Agronomic performance of canola hybrids in Campos das Vertentes - MG[1]

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ABSTRACT

Canola has considerable global significance in edible oil and biodiesel production. In Brazil, canola has adapted to the temperate South region, where production is now concentrated. However, research indicates potential for growing the crop in warmer regions. This study evaluated the performance of canola hybrids under growing conditions in the Campo das Vertentes mesoregion, Minas Gerais, during the 2019 and 2021 harvests. The experiments were conducted in a randomized block 6 × 6 factorial design, with four replicates. Six canola hybrids, Hyola 433, Hyola 575 CL, Nuola 300, Hyola 571 CL, Diamond, and ALHT B4, and six sowing dates: 02/15/2019, 02/28/2019, 03/20/2019, 04/09/2019, 02/22/2021, and 03/11/2021 were tested. The plant height, total number of siliques per plant, number of grains per silique, grain yield, and canola oil yield were evaluated. The Nuola 300 and Hyola 575 CL hybrids showed superior grain and oil yields, indicating potential success in growing in the Brazilian Cerrado region. Findings indicated an optimal sowing period in the Campo das Vertentes region until March. These results stress the importance of strategically selecting hybrids and sowing timelines to maximize canola yield in the region under study.

Keywords: *Brassica napus* L. var. *oleifera*, rapeseed, production, tropicalization.

INTRODUCTION

Canola (*Brassica napus* L. var. *oleifera*) was introduced in Brazil in the states of Rio Grande do Sul (1970s) and Paraná (1980s) and currently is considered a good option for crop rotation in autumn and winter because it has high potential yield for production of biodiesel and of edible oil with high nutritional value. In the world, canola is predominantly grown in temperate climate regions, and in Brazil, most production of this oilseed grain is concentrated in the South region of the country; 95% of production areas are concentrated in the states of Rio Grande do Sul and Paraná (CONAB, 2023).

Although Brazilian canola production accounts for less than 2% of canola production worldwide, there is significant potential for expansion, especially in high-altitude areas of the Cerrado, which experience milder climate conditions during the second crop season. Data from the Brazilian national agricultural supply agency - CONAB (2023) indicate that not even 50% of the area planted to soybean in the first crop season (approximately 44 million hectares) is occupied with a second crop during the winter crop season, showing the potential for canola cultivation.

As there will be a pressing need to increase food production in the world in the coming years, the possibility of increasing canola production in the second crop season in an area already occupied by soybean in the first crop season would represent a significant advance, in accord with the

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principles of circular agriculture (Moreira *et al.*, 2023), that is, increasing food production with the least possible environmental impact.

However, a primary limitation in development of canola is climatic adaptation, particularly adaptation to temperature. This affects flower retention and pod dehiscence, due to natural opening of mature siliques before harvest. Studies indicate a thermal limit (27 °C) beyond which sterility and flower abortion intensify (Morrison, 1993; Wang *et al.*, 2006). Additionally, locations with higher temperatures lead to a shorter canola cycle (Tomm, 2007). Furthermore, heat stress reduces seed oil concentration overall by 5%, dropping by a notable 14% when heat stress was applied under controlled conditions early in the flowering stage. In contrast, heat stress enhances protein concentration by 5% (Secchi *et al.*, 2023). However, whether current cultivars can adapt to the high-altitude regions of the Brazilian Cerrado needs to be assessed.

Although genetic breeding is an important tool in making high-yielding cultivars available, many barriers still need to be overcome, such as the need to identify genotypes with the best adaptation to the different regions of the country, as well as the best sowing dates, especially at high latitudes, temperatures below 35 °C, and altitudes above 600 meters (Estevez *et al.*, 2014). Hypothesizing that it is possible to cultivate canola economically in the high-altitude regions of the Brazilian Cerrado, the aim of the present study was to evaluate the agronomic performance of canola hybrids under the growing conditions of the Campo das Vertentes mesoregion, MG.

MATERIALS AND METHODS

The study was conducted in the autumn-winter of the 2019 and 2020 crop seasons at the Center for Scientific and Technological Development of the Federal University of Lavras (Universidade Federal de Lavras - UFLA) - Fazenda Muquém, at 21°14'43'' S and 44°59'59'' W. The soil of the site is characterized as a *Latossolo Vermelho-Amarelo* according to the Brazilian Soil Classification System (Santos *et al.*, 2018) and a Typic Hapludox according to Soil Taxonomy (Soil Survey Staff, 2022). The climate is Cwa (dry-winter humid subtropical climate according to the Köppen Climatic Classification), with a cold and dry winter and a hot and humid summer, as described by Peixoto *et al.* (2019). The average annual temperature is 20 °C, average annual rainfall, 1460 mm, and potential evapotranspiration, 873 mm (Dantas *et al.*, 2007).

The average monthly climate data of rainfall (mm) and maximum and minimum temperatures (°C) throughout the period in which the experiment was conducted, according to Inmet (the National Institute of Meteorology, Brazil), are represented in Figure 1.

The experiment was conducted in a 6 × 6 factorial randomized block design with four replicates, for a total of

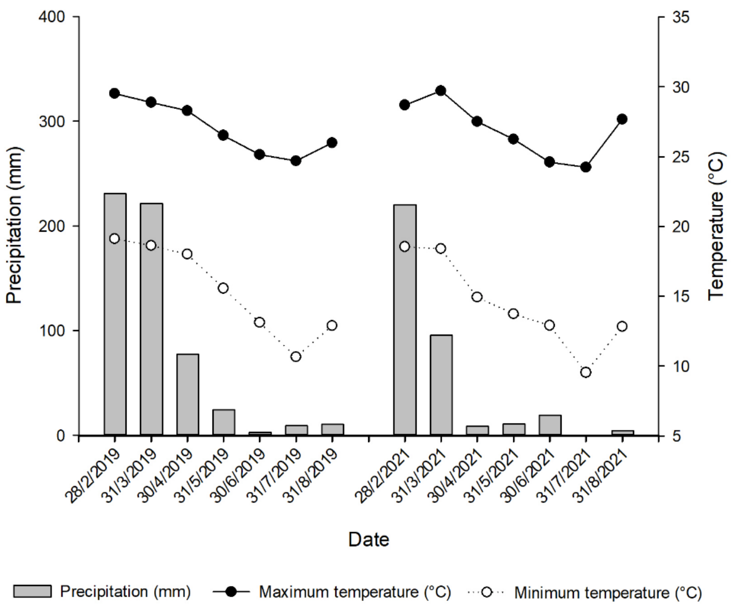

Figure 1: Monthly average climate data of rainfall (mm) and maximum and minimum temperatures (°C) in the period in which the experiment was conducted in Lavras, MG, Brazil

144 plots. The first factor consisted of six canola hybrids, supplied by the Brazilian Agricultural Research Corporation – Agroenergia (Embrapa Agroenergia), namely, Hyola 433, Hyola 575 CL, Nuola 300, Hyola 571 CL, Diamond, and ALHT B4. The second factor consisted of six sowing dates: 02/15/2019, 02/28/2019, 03/20/2019, 04/09/2019, 02/22/2021, and 03/11/2021.

The hybrids were selected due to their availability in the Brazilian market during the planting seasons under consideration. Additionally, selection was guided by desirable traits such as herbicide resistance, resistance to blackleg disease, and proven high grain and oil yield. All these hybrids are of Australian origin, solidifying their inclusion in the study based on their unique properties and demonstrated effectiveness under similar conditions.

The experimental area was prepared using a minimum tillage system, and plots consisted of five 5-m-length rows with a between-row spacing of 0.20 m, i.e., 5 m^2. The three central rows in their central four meter length, corresponding to 2.4 m^2, were used for data collection. The final population was approximately 40 plants/m^2.

Pests and diseases were managed as monitored according to crop needs. Monoammonium phosphate (MAP) fertilizer, with a composition of 11% N and 52% $P_2 0_5$, was applied at sowing (220 kg.ha^{-1}), and 20 kg.ha^{-1} N and 45 kg.ha^{-1} K_2O were applied as topdressing when the plants had four developed leaves, according to crop needs for obtaining high yields.

The traits evaluated were days from emergence to flowering (DEF), total cycle (days), plant height, total number of siliques per plant, number of seeds per silique, grain yield (kg.ha^{-1}), grain oil content (%) and oil yield per hectare (kg.ha^{-1}). Grain yield was corrected to 10% moisture content.

The grain oil content was determined at the Biodiesel Laboratory of UFLA. For that purpose, uniform grain samples were dried in an oven with forced air circulation at 65 °C for 48 h to achieve uniform moisture content. After drying, the grain was milled with hulls, and the oil content was determined. The meal from the grain was packed in paper cartridges at 2 g per cartridge in duplicate per experimental unit. The methodology described in IUPAC (1979) was adopted for oil extraction, using the Soxhlet system; petroleum ether was used as extraction solvent, with extraction time of 6 h. After extraction, the cartridges were kept in an oven at 60 °C for 24 h for complete evaporation of petroleum ether.

For statistical analysis, the count and percentage data were square root (x + 0.5) transformed to meet the assumptions of analysis of variance. Analysis of variance was performed on the data obtained, and when appropriate, the Scott–Knott grouping of averages test was performed ($p < 0.05$ significance) using the Sisvar statistical program (Ferreira, 2019). The averages in the tables are the original data without transformation.

In addition, cluster analysis was performed, and a dendrogram was generated using the Past3 software (Paleontological Statistics, Version 3.20, Oslo, Norway), in which the Euclidean similarity index was calculated for each combination of two samples. The matrices were standardized by dividing the value of each element by the standard deviation of the respective matrix to reduce the range of variation in each matrix.

RESULTS AND DISCUSSION

A summary of the analysis of variance (ANOVA) is shown in Table 1. There was a significant interaction between the hybrids (H) and sowing dates (D) for all the components evaluated, except for the height trait, where there was statistical difference only between the sowing dates.

Rapeseed is highly responsive to climatic conditions (Canola Council of Canada, 2023), and as expected, the sowing dates affected all yield components, with a significant relationship with maximum temperatures close to 30 °C and prolonged drought periods. There was a significant difference in the cycle of the hybrids for the second sowing date (2/28/2019). The hybrids Diamond and Hyola 575 CL were the earliest, and were earliest for the fifth and sixth sowing date (02/22/2021 and 03/11/2021, respectively) as well. The Diamond hybrid had a overall average cycle of 108 days, characteristic of early maturity (Table 2). This information shows that the environment affected the performance of the hybrids according to the sowing date.

The fourth sowing date (04/09/2019) showed the longest cycles for all the hybrids in this study. This result was due to late sowing, coinciding with low rainfall and low temperatures, conditions that lead to a longer cycle. In contrast, the maximum temperature during the entire vegetative phase of the first sowing season (year 2019) was close to 30 °C, which caused reduction in the cycle of all the materials in this study, especially the Diamond and Hyola 433 hybrids, characterized as early hybrids.

Comparison of the overall average of the cycles of the hybrids shows that Diamond had the shortest cycle (Table 2).

Table 1: Summary of analysis of variance for total cycle (days), days from emergence to flowering (DEF), height (m), number of siliques per plant (NSP), number of seeds per silique (NSS), grain yield (kg.ha^{-1}), oil content (%), and oil yield (kg.ha^{-1})

SV	DF	Total cycle	DEF	Height	NSP	NSS	Grain yield	Oil content	Oil yield
		F calculated							
Hybrids (H)	5	15.73 **	9.35 **	1.97 ns	5.76 **	8.58 **	6.24 **	31.67 **	14.33 **
Sowing dates (D)	5	89.96 **	77.69 **	24.56 **	194.26 **	11.99 **	111.50 **	113.00 **	177.57 **
H*D	25	4.27 **	6.84 **	1.23 ns	4.47 **	5.43 **	7.27 **	21.32 **	12.29 **
Block	3	0.53 ns	0.53 ns	1.75 ns	0.27 ns	3.02 *	0.378 ns	2.37 ns	0.79 ns
error	105								
Total	143								
CV (%)		5.41	8.19	19.82	12.79	10.16	18.48	4.28	18.09
Overall average		118.78	52.93	1.23	502.35	16.76	1300.40	25.78	341.36

SV: source of variation; DF: degrees of freedom; CV: coefficient of variation. ns, *, **: not significant, significant at $p \leq 0.05$, and significant at $p \leq 0.01$ by the F test, respectively.

Laviola *et al.* (2019) observed that the Diamond hybrid was also among the materials with a reduced cycle when grown in the Brasília region in the winter season. They affirmed that early materials can be inserted in soybean/maize production systems, bringing benefits such as reducing disease incidence, as well as enabling production of vegetable oils in the off-season.

Shorter cycles of the materials studied was observed for the first sowing date, with high initial temperatures and water restriction after the cultivars flowered in April (Table 2). This was expected because rapeseed is originally a plant adapted to the conditions of mild temperatures and rainfall regularly distributed throughout its growth period. Moisture and temperature are the most important environmental variables in growth and development of the crop (Canola Council of Canada, 2023). Dogan *et al.* (2011) also observed results similar to those found in this study, where water restriction at flowering shortened the cycle of the canola materials. Water restriction acts by reducing the speed of physiological and biochemical processes. Canola seedlings under low moisture conditions have more limited development, causing less accumulation of dry biomass (Da Costa *et al.*, 2020), while high temperatures reduce the duration of the total plant cycle (Panozzo *et al.*, 2014). In contrast, for the later sowing dates, lower temperatures resulted in a longer cycle, due to slow plant development (Table 2).

Table 2: Total cycle (days) of six canola hybrids according to different sowing dates in Lavras, MG, Brazil

Hybrid	Sowing Date (mm/dd/yy)						
	02/15/19	02/28/19	03/20/19	04/09/19	02/22/21	03/11/21	Average
ALHT B4	105 aC [1]	122 bB	118 aB	137 aA	120 aB	130 aA	122 a
Diamond	94 aC	100 cC	118 aB	137 aA	103 bC	101 bC	108 b
Nuola 300	100 aC	122 bB	118 aB	137 aA	120 aB	130 aA	121 a
Hyola 571 CL	100 aC	132 aA	118 aB	137 aA	120 aB	130 aA	123 a
Hyola 575 CL	101 aC	100 cC	118 aB	137 aA	120 aB	130 aA	117 a
Hyola 433	94 aC	122 bB	118 aB	137 aA	120 aB	130 aA	120 a
Average	99 D	116 C	118 C	137 A	117 C	125 B	
CV (%): 5.4							

[1]Averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

Similar to the length of the cycle, the days from the emergence to flowering (DEF) subperiod is highly affected by climate. Differences in DEF were observed in comparing the materials at all sowing dates, where the last sowing date of the 2019 crop treatment led to an increase in the period from emergence to early flowering. The third sowing date in 2019 had a average DEF of 44 days, and the sixth sowing date in 2021 had a average DEF of 54 days (Table 3).

The early hybrids Diamond, Hyola 433, Hyola 571 CL, and Hyola 575 CL consequently had shorter intervals in each subperiod, an expected response since the same hybrids had the shortest average cycles (Table 2). The Nuola 300 hybrid, though classified as an early hybrid, had higher DEF compared to the other materials, showing greater sensitivity to climatic variations across the sowing dates (Table 3).

Similar to the cycle (Table 2), the DEF also lengthened for all hybrids for the fourth sowing date. This response showed the effects of environment on the development of the materials, and the low rainfall and reduction in temperature were climatic factors that affected the canola development cycle and subperiods. Laviola *et al.* (2019) also observed a shorter period from germination to flowering for the Diamond hybrid, an average of 49 days, similar to that found in this study, which led to rapid development of the plants. Luz *et al.* (2012) studied several canola subperiods and their relationship to temperature, including emergence to the beginning of flowering (EBF) and the cycles of Hyola 61 and Hyola 433. The results were similar to those of this study for the first three seasons, in which the authors identified an average duration of 58 days for both hybrids when sown at the earliest date proposed in their study (04/03/2009), confirming shorter subperiods of the early hybrid, regardless of the sowing date. This partially corroborates the present study, where the hybrids Diamond, Hyola 571 CL, Hyola 575 CL, and Hyola 433 generally had the shortest subperiods from emergence to flowering (DEF) (Table 3). For the first three sowing dates, the rainfall distribution was more regular, and the temperatures were milder in the period from emergence to flowering.

The ALHTB4 hybrid remained among the materials with the highest DEF; it is a material classified as late and tends to maintain a longer subperiod as well as a longer cycle. Only in the fourth sowing date of 2019 did this hybrid have longer DEF, and this response was due to reduction in rainfall during the vegetative phase brought about by late sowing. Rosa *et al.* (2020) found that, regardless of the sowing date, the medium cycle hybrids Hyola 50 and Hyola 61 had a longer duration of emergence to the beginning of flowering (EBF). Climatic variations, especially an increase in temperature and reduction in water availability, negatively affect the vegetative phase of canola hybrids. Tomm *et al.* (2008) reported that the intrinsic genetic characteristics of each hybrid influence the development of the crop and its response to different environments and climatic conditions.

A significant difference was observed for the plant height variable only among the sowing dates, and there was greater growth of plants sown on the first three sowing dates, an average of 1.4 m (Table 4). This result may be linked to the variable climatic conditions according to sowing dates and crop years, which corroborates the results found in the literature (Panozzo *et al.*, 2014; Rigon *et al.*, 2017). Delay in canola sowing, regardless of

Table 3: Days from emergence to flowering (DEF) according to different canola hybrids and sowing dates (mm/dd/yyyy) in Lavras, MG, Brazil

Hybrid	Sowing Date (mm/dd/yy)						
	02/15/19	**02/28/19**	**03/20/19**	**04/09/19**	**02/22/21**	**03/11/21**	**Average**
ALHT B4	52 aB [1]	54 aA	49 aB	60 cA	50 cB	55 aA	53 b
Diamond	40 bC	40 bC	42 bC	77 aA	50 cC	55 aB	51 b
Nuola 300	56 aB	56 aB	49 aC	65 bA	68 aA	55 aB	58 a
Hyola 571 CL	53 aB	47 bC	44 bC	65 bA	53 bB	53 aB	52 b
Hyola 575 CL	53 aB	45 bC	42 bC	72 aA	55 bB	50 aB	53 b
Hyola 433	42 bB	42 bB	42 bB	58 cA	63 aA	58 aA	51 b
Average	49 C	47C	44C	66 A	56 B	54 B	
CV (%): 8.2							

[1]Averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

Table 4: Average height (m) according to the different canola sowing dates in Lavras, MG, Brazil

Sowing Date (mm/dd/yyyy)					
02/15/2019	02/28/2019	03/20/2019	04/09/2019	02/22/2021	03/11/2021
1.44 A[1]	1.47 A	1.42 A	1.16 B	1.02 B	0.88 C
Average: 1.23 C.V. (%): 19.8					

[1]Averages followed by the same uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

the hybrids, negatively affected plant height and the number of seeds per silique (Rigon *et al.*, 2017).

For number of siliques per plant, late sowing tended to decrease the number of siliques, since low temperatures and rainfall increase floral abortion. Thus, over time, there was a successive and significant reduction in the number of siliques per plant, and, there was a significant reduction at each sowing date, representing a decrease of up to 35%, depending on the sowing date (Table 5).

Comparison of the hybrids shows a trend toward a larger number of siliques for the materials with a longer cycle, such as ALHT B4, when sown on the first sowing date (02/15/2019). For the second sowing date, in turn, the Hyola 575 CL hybrid stands out because it was the material with the best performance of all, producing more than 1000 siliques per plant; it proved to be a stable material and is recommended for sowing on the second sowing date of February (Table 5). In general, the climatic conditions of 2021 were not favorable, because the rainfall that occurred during the initial establishment of the plants and throughout the cycle of the two sowing dates was low, 161 mm and 72.2 mm, respectively, which generally reduced the number of siliques per plant for all hybrids in the 2021 crop year (Table 5) compared to 2019. In the first crop year, the cumulative rainfalls throughout the cycles of the first two sowing dates were 565.8 mm and 335 mm, respectively.

The number of siliques per plant is a trait of quantitative inheritance and, therefore, it is controlled by many genes with little effect on the expression of the trait. The number of siliques per plant is strongly responsive to changes in the environment and is directly affected by the factors that affect plant growth and branching, as well as the climatic conditions during flowering and early silique formation (Shirani-Rad *et al.*, 2014). That explains the reduction in the number of siliques per plant for late sowing dates (Table 5), where rainfall and temperature were reduced, impacting floral abortion and silique abscission.

The number of seeds per silique showed a significant

Table 5: Number of siliques per plant as a function of different canola hybrids and sowing dates in Lavras, MG, Brazil

Hybrid	Sowing Date (mm/dd/yy)						
	02/15/19	**02/28/19**	**03/20/19**	**04/09/19**	**02/22/21**	**03/11/21**	**Average**
ALHT B4	1407.3 aA[1]	765.3 bB	640.7 aB	353.7 aC	191.0 aC	161.5 aC	586.5 a
Diamond	1059.3 bA	492.0 bB	590.0 aB	280.3 aC	178.0 aC	136.5 aC	456.0 b
Nuola 300	1005.5 bA	527.3 cC	735.3 aB	523.3 aC	199.0 aD	172.8 aD	527.2 a
Hyola 571 CL	954.0 bA	290.3 cC	593.7 aB	378.5 aC	149.0 aD	129.8 aD	415.8 b
Hyola 575 CL	862.0 bB	1139.3 aA	624.0 aC	378.3 aD	170.8 aE	123.5 aE	549.6 a
Hyola 433	850.5 bA	665.8 bB	572.8 aB	474.3 aB	218.0 aC	91.5 aC	478.8 b
Average	1023.1 A	646.7 B	626.1 B	398.1 C	184.3 D	135.9 D	
CV (%): 12.8							

[1]Averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

effect for the sowing date × hybrid interaction (Table 6). Comparing the averages of each sowing date, the plants sown for the fifth period (on 02/22/2021) showed a higher average number of seeds per pod, followed by the sixth period. On the fifth sowing date, the Hyola 571 CL hybrid stood out, which produced an average of 32.8 seeds per silique, followed by the Hyola 575 CL hybrid on the sixth sowing date, with an average of 31.2 seeds per silique (Table 6). Regarding the materials studied, the ALHT B4 hybrid showed greater stability than other canola hybrids, with no difference in the number of seeds per silique for different sowing dates. When canola hybrids are under stress conditions, they tend to undergo changes in the number of siliques per plant and seeds per silique, as well as in grain weight and size (Canola Council of Canada, 2023). The results observed in this study corroborate the average variation of 17 to 24 seeds per silique observed in different canola genotypes (Young *et al.*, 2004; Laviola *et al.*, 2019; Guimarães *et al.,* 2022).

Plants sown on the first sowing date (02/15/2019) showed higher canola grain yields (2073 kg.ha^{-1}) (Figure 2). The hybrids ALHT B4 (2462 kg.ha^{-1}), Nuola 300 (2472 kg.ha^{-1}), and Hyola 571 CL (2275 kg.ha^{-1}) were the highest-yielding materials on this sowing date, indicating that this may be a promising season for the implementation of canola in the Campo das Vertentes mesoregion of MG. The average yields were much higher than the national average for canola grain production, which was 1399 kg.ha^{-1} in 2021, and higher than that forecast for 2023 of 1743 kg.ha^{-1} (CONAB, 2023).

In general, the highest-yielding hybrid was Nuola 300, with an average of 1497 kg.ha^{-1} of grain, with oscillations among the sowing dates. In turn, the Hyola 575 CL hybrid showed greater yield stability over four sowing dates (02/15/2019, 02/28/2019, 03/20/2019, and 02/22/2021), which is a material with greater adaptability that can be used within a longer sowing period in the “off-season”. For the other hybrids, there was greater fluctuation among sowing dates (Figure 2). The lowest yields were observed when sowing was performed on April 9 and in February (2019) and on March 11 (2021). This is a result of a smaller number of siliques per plant, combined with unfavorable weather conditions for flowering and development of the siliques (Figure 2 and Table 5). Other studies conducted in other regions of the country show that delays in sowing cause a reduction in grain yield (Rosa *et al.*, 2020; Araújo *et al.*, 2021; Santiago *et al.*, 2022), as observed in this study.

Different researchers report that different canola hybrids respond to sowing dates, and in general, cultivation carried out between the first fortnight of February and the first fortnight of March in the Center-South region of Brazil obtained the best responses in crop yield (Rosa *et al.*, 2020; Araújo *et al.*, 2021; Santiago *et al.*, 2022). In the Agricultural Zoning of Climate Risk (MAPA, 2021) for canola, it is reported that the months of February and March are the best growing seasons, depending on the cycle of the hybrid to be used. Additionally, according to MAPA (2021), water deficit mainly affects grain yield when it occurs at crop establishment and at flowering/grain filling.

Table 6: Number of seeds per silique according to different materials and canola sowing dates in Lavras, MG, Brazil

Hybrid	Sowing Date (mm/dd/yy)						
	02/15/19	02/28/19	03/20/19	04/09/19	02/22/21	03/11/21	Average
ALHT B4	14.9 aA [1]	14.1 aA	11.9 aA	14.5 aA	15.6 dA	11.5 bA	13.7 c
Diamond	13.4 aB	17.3 aB	13.2 aB	13.9 aB	27.6 bA	11.8 bB	16.2 b
Nuola 300	19.3 aA	14.9 aB	12.5 aB	14.9 aB	17.9 cA	21.6 bA	16.8 b
Hyola 571 CL	18.1 aB	17.6 aB	15.9 aB	16.1 aB	32.8 aA	19.5 bB	18.2 a
Hyola 575 CL	13.9 aC	16.3 aC	12.2 aC	14.9 aC	20.5 cB	31.2 aA	20.1 a
Hyola 433	16.1 aA	19.3 aA	16.8 aA	12.2 aB	12.5 dB	16.8 bA	15.6 b
Average	15.9 D	16.6 C	13.7 D	14.4 C	21.1 A	18.7 B	
CV (%): 10.2							

[1]Averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

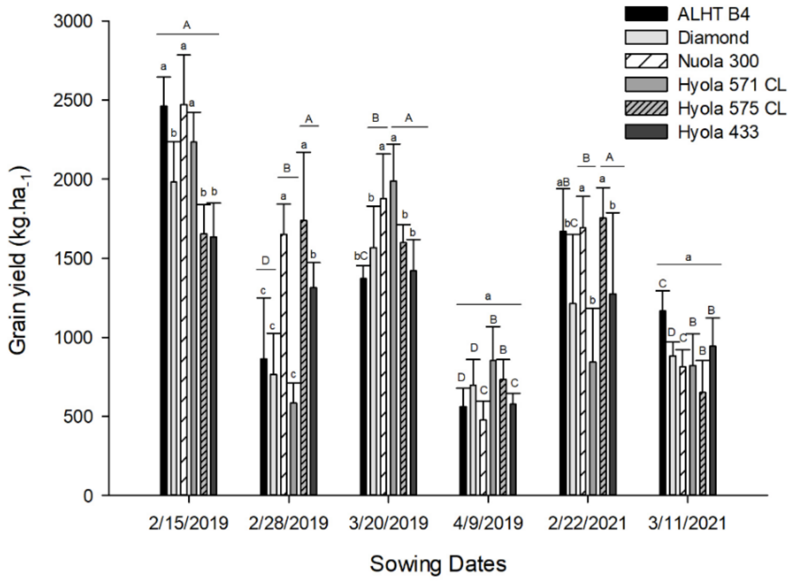

Figure 2: Grain yield (kg.ha^{-1}) as a function of different sowing dates (mm/dd/yyyy) and canola hybrids in Lavras, MG, Brazil. Capital letters = sowing dates, lowercase letters = canola hybrids. Averages followed by the same letter do not differ statistically at 5% probability by the Scott-Knott test. Bars represent standard deviation.

These findings indicate the feasibility of growing canola in the Campo das Vertentes mesoregion, MG. This discovery could open up new prospects for local grain farmers, considering that canola ranks as the third most crucial oilseed globally, and it follows soybean for production of edible oils (USDA, 2023). In Brazil, cultivation is expanding, but there is a need for research support to understand the crop response and for investments in genetic breeding programs through tools such as path analysis, which allow the identification of traits and their correlations with significant gains in crop yields and consequent expansion of planted area (Santiago *et al.*, 2022).

Regarding oil content, there was a significant difference among the hybrids for the four different sowing dates (02/15/2019, 02/28/2019, 02/22/2021, and 03/11/2021) (Table 7). The Hyola 575 CL hybrid had greater stability than the other hybrids and across the sowing dates, maintaining oil content of 27.9%. Among the sowing dates, the plants grown in the second sowing period had a higher oil percentage, an average of 30.9%. Thus, late sowing is reflected not only in the yield components and yield but also in reduction in the oil content in the canola grain, as

Table 7: Oil content (%) as a function of different canola hybrids for six sowing dates in Lavras, MG, Brazil

Hybrid	Sowing Date (mm/dd/yy)						
	02/15/19	02/28/19	03/20/19	04/09/19	02/22/21	03/11/21	Average
ALHT B4	30.3 aB	35.7 aA	28.3 aC	24.9 aD	13.2 cE	23.3 bD	25.9 b
Diamond	22.9 bB	24.6 cB	27.9 aA	24.7 aB	11.4 cC	21.6 bB	22.2 c
Nuola 300	29.8 aA	30.8 bA	29.1 aA	27.7 aA	17.2 cB	12.5 cC	24.5 b
Hyola 571 CL	28.9 aA	30.8 bA	29.2 aA	27.4 aB	25.3 bB	25.8 aB	28.7 a
Hyola 575 CL	29.2 aA	31.9 bA	28.1 aA	25.3 aA	28.9 aA	28.5 aA	27.9 a
Hyola 433	30.3 aA	31.7 bA	28.9 aA	24.1 aB	26.8 bB	10.6 cC	24.4 b
Average	28.6 B	30.9 A	28.6 B	25.7 C	20.5 D	20.4 D	
CV (%): 4.3							

[1]Averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ from each other according to the Scott-Knott test at 5%. CV: coefficient of variation.

water deficit combined with high temperatures affects the formation of fatty acids (Si *et al.*, 2003). That contrasts with what is observed in the South region of Brazil, where the harvested grain contains approximately 38% oil, due to mild temperatures (Tomm, 2005).

For oil yield per hectare, the lowest averages were obtained for the fourth, fifth, and sixth sowing dates, periods that had some of the lowest grain yield averages (kg.ha^{1}), closely linked to low water availability. Among the hybrids, the highest oil yield was obtained by Hyola 575 CL (394.8 kg.ha^{-1}) and Nuola 300 (385.5 kg.ha^{-1}) (Figure 3).

As water restriction and temperature variation affect the agronomic components, the same occurs for chemical partitioning of the grain, affecting the oil yield when plants go through periods of stress, as occurred for the last three sowing dates (Figure 3). According to Si *et al.* (2003), the photosynthesis performed by the silique wall during the grain filling process is significantly reduced under environmental stress conditions. The authors report that water availability and temperatures between 10 and 25 °C are fundamental environmental requirements for the physiological activities of plants, such as transport of photoassimilates and formation of the fatty acids present in the oil extracted from canola.

Regarding cluster analysis, a dendrogram was obtained through application of the classical method for the average values of four variables, i.e., the total cycle (TC), grain yield (kg.ha^{-1}), grain oil content (%), and oil yield per hectare (kg.ha^{-1}) (Figure 4). Initially, four groups were indicated based on the variance among the aforementioned canola hybrids.

The hybrids Diamond (group 1), Nuola 300 (group 2) and Hyola 575 CL (group 3) had more discrepant values, and each was classified into a distinct group, further from the other groups, especially the Diamond hybrid. Another group corresponded to the hybrids Hyola 433, Hyola 571 CL, and ALHT B4 (group 4), with shorter Euclidean distances (Figure 4).

The response indicated in the dendrogram shows that the Diamond hybrid, the most isolated and distant (Figure 4), had values below the average of the four variables evaluated. According to Araújo *et al.* (2021), the Diamond hybrid exhibited a shorter growth cycle, consistent with our study; however, it showed higher yield.

The Nuola 300 and Hyola 575 CL hybrids had prominent positive responses, with values higher than the average of the hybrids evaluated. The Nuola 300 hybrid showed higher average values regarding the grain yield (kg.ha^{-1}) trait. The Hyola 575 CL hybrid had higher average values for the oil yield trait (kg.ha^{-1}); average values were higher than those of the other canola hybrids. Lima *et al.* (2023) mention that the Hyola 575 CL hybrid showed lower potential for oil content, diverging from our findings. Such discrepancies can be attributed to variations in growing conditions and geographical location.

This clustering procedure provides valuable insights

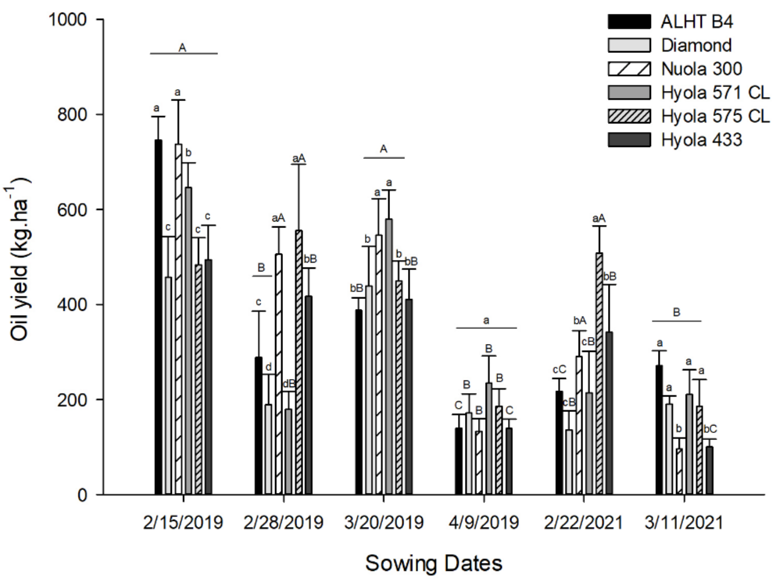

Figure 3: Oil yield (kg.ha^{-1}) as a function of different canola hybrids for six sowing dates (mm/dd/yyyy) in Lavras, MG, Brazil. Capital letters = sowing dates, lowercase letters = canola hybrids. Averages followed by the same letter do not differ statistically at 5% probability by the Scott-Knott test. Bars represent standard deviation.

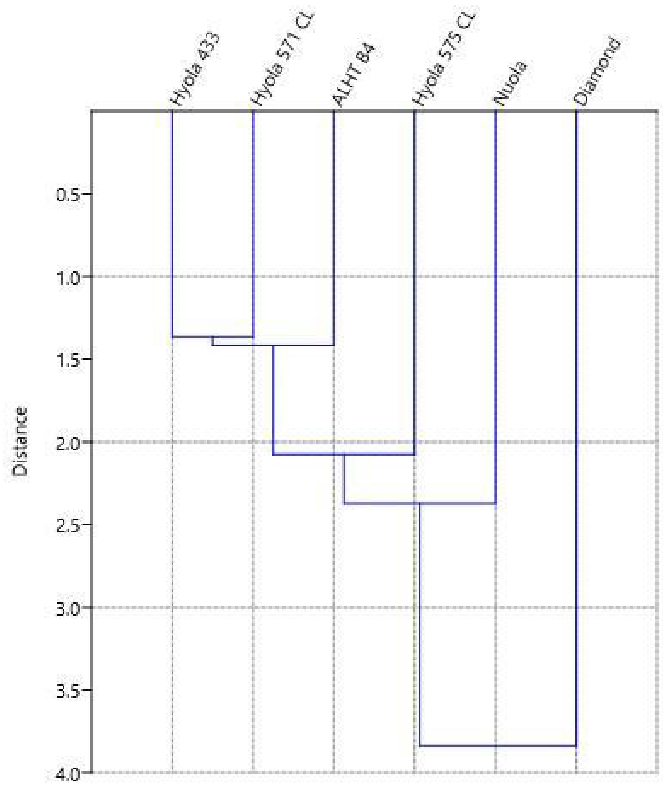

Figure 4: Dendrogram of phenotypic dissimilarity among six canola hybrids in a study conducted in the municipality of Lavras, MG, Brazil, based on four variables: total cycle, grain yield, grain oil content, and oil yield per hectare.

into performance variations among canola hybrids, aiding in identification of superior hybrids for specific traits. These results emphasize the utility of cluster analysis in elucidating phenotypic diversity and in guiding breeding or growing strategies for optimizing canola yield.

CONCLUSIONS

The sowing of canola in the Campo das Vertentes mesoregion, MG, should be carried out until the month of March, requiring average rainfall during the cycle of at least 300 mm. After that sowing date, abiotic stress conditions are accentuated, with low rainfall compromising the yield and agronomic components, regardless of the canola hybrid sown.

Nuola 300 and Hyola 575 CL stood out among the canola hybrids and had higher grain and oil yields per hectare, respectively, across the evaluated sowing dates and environmental conditions.

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