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CROP PRODUCTION

Productive performance of canola hybrids and the contribution of winter crops to the productivity of soybean grown in succession

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ABSTRACT. Diversifying and rotating crops are of paramount importance in production systems; these practices aim to mitigate environmental risks and introduce new crops, thus supporting agricultural sustainability. Thus, the present study aimed to evaluate the productive performances of canola hybrids and to analyze the contribution of winter crops to the productivity of soybean grown in succession. Two experiments were conducted at two locations (Monsenhor Paulo and Luminárias, Minas Gerais, Brazil). The first experiment evaluated the performances of different canola hybrids: ALHT B4, Diamond, Hyola 433, Hyola 571 CL, Hyola 575 CL, and Nuola 300. The oil content (%), grain yield, and oil yield (kg ha^{-1}) of the plants were assessed. The second experiment evaluated the performances of soybean varieties grown after canola, white oats, and a fallow period. The Diamond and ALTH B4 hybrids exhibited high grain and oil productivity levels in Monsenhor Paulo, MG. The Hyola 575 CL hybrid excelled in Luminárias and had the highest levels of grain and oil productivity. In both locations, soybean yield and stand density were not influenced by the preceding crop (canola or oats) or fallow period. Among the other evaluated characteristics, only plant height was affected in Monsenhor Paulo, MG, and was greater after oat cultivation. In Luminárias, MG, there was an increase in the number of pods after oat cultivation.

Keywords: *Brassica napus* L. var. *oleifera*; oilseed; crop production; oats.

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Introduction

As the population increases, agricultural production systems will be increasingly exploited to meet the demand for nutritious and functional foods and raw materials, both for human and animal consumption and for industrial purposes. However, maintaining sustainability in these systems is challenging. In this context, the diversification of management approaches and crop rotation in agricultural systems to achieve more sustainable production has been growing. Oilseed crops have been gaining popularity for winter cultivation due to their potential use in product generation and opportunities for expansion in agroecosystems.

Canola (*Brassica napus* L. var. *oleifera*) is an oilseed crop belonging to the Brassicaceae family. This oilseed variety was developed through genetic improvement in rapeseed (Kaefer et al., 2014). The difference between these crops lies in their chemical profiles of fatty acids and glucosinolates. Generally, industrial rapeseed refers to any type of rapeseed that produces oil with a high content of erucic acid (45% or more), while canola oil is characterized by low levels of erucic acid (less than 2%) and low levels of glucosinolates (less than 30 micromoles) (Friedt et al., 2018).

As a winter crop, canola does not directly compete for area with soybeans, one of the country's main annual crops (Durigon et al., 2016). In certain areas in southern Brazil, it is an excellent option for winter cultivation along with second-crop maize and wheat. Furthermore, canola succession is suitable for soybean cultivation due to its adaptability to edaphoclimatic conditions, advantageous prices (Kaefer et al., 2014), and ability to reduce problems related to the incidence of diseases in legumes (such as soybeans and beans) and grasses (such as maize, wheat, and other cereals). These advantages contribute to the stability and quality of grain production (Tomm, 2006), increasing the yield of subsequently cultivated crops (Durigon et al., 2016). Additionally, by eliminating fallow periods, canola can help reduce soil degradation (Vale & Veloso, 2012).

In Brazil, some canola hybrids are available on the market. When well managed, this crop demonstrates adaptability to various growing conditions, making it a viable option for increasing a producer's income, and due to the quality of canola oil, cultivation of this crop is expanding (Companhia Nacional de Abastecimento [CONAB], 2024).

Thus, the introduction of canola into production systems represents an important step in the tropicalization of this crop in the southern region of Minas Gerais State, especially in areas with logistical challenges. Therefore, given the scarcity of information on this subject, the evaluation of the performances of canola hybrids adapted to the region as well as their impacts on succeeding crops will contribute to the sustainability and diversification of agricultural systems.

The objective of this study was to evaluate the productivity of canola hybrids in the southern region of Minas Gerais State and the contribution of winter plants to soybean productivity grown in succession.

Material and methods

The experiments were conducted during the 2022/2023 growing season at two locations. The first location is in the municipality of Monsenhor Paulo, in the southern mesoregion of Minas Gerais State, Brazil, where sowing occurred on April 2, 2022. This location has an elevation of 911 m and geographic coordinates of 21°41'40.75" south and 45°29'28.04" west. The second location is situated in the municipality of Luminárias, Minas Gerais State, in the Campo das Vertentes mesoregion, where sowing was performed on April 8, 2022. The elevation of this location is 1,014 m, with geographic coordinates of 21°30'36.88" south and 44°58'42.37" west. Precipitation and temperature data were collected from the records of the National Institute of Meteorology (INMET; Figure 1).

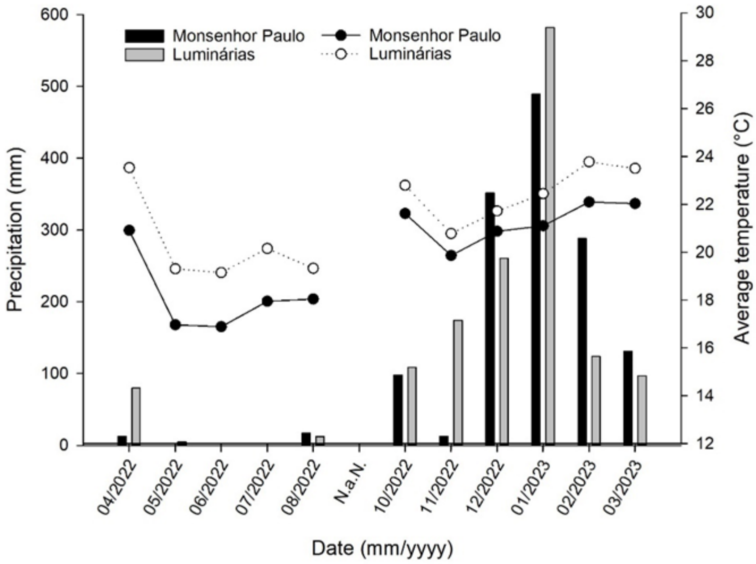

Figure 1. Average temperature and accumulated precipitation (mm) data for the 2022/23 growing season in the municipalities of Monsenhor Paulo and Luminárias, Minas Gerais State, Brazil. The bar represents precipitation, and the line represents temperature.

The soil at both locations was classified as Yellow-Red Latosol with a clayey texture (Santos et al., 2018), and samples were collected from the 0-10 and 10-20 cm layers for determination of the chemical characteristics. The chemical characteristics of the soil in the 0-10 and 10-20 cm layers at the Monsenhor Paulo, Minas Gerais State, Brazil, site were as follows: pH (H_2O), 5.9 and 5.7; M.O., 4.3 and 3.2%; P, 7.4 and 6.7 mg dm^{-3}; K, 209.9 and 84.7 mg dm^{-3}; H + Al, 2.4 and 3.7 $cmol_c$ dm^{-3}; Al, 0 and 0.1 $cmol_c$ dm^{-3}; Ca, 4.7 and 0.8 $cmol^c$ dm^{-3}; Mg, 1.7 and 0.8 $cmol_c$ dm^{-3}; CTC (T), 9.3 and 7.2 $cmol_c$ dm^{-3}; V, 74.4 and 49%; m, 0 and 2.7%; Zn, 15.2 and 10.3 mg dm^{-3}; Fe, 37.6 and 61.1 mg dm^{-3}; Cu, 0.9 and 1.6 mg dm^{-3}; B, 0.5 and 0.3 mg dm^{-3}; S, 25.6 and 58.4 mg dm^{-3}, respectively. The chemical characteristics of the soil in the 0-10 and 10-20 cm layers at the Luminárias, Minas Gerais State, Brazil, site were as follows: pH (H_2O), 6.6 and 6.9; M.O., 3.2 and 3.7%; P, 3.3 and 2.5 mg dm^{-3}; K, 60.5 and 39.6 mg dm^{-3}; H + Al, 1.3 and 1.6 $cmol_c$ dm^{-3}; Al, 0.0 and 0.0 $cmol_c$ dm^{-3}; Ca, 5.3

and 4.7 $cmol_c$ dm^{-3}; Mg, 1.5 and 1.3 $cmol_c$ dm^{-3}; CTC (T), 8.4 and 7.9 $cmol_c$ dm^{-3}; V, 83.9 and 78.9%; m, 0.5 and 0.7%; Zn, 1.2 and 1.1 mg dm^{-3}; Fe, 35.6 and 31.5 mg dm^{-3}; Cu, 0.6 and 0.7 mg dm^{-3}; B, 0.3 and 0.3 mg dm^{-3}; and S, 12.4 and 7.9 mg dm^{-3}, respectively.

Performance of canola hybrids

The experiments were conducted during the 2022 agricultural year using a no-till planting system, with seeds sown manually. A randomized block design with a 6 × 2 factorial scheme consisting of 4 repetitions was used. The first factor comprised six canola hybrids: Hyola 433, Hyola 571 CL, Hyola 575 CL, Nuola 300, ALHT B4, and Diamond. The second factor consisted of two locations.

In Monsenhor Paulo, Minas Gerais State, Brazil, the plots were represented by 11 rows 5.0 m in length with a spacing of 0.158 m between rows, totaling 8.69 m^2 each, with 0.5 m between the firebreak plots. In Luminárias, MG, the plots consisted of 10 rows 5.0 m in length with a spacing of 0.170 m between rows, totaling 8.5 m^2 each, with 0.5 m between the firebreak plots. The experimental areas were maintained under a no-till system.

Pest and disease management were carried out according to monitoring and crop needs. Fertilization at planting and topdressing for both locations were based on soil analysis and crop requirements to achieve high yields (Comissão de Química e Fertilidade do Solo [CQFS], 2016).

The evaluated traits were grain yield (kg ha^{-1}), oil content in grains (%), and oil yield per hectare (kg ha^{-1}). For both locations, grain yield assessments were based on harvests from two central rows of plants 4 m in length, excluding 0.5 m from the border ends, totaling 1.26 m^2 and 1.36 m^2 of useful area, respectively.

Harvesting was performed manually, and the plants were kept in bags to air dry until they reached approximately 10% moisture content and then threshed using a plot thresher. Subsequently, the grain samples were cleaned using a set of sieves.

The oil content in the grains was determined at the UFLA Biodiesel Laboratory. Uniform grain samples were dried in a forced-air oven at 65°C for 48 hours to standardize the moisture content. After drying, the grains with husks were milled, and the oil content was determined. The grain meal was packed in paper cartridges (2 g per cartridge), and each experimental unit was duplicated. For extraction, the method described by the International Union of Pure and Applied Chemistry [IUPAC] (1979) was adopted, using the Soxhlet system and petroleum ether as the extracting solvent with an extraction time of 6 hours. After extraction, the cartridges were kept in an oven at 60°C for 24 hours to completely evaporate the petroleum ether.

Productivity of soybeans grown in succession with winter crops

Experimental procedure

The experiments were conducted during the agricultural year 2022/2023 at two distinct locations: Monsenhor Paulo, Minas Gerais State, Brazil (southern Minas Gerais) and Luminárias, Minas Gerais State, Brazil (Campo das Vertentes). The experiments were conducted separately, in strips, with 9 repetitions. The strips/treatments consisted of a range of crops and soybeans, namely, canola (hybrids), white oats (URS Taura variety in Monsenhor Paulo, Minas Gerais State, Brazil and URS Monarca in Luminárias, Minas Gerais State, Brazil, and a fallow strip.

In Monsenhor Paulo, Minas Gerais State, Brazil, the soybean cultivar Nidera 5700 IPRO was used, and in Luminárias, Minas Gerais State, Brazil, the cultivar BMX Desafio RR was used. Sowing was performed mechanically in a no-till system.

For the experiment in Monsenhor Paulo, Minas Gerais State, Brazil, a Tatu PST Plus seeder with 8 rows for no-till planting and a spacing of 50 cm between rows was used, and the soybean cultivar Nidera 5700 IPRO was planted. In Luminárias, Minas Gerais State, Brazil, seeding was carried out with a Jumil Exata seeder with 13 rows, and the soybean cultivar used was BMX Desafio RR. The temperature and accumulated precipitation data are shown in Figure 1.

Phytosanitary management was conducted according to monitoring and crop needs. Fertilization at planting and topdressing, for both locations, was based on soil analysis and crop needs.

Harvesting was performed manually at both locations. Plant height (10 plants per plot), stand density (plants ha^{-1}), and number of pods per plant were evaluated. Subsequently, grain yield assessments were conducted by harvesting two central rows 5 m in length, excluding 0.5 m from the border ends, totaling 5 m^2

of useful area in the respective locations. After harvest, the plants were threshed using a plot thresher. Then, the grain samples were cleaned using a set of sieves, the moisture content was measured, and the moisture content was adjusted to 13%.

Statistical analysis

One-way analysis of variance was performed for all the experiments using the F test. For statistical analysis, count and percentage data were square root-transformed (x + 0.5) to meet the assumptions of ANOVA. Subsequently, a joint analysis of data from both locations for the first experiment (item 2.1) was conducted. Means were subjected to the Scott–Knott test at a 5% probability level; this test was performed using SISVAR® statistical software (Ferreira, 2019). The means shown in the tables are from the original data without transformation.

Additionally, a cluster analysis was performed, and a dendrogram was generated for the first experiment (item 2.1) using Past3 software (Paleontological Statistics, Version 3.20, Oslo, Norway) (Hammer et al., 2001), where the Euclidean similarity index was calculated for each pair of samples. The matrices were standardized by dividing the value of each element by the standard deviation of the respective matrix to reduce the amplitude of variation in each matrix.

Results and discussion

There was a significant difference in grain productivity of the hybrids at both cultivation sites, with the Hyola 575 hybrid standing out in Luminárias and the ALHT B4 and Diamond hybrids in Monsenhor Paulo, yielding 1,018.7, 851.1, and 863.3 kg ha^{-1}, respectively (Figure 2). Araújo et al. (2021), when evaluating the performance of eight canola hybrids, found the Diamond hybrid to have the best performance, corroborating the results obtained in this study for the Monsenhor Paulo region.

According to the Brazilian National Supply Company (CONAB), the average grain productivity for the crop is 1,464 kg ha^{-1}, indicating that the productivity found in this study is below the national average (CONAB, 2024). However, this information is based solely on the southern region of the country, the only region considered in the canola crop survey.

Furthermore, during the course of the study, the average precipitation was approximately 29.4 mm in Luminárias and 97.3 mm in Monsenhor Paulo. It is noteworthy that canola is very demanding in terms of environmental resource availability (Melgarejo Arrua et al., 2014), requiring water availability between 312 mm and 500 mm, and average temperatures of 20°C during its growth cycle (Tomm et al., 2009). Hergert et al. (2016) evaluated the development of canola over four years at three locations, through irrigation. In all years and locations, productivity was lower in the non-irrigated treatment, showing similar yields to those found in this study.

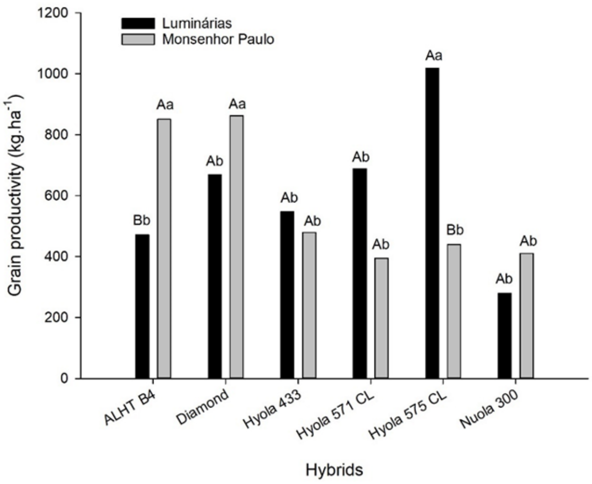

Figure 2. Grain productivity (kg ha^{-1}) of canola hybrids cultivated in Luminárias and Monsenhor Paulo, Minas Gerais State, Brazil. Means followed by the same uppercase letter between locations and lowercase letter between hybrids do not differ from each other according to the Scott-Knott test (p > 0.05).

In terms of oil productivity, there was a significant interaction effect between the hybrids and location on oil productivity. However, in Luminárias, the highest productivities were observed in the Hyola 575 CL hybrid, and in Monsenhor Paulo, the hybrids ALHT B4 and Diamond had the highest productivities, with 358.1, 282.3, and 281.1 kg ha^{-1}, respectively. The oil content varied from 30% to 34.7% on average for hybrids in Luminárias and Monsenhor Paulo, respectively (Figure 3).

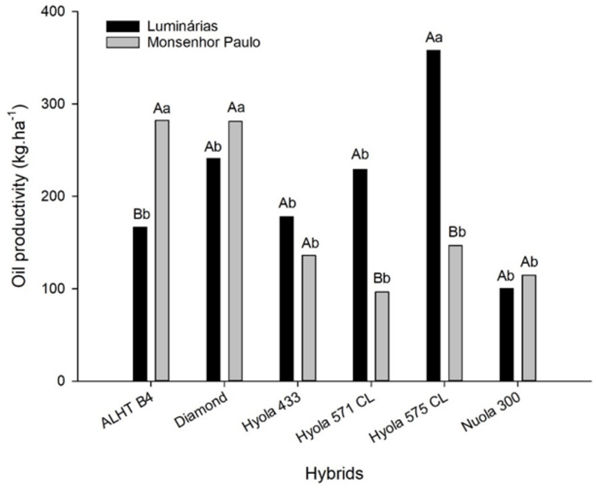

Figure 3. Oil productivity (kg ha^{-1}) of canola hybrids cultivated in Luminárias and Monsenhor Paulo, Minas Gerais State, Brazil. Means followed by the same uppercase letter between locations and lowercase letter between hybrids do not differ from each other according to the Scott–Knott test ($p > 0.05$).

Canola is considered a versatile crop, as the oil content in its seeds allows for various uses and destinations, ranging from human and animal consumption to biodiesel production for the energy matrix (Micuanski et al., 2014). Depending on the growing conditions and sowing time, some studies have demonstrated that the oil content in crops can vary from 25 to 46% (Vale & Veloso, 2012; Hergert et al., 2016; Mohtashami et al., 2020; Santiago et al., 2022). The oil contents obtained in this study fall within the average oil content range of this crop.

Cluster analysis was performed using the classic method to obtain a dendrogram (Figure 4) for the average values of two parameters: grain yield (kg ha^{-1}) and oil yield per hectare (kg ha^{-1}). Initially, 2 (two) groups could be identified based on the variance among the canola hybrids.

The hybrids Diamond, ALHT B4, and Hyola 575 CL (group 2) showed more differences and were classified into a distinct group that was further away from the other cluster (group 1). Group 1 was represented by the hybrids Hyola 433, Hyola 571 CL, and Nuola 300, which had smaller Euclidean distances (Figure 4).

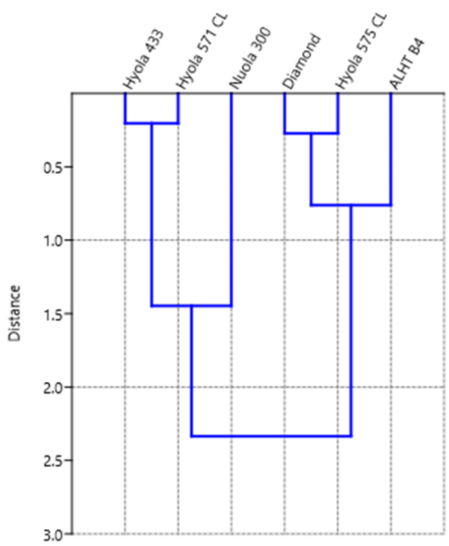

Figure 4. Dendrogram of phenotypic dissimilarity.

Considering the patterns revealed in the dendrogram, the hybrids in Group 1 (Figure 1) had values that fell below the average of the two evaluated parameters regardless of the location. However, the hybrids Diamond, ALHT B4, and Hyola 575 CL had positive results, with values above the average of the evaluated parameters.

This clustering procedure provides valuable information about variations in performance among canola hybrids, assisting in the identification of superior hybrids for specific traits. These results underscore the utility of cluster analysis in elucidating phenotypic diversity and guiding breeding or cultivation strategies to optimize canola yield.

The results verified in the present study are promising, as they indicate the adaptability and cultivation potential of this crop in the challenging environment of the Brazilian Cerrado, especially under rainfed conditions.

Productivity of soybeans grown in succession to winter crops

In both cultivation locations (Luminárias and Monsenhor Paulo, Minas Gerais State, Brazil), there was no significant difference in grain productivity or stand density. However, when cultivated on oat straw, soybean plants had a greater number of pods in Luminárias (85.44) and greater height in Monsenhor Paulo (91.41 cm) (Table 1).

The variations caused by different winter crops, such as canola and oats, may have been less significant than other factors associated with soil cover, sowing time, and precipitation. In some studies, the advantages of winter crops and cover crops in terms of soil chemistry, physics, and health-related variables have been demonstrated, such benefits do not seem to directly influence soybean grain productivity (Guimarães et al., 2003; Carvalho et al., 2004; Muraishi et al., 2005; Machado & Assis, 2010). For a more precise assessment of the effects of the production system, extending the experimental period is recommended.

Table 1. Grain productivity (PROD, kg ha^{-1}), stand density, number of pods per plant (NPP), and height of BMX Desafio RR soybean plants in Luminárias and Nidera 5700 IPRO in Monsenhor Paulo, Minas Gerais State, Brazil[1].

Preceding crop	PROD (kg ha^{-1})	Stand density (plantas ha^{-1})[2]	NPP*	Height (cm)
	---------- Luminárias ----------			
Canola	6,004.32 a	185,333.00 a	57.16 b	91.90 a
Aveia	5,328.75 a	208,666.00 a	85.44 a	91.41 a
Pousio	5,799.11 a	186,666.00 a	67.33 b	87.66 a
Média geral	5,710.72	193,555.55	69.98	90.32
CV (%)	13.57	6.06	17.97	8.11
	---------- Monsenhor Paulo ----------			
Canola	4,833.63 a	267,333.00 a	42.55 a	91.75 b
Aveia	4,774.47 a	262,000.00 a	39.94 a	94.91 a
Pousio	5,033.50 a	267,333.00 a	38.44 a	91.50 b
Average	4,880.53	265,555.55	40.31	92.72
CV (%)[3]	13.69	2.83	14.09	3.66

[1] Means followed by the same letter do not differ from each other according to the Scott–Knott test at 5% probability. [2] Transformed data. [3] Coefficient of variation (CV).

Although there was no significant difference in soybean productivity, the yield of canola increased, reaching 6,000 kg ha^{-1} compared to that of oats and fallow crops. However, assessing the contribution of the preceding crop to the subsequent crop goes beyond growth and development parameters.

Crop rotation provides immeasurable benefits to agricultural systems due to the nutrient cycling dynamics, reduction in phytosanitary problems and increase in system sustainability driven by this practice (Tomm, 2006). Furthermore, even though only spring canola is grown in Brazil, late winter cultivation could also be performed, with the plants serving as a vegetative cover for the soil and contributing to optimizing agricultural resources, thus increasing income (Melgarejo Arrua et al., 2014).

The results obtained in this study highlight the benefits and potential of canola in this region and can be used to develop further research related to the optimization of the management of this crop.

Conclusion

Based on its productivity, canola has demonstrated cultivation potential in Minas Gerais State, Brazil, with the hybrids Diamond, ALTH B4, and Hyola 575 CL having higher grain and oil productivity levels. Soybean productivity was not influenced by preceding crops or fallow areas in either cultivation location.

Data availability

Does not apply.

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