genotype with the greatest height of first pod insertion was BAF 7 (32.7 cm) and the lowest was BAF 192 (11.5 cm), with an average of 20.1 cm. The number of nodes on the genotypes in Joaçaba varied between 18.1 (BAF 50) and 5.6 (BAF 97), with an average of 9.3 nodes per plant. In Lages, the genotypes showed a variation of between 13.3 (BAF 121) and 6.2 (BAF 4), with an average of 9.6 nodes (Table 2).

Among the landrace genotypes, BAF 7 was notable, presenting elevated values for all of the architecture characteristics evaluated at both locations, whereas BAF 47 presented low characteristic values at both locations. Among the commercial genotypes, BAF 121 was prominent, presenting elevated plant height, height of the first pod insertion, stem diameter, and number of nodes values in Lages and increased stem diameter and number of nodes in Joaçaba (Table 2).

For characteristics related to the culture cycle and yield, the genotypes studied presented different behavior within and between each location (Table 3). Various studies have reported a genotype x environment interaction and genetic diversity in the cycle (BARELLI et al., 1999; BURATTO et al., 2007; DALLA CORTE et al., 2002; RIBEIRO et al., 2004).

Table 2. Growth habit, plant height, stem diameter, height of the first pod insertion and number of internodes of common bean genotypes cultivated in Joaçaba and Lages, Santa Catarina State, during the 2008/2009 crop season.

BAF	(1)Growth habit		(2)Habit		(3)/ Plant height (cm)		Stem diameter (cm)		First pod height (cm)		Internodes number		Emergence (%)	
	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages
3	I	I	2	1	A 55.4 e	A 43.8 b	0.8a	0.6a	19.3b	21.9a	7.2a	7.1b	81.1b	69.5a
4	I	I	1	1	A 45.9 f	A 39.0 b	0.6b	0.5b	17.0b	17.4a	7.2a	6.2b	78.9b	54.6a
7	III	III	2	2	A 80.2 b	A 90.1 a	0.8a	0.6a	33.4a	32.7a	9.8a	12.4	75ba	87.9a
13	II	II	1	1	A 83.6 b	A 65.6 a	0.7a	0.6a	35.5a	26.2a	7.3a	9.8a	88.9a	83.9a
23	I	I	1	1	A 57.0 e	A 42.7 b	0.6b	0.6b	19.8b	18.0a	8.2a	6.4b	74.2b	57.7a
36	II	II	1	1	A 70.4 c	A 73.8 a	0.7b	0.6a	14.8b	25.4a	8.4a	8.9a	80b	86.3a
42	I	I	1	1	A 75.9 c	A 45.7 b	0.8a	0.6a	15.5b	16.0a	10.2a	9.9a	76.7b	67.4a
44	III	II	2	1	A 71.6 c	A 69.9 a	0.6b	0.5b	15.8b	20.3a	9.3a	10.9	85a	80.9a
46	II	III	1	2	A 74.0 c	A 77.4 a	0.6b	0.6a	20.8b	23.1a	9.0a	9.1a	93.9a	84.1a
47	II	II	1	1	A 68.7 d	A 49.7 b	0.6b	0.5b	14.0b	16.7a	7.9a	8.1b	88.6a	63.6a
50	II	II	2	1	A 83.0 b	A 51.2 b	0.7b	0.5b	21.2b	18.7a	18.1a	12.7a	88.3a	62.2a
55	II	II	1	1	A 66.9 d	A 47.1 b	0.8a	0.6a	20.1b	18.9a	10.6a	9.4a	90.6a	69.1a
57	II	II	1	1	A 66.4 d	A 54.7 b	0.6b	0.5b	23.1b	16.1a	7.2a	8.1b	91.1a	69.8a
60	I	I	1	1	A 66.3 d	A 49.1 b	0.7b	0.6a	22.7b	17.3a	10.8a	9.8a	84.2a	66.5a
68	I	I	1	1	A 50.3 f	A 47.3 b	0.6b	0.5b	16.8b	24.1a	6.9a	7.7b	84.7a	59.6a
75	II	II	1	1	A 80.6 b	A 85.7 a	0.7b	0.7a	24.6b	23.8a	9.7a	9.1a	85.8a	88.6a
81	II	II	1	1	A 87.3 b	B 38.4 b	0.8a	0.6a	20.7b	17.6a	10.4a	11.5a	82.8a	57.9a
84	I	I	1	1	A 72.5 c	A 40.5 b	0.7b	0.5b	18.3b	22.2a	10.9a	10.8a	84.4a	67.9a
97	I	I	1	1	A 62.3 d	A 47.1 b	0.6b	0.5b	23.3b	18.1a	5.6a	6.5b	89.7a	63.3a
102	II	III	1	2	A 72.8 c	A 71.0 a	0.7a	0.6a	16.0b	22.5a	9.8a	10.4a	84.2a	81.7a
108	IV	IV	3	3	A 100.5 a	A 85.8 a	0.6b	0.6b	20.7b	21.2a	12.7a	10.2a	70.8b	76.8a
112	II	II	1	1	A 71.8 c	A 43.6 b	0.8a	0.6a	23.6b	16.8a	9.5a	12.1a	90.3a	66.6a
115	II	II	1	1	A 83.3 b	B 44.9 b	0.8a	0.6a	18.5b	14.1a	10.0a	11.0a	86.4a	66.1a
120	I	I	1	1	A 57.4 e	A 35.6 b	0.8a	0.5b	23.7b	16.2a	7.3a	6.9b	85a	66.9a
121	II	II	1	1	A 74.6 c	A 88.1 a	0.8a	0.7a	19.2b	26.1a	11.2a	13.3a	78.3b	97.7a
192	I	I	1	1	A 57.2 e	A 38.8 b	0.7b	0.5b	20.6b	11.6a	6.5a	11.1a	86.1a	63.4a
Average					70.6	56.4	0.7	0.6	20.7	20.1	9.3	9.6	84.0	81.3
C.V.					6.1	17.7	6.1	8.0	18.4	23.5	9.3	6.6	5.2	8.0

(1) I (determined); II (undetermined shrubby); III (undetermined prostrate); IV (undetermined climber). (2) 1 (upright); 2 (semi–upright); 3 (prostrate). (3)/Averages followed by the same capital letter do not significantly differ between the cultivation locations (rows) using the Tukey test at 5% probability. Averages followed by the same lowercase letter do not significantly differ in each cultivation location (columns) using the Scott-Knott test at 5% probability.

Table 3. Duration in the number of days of the emergence-physiological maturity, emergence-flowering and flowering-physiological maturity periods of bean genotypes cultivated in Joaçaba and Lages, Santa Catarina State, during the 2008/2009 crop season.

BAF	V1–R9 (days)		V1–R6 (days)		R6–R9 (days)		Yield (kg ha^{-1})	
	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages	Joaçaba	Lages
3	[1/]A 68 c	A 79 b	B 31 g	A 36 b	A 37 a	A 43 b	A 2617 b	A 1220 a
4	A 68 c	A 81 b	B 30 h	A 34 c	A 38 a	A 47 b	A 2011 b	A 1656 a
7	A 84 a	A 90 a	B 42 a	A 48 a	A 42 a	A 43 b	A 2776 b	AB 1938 a
13	A 68 c	A 79 b	A 34 d	A 34 c	A 34 b	A 45 b	A 3768 a	A 3065 a
23	B 68 c	A 85 a	B 30 h	A 33 c	B 38 a	A 52 a	A 2788 b	B 571 a
36	B 67 d	A 86 a	B 30 h	A 34 c	A 37 a	A 53 a	A 3327 b	A 1605 a
42	A 67 c	A 79 b	A 34 e	A 34 c	A 33 b	A 45 b	A 4452 a	AB 2470 a
44	B 68 c	A 90 a	B 34 e	A 37 b	B 34 b	A 53 a	A 2282 b	A 1957 a
46	B 66 e	A 81 b	A 30 h	A 31 d	A 36 b	A 50 a	A 3724 a	B 1541 a
47	B 66 e	A 81 b	B 30 h	A 33 c	A 36 b	A 48 a	A 2661 b	A 1107 a
50	A 77 b	A 86 a	A 42 a	B 36 b	B 35 b	A 51 a	A 3665 a	A 2646 a
55	A 68 c	A 82 b	A 34 e	A 36 b	A 34 b	A 46 b	A 3766 a	A 1806 a
57	A 65 e	A 78 b	B 30 h	A 33 c	A 35 b	A 45 b	A 5096 a	B 492 a
60	A 67 c	A 82 b	A 34 e	A 36 b	A 33 b	A 46 b	A 3941 a	B 1714 a
68	B 68 c	A 90 a	B 30 h	A 37 b	B 38 a	A 54 a	A 2761 b	A 750 a
75	A 68 c	A 73 b	A 34 f	A 36 b	A 34 b	A 37 c	A 3956 a	B 1519 a
81	A 77 b	A 73 b	A 35 c	A 34 c	A 42 a	A 39 c	A 3693 a	A 2330 a
84	A 68 c	A 73 b	B 34 f	A 37 b	A 34 b	A 36 c	A 3949 a	B 1430 a
97	B 66 e	A 85 a	A 29 i	A 31 d	B 37 a	A 54 a	A 3104 b	A 1058 a
102	A 67 d	A 73 b	A 34 d	A 34 c	A 33 b	A 39 c	A 5018 a	B 2673 a
108	A 77 b	A 78 b	A 38 b	A 36 b	A 39 a	A 42 b	A 2750 b	A 1888 a
112	A 68 c	A 78 b	A 34 f	A 34 c	A 34 b	A 44 b	A 4386 a	B 1931 a
115	A 68 c	A 81 b	A 34 f	A 36 b	A 34 b	A 45 b	A 3856 a	A 1871 a
120	B 68 c	A 86 a	B 30 h	A 34 c	A 38 a	A 53 a	A 2822 b	A 982 a
121	A 68 c	A 78 b	A 34 f	A 36 b	A 34 b	A 42 b	A 4019 a	A 2524 a
192	B 65 e	A 81 b	A 30 h	A 31 d	A 35 b	A 50 a	A 3247 b	B 706 a
Average	68.8	80.8	33.1	34.9	35.7	45.9	3478.3	1671.1
C.V.	0.4	2.3	0.1	1.2	0.8	4.2	15.0	33.5

[1/]Averages followed by the same capital letter do not significantly differ between the cultivation locations (rows) using the Tukey test at 5% probability. Averages followed by the same lowercase letter do not significantly differ in each cultivation location (columns) using the Scott-Knott test at 5% probability. V1-R9=emergence-physiological maturity; V1-R6=emergence-flowering; R6-R9=flowering-physiological maturity.

BAFs 23, 36, 44, 46, 47, 68, 97, 120 and 192 presented a shorter cycle period between emergence and physiological maturity in Joaçaba in comparison to Lages. The reduction in the number of days varied from 15 days (BAF 46 and BAF 47) to 22 days (BAF 44 and BAF 68). For the period between emergence and flowering, BAFs 3, 4, 7, 23, 36, 44, 47, 57, 68, 84 and 120 presented reduced cycles in Joaçaba compared to Lages, with the observed variation being from 3 days (BAFs 23, 44, 47 and 57) to 6 days (BAF 7). The exception was for BAF 50, which presented a longer cycle (6 days) in Joaçaba than in Lages. In the flowering-physiological maturity period, BAFs 36, 44, 50, 68 and 97 had shorter cycles in Joaçaba, with variation amplitude of 16 days (BAFs 36, 50 and 68) to 19 days (BAF 44) (Figure 1a and b).

The duration of the emergence-flowering period presented a distinct variation for the genotypes at both locations. In Joaçaba, the genotypes' cycle duration was from 84 to 65 days, with BAFs 46, 47, 57, 97 and 192 being the shortest. In Lages, the variation in the total cycle was 90 to 73 days, with BAFs 75, 81, 84 and 102 all having a cycle of 73 days. BAF 7 presented the longest cycle in both locations.

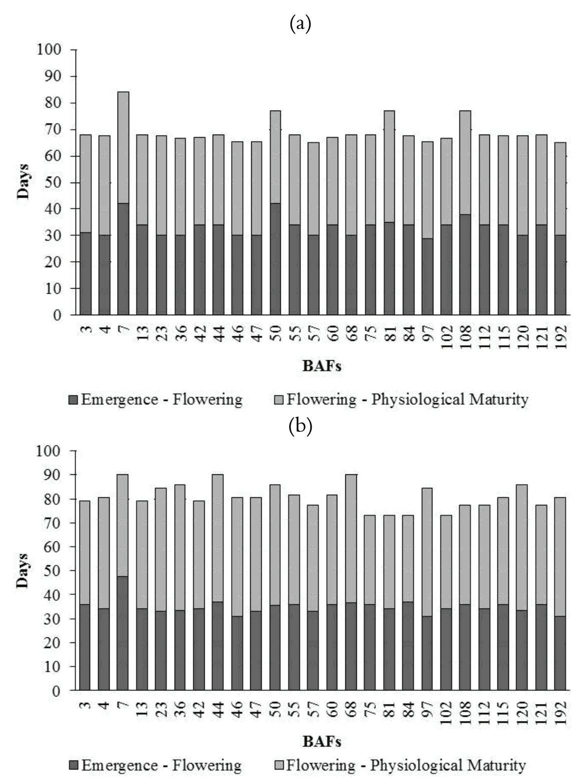


Figure 1. Comparison between the emergence-flowering and flowering-physiological maturity periods during the total cycle of bean genotypes cultivated in Joaçaba (a) and Lages (b) for the 2008/2009 crop season.

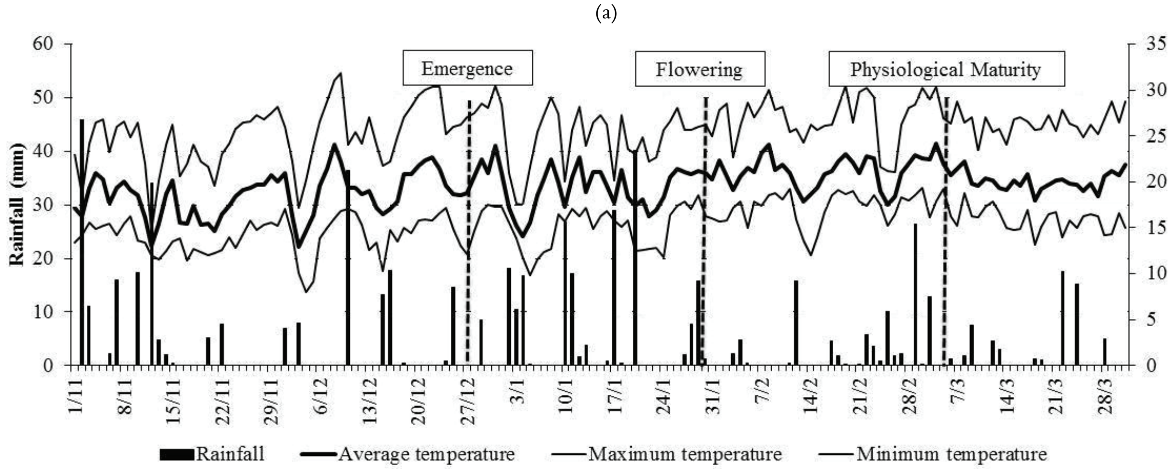
The number of days to flowering in Joaçaba varied from 42 (BAF 7) to 29 days (BAF 97) and varied from 48 (BAF 7) to 31 days (BAF 192) in Lages, with BAFs 46, 97 and 192 presenting the earliest flowering at both locations. BAF 7 also presented the longest number of days to flowering. The flowering-physiological maturity period in Joaçaba varied from 42 (BAF 7) to 33 days (BAF 102), with BAFs 42, 60 and 102 having 33 days; in Lages, the variation was from 54 (BAF 68) to 36 days (BAF 84).

The shortest cycle genotypes have been defined as those with the lowest average number of days necessary to initiate flowering (RAMALHO et al., 1993; SILVA et al., 2007). However, in the current study, the genotypes with the shortest emergence-flowering period duration are different from those labeled as short-cycle varieties (RIBEIRO et al., 2004).

The results show that the greatest differences between the genotypes' total cycle and location, principally in the flowering-physiological maturity period, must be due to pluviometric precipitation during this period, which was greater in Lages than in Joaçaba (Figure 2a and b).

Regions suitable for common bean cropping must present temperatures between 15 and 29.5°C and an average rainfall of 300 mm (FANCELLI; DOURADO NETO, 2007). During the emergence-physiological maturity period, the average temperature in Joaçaba was 20.3°C, whereas the average temperatures registered were 19.5 and 21.2°C during the emergence-flowering and flowering-physiological maturity periods, respectively. In Lages, the temperatures were similar to those registered in Joaçaba, with the emergence-physiological maturity period average temperature being 20.2°C and 19.3 and 20.1°C during the emergence-flowering and flowering-physiological maturity periods, respectively. Therefore, the average temperatures that occurred during the 2008/2009 crop period in Joaçaba and Lages were ideal for the cultivation of beans. These thermal conditions indicate that the lower yields observed in Lages were not due to flower and pod abortion caused by elevated temperatures during the flowering-physiological maturity period.

(a)



(b)

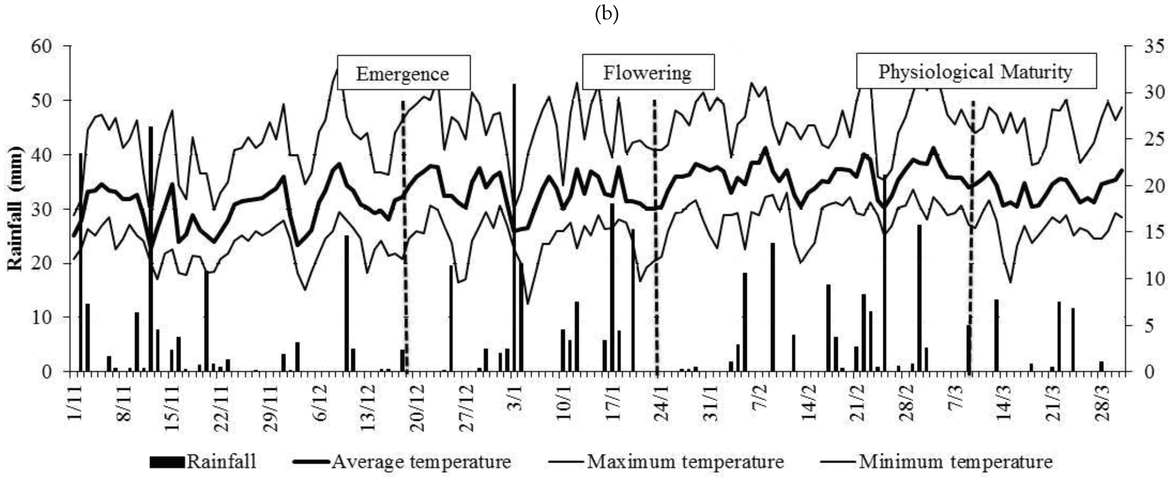


Figure 2. Maximum, average and minimum temperatures and pluvial precipitation for the months of November 2008 through March 2009 in Joaçaba (a) and Lages (b).

In Joaçaba, the total pluvial precipitation during the bean cycle was 296 mm, whereas it was 387 mm in Lages; thus, there was no hydric deficiency for the crops in either location. The pluvial precipitation during the period between emergence and flowering was similar in both locations (206 mm in Joaçaba and 201 mm in Lages). However, during the period between flowering and physiological maturity, an elevated pluvial precipitation was recorded in Lages (181 mm) compared to Joaçaba (95 mm). These facts explain the observation that, on average, the genotypes in Lages presented a greater number of days between flowering and physiological maturity than in Joaçaba.

The lower yield of the Lages genotypes could be due to the lower luminosity associated with an excess of rainfall during the period between flowering and physiological maturity. While studying the problem of low luminosity, Liu et al. (2010) and Liu et al. (2006) concluded that the occurrence of long periods of greater cloud cover can cause photosynthetic deficiency and, as a consequence, a reduction in yield. According to Santos et al. (2003), in common beans, soybeans and weed plants, the yield is generally limited by photosynthetic capacity from the start of pod formation and as a result, a reduction in the rate of photosynthesis causes variations in the grain yield or biomass production.

Comparing the year with the least precipitation to the year with the highest amount of precipitation, while evaluating bean genotypes over three years of cultivation in terms of the cycle duration and yield, Ribeiro et al. (2004) observed that there was an increase in the length of the cycle during the flowering-physiological maturity period. In the same study, it was observed that the reduction in the cycle length was associated with greater yield. According to Albayrak and Töngel (2006), vetch genotypes grown under different amounts of precipitation presented a negative correlation between the number of days to maturity and yield, with the harvest index and biological yield being the principal characteristics that determine the correlation value. Türk et al. (2008) observed a negative correlation between the yield and the number of days to flowering in *Vicia narbonensis* L. and described the harvest index and biological yield as the most important characteristics in determining the magnitude and direction of the correlation.

Conclusion

The common bean canopy characteristics were not affected by environmental influences, except plant height. The genotypes showed diversity of the cycle, and there was a cultivation location effect on each genotype, particularly, the differences on reproductive phase. The genotypes with the longest cycles presented the lowest yields. The phase from flowering to physiological maturity must coincide with a period of regular rainfall associated with a minimum of cloudy days leading to a decrease in the cycle length. Considering the 26 genotypes studied, Joaçaba/SC presents better climatic conditions and, thus, a higher potential yield for beans in comparison to Lages, Santa Catarina State.

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