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Crescimento e produtividade de cultivares de feijão preto após monocultivo sucessivo

Growth and yield of black bean cultivar after successive monocultivation

Crecimiento y rendimiento del cultivar de frijol negro después de sucesivos monocultivos

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Resumo

A produtividade do feijão (*Phaseolus vulgaris* L.) é afetada pelas condições bióticas e abióticas, assim como pelo manejo dos agricultores. Na região Centro-Sul do Estado do Paraná, o cultivo sucessivo de cultivares de feijão preto é comum. O objetivo deste estudo foi avaliar o crescimento e o rendimento de seis cultivares de feijão preto após sucessivos monocultivos. O experimento foi conduzido em campo com seis cultivares de feijão preto e quatro repetições (blocos). A cultivar com maior rendimento de grãos foi a BRS Esplendor, cultivar com alta produção de grãos por área. A cultivar IPR Tuiuiú teve o segundo melhor rendimento de grãos por causa de seu alto índice de colheita. A monocultura contínua resultou em baixa produtividade de grãos devido à alta incidência de *Colletotrichum lindemuthianum*. Embora comum, a prática de monocultivo contínuo de cultivares de feijão preto na região Centro-Sul do Paraná resulta em baixa produtividade de grãos e deve ser evitada.

Palavras-chave: Antracnose; Monocultura; *Phaseolus vulgaris* L.; Rendimento; Rotação de cultura; Variedade.

Abstract

Grain yield of bean (*Phaseolus vulgaris* L.) is affected by biotic and abiotic conditions, as well as by farmers' management. In the Center-South region of Parana State, the successive cultivation of black bean cultivars is common. The objective of this study was to evaluate the growth and yield of six black bean cultivars after successive monocultivation. The experiment was conducted in the field with six black bean cultivars and four repetitions (blocks). The cultivar with the highest grain yield was BRS Esplendor, a cultivar with a high number of grains per area. IPR Tuiuiú had the second-best grain yield because of its high harvest index. The continuous monocultivation resulted in low grain yield because of the high incidence of *Colletotrichum lindemuthianum*. Although common, the practice of continuous monocultivation of black bean cultivars in the Center-South region of Parana results in low grain yield and should be avoided.

Keywords: Anthracnose; Crop rotation; Monoculture; Productivity; *Phaseolus vulgaris* L., Variety.

Resumen

El rendimiento del frijol (*Phaseolus vulgaris* L.) se ve afectado por las condiciones bióticas y abióticas, así como por la gestión de los agricultores. En la región centro-sur del Estado de Paraná es común el cultivo sucesivo de variedades de frijol negro. El objetivo de este estudio fue evaluar el crecimiento y el rendimiento de seis cultivares de frijol negro después de un monocultivo sucesivo. El experimento se llevó a cabo en el terreno con seis cultivares de frijol negro y cuatro repeticiones (bloques). El cultivar con mayor rendimiento de granos fue el BRS Esplendor, una cultivar con un alto número de granos por área. El IPR Tuiuiú tuvo el segundo mejor rendimiento de granos debido a su alto índice de cosecha. El monocultivo continuo dio como resultado un bajo rendimiento de granos debido a la alta incidencia de *Colletotrichum lindemuthianum*. Aunque es común, la práctica del monocultivo continuo de cultivares de frijol negro en la región centro-sur de Paraná da lugar a un bajo rendimiento de los granos y debe evitarse.

Palabras clave: Antracnose; Monocultivo; *Phaseolus vulgaris* L.; Productividad; Rotación de cultivos; Variedad.

1. Introduction

Beans (*Phaseolus vulgaris* L.) are highlighted in Brazilian agriculture as an essential food, being the most consumed legume by the population. It is the primary food source of plant protein because it satisfactorily replaces some animal-based foods, mainly due to its lower cost and its high protein content, in addition to calories and dietary fiber (Ferreira & Nalepa, 2013).

In southern Brazil, there is high consumption of black beans, and this preference is cultural (Kläsener et al., 2020). The maintenance of the visual quality of black beans is higher than that of Carioca beans, especially in regions of high rainfall at harvest time, because black beans have less loss of grain color due to moisture (Faroni et al., 2006). Brazil is expected to produce over 3 million tons of beans in the 2019/20 cropping season (CONAB, 2020). Of this total, more than 500,000 tons are black beans, with only the State of Paraná expected to produce about 70% of this amount (CONAB, 2020).

Bean cultivation is greatly affected by the incidence of diseases such as anthracnose, caused by the pathogen *Colletotrichum lindemuthianum*, spread by contaminated seed or inoculum in the cultivation area (Gillard et al., 2011). Anthracnose is one of the most important diseases for the common bean plant, benefited by moderate and cold temperatures and high relative air humidity (Padder et al., 2017), a climate often found in the south of the country. The yield losses caused by this disease can reach 100% if conditions are favorable, or if the disease appears in the early stages of plant development (Santini et al., 2005).

It is important to seek alternatives to improve grain yield, such as changes in the row spacing and, consequently, in plant population, resulting in a microclimate less prone to disease incidence (Didonet & Costa, 2004). Besides the high susceptibility to diseases, the bean plant may suffer a reduction in its yield potential due to climatic factors. Among the climatic factors, temperature and rainfall are the most important. The ideal temperature for bean cultivation ranges from 17.5 to 25.0 ºC, with low temperatures causing a reduction in the germination rate, compromising the plant population, and final yield. In the vegetative growth phase, low temperatures can reduce the plant size and trigger seed abortion (Pereira et al., 2014).

Bean plant needs between 300 and 600 mm of water during the whole cycle and a minimum of 100 mm per month to guarantee its basic development processes, such as photosynthesis, translocation of assimilated, flowering and grain filling, which will determine the final yield of the crop (Pereira et al., 2014). However, the excess rainfall in the final phase of the crop growth may lead to the germination of the seed in the pod and the appearance of spots on the grains, which decrease its quality and commercial value (Lima et al., 2013).

In the municipality of Guarapuava-PR, the agricultural zoning of beans for the 2017-2018 crop season allowed sowing only for the first and second crop seasons, that is, between September 11th and November 30th and December 1st and January 31st, respectively. Therefore, sowing after this date (third crop) is not recommended, due to unfavorable climatic factors for the crop (MAPA, 2020).

A relatively common practice among bean growers in the region of Guarapuava is to sow the crop after the main crop harvest as an alternative for increasing the profitability of the business. For example, some growers sow bean after potato and use less fertilizer to this second crop (Silva et al., 2001). The successive cultivation is seen as beneficial in maintaining the quality of the soil attributes, mainly due to its protection against the climatic storms to the following crop. However, little is now about the effect of continuous cultivation in the growth and yield of bean cultivars.

The objective of this study was to evaluate the growth and yield of black bean cultivars after continuous bean cultivation in southern Paraná State.

2. Material and Methods

The experiment was conducted in the experimental field of the Agronomy Department of the Midwestern Parana State University (UNICENTRO), in Guarapuava - PR, located at latitude 25º 23'S and longitude 51º 29'O, and altitude 1029 m. The nature of the study was quantitative (Pereira et al., 2018). The climate is classified as Cfb, according to Köppen's classification (Alvares et al., 2013).

The soil of the experimental area is very clayey Typic Hapludox (USDA, 1999). From the chemical analysis of the soil performed at a depth of 0-20 cm, the following results were observed: Al: 0.0 $cmol_c$ dm^{-3}; H + Al: 4.36 $cmol_c$ dm^{-3}; P: 3.5 mg dm^{-3}; Ca: 2.9 $cmol_c$ dm^{-3};

Mg: 2.6 $cmol_c$ dm^{-3}; K: 0.10 $cmol_c$ dm^{-3}; pH in CaCl2: 5.4. According to the technical recommendation, no correction of soil acidity was necessary (Pauletti & Vargas Motta, 2019).

The experimental design was completely randomized blocks with 4 repetitions and 6 treatments (black bean cultivars): BRS Campeiro, BRS Esplendor, FT Soberano, IPR Tuiuiú, IPR Uirapuru, and IPR Tiziu. These were the main black bean cultivars used by growers in the region of Guarapuava. Each plot consisting of 4 rows 8 m long and 0.4 m apart, totaling 12.8 m^2.

The experiment was carried out in continuous cultivation. That is, in the same area, beans were sown after harvesting bean. In October 2013, we sowed the six black bean cultivars, and after harvest, we sowed the same six cultivars in the same plot. Glyphosate herbicide was used to weed control at a dose of 3 L ha^{-1} in a spray volume of approximately 200 L ha^{-1}, 10 days before sowing. The experiment was implemented on February 24th, 2014. The initial sowing density was 400,000 seeds ha^{-1}, and at 15 days after germination, the plants were thinned to reach a population of 220,000 plants ha^{-1} (i.e., 22 plants m^{-2}).

For sowing 571 kg ha^{-1} of the compound fertilizer 04-14-08 applied in the furrow was used, providing: 23, 80, and 46 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. Nitrogen topdressing was performed in a dose of 40 kg ha^{-1} of urea (45% of N), totaling 18 kg of N ha^{-1}, applied 25 days after sowing, at the vegetative stage V3 (Pauletti & Vargas Motta, 2019). Management of weeds, pests, and diseases was based on the daily monitoring of the crop, and the application of phytosanitary products was performed whenever the level of control was reached.

During the experiment, quantification of total plant dry weight (DW) was performed, with samplings at stages: V4 (pre-flowering), R6 (full flowering), R7 (pod formation) and R8 (grain filling), according to the stage scale for bean cultivation (Fernández et al., 1986). Plant samples (leaves, stems, and pods) in an area of 0.32 m^2 were oven-drying at a temperature of 70 °C for three days to obtain DW.

After plants reached physiological maturity (R9), they were harvested by hand, pulling them from the two central rows of the plots, removing 4 m in each row, totaling 3.2 m^2 of harvested area per plot. The yield was determined by weighing the grains in this area (3.2 m^2), and grains humidity was corrected to 13%.

Quantifications were made of the thousand grains weight, the number of grains per area, and the number of plants per area, using the same plants that were analyzed for the yield estimation. We measured harvest index, calculated from the mass of grains harvested per plot corrected for 0% humidity, divided by the plant total DW at R8 (the stage with the highest

DW), according to equation 1:

$$HI (\%) = (\text{grain mass (g)} \times 100)/(\text{total plant dry weight (g)}) \quad (1)$$

We submitted data to the analysis of variance, and the Shapiro-Wilk normality test. If significant, means were compared by the Tukey test at 5% probability (Assistat 3.0). All data had a normal distribution, and therefore no data transformation was performed.

3. Results and Discussion

Table 1 shows the duration of growth stages intervals and climatic data during the period of the experiment. We can observe a small lengthening of the crop cycle: 86 days, on average, from emergency to physiological maturity. This duration is longer than the average duration of the cultivars reported by the producing companies (Embrapa, Iapar, and FT Sementes): 84 days. This result was probably due to low average temperature recorded throughout the development of the bean plant during the experimental period, which was below the need demanded by the plant: between 17.5 to 25 ºC (Pereira et al., 2014).

Table 1. Growth stage duration (days) of the black bean cultivars and climatic data during the experiment (February to June), Guarapuava – PR, 2014.

Growth stage interval	Growth stage duration (days)	Minimum temperature (ºC)		Mean temperature (ºC)		Accumulated rainfall (mm)		Acumulated solar radiation (MJ m^{-2})	
		Exp.	HA[2)]	Exp.	HA	Exp.	HA	Exp.	HA
SW~V4[1)]	42	16	16	20	20	314	161	662	700
V4~R6	13	14	16	20	18	111	53	171	209
R6~R7	9	13	13	17	15	20	75	112	140
R7~R8	13	11	12	16	13	20	52	185	192
R8~R9	9	9	12	16	17	102	52	93	126
Total / Ave.	86	13	14	16	17	567	393	1,223	1,367

1) SW~V4: sowing to third trifoliate leaf; V4~R6: third trifoliate leaf to full flowering; R6~R7: flowering to pod formation; R7~R8: pod formation to gran filling; R8~R9: grain filling to physiological maturity. 2) HA: historical average, 15 years average (1997 to 2012) from Simepar meteorological station located 50 m distant from the experiment. Source: The authors.

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Solar radiation accumulated during the experiment was lower than the historical average, mainly between sowing to V4. This low solar radiation may favor the slow vegetative development of the plants. Solar radiation is an essential factor affecting the production of photoassimilates and plant biomass, which are related to the formation and filling of pods and final grain yield (Goulart et al., 2010). Rainfall was sufficient for crop growth. However, it was unevenly distributed: it was concentrated at the beginning and end of the growth cycle. From full flowering (R6) to grain filling (R8) stages, we observed a total of 40 mm of rainfall.

The results of the analysis of variance (anova) are shown in Table 2. The average grain yield was 929 kg ha^{-1} and differed among cultivars. The highest yields were from BRS Esplendor and IPR Tuiuiú: 1,348 kg ha^{-1} and 1,314 kg ha^{-1}, respectively (Figure 1A). On the other hand, cultivars BRS Campeiro and IPR Tiziu had the lowest yields: 482 kg ha^{-1} and 365 kg ha^{-1}, respectively. The grain yields of cultivars FT Soberano (1,119 kg ha^{-1}) and IPR Uirapuru (948 kg ha^{-1}) were intermediate, not differing from the other cultivars. Excessive rainfall in the final growth stage caused grain germination in the pods and abortions, contributing to a reduction in quality and yield (Table 2). We observed a high incidence of anthracnose (*Colletotrichum lindemuthianum*) in all plants during the experiment. The high incidence was probably due to high relative humidity and mild temperatures (Table 1), conditions suitable for the pathogen development (Singh & Schwartz, 2010). The onset of symptoms occurred early in the vegetative phase (SW-V4) and aggravated close to the harvest (R9). The disease increase was due to excessive rainfall in this stage. Moreover, continuous bean cultivation contributed to increasing the anthracnose incidence because, in the previous cycle of the crop, a high occurrence of the disease had already been detected. Since *Colletotrichum lindemuthianum* has the necrotrophic phase during the most extended period of its activity (Padder et al., 2017), this pathogen probably remained in the plant debris of the previous crop, attacking again when it found a susceptible host and favorable weather conditions.

Table 2. ANOVA result and general mean of final grain yield, number of grain, thousand-grain weight (TGW), number of plants (stand), total plant dry weight at V4, R6, R7, and R8 growth stages and harvest index (HI), of six black bean cultivars after two successive cultivation, 2014.

Variable	Grain yield	Grain	TGW	Plants	Total plant dry weight				HI
					V4	R6	R7	R8	
	(kg ha^{-1})	(n^{o} m^{-2})	(g)	(n^{o} m^{-2})	(g m^{-2})				(%)
Treatments	**[1)]	**	ns	ns	**	ns	ns	**	*
General mean	929	543.4	137	17.4	113	162	229	357	22.8
CV[2)]%	37.1	29.8	16.4	14.3	15.9	22.9	18.8	16.3	30.7

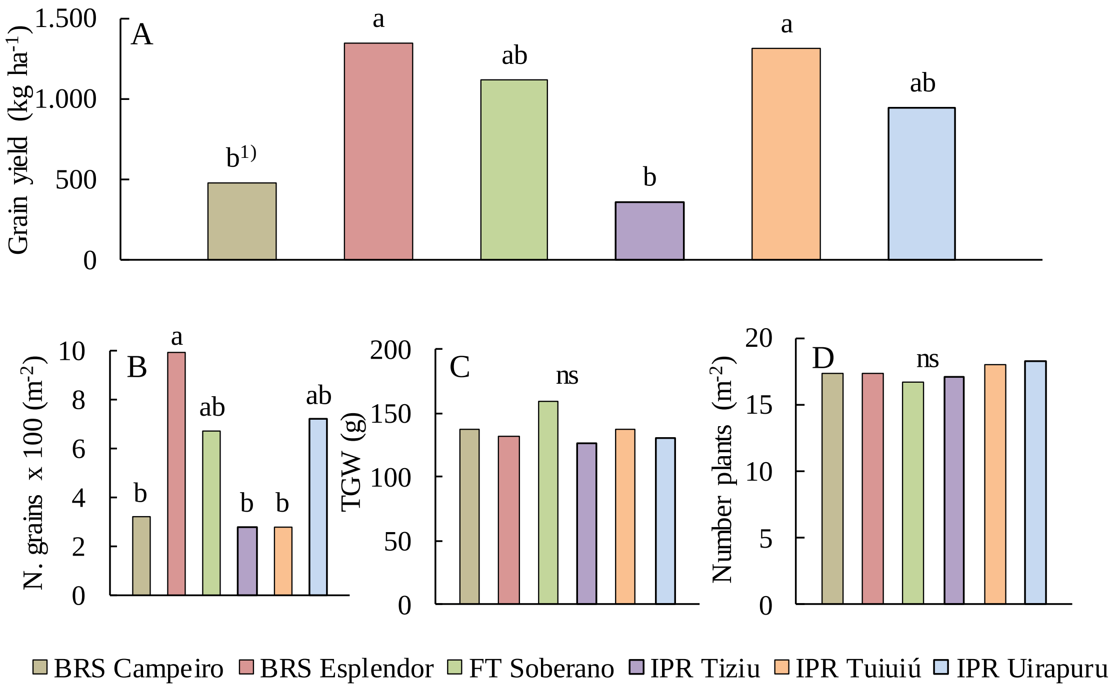
1) ** and *: significative by Tukey test at 1% and 5%, respectively. ns: not significative. 2) CV: coefficient of variation. Source: The authors.

The yield observed in the experiment with black beans cultivars was higher than the national average forecast for the same sowing period of the 2017-2018 agricultural year, which estimates an average yield of 687 kg ha^{-1} (CONAB, 2020). Thus, even though the crop was sown outside the agricultural zoning, grain yield was higher than the average yields in the locations where sowing of the winter crop is allowed. However, a study in the State of Mato Grosso, the performance of several bean cultivars in the same sowing period was higher than those found in this study, with 2,675 and 2,539 kg ha^{-1} for BRS Esplendor and BRS Campeiro cultivars, respectively (Pereira et al., 2012). Possibly, this higher yield in Mato Grosso was due to the higher solar radiation accumulated, added to the use of irrigation during cultivation, which made it possible to meet the water needs of the crop. In contrast, a study comparing the performance of black bean cultivars in the municipality of Jataí - GO in similar sowing period, obtained yield of 1,639 and 1,113 kg ha^{-1} for BRS Esplendor and BRS Campeiro, respectively (Carmo et al., 2013), i.e., performance similar to the present work for BRS Esplendor (1,348 kg ha^{-1}), and superior performance for BRS Campeiro (482 kg ha^{-1}).

Other studies evaluating yield components of bean cultivars in the municipality of Caçador - SC sowed in December, found higher grain yield of FT Soberano and IPR Uirapuru cultivars (2,904 and 2,880 kg ha^{-1}, respectively) (Hawerroth et al., 2011) than the yield of this experiment. These results highlight the importance of avoiding successive bean cultivation to skip high initial disease inoculum and unfavorable weather conditions during plant development, lowering yield potential.

We observed differences among cultivars in the number of grains per area (Table 2). Figure 1 shows the final grain yield and yield component of the six evaluated cultivars. The cultivar that had the highest number of grains per area was the cultivar that also had the highest yield: BRS Esplendor with 991 grains m^{-2} (Figure 1B). Cultivars BRS Campeiro, IPR Tiziu, and IPR Tuiuiú had a lower number of grains than BRS Esplendor: 319, 279 and 279 grains m^{-2}, respectively. The other cultivars obtained intermediate values for this variable. A study evaluating the number of grains per plant of the cultivar FT Soberano, obtained 80.2 grains plant^{-1} (Hawerroth et al., 2011), which is equivalent to 1,396 grains m^{-2}. In our work, this cultivar obtained a lower performance for this variable with 672 grains m^{-2}, resulting in lower yield.

Figure 1. Grain yield (A), number of grains (B), thousand-grain weight (TGW, C), and final number of plants (D) at harvest for six black bean cultivars after two successive cultivation, 2014.



1) Means followed by the same letter did not differ according to Tukey's test at 5% of probability. Source: The authors.

Carmo et al. (2013) evaluated grain yield for black bean cultivars and quantified the number of grains per plant. With this variable, it is possible to estimate the number of grains per area, obtained from the final stand (17,4 plants m^{-2}) of this work. The authors obtained for BRS Campeiro and BRS Esplendor 1,295 and 1,410 grains m^{-2} (60.8 and 83.8 grains plant^{-1}, respectively), being these values higher than those obtained in this experiment, with 319 and 991 grains m^{-2}.

The variables thousand-grain weight and the number of plants per area did not differ among the cultivars (Table 2). The number of plants per area was lower than initially planned (220,000 plants ha^{-1}) due to the death of plants caused by the incidence of anthracnose.

The number of plants per area is a result of the number of grains sowed, which is dependent on the growth habit of the plants and climatic conditions of cultivation, thus favoring higher or lower vegetative development and consequently affecting final yield. A study evaluating yield of cultivar IPR Uirapuru under direct planting in the straw of fodder species and three different locations in the State of Santa Catarina using a sowing density of 22 plants m^{-2}, obtained an average yield of 2,858 kg ha^{-1} (Balbinot Junior et al., 2009). This yield is higher than the yield found in our experiment (929 kg ha^{-1}) because, in our experiment, we observed plant deaths caused by anthracnose. These deaths were probably due to adverse climatic conditions and successive bean cultivation.

Accumulation of carbohydrates and their distribution during the growth of the plants are shown in Figure 2. Total plant DW differed among cultivars at V4 and R8 growth stages (Figure 2A). At the V4 growth stage, cultivar IPR Tuiuiú had higher plant DW than other cultivars, producing 160 g m^{-2}. However, at the R8 growth stage, this cultivar did not follow the development of the other cultivars during the cycle, particularly IPR Uiarapuru, BRS Esplendor, and FT Soberano, which had the highest plant DW at this stage: 434, 407 and 400 g m^{-2}, respectively.

IPR Tuiuiú and BRS Esplendor had the highest HI while IPR Tiziu and BRS Campeiro, the lowest (Figure 2B). Similar patterns were observed for grain yield (Figure 1A). Therefore, we can speculate that cultivars with high HI obtained high grain yield. No evaluated cultivar had HI higher than 34%. This HI is lower than that found in other works with modern cultivars and HI close to 50% (Berrocal-Ibarra et al., 2002). The HI shows the extent of photoassimilates sent to grain and, consequently, plant translocation efficiency. In an experiment evaluating HI and the relationship with grain yield in the State of Rio de Janeiro, the average HI of cultivars was 61.9%, higher than that found in the present study (Araújo & Teixeira, 2012). The reason for the low HI observed in our study was probably due to the high incidence of anthracnose. It negatively influenced the translocation of the assimilated during grain filling, reducing the number of grains per area. Another reason for the low HI was the high rainfall during and after physiological maturity. This high rainfall caused yield reduction by the deterioration of grains and pods.

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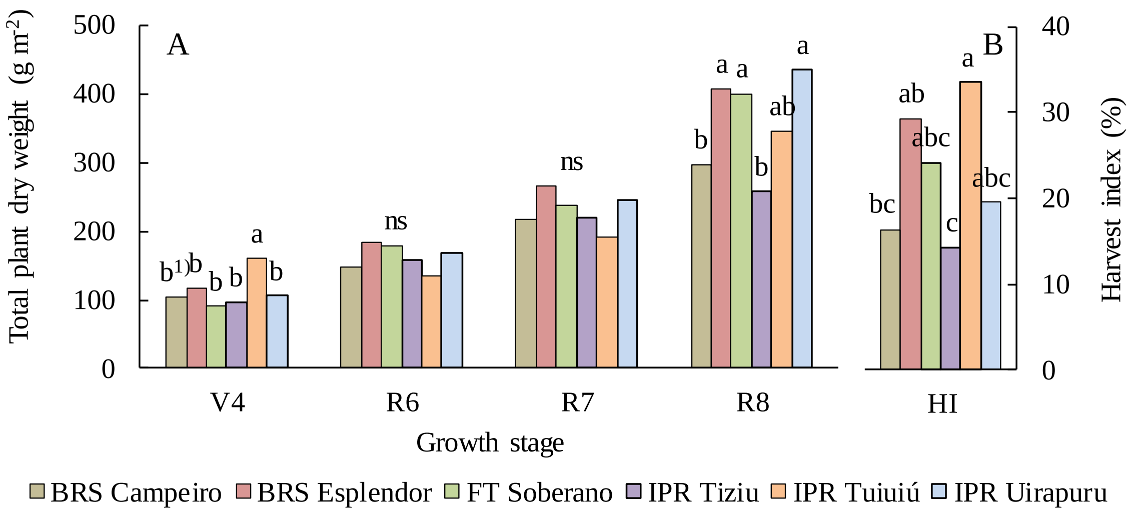
A study in the State of Minas Gerais evaluated the DW partition in different phases of the bean cycle, particularly for the cultivar Ouro Negro (Andrade et al., 2009). This study reported total plant DW of 95, 390, 635, and 530 g m^{-2}, at V4, R6, R7, and R8 growth stages, respectively. These results are higher than the results of our study, except for stage V4 (113, 162, 229, and 357 g m^{-2} for V4, R6, R7, and R8, respectively). The higher accumulation of plant DW at the V4 growth stage was probably due to the more significant precipitation in this period, higher than the historical average (314 mm vs. 161 mm), thus favoring a more significant vegetative development of the plants. In other growth stages, the plant DW did not have significant evolution due to the high incidence of anthracnose in plants, excessive rainfall (mainly in stage R8), and lower accumulated solar radiation in all stages.

Figure 2. Total plant dry weight at V4, R6, R7, and R8 growth stages (A) and harvest index (HI, B) at harvest of six black bean cultivars sowed after two successive cultivation, 2014.



1) Means followed by the same letter did not differ according to Tukey's test at 5% of probability. Source: The authors.

4. Final Considerations

The sowing of black bean cultivars after two successive cultivation reduces the yield due to the high incidence of *Colletotrichum lindemuthianum*. Cultivars BRS Esplendor had the highest grain yield due to a higher number of grains per area, while IPR Tuiuiú had the second-best yield due to the higher harvest index compared with the other cultivars.

Future researches focusing on the crop rotation that improves grain yield of dry bean cultivation is needed.

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