Acta Scientiarum
http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v46i1.67694



# Analysis of the cultivation of canola hybrids at different sowing dates

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**ABSTRACT.** Rich in oil and protein, canola is a significantly promising crop and is widely explored as an alternative to grain cultivation in the winter period. Recently, canola oil has been largely consumed due to a variety of health benefits and low production costs. Nonetheless, impasses such as determining the correct sowing date and optimizing harvesting methods make it difficult to expand cultivation. Accordingly, the purpose of the study was to evaluate the performance of two canola hybrids on three sowing dates and distinct harvesting procedures. The study was conducted in Cachoeira do Sul, Rio Grande do Sul, Brazil, on three sowing dates (2019, 2020, and 2021), with two hybrids (Hyola 433 and Hyola 575 CL). The methods of direct harvesting, direct harvesting with the application of adjuvant, cut-row, and cut-row with the application of adjuvant were evaluated. The main yield components were determined, in addition to biochemical parameters, such as oil and protein content and determination of oil quality (acid, peroxide, iodine, extinction, and saponification indices). Appropriately, this study indicated that canola is significantly sensitive to climatic conditions, mainly to temperature and sowing time, reducing grain and biomass yield in late sowing and resulting in serious harvest losses. Oil and grain protein contents were affected by climatic conditions. Nevertheless, the protein content was not affected by late sowing. Canola oil presented significant chemical conditions, with a correlation between the crops with higher oil yield and better oil quality.

**Keywords:** *Brassica napus* L.; agronomic performance; canola management; grain yield; oil quality; sowing dates.

Received on March 28, 2023.
Accepted on September 18, 2023.

## Introduction

Canola (*Brassica napus* L.) is a species of significant importance for food security in several regions globally (Pixley et al., 2022). Exploited as an excellent option for crop rotation, the species acts directly on the use and efficiency of water and nutrients, making these resources available for the subsequent crop (Madsen, Parks, Friesen, & Clark, 2022). Additionally, canola oil and flour are important products applied to a diversity of fields such as industry, agriculture, and livestock (Huang et al., 2021). Currently, canola oil consumption is the third largest of edible oils, after soybean and palm oils (Flakelar et al., 2022). The species is characterized as the second-largest oilseed, representing approximately 13% of world production (Iqbal et al., 2022).

Although canola is a promising crop, some gaps generate impasses in its cultivation and productivity, such as the sowing date due to the sensitivity of the crop to climatic conditions and the difficulties at the time of harvest. Canola is established in a variety of climatic zones, from low-temperature environments to regions with low annual precipitation performance (Butkevičienė et al., 2021). Canola growth is controlled from seedling emergence to flowering by photothermal factors and from flowering to maturity by temperature (Marjanović-Jeromela et al., 2019). Canola sowing date is chosen to optimize growth and development under different environmental conditions. In the Northern Hemisphere, early autumn sowing dates may correspond to dry conditions, and later sowing dates may not allow adequate growth for winter survival, mainly due to low temperatures in the early phenological periods (Rahimitanha, Woodcock, Spink, Forristal, & Berry, 2022). A similar scenario was observed in Brazil, where studies have highlighted that the delay in sowing resulted in shorter flowering duration, grain yield, and oil content (Rosa et al., 2020). Accordingly, the ideal sowing period is a fundamental parameter to obtain high yields, and establishing the optimization of this variable allows for the increase in potential and economically viable production gains of canola planting in these regions (Butkevičienė et al., 2021). Appropriately, the optimization of management practices that directly affect the agronomic components of plants is a crucial strategy to increase grain yield and resource use efficiency.

Furthermore, the sowing date directly affects fundamental agronomic parameters, such as plant height, the number of pods per plant, and seed weight (Butkevičienė et al., 2021). Studies have indicated that a delay in sowing by approximately 30 days after the appropriate sowing dates resulted in reduced grain yield (Neupane, Solomon, Mclennon, Davison, & Lawry, 2019). This scenario is a result of a longer growing season and an earlier reproductive stage, in which the plant is not influenced by high humidity in late spring and heat stress. On the other hand, the late sowing date can result in an anticipation of flowering and a shortening of the cycle, causing the reproductive cycle to remain in periods of water restriction and a reduction in grain yield and quality (Monfared, Noormohamadi, Rad, & Hervan, 2020).

Nonetheless, the viability of a long sowing period, from late summer to late autumn, when soil and climate conditions significantly limit seed germination and, consequently, grain yield, is a significant gap to be filled, mainly due to the precision of the sowing date and how much its adjustments affect agricultural production in subtropical environments (Meier, Lilley, Kirkegaard, Whish, & McBeath, 2020). Contextually, the exploration of appropriate agronomic management practices has been one of the key points of modern agriculture to set light on strategies to maximize the productive potential of crops and provide the final product based on growing demand and under sustainable principles (Zhang et al., 2020). Currently, the scientific scenario reports a lack of information about studies focusing on the sowing date and management practices and their impacts on the yield and quality components of canola grains. Accordingly, the purposes of this study were: i) to identify the ideal sowing date for different canola cultivars in a subtropical region, ii) to establish the performance of key agronomic and biochemical parameters, and iii) to explore the application of different harvesting practices as an increment to the establishment of optimal parameters for canola cultivation.

## Material and methods

### Location characterization

The study was conducted at the Laboratory of Agroindustrial Process Engineering (LAPE) of the Federal University of Santa Maria, in partnership with the Agronomic Station of the State University of Rio Grande do Sul, Cachoeira do Sul, Rio Grande do Sul State, Brazil (30°02'20'' S, 52°53'38'' W; altitude of 125 m above sea level). The experiments were conducted during the 2019, 2020, and 2021 crop seasons. The climate of the region is classified as Cfa, a humid subtropical climate, with an average annual precipitation ranging from 1,600 to 1,900 mm and an average annual temperature of 20°C (Beck et al., 2018).

### Experimental design

The experiment was conducted on three sowing dates, suitable according to the climatic factors of each year. In 2019, the cultivation was implemented on the dates of June 7th, June 21st, and July 5th. In 2020, sowings were conducted on May 7th, May 27th, and June 12th. Finally, in 2021, sowings were established on April 27th, May 12th, and May 25th.

The Hyola 575 CL and Hyola 433 hybrids were used, implanted at a spacing of 34 cm, and sowing depth of approximately 2 cm, maintaining a population density of 440,000 plants ha$^{-1}$. The harvesting procedure was conducted manually, using the methods of harvesting by cut-row with and without adjuvant and direct harvest with and without adjuvant, with previous desiccation with the contact herbicide Diquat 200 SL Rainbow (Diquat dibromide; Diquate) at the dose of 1.5 L ha$^{-1}$. A latex-based adjuvant (Podstik) was used at a dose of 1.5 L ha$^{-1}$. The harvesting procedure was performed when the grain moisture was around 18 wt.%. The cut-row was performed when the plants reached physiological maturity.

The adopted experimental design was randomized blocks with four replications, with each experimental unit consisting of 4 m². Base fertilization was conducted with 250 kg ha$^{-1}$ of N, P, and K in the 2-30-15 formulation, and topdressing N fertilization of 120 kg ha$^{-1}$, according to the interpretation of the soil analysis of the Fertilization Manual. Crop harvesting and threshing were performed manually to quantify grain yield and biomass production (stems and siliques). Samples of canola obtained from a commercial cultivation area, provided by a rural producer in Cachoeira do Sul for the three crop seasons (2019, 2020, and 2021), were evaluated to compare the obtained values. These samples consisted of the Diamond hybrid, which was determined as a commercial hybrid.

### Agronomic components and harvest procedures

The agronomic components determined were grain yield (kg $ha^{-1}$), 1,000-grain weight, and biomass production (kg $ha^{-1}$). These evaluations were conducted separately for stalks and siliques, which were manually separated. Furthermore, four harvesting methods were performed: the direct harvest method (DH), harvest by cut-row (CR), direct harvest with the addition of adjuvant (DHA), and harvest by cut-row with the addition of adjuvant (CRA). Additionally, the grain yield was determined for each harvesting method.

### Grain analytical procedure

Lipid content was analyzed according to the method of Association of Official Analytical Chemists [AOAC] (1995). Accordingly, 2 g of the ground grain sample of each canola hybrid was weighed and placed in cartridges in a Soxhlet extractor device. The samples in the cartridges were inserted into the extraction chamber suspended above a flask, which contained 200 mL of 95 vol.% PA n-hexane (Dinâmica, Brazil). The flask was heated to evaporate the solvent, which moves in the gas phase towards the condenser (31-mm medium extractor condenser), converting into liquid and dripping into the cartridge containing the sample. The extraction chamber was designed to allow the solvent surrounding the sample to overflow into a flask when it is higher than the maximum height of the siphon, being then heated and evaporated, completing a six-hour cycle, completing a cycle for six hours. After extraction, the solvent was evaporated from the sample by a rotary evaporator (RE – 52A). Thereafter, the sample was placed in a desiccator to remove moisture.

Moreover, the acidity index was calculated by converting the percentage of free fatty acids in the sample into the amount (mg) of potassium hydroxide required to neutralize 1 g of the evaluated sample, according to the methodology described by American Oil Chemisys Society [AOCS] (2004).

The peroxide value was determined by the iodometric method, which is based on the measurement of the iodine ($I_2$) produced by oxidation from potassium iodide (KI) by the hydroperoxides present in the canola oil. The iodine produced was titrated with sodium thiosulfate ($Na_2S_2O_3$) in the presence of starch as an indicator. The peroxide index was expressed in terms of milliequivalents of $O_2$ per kilogram of oil (Moretto, Fett, Gonzaga, & Kuskoski, 2002).

The iodine value was determined according to the methodology proposed by Moretto et al. (2002). The procedure consisted of measuring the degree of unsaturation of fats since each double bond of fatty acid can incorporate two halogen atoms. More specifically, it is the number of grams of iodine absorbed per 100 g of fat or oil. Accordingly, the higher the unsaturation of fatty acid, the higher its iodine absorption capacity and, consequently, the bigger the iodine number.

The extinction coefficient was verified by the oil degree of oxidation, measured in ultraviolet spectrophotometric (UV-1900, Shimadzu, Japan) analysis by means of absorption at 232 and 268 nm by compounds present in the oil resulting from oxidative deterioration. The method consisted of the spectrophotometric measurement of the absorbance between 220 nm and 320 nm (scanning) or punctually at 232 nm and 268 nm of a solution of the sample diluted in an optically neutral solvent, as described by AOCS (1993). To perform this analysis, the oil was diluted in isooctane so that the absorbance reading was between 0.2 and 0.8. Flasks of 25 or 50 mL capacity were utilized, depending on the oxidative state of the oil. Finally, the saponification value was determined according to the methodology described by Moretto et al. (2002). The procedure verified the volume in mg of NaOH or KOH required to saponify 1 g of the fat sample.

The statistical effects of sowing date and different harvesting procedures on agronomic components and the quality of canola oil were evaluated. The Sisvar® 5.6 software was applied and a 95% ($p < 0.05$) significance level was considered.

## Results and discussion

Table 1 shows the low canola yield in the distinct crop seasons. Season 1 was the most productive for hybrid Hyola 433 and season 2 for hybrid Hyola 575 CL. Biomass, stalk, and silique productions were higher in the first crop season. The periods of late sowing occurred due to severe weather conditions, as water excess at the sowing time led to the need to reseed the cultivars. This yield is below the average for the State of Rio Grande do Sul (approximately, 1,422 kg ha$^{-1}$) (Companhia Nacional de Abastecimento [CONAB], 2020). This low productivity is due to the excessive rainfall activity that occurred in the region, which caused the reseeding of the experiment in late seasons outside the regional agroclimatic zoning, which indicates the sowing period between the second half of April and the first half of June.

In the 2020 crop season, hybrid Hyola 433 showed higher yields on the first and second sowing dates, while hybrid Hyola 575 CL presented a higher performance on the second sowing date, with a drastic productivity reduction for both hybrids on the third sowing date. Regarding biomass production, the highest results for both stalk and silique mass were found for hybrid Hyola 575 CL in the first and second sowing dates.

In the 2021 crop season, the highest grain yield was obtained on the first sowing date for both Hyola 433 and Hyola 575 CL hybrids. The biomass production of stalks was more expressive in the first and second sowing dates for hybrid Hyola 575 CL, whereas the highest biomass yield for silique production was obtained for hybrid Hyola 433 in the second sowing date. The 1,000-grain weight can be related to the crop productivity and is higher in higher-productivity crops although there is no statistical difference between the results.

**Table 1.** Grain yield and biomass (stems and siliques) of Hyola 575 CL and Hyola 433 hybrids on three sowing dates.

| Crop season 2019 | | | |
|---|---|---|---|
| Cv. | Sowing date 1 | Sowing date 2 | Sowing date 3 |
| | | Grain yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 374.22 $^{Bb}$ | 459.98 $^{Aa}$ | 201.57 $^{Cb}$ |
| Hyola 433 | 435.53 $^{Aa}$ | 289.99 $^{Cb}$ | 346.69 $^{Ba}$ |
| | | 1,000-grain weight (g) | |
| Hyola 575 CL | 2.62 $^{Aa}$ | 2.94 $^{Aa}$ | 2.73 $^{Aa}$ |
| Hyola 433 | 2.84 $^{Aa}$ | 2.61 $^{Aa}$ | 2.76 $^{Aa}$ |
| | | Stalk yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 2,400.00 $^{Aa}$ | 1,626.25 $^{Ba}$ | 593.75 $^{Bb}$ |
| Hyola 433 | 1,825.00 $^{Ab}$ | 672.50 $^{Ba}$ | 773.75 $^{Ba}$ |
| | | Silique yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 492.50 $^{Aa}$ | 426.25 $^{Aa}$ | 167.50 $^{Bb}$ |
| Hyola 433 | 517.50 $^{Aa}$ | 228.75 $^{Bb}$ | 288.75 $^{Ba}$ |
| Crop season 2020 | | | |
| Cv. | Sowing date 1 | Sowing date 2 | Sowing date 3 |
| | | Grain yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 1,165.00 $^{Aa}$ | 1,162.50 $^{Aa}$ | 500.00 $^{Bb}$ |
| Hyola 433 | 810.00 $^{ABb}$ | 1,165.00 $^{Aa}$ | 750.00 $^{Ba}$ |
| | | 1,000-grain weight (g) | |
| Hyola 575 CL | 4.58 $^{Aa}$ | 4.65 $^{Aa}$ | 4.21 $^{Aa}$ |
| Hyola 433 | 4.31 $^{Aa}$ | 4.26 $^{Aa}$ | 4.28 $^{Aa}$ |
| | | Stalk yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 1,100.00 $^{Aa}$ | 1,112.00 $^{Aa}$ | 612.50 $^{Ba}$ |
| Hyola 433 | 580.00 $^{Ab}$ | 540.00 $^{Ab}$ | 620.00 $^{Aa}$ |
| | | Silique yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 1,250.00 $^{Aa}$ | 1,425.00 $^{Aa}$ | 925.00 $^{Ba}$ |
| Hyola 433 | 540.00 $^{Bb}$ | 732.50 $^{ABb}$ | 825.00 $^{Aa}$ |
| Crop season 2021 | | | |
| Cv. | Sowing date 1 | Sowing date 2 | Sowing date 3 |
| | | Grain yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 1,083.00 $^{Aa}$ | 820.31 $^{Ba}$ | 815.94 $^{Ba}$ |
| Hyola 433 | 1,171.87 $^{Aa}$ | 940.31 $^{Ba}$ | 627.50 $^{Cb}$ |
| | | 1,000-grain weight (g) | |
| Hyola 575 CL | 3.14 $^{Aa}$ | 3.60 $^{Aa}$ | 3.37 $^{Aa}$ |
| Hyola 433 | 3.64 $^{Aa}$ | 3.10 $^{Aa}$ | 3.28 $^{Aa}$ |
| | | Stalk yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 1,046.88 $^{Aa}$ | 1,106.25 $^{Aa}$ | 915.62 $^{Ba}$ |
| Hyola 433 | 896.87 $^{Bb}$ | 1,150.00 $^{Aa}$ | 962.50 $^{Aba}$ |
| | | Silique yield (kg ha$^{-1}$) | |
| Hyola 575 CL | 921.87 $^{Ab}$ | 891.25 $^{Aa}$ | 865.68 $^{Ab}$ |
| Hyola 433 | 1,093.75 $^{Aa}$ | 886.00 $^{Ba}$ | 1,000.00 $^{Aa}$ |

*Upper letter: comparison in the row; lowercase letter: comparison in the column.

The data shown in Table 1 corroborate the results reported by Lundin, Myrbeck, and Bommarco (2018), who observed that late canola sowing negatively affected plant height and the number of seeds per silique regardless of the hybrid, causing a reduction in grain and biomass production. It is due to an increase in temperature and solar radiation, harming the development of the plant, which prefers a mild climate (Fatima et al., 2020). Accordingly, Figure 1 shows the climatic scenario during the 2019 (A), 2020 (B), and 2021 (C) crop seasons.

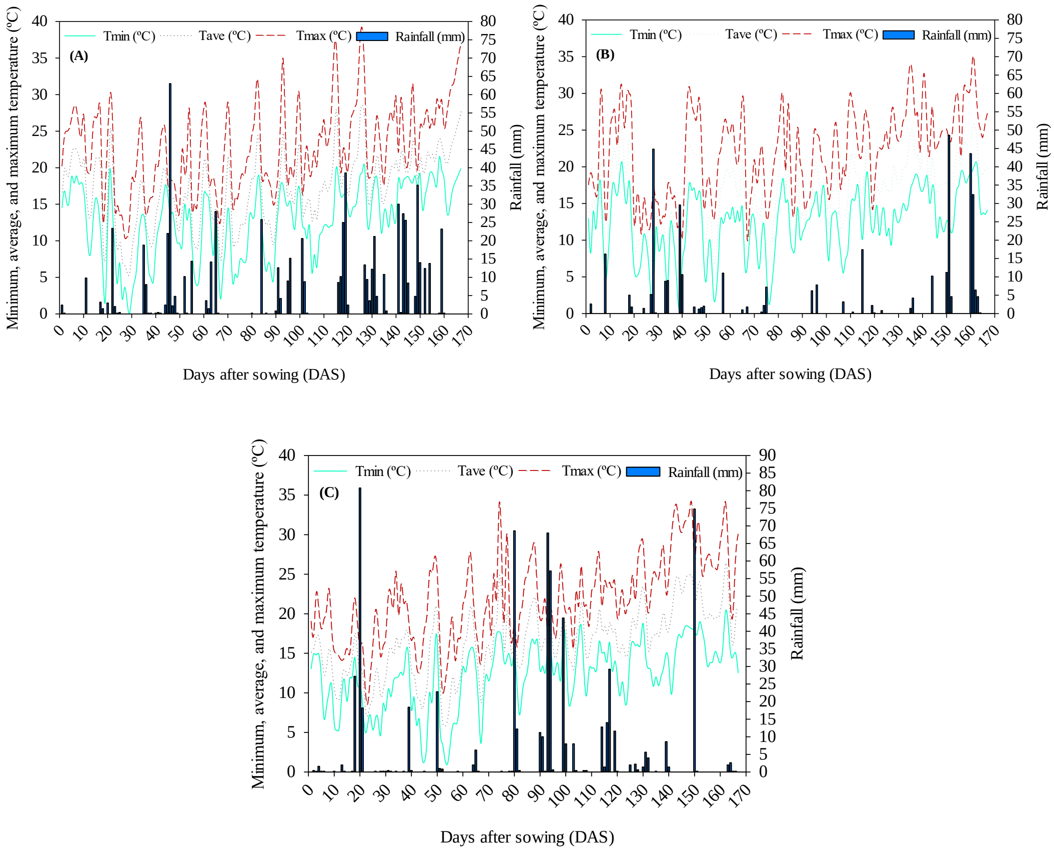


**Figure 1.** Climatic characterization in the different crop seasons in 2019 (A), 2020 (B), and 2021 (C) based on the minimum temperature (Tmin, °C), average temperature (Tave, °C), maximum temperature (Tmax, °C), and rainfall (mm) in Cachoeira do Sul, Rio Grande do Sul, Brazil.

Canola yield is directly related to the climatic conditions and sowing time. Although the canola crop has a relatively low water requirement during its cycle, i.e., around 500 mm, it is sensitive to water deficit during the flowering and grain-filling phases, which can lead to a reduction in its vegetative period (Mohammadi & Rokhzadi, 2012). Furthermore, Safavi Fard, Heidari Sharif Abad, Shirani Rad, Majidi Heravan, and Daneshian (2018) indicated that late sowing leads to a reduction in the cycle of the two hybrids, and the effect of air temperature on the duration of the sub-periods is more marked in canola flowering. During the 2019 crop season, the sowing date, emergence, and rosette stage of plants sown in the first season had rainfalls of 48 and 177.8 mm in June and July, respectively. The average temperature in June was 16.6°C, with temperature peaks below 5°C and close to 30°C. Similar temperature conditions were observed in July and August. Nonetheless, the monthly average temperature was below 10°C in September and October, a period of flowering and grain formation, with rainfall of 80 and 244.2 mm and average temperatures of 9.5 and 17.5°C, respectively. However, extremely high-temperature peaks were recorded (35 to 40°C) (Figure 1).

In the 2020 crop season, a rainfall of 215.4 mm was recorded in the initial periods of crop development and an average temperature of 19.1°C, with peaks above 30°C, was observed in May (Figure 1). In June, a precipitation of 143.2 mm, with an average monthly temperature of 10.6°C and peaks above 30 and 5°C. In July, temperatures below 5°C were recorded. In September and October, the period of flowering and grain filling, the rainfall recorded was 236.4 and 67 mm, respectively, while September had mild temperatures, with an average of 12.2°C, and October had an average temperature of 22.8°C, with peaks close to 35°C.

In 2021, a period of drought was observed in April, with accumulated rainfall of 7.8 mm and high temperatures, with an average of 27.6°C. In May, rainfall was 215.4 mm, with a mild temperature (19.8°C) compared to the previous month. June had an average temperature of 13.2°C, with values ranging from 5 to 30°C, while the accumulated precipitation was 143.2 mm. The accumulated precipitation in September and October was 236.4 and 67 mm, respectively, with mild average temperatures of 21.4 and 18.97°C, with peaks above 25°C.

Accordingly, canola seed germination can occur in a wide temperature range, the ideal ranging from 12 to 33°C, and temperatures above 35°C inhibit crop germination (Butkevičienė et al., 2021). Low temperatures lead to a reduction in germination, which may be related to a loss or delay in the mobilization of seed reserve compounds (Luo et al., 2021). The ideal average temperature during the cycle is 20°C for good crop development, reducing the development and growth of the plant at temperatures below 5°C (Wang, Xiong, Zhang, Wu, & Liu 2022). Nonetheless, the critical period for determination of canola yield occurs from the beginning of flowering to the period of grain fixation (Kirkegaard, Lilley, Brill, Ware, & Walela, 2018).

The occurrence of frosts at the flowering stage can cause flower and silique abortion, directly influencing crop productivity. Similarly, high temperatures at this stage can also cause the same damage. The flowering and grain-filling phases are also the most sensitive to water deficit, in addition to the shortening of the vegetative period (Koscielny, Gardner, & Duncan, 2018). Damages such as the reduction of siliques per plant, thousand-grain mass, and production are also caused by water deficits (Elferjani & Soolanayakanahally, 2018).

Moreover, the harvesting systems by cut-row and cut-row with the addition of adjuvant presented the lowest harvest losses (Table 2). The CRA harvesting system had the highest grain yield. In the 2020 crop season, the grain yield difference was 38.8% between the CRA and CR methods. In the 2021 crop season, the yield obtained by the CRA method was 32.7% higher than that of the DH method. The cut-row harvesting system accelerates and standardizes grain drying, in addition to reducing threshing losses, especially under adverse weather conditions through the formation of a compacted mass with half the height of the plants that remain upright in conventional crops (Pizolotto, Boller, Lângaro, & Tomm, 2018).

Additionally, canola harvesting methods with prior chemical desiccation and direct harvesting with adhering adjuvant promote lower losses. The bonding adjuvant acts as an adhesive agent, favoring the deposition and retention of the product applied to the siliques, preventing or delaying their opening during maturation (Haile, Gulden, & Shirtliffe, 2014).

**Table 2.** Grain yield (kg $ha^{-1}$) obtained with distinct harvesting methods.

| Crop season | Harvest procedure | | | |
|---|---|---|---|---|
| | DH* | CR** | DHA*** | CRA**** |
| 2019 | 291.20 $^{B}$ | 409.22 $^{A}$ | 323.42 $^{B}$ | 457.91 $^{A}$ |
| 2020 | 919.06 $^{AB}$ | 665.83 $^{C}$ | 892.91 $^{B}$ | 1,088.64 $^{A}$ |
| 2021 | 744.58 $^{C}$ | 938.54 $^{AB}$ | 848.96 $^{BC}$ | 1,107.71 $^{A}$ |

*Direct harvest method (DH); **harvest by cut-row (CR); ***direct harvest with the addition of adjuvant (DHA); and ****harvest by cut-row with the addition of adjuvant (CRA).

Oil content was also reduced in this crop, with the highest oil yield found in hybrid Hyola 575 CL on the first sowing date (26.8 wt.%). Although the oil contents were affected by the crop season conditions, the values were higher than those found in the commercial crop sample (13.7 wt.%) (Figure 2). In the 2020 crop season, hybrid Hyola 575 CL stood out on all sowing dates, with more than 40 wt.% oil content, while the commercial crop sample had 31.4 wt.% oil content. In the 2021 crop season, no significant difference was observed between hybrids and crop seasons, with all hybrids showing oil contents above 30 wt.%, while the commercial crop sample had 23.4 wt.% (Figure 2).

The acid index can be defined as the amount of potassium hydroxide in mg required to neutralize the free fatty acids (R-COOH) of 1 g of the oil sample under analysis. The lowest acidity indices of the oils were found in the 2019 crop season. High acidity indices were found in hybrid Hyola 575 CL on the first and third sowing dates in the 2020 season (Figure 3). The values were close to those found by Encinar, Nogales-Delgado, Sánchez, and González (2020), who observed acid indices in canola oil of 0.175 mg KOH $g^{-1}$. These values were also compatible with the literature, which states that commercially available crude oils have an acidity index between 0.5 and 3% (Kusdiana & Saka, 2001). Rovere, Rodrigues, and Teleken (2020) found an acidity index for the canola crop of 8 mg KOH $g^{-1}$.

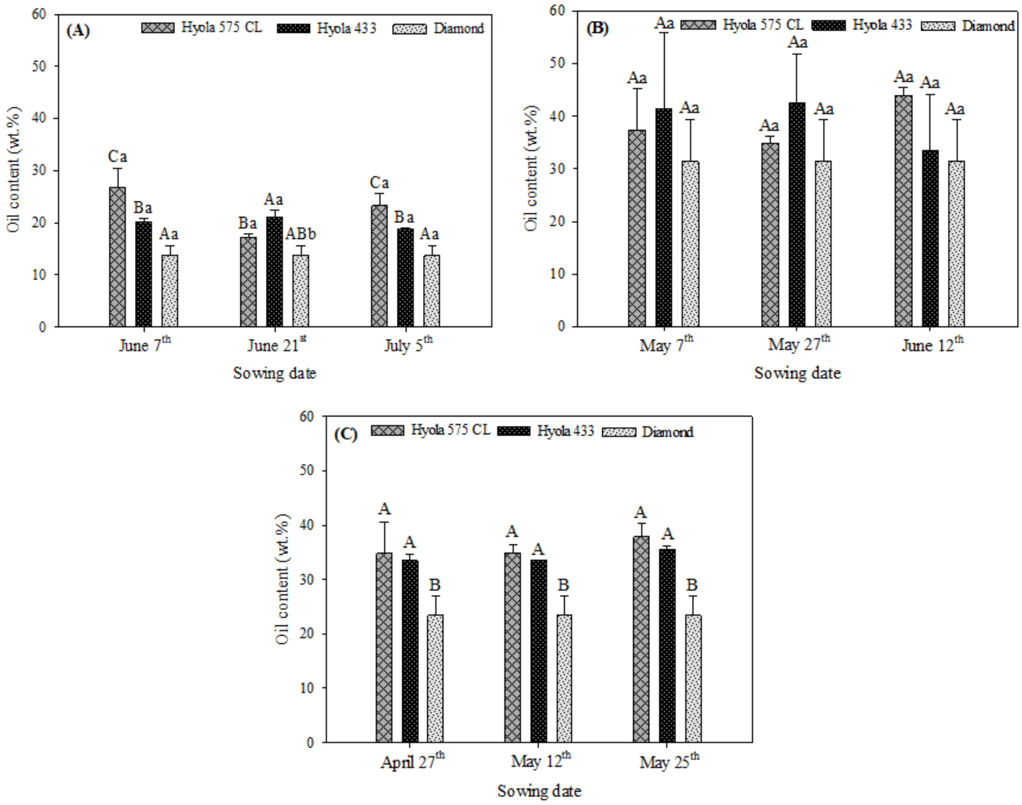


**Figure 2.** Oil content (wt.%) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for the (A) 2019, (B) 2020, and (C) 2021 crop seasons.

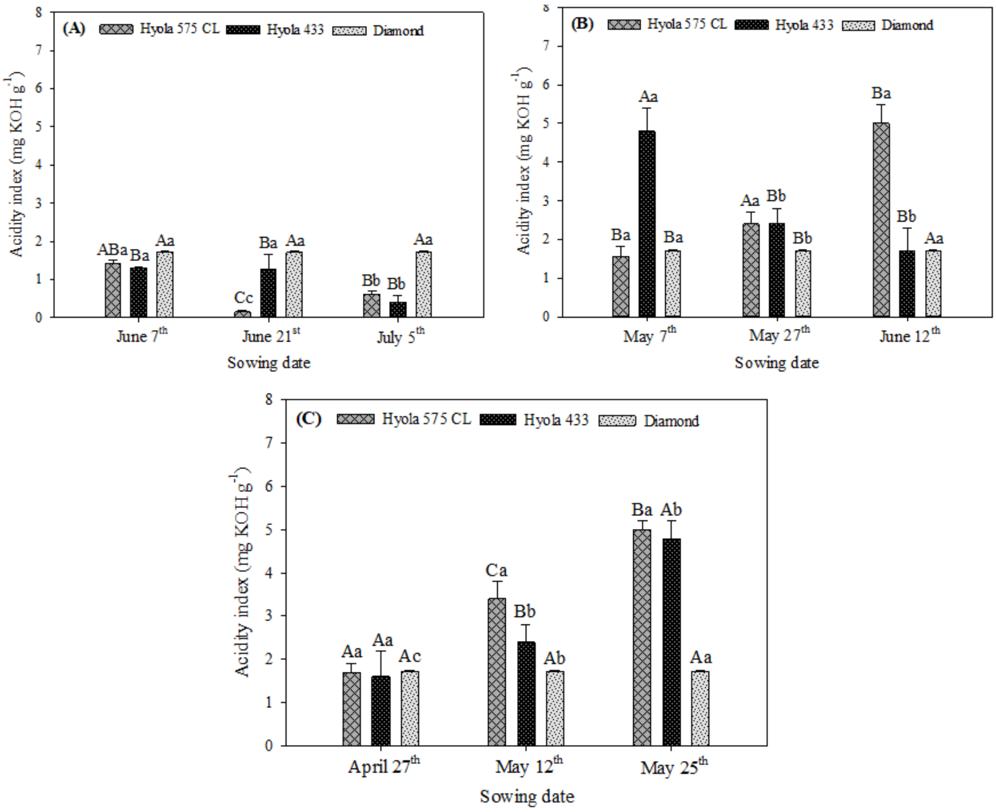


**Figure 3.** Acidity index (mg KOH $g^{-1}$) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for the (A) 2019, (B) 2020, and (C) 2021 crop seasons.

The acidity index reveals the state of oil conservation. The decomposition of glycerides is accelerated due to heating and light, and rancidity is almost always accompanied by the formation of free fatty acids. The free acidity of fat results from the partial hydrolysis of glycerides. Therefore, it is not a constant or characteristic, but a variable closely related to the nature and quality of the raw material, the quality and degree of purity of the fat, and the processing and, mainly, the conservation conditions of the fat (Di Pietro, Mannu, & Mele, 2020). Rocha, Bôas, Biaggio, Castro, and Giordani (2018) reported canola raw materials with an acidity index of approximately 0.13 mg KOH g-1 and raw materials with higher values cannot be used for biodiesel production, as free fatty acids react with the basic catalyst (KOH or NaOH), forming soap, reducing the reaction yield due to the consumption of catalyst in the parallel reaction.

Furthermore, a notable and effective difference was observed between the levels of acidity between distinct canola cultivars in different crop seasons. Considering that a high degree of acidity leads to a higher oil deterioration performance, the 2019 crop season showed reduced acidity index values (Jimenez-Lopez et al., 2020). This scenario may be directly associated with lower rainfall and milder temperatures in the months of plant reproductive development. Higher moisture levels result in higher damage due to the intensity of lipase action, drastically reducing oil acidity, which directly affects oil conservation and quality (Morcillo et al., 2013).

Accordingly, the peroxide index is a classic method for determining hydroperoxides, primary oxidation products. The peroxide index was higher for both hybrids in the first date season of the 2019 crop season, with the lowest value for hybrid Hyola 575 CL grown in the second season. In 2020, the peroxide index of the hybrids was very close, except for Hyola 575 CL on the first sowing date, which had a value of 0.96 mEq kg-1. Similarly, in the 2021 crop season, little variation in the peroxide index was observed between hybrids and growing seasons, with values close to 2 mEq $kg^{-1}$ and 3 mEq $kg^{-1}$ (Figure 4). Freitas & Jorge (2022) observed similar values when analyzing crude canola oil from different brands, with values between 2.07 and 3.38 mEq $kg^{-1}$. These results also agree with Ortegón-Morales, González-Quintero, Díaz-Franco, and Castillo-Torres (2009), who reported that the oxidation rate depends on several factors, such as oxygen availability, the presence of light, and temperature. Auto-oxidation, which occurs in the absence of light, follows a free radical mechanism, in which the absorption of oxygen initially results in the formation of hydroperoxides.

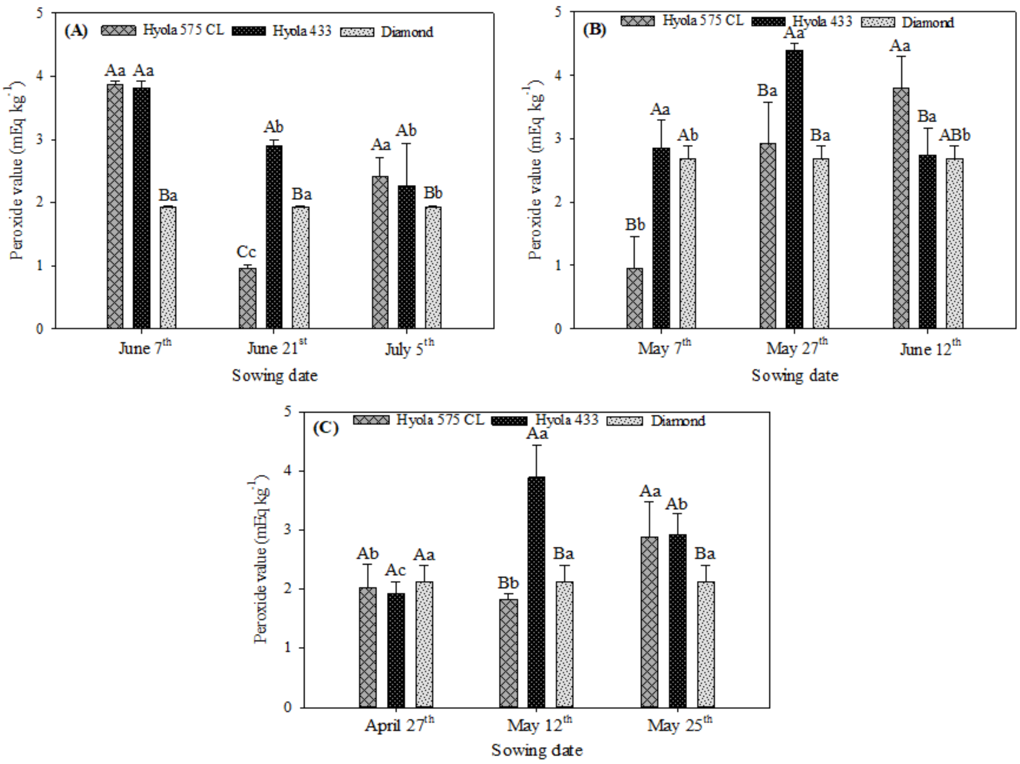


**Figure 4.** Peroxide value (mEq $kg^{-1}$) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for the (A) 2019, (B) 2020, and (C) 2021 crop seasons.

A collaborative study with the (American Oil Chemists' Society [AOCS], 1993) suggested a classification for the level of oxidation of vegetable oils considering their peroxide indices: oils with values ranging from 3 to 5 mEq $kg^{-1}$ were considered low oxidized, 10 to 12 mEq $kg^{-1}$ had moderate oxidation, and 16 to 18 mEq $kg^{-1}$ had a high oxidation level.

Contextually, the peroxide value indicated effectively low values, which means a low biomaterial degradation. Moreover, a standard performance was not identified, considering the different canola cultivars and crop seasons. In the 2019 crop season, a drastic reduction in peroxide value was observed on the different sowing dates. The other crop seasons showed a slight increase as the sowing date was later. This assertion is associated with the acidity index, which presented higher values in the 2020 and 2021 crop seasons. Considering that the peroxide value is an indication of the degree of oil oxidative degradation, as well as the acidity index, drier years with less rainfall in the reproductive period and close to harvest resulted in lower peroxide value and acidity index values. This scenario is shown in Figure 4 (a), which indicated a higher acidity index on the sowing date of June 7$^{th}$, 2019. Furthermore, the rainfall pattern in this crop season was heterogeneous, with a higher incidence of rainfall precisely in the vegetative stage of the plant and close to harvest, which can drastically affect product quality and intensify degradation. Also, the profile of higher peroxide value in later sowings corroborates the influence of temperature and sun exposure on oil degradation. The increase in peroxide value reported that exposure to higher solar radiation and high temperature intensifies the synthesis of lipid peroxide molecules (Almeida, Viana, Costa, Silva, & Feitosa, 2018).

Appropriately, Figure 5 shows low values of the iodine index in the 2019 crop season, with hybrid Hyola 575 CL in the third growing season and the commercial crop sample showing the highest values, above 120 mg KI g$^{-1}$. Values above 100 mg KI g$^{-1}$ were observed in the 2020 crop season, except for the commercial crop sample, with a value of 63.6 mg KI g$^{-1}$. In 2021, only hybrid Hyola 575 CL in the second growing season and the sample from the commercial crop showed values above 100 mg KI g$^{-1}$.

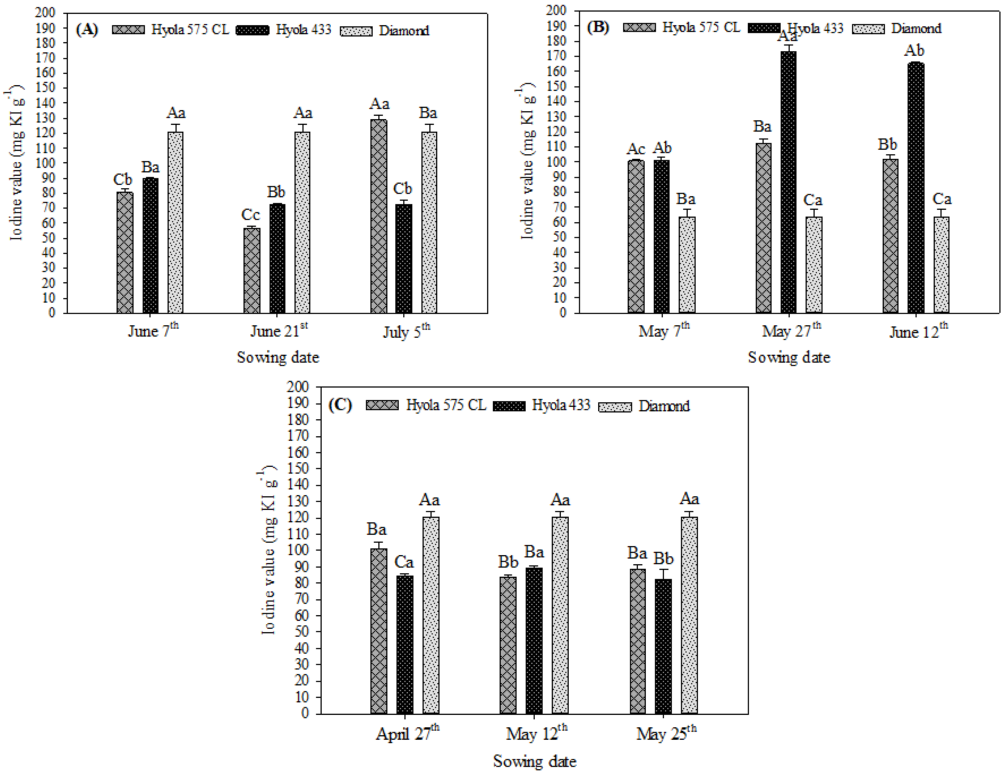


**Figure 5.** Iodine value (mg KI g$^{-1}$) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for the (A) 2019, (B) 2020, and (C) 2021 crop seasons.

The low values for this index were due to the breakage of double bonds resulting from polymerization, cyclization, and oxidation reactions, always associated with an increase in the melting point and consistency of the sample, mainly due to the incorporation of saturated fats into the oil. Iodine can be quantitatively introduced into the double bonds of unsaturated fatty acids and triglycerides under certain conditions (Dymińska et al., 2017). Therefore, the iodine index provides a measure of the degree of unsaturation of ether-extracted fats. Consequently, the higher the unsaturation of fatty acid, the higher its iodine absorption capacity and the iodine index (Arab et al., 2022).

Additionally, the oxidation of polyunsaturated fatty acids can be analyzed by the increase in absorbance in the range of the ultraviolet spectrum. During oxidation, lipids containing dienes or polyenes show significant alterations in the position of their double bonds as a result of isomerization and conjugation. The formation of dienes and trienes is proportional to the gain of oxygen and the formation of peroxides during the initial stages of oxidation (Lukešová, Dostálová, El-Moneim Mahmoud, & Svárovská, 2009).

According to this study, in 2019, the highest absorbance indices were observed at the range of $K_{232nm}$ for hybrid Hyola 575 CL in the first and third growing seasons and Hyola 433 in the third growing season, with values above 4 $E^{1\%}$1cm. The values found in the 2020 crop season were low compared to the previous crop, specifically for hybrid Hyola 575 CL, with a value of 0.64 $E^{1\%}$1cm. Similar values were observed in the 2021 crop season, as observed in hybrid Hyola 433 in the first growing season (1.03 $E^{1\%}$1cm) and the commercial crop sample (3.16 $E^{1\%}$1cm) (Table 3).

**Table 3.** Extinction coefficient ($E^{1\%}$1cm) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for 2019, 2020, and 2021 crop seasons.

| | | Extinction coefficient ($E^{1\%}$1cm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Crop season 2019 | | Crop season 2020 | | Crop season 2021 | |
| Sowing date | Cv. | $K_{232\ nm}$ | $K_{270\ nm}$ | $K_{232\ nm}$ | $K_{270\ nm}$ | $K_{232\ nm}$ | $K_{270\ nm}$ |
| 1 | Hyola 433 | 3.64 ± 0.13 | 1.13 ± 0.18 | 1.68 ± 0.15 | 0.35 ± 0.04 | 1.03 ± 0.01 | 0.28 ± 0.03 |
| 1 | Hyola 575 CL | 4.62 ± 1.50 | 2.51 ± 0.25 | 0.64 ± 0.09 | 0.35 ± 0.07 | 2.25 ± 0.17 | 0.41 ± 0.03 |
| 2 | Hyola 433 | 3.48 ± 1.19 | 0.90 ± 0.08 | 1.77 ± 0.41 | 0.55 ± 0.03 | 2.18 ± 0.15 | 0.25 ± 0.07 |
| 2 | Hyola 575 CL | 2.58 ± 0.15 | 0.77 ± 0.07 | 2.61 ± 0.27 | 0.27 ± 0.03 | 2.58 ± 0.09 | 0.6 ± 0.01 |
| 3 | Hyola 433 | 4.15 ± 0.38 | 1.00 ± 0.13 | 1.41 ± 0.11 | 0.46 ± 0.10 | 2.89 ± 0.27 | 0.31 ± 0.02 |
| 3 | Hyola 575 CL | 4.03 ± 1.11 | 2.25 ± 0.30 | 1.56 ± 0.38 | 0.76 ± 0.05 | 1.78 ± 0.14 | 0.59 ± 0.03 |
| - | Diamond | 2.50 ± 0.28 | 1.00 ± 0.46 | 1.06 ± 0.17 | 0.38 ± 0.01 | 3.16 ± 0.70 | 0.82 ± 0.03 |

The absorptivity in the range of $K_{270nm}$ shows that the 2019 crop season had higher values than the other crops, with similar values only in the hybrids grown in the second season, that is, 0.90 and 0.77 $E^{1\%}$1cm for Hyola 575 CL and Hyola 433, respectively. Similar values were obtained for both hybrids and their different growing seasons in the 2020 and 2021 seasons, with the highest indices identified for Hyola 575 CL in the third growing season (0.76 $E^{1\%}$1cm) in 2020 and commercial hybrid sample (0.82 $E^{1\%}$1cm) in 2021. According to Ghorbani Gorji, Calingacion, Smyth, and Fitzgerald (2019), the presence of a higher amount of linoleic acid makes the oil more susceptible to lipid oxidation.

Furthermore, the saponification index is a factor of considerable importance in determining the quality of the raw material for biodiesel production. According to Pasha, Dai, Liu, Guo, and Du (2021), the saponification reaction formed by the free fatty acids increases the solubility of the esters formed in the glycerol, which can interfere with the phase separation or even cause the loss of esters at the time of separation of glycerol with the glycerol of the biodiesel. Appropriately, Figure 6 shows the saponification values of the oils obtained in the 2020 and 2021 crop seasons. There was not enough raw material to extract enough oil for all the analyses due to the low yield of the 2019 crop season. Accordingly, this study indicates a close relationship between values for both hybrids and their different sowing dates.

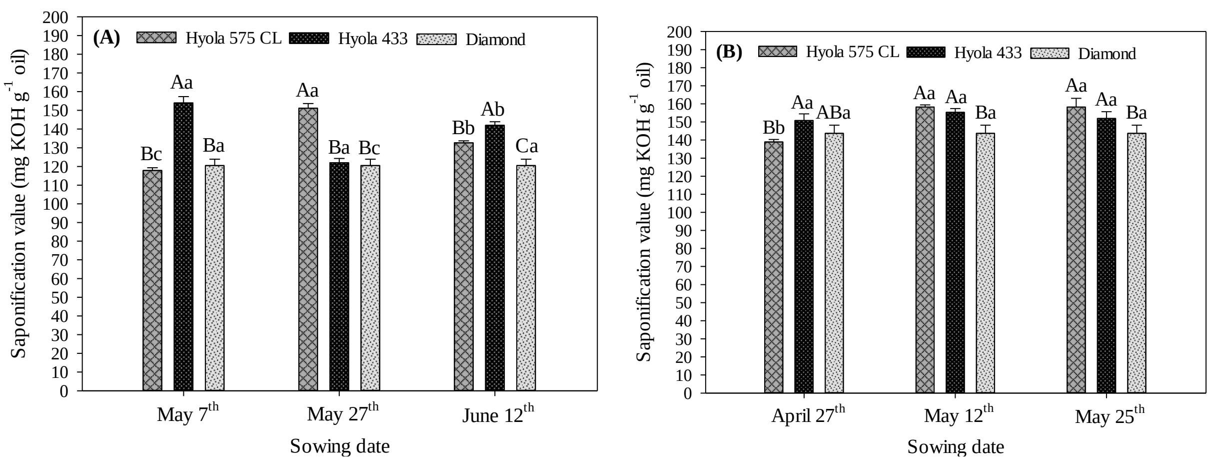


**Figure 6.** Saponification value (mg KOH $g^{-1}$ oil) of hybrids Hyola 575 CL, Hyola 433, and Diamond on three sowing dates for the (A) 2020 and (B) 2021 crop seasons.

## Conclusion

This study indicated that canola is extremely sensitive to climatic conditions, mainly temperature. Moreover, temperature peaks directly affected its productivity, as well as the sowing date, reducing grain and biomass yield in late sowing. The cut-row harvesting method with the addition of a sealant adjuvant is the most efficient in minimizing harvest losses. The oil and grain quality were also factors significantly influenced by the weather conditions. Finally, canola oil has a high potential mainly due to its biochemical properties, indicating a correlation between cultivars with higher oil yield and better oil quality.

## Acknowledgements

This study was supported by the Coordination for the Improvement of Higher Education Personnel (CAPES), the National Council of Scientific and Technological Development (CNPq), and the Research Support Foundation of the State of Rio Grande do Sul (FAPERGS - 21/2551-0002253-1). G. L. Zabot thanks CNPq (304882/2018-6) for the productivity grant. M. V. Tres thanks CNPq (308936/2017-5; 428180/2018-3; 306241/2020-0) for the productivity grant.

## References

Almeida, D. T., Viana, T. V., Costa, M. M., Silva, C. S., & Feitosa, S. (2018). Effects of different storage conditions on the oxidative stability of crude and refined palm oil, olein and stearin (*Elaeis guineensis*). *Food Science and Technology*, *39*(Suppl. 1), 211-217. DOI: https://doi.org/10.1590/fst.43317

American Oil Chemists' Society [AOCS]. (1993). *Official methods and recommended practices 3* (4th ed.). Champaign, US: AOCS.

American Oil Chemisys Society [AOCS]. (2004). *Official Methods and Recommended Practices of the American Oil Chemists Society*. Champaign, US: AOCS.

Arab, R., Casal, S., Pinho, T., Cruz, R., Freidja, M. L., Lorenzo, M., ... Boulekbache-Makhlouf, L. (2022). Effects of seed roasting temperature on sesame oil fatty acid composition, lignan, sterol and tocopherol contents, oxidative stability and antioxidant potential for food applications. *Molecules*, *27*(14), 1-15. DOI: https://doi.org/10.3390/molecules27144508

Association of Official Analytical Chemists [AOAC] (1995). *Official methods of analysis of the Association of Official Analytical Chemists* (16th ed.). Washington, DC: AOAC.

Beck, H. E, Zimmermann, N. E, McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data*, *5*, 1-12. DOI: https://doi.org/10.1038/sdata.2018.214

Butkevičienė, L. M., Kriaučiūnienė, Z., Pupalienė, R., Velička, R., Kosteckienė, S., Kosteckas, R., & Klimas, E. (2021). Influence of sowing time on yield and yield components of spring rapeseed in Lithuania. *Agronomy*, *11*(11), 1-15. DOI: https://doi.org/10.3390/agronomy11112170

Companhia Nacional de Abastecimento [CONAB] (2020). *Acompanhamento da safra brasileira de grãos 7 - Safra 2019/20*. Retreived on Dec. 10, 2022 from https://www.conab.gov.br/

Di Pietro, M. E., Mannu, A. & Mele, A. (2020). NMR determination of free fatty acids in vegetable oils. *Processes*, *8*(4), 1-15. DOI: https://doi.org/10.3390/PR8040410

Dymińska, L., Calik, M., Albegar, A. M. M., Zając, A., Kostyń, K., Lorenc, J., & Hanuza, J. (2017). Quantitative determination of the iodine values of unsaturated plant oils using infrared and Raman spectroscopy methods. *International Journal of Food Properties*, *20*(9), 2003-2015. DOI: https://doi.org/10.1080/10942912.2016.1230744

Elferjani, R., & Soolanayakanahally, R. (2018). Canola responses to drought, heat, and combined stress: shared and specific effects on carbon assimilation, seed yield, and oil composition. *Frontiers in Plant Science*, *9*(1224), 1-17. DOI: https://doi.org/10.3389/fpls.2018.01224

Encinar, J. M., Nogales-Delgado, S., Sánchez, N., & González, J. F. (2020). Biolubricants from rapeseed and castor oil transesterification by using titanium isopropoxide as a catalyst: production and characterization. *Catalysts*, *10*(4), 1-12. DOI: https://doi.org/10.3390/catal10040366

Fatima, Z., Ahmed, M., Hussain, M., Abbas, G., Ul-Allah, S., Ahmad, S., ... Hussain, S. (2020). The fingerprints of climate warming on cereal crops phenology and adaptation options. *Scientific Reports*, *10*, 1-21. DOI: https://doi.org/10.1038/s41598-020-74740-3

Flakelar, C. L., Adjonu, R., Doran, G., Howitt, J. A., Luckett, D. J., & Prenzler, P. D. (2022). Phytosterol, tocopherol and carotenoid retention during commercial processing of *Brassica napus* (Canola) oil. *Processes*, *10*(3), 1-15. DOI: https://doi.org/10.3390/pr10030580

Freitas, I. R., & Jorge, N. (2022). Caraterização físico-química de óleos brutos de soja, canola, milho e girassol. In C. M. Veronezi, A. C. Silva, I. R. Freitas, & N. Jorge (Orgs.), *Óleos vegetais: propriedades físico-químicas, bioativas e antioxidantes* (p. 45-59). Jardim do Seridó, RN: Agron Food Academy. DOI: https://doi.org/10.53934/9786585062022-3

Ghorbani Gorji, S., Calingacion, M., Smyth, H. E., & Fitzgerald, M. (2019). Comprehensive profiling of lipid oxidation volatile compounds during storage of mayonnaise. *Journal of Food Science and Technology*, *56*, 4076-4090. DOI: https://doi.org/10.1007/s13197-019-03876-6

Haile, T.A., Gulden, R. H., & Shirtliffe, S. J. (2014). On-farm seed loss does not differ between windrowed and direct-harvested canola. *Canadian Journal of Plant Science*, *94*(4), 785-789. DOI: https://doi.org/10.4141/CJPS2013-344

Huang, J., Huang, G., Xin, X., Halstead, D., Gaetz, K., Benmerrouche, L., ... Zhang, J. (2021). Characterization of canola growth and in-vivo element fate in Canadian prairie under the interferences of tillage and residue treatment. *Journal of Cleaner Production*, *32*, 128707. DOI: https://doi.org/10.1016/j.jclepro.2021.128707

Iqbal, W., Afridi, M. Z., Jamal, A., Mihoub, A., Saeed, M. F., Zia, A., ... Pompelli, M. F. (2022). Canola seed priming and its effect on gas exchange, chlorophyll photobleaching, and enzymatic activities in response to salt stress. *Sustainability*, *14*(15), 1-22. DOI: https://doi.org/10.3390/su14159377

Jimenez-Lopez, C., Carpena, M., Lourenço-Lopes, C., Gallardo-Gomez, M., Lorenzo, J. M., Barba, F. J., ... Simal-Gandara, J. (2020). Bioactive compounds and quality of extra virgin olive oil. *Foods*, *9*(8), 1-31. DOI: https://doi.org/10.3390/foods9081014

Kirkegaard, J. A., Lilley, J. M., Brill, R. D., Ware, A. H., & Walela, C. K. (2018). The critical period for yield and quality determination in canola (*Brassica napus* L.). *Field Crops Research*, *222*, 180-188. DOI: https://doi.org/10.1016/j.fcr.2018.03.018

Koscielny, C. B., Gardner, S. W., & Duncan, R. W. (2018). Impact of high temperature on heterosis and general combining ability in spring canola (*Brassica napus* L.). *Field Crops Research*, *221*, 61-70. DOI: https://doi.org/10.1016/j.fcr.2018.02.014

Kusdiana, D., & Saka, S. (2001). Methyl esterification of free fatty acids of rapeseed oil astreated in supercritical methanol. *Journal of Chemical Engineering of Japan*, *34*(3), 383-387. DOI: https://doi.org/10.1252/jcej.34.383

Lukešová, D., Dostálová, J., El-Moneim Mahmoud, E., & Svárovská, M. (2009). Oxidation changes of vegetable oils during microwave heating. *Czech Journal of Food Science*, *27*(10), 178-181. DOI: https://doi.org/10.17221/929-cjfs

Lundin, O., Myrbeck, A., & Bommarco, R. (2018). The effects of reduced tillage and earlier seeding on flea beetle (*Phyllotreta* spp.) crop damage in spring oilseed rape (*Brassica napus* L.). *Journal of Crop Protection*, *107*, 104-107. DOI: https://doi.org/10.1016/j.cropro.2017.10.019

Luo, T., Zhang, Y., Zhang, C., Nelson, M. N., Yuan, J., Guo, L., & Xu, Z. (2021). Genome-wide association mapping unravels the genetic control of seed vigor under low-temperature conditions in rapeseed (*Brassica napus* L.). *Plants*, *10*(3), 1-19. DOI: https://doi.org/10.3390/plants10030426

Madsen, I. J., Parks, J. M., Friesen, M. L., & Clark, R. E. (2022). Increasing biodiversity and land-use efficiency through pea (*Pisum aestivum*) -Canola (*Brassica napus*) intercropping (Peaola). *Frontiers in Plant Science*, *2*(818862), 1-12. DOI: https://doi.org/10.3389/fsoil.2022.818862

Marjanović-Jeromela, A., Terzić, S., Jankulovska, M., Zorić, M., Kondić-Špika, A., Jocković, M., ... Nagl, N. (2019). Dissection of year related climatic variables and their effect on winter rapeseed (*Brassica napus* L.) development and yield. *Agronomy*, *9*(9), 1-21. DOI: https://doi.org/10.3390/agronomy9090517

Meier, E., Lilley, J., Kirkegaard, J., Whish, J., & McBeath, T. (2020). Management practices that maximise gross margins in Australian canola (*Brassica napus* L.). *Field Crops Research*, *252*, 107803. DOI: https://doi.org/10.1016/j.fcr.2020.107803

Mohammadi, K., & RokhzadI, A. (2012). An integrated fertilization system of canola (*Brassica napus* L.) production under different crop rotations. *Industrial Crops and Products*, *37*(1), 264-269. DOI: https://doi.org/10.1016/j.indcrop.2011.12.023

Monfared, B. B., Noormohamadi, G., Rad, A. H. S., & Hervan, E. M. (2020). Effects of sowing date and chitosan on some characters of canola (*Brassica napus* L.) genotypes. *Journal of Crop Science and Biotechnology*, *23*(1), 65-71. DOI: https://doi.org/10.1007/s12892-019-0177-0

Morcillo, F., Cros, D., Ngando-Ebongue, G.-F., Domonhédo, H., Pizot, M., Cuéllar, T., ... Arondel, V. (2013). Improving palm oil quality through identification and mapping of the lipase gene causing oil deterioration. *Nature Communications*, *4*(2160), 1-8. DOI: https://doi.org/10.1038/ncomms3160

Moretto, E., Fett, R., Gonzaga, L., Kuskoski, E. (2002). *Introdução à ciência de alimentos*. Florianópolis, SC: Editora UFSC.

Neupane, D., Solomon, J. K. Q., Mclennon, E., Davison, J., & Lawry, T. (2019). Sowing date and sowing method influence on camelina cultivars grain yield, oil concentration, and biodiesel production. *Food and Energy Security*, *8*(3), 1-17. DOI: https://doi.org/10.1002/fes3.166

Pasha, M. K., Dai, L., Liu, D., Guo, M., & Du, W. (2021). An overview to process design, simulation and sustainability evaluation of biodiesel production. *Biotechnology for Biofuels and Bioproducts*, *14*(129), 1-23. DOI: https://doi.org/10.1186/s13068-021-01977-z

Pixley, K. V., Falck-Zepeda, J. B., Paarlberg, R. L., Phillips, P. W. B., Slamet-Loedin, I. H., Dhugga, K. S., ... Gutterson, N. (2022). Genome-edited crops for improved food security of smallholder farmers. *Nature Genetics*, *54*(4), 364-367. DOI: https://doi.org/10.1038/s41588-022-01046-7

Pizolotto, C. A., Boller, W., Lângaro, N. C., & Tomm, G.O. (2018). Management to reduce losses in canola pre-harvest under high rainfall. *Revista de Ciências Agroveterinarias*, *17*(2), 219-225. DOI: https://doi.org/10.5965/223811711722018219

Ortegón-Morales, A. S., González-Quintero, J., Díaz-Franco, A., & Castillo-Torres, N. (2009). Canola (*Brassica napus* L.) yield components in low density crops. *Universidad y Ciencia*, *25*, 267-272.

Rahimitanha, S., Woodcock, T., Spink, J., Forristal, P. D., & Berry, P. M. (2022). The impact of sowing date on soil mineral nitrogen uptake efficiency and fertilizer N uptake efficiency for winter oilseed. *Agronomy*, *12*(7), 1-14. DOI: https://doi.org/10.3390/agronomy12071551

Rocha, M. R., Bôas, R. N. V., Biaggio, F. C., Castro, H. F., & Giordani, D. S. (2018). Effect of the catalyst on the physical and aroma attributes of interesterified milk fat-vegetable oil blends. *Brazilian Journal of Food and Technology*, *21*, 1-10. DOI: https://doi.org/10.1590/1981-6723.03618

Rosa, W. B., Duarte Júnior, J. B., Tomm, G. O., Perego, I., Queiroz, S. B., Rinaldi, L. C., ... Costa, A. C. T. (2020). Influence of sowing times on subperiods and agronomic performance of canola hybrids. *Brazilian Journal of Development*, *6*(9), 65774-65788. DOI: https://doi.org/10.34117/bjdv6n9-126

Rovere, B. O., Rodrigues, J. H., & Teleken, J. G. (2020). Reduction of the acidity index through neutralization and esterification for biodiesel production. *Brazilian Journal of Development*, *6*(5), 24678-24686. DOI: https://doi.org/10.34117/bjdv6n5-064

Safavi Fard, N., Heidari Sharif Abad, H., Shirani Rad, A. H., Majidi Heravan, E., & Daneshian, J. (2018). Effect of drought stress on qualitative characteristics of canola cultivars in winter cultivation. *Industrial Crops and Products*, *114*, 87-92. DOI: https://doi.org/10.1016/j.indcrop.2018.01.082

Wang, P., Xiong, X., Zhang, X., Wu, G., & Liu, F. (2022). A Review of erucic acid production in Brassicaceae oilseeds: progress and prospects for the genetic engineering of high and low-erucic acid rapeseeds (*Brassica napus*). *Frontiers in Plant Science*, *13*, 1-13. DOI: https://doi.org/10.3389/fpls.2022.899076

Zhang, Z., Cong, R., Ren, T., Li, H., Zhu, Y., & Lu, J. (2020). Optimizing agronomic practices for closing rapeseed yield gaps under intensive cropping systems in China. *Journal of Integrative Agriculture*, *19*(5), 1241–1249. DOI: https://doi.org/10.1016/S2095-3119(19)62748-6