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Sowing times influence canola grain yield and oil quality

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ABSTRACT

The aim of this study was to evaluate the environmental effect of different sowing times on the productivity and quality of hybrid canola grains Hyola 60, Hyola 61, Hyola 401 and Hyola 432 sown on the dates 05/12/08, 05/31/08, 06/21/08 and 08/02/08, with a sowing test on 04/18/08 with Hyola 401 and Hyola 61 hybrids. The experimental design consisted of randomized blocks in a factorial 4 dates x 4 hybrids. The local environment was characterized by air temperature, relative humidity and rainfall. With these data, we computed the actual (ETR) and reference (ETo) evapotranspiration. The effect of the soil moisture was evaluated with regards to ETR ETo^{-1}. The results were submitted to analysis of variance and the Tukey test at 5% significance for comparison of means. The environmental effect was evaluated by regression analysis. The hybrid Hyola 401 had better productivity while Hyola 60 showed the lowest productivity. The hybrid Hyola 401 presented the best quality indicators. There was a trend of reduction in grain productivity and quality with delayed sowing. The mean air temperature was found to be the main environmental factor affecting yield and quality, particularly in the filling-maturity of grains in the sub-period and throughout the cycle, with reduced production at higher air temperatures.

Introduction

Canola (*Brassica napus* L. var. *oleifera*) is a crop genetically improved from oilseed rape (Daun, 1983) and adapted to temperate climates. Although its production in Brazil is relatively recent, it shows great potential in southern Brazil and other regions of the country, such as the tropical region (Tomm et al., 2012). Canola oil is one of the most widely produced and consumed oilseeds in the world because it is considered to be one of the healthiest oils, due to high amounts of Omega-3 and lower amounts of saturated fat content compared to other vegetable oils (Bell, 1993). In addition to the oil, the bran can be used as a source of protein in animal feed production, contributing to the diversification of raw materials for the animal feed industry. As a winter crop with a pivoting root system and belonging to a different family from that of the main winter cereal produced in the Center-South of Brazil, canola can be used in crop rotation systems, as an important plant for breaking disease cycles and assisting in soil recovery.

The canola grain yield is strongly influenced by water availability conditions of the soil as well as the weather conditions during the production cycle (Dalmago et al., 2009). High air temperatures have been related to lower canola grain yields, in addition to reducing the quality of the grains and oil yield (Hassan et al., 2005). The most pronounced effects of high air temperatures were observed during periods of low precipitation (Hassan et al., 2005), indicating a probable interaction between these weather variables. On the other hand, plants that are not acclimated to the cold can suffer significant damage during vegetative growth when air temperatures approach 0 °C, harming crop performance for both grain production and oil. However, acclimated plants tolerate air temperatures of down to -3.5 °C (Dalmago et al., 2010). During the reproductive phase, both very low and high air temperatures may result in flower abortion and fall of seedpods, causing greater unevenness in the maturation of the crop and interfering with the efficiency and quality of the oil produced.

Although during autumn and winter the atmospheric water demand is the lowest of the year, in the Western region of Paraná the occurrence of prolonged periods without precipitation can lead to reduction of soil moisture levels harmful to the production of canola, especially in regards to the weeks of April and May, when air temperature and solar radiation are still relatively high. Water deficiency in the soil during the growing phase of the canola plants reduces the accumulation of dry matter (DM) and, according to Wright et al. (1995), the dry matter accumulated at the peak of flowering is associated with the canola grain yield and therefore also the oil yield. Experimental results of Champolivier & Merrien (1996) demonstrated that canola and mustard have significant production losses under water deficiency conditions, especially when they occur at the beginning of vegetative development and during flowering (Bouchereau et al., 1996).

In addition to the losses of grain production, the quality and quantity of oil produced by canola are also influenced by weather conditions that occur during the crop cycle, notably from flowering (Champolivier & Merrien, 1996; Sinaki et al., 2007). Despite the research history with canola oil in Brazil and the high weather variability in southern Brazil, there are still difficulties in establishing the most suitable sowing times and adjusting management technologies aimed at reducing canola losses. Data regarding the grain quality and yield and canola oil as a function of the sowing time are still scarce. Therefore, the objective of this work was to evaluate canola grain yield and oil content its quality in hybrids sowed on different dates.

Materials and Methods

The experiment was installed in the experimental area of Pontifícia Universidade Católica do Paraná (PUCPR) at the Toledo Campus (24° 42' 49" S; 53° 44' 35" W; 574 m). According to Köppen's classification of subtropical type (Cfa), the local climate has no set dry season and an average annual pluvial precipitation around 1800 mm, hot summers and infrequent frosts (Instituto Agronomico do Paraná, 1998). The experiment was set up and conducted in the period of May 12 to November 30, 2008.

The experimental design was completely randomized, with treatments arranged in factorial 4 x 4, with four repetitions, wherein the factors were: sowing dates and canola hybrids. Each parcel was 5 m long and 3.5 m wide, which totaled an area of 17.5 m^2. The sowings were performed on four dates: in 5/12/2008 (E1), 5/31/2008 (E2), 6/21/2008 (E3) and 8/2/2008 (E4) with the hybrids Hyola 401, Hyola 61, Hyola 432 and Hyola 60.

Sowing was carried out manually, in rows spaced 0.45 m apart. Ten days after emergence, for each sowing time, the thinning of the plants was conducted in order to obtain a stand of 40 plants m^{-2}. Base fertilization corresponded to 300 kg ha^{-1} of NPK 08-20-20 formulation, defined according to soil analysis and crop needs. For the top dressing, 100 kg ha^{-1} of ammonium sulphate was applied when the plants were at the G4 stage (four true leaves), approximately 30 days after emergence. For the determination of grain yield, 2 m^2 of the central area of each installment was harvested and performed manually when 50 to 60% of the grains of the main stem had brown or black coloring (Portella & Tomm, 2007). The grains were threshed manually and the grain yield was estimated from the total mass of the harvested grain area, which was adjusted to 13% humidity (Brasil, 1992). For the thousand-grain mass, four samples of 100 grains for each part of each treatment were counted at random. Then, these samples were weighed on an analytical balance with a resolution of 0.0001 g and the mean values were expressed in g of 1000 seeds (Brasil, 1992).

The quantification of the levels of lipid and protein was performed in the laboratory of environmental sanitation of the Universidade Estadual do Oeste do Paraná (UNIOESTE) – Cascavel Campus, and the determination of acidity was carried out in the laboratory of Biochemistry at the Pontifícia Universidade Católica do Paraná (PUCPR) Toledo Campus. The determination of lipids was carried out using the method of direct extraction in Soxhlet, while protein was based on the determination of nitrogen by the Kjeldahl digestion process, according to the Instituto Adolfo Lutz (1985) and oil acidity using the method of the Instituto Adolfo Lutz (1985).

A complete crop phenology evaluation was performed for sowings E1 and E4, plus a sowing test on 04/18/08 for which only hybrids Hyola 61 and Hyola 401, were produced, thus determining the emergence start dates, stages of rosette, elongation, flowering, filling and grain maturation, as described by Basf, Bayer, Ciba-Geigy and Hoesht (BBCH). In the remainder of the sowings, the phenological monitoring was conducted from the thermal constants obtained with the information from the experiment. Since there was reasonable difference in thermal constants obtained on the test dates and E1 and those from E4, we used the average thermal sums obtained on the test date and/or E1 and on E4 to estimate the duration of sub-periods and cycle in seasons E2 and E3.

For the characterization of the weather conditions, during the experiment, the air temperature and relative humidity were recorded with a thermohygrograph installed in the weather shelter at a height of 1.5 m. In addition, at the experiment site, the pluvial precipitation was quantified with a PVC rain gauge built on the PUCPR campus, with a 200 mm diameter nozzle (314.16 catchment area cm^2), which was installed at a height of 2.0 m. The daily average values (T), maximum (TM) and minimum (Tm) air temperature were determined in °C and the total daily pluvial precipitation height (P, mm d^{-1}) during the crop cycle. The reference evapotranspiration (ETo, mm d^{-1}) was calculated with the daily air temperature values using the Hargreaves-Samani method:

$$ETo = 0.0023 Ko{\downarrow} (TM - Tm)^{0.5} (T + 17.8) \quad (1)$$

where Ko↓ is the global solar radiation incident at the top of the atmosphere, equivalent to evaporation (mm d^{-1}), T, TM and Tm, respectively, the average, maximum and minimum daily air temperatures in °C.

With this meteorological information and data of maximum soil water storage (90 mm), which was estimated from data of Pessoa et al. (2003) and Centurion & Andrioli (2000) for Eutroferric Red Latosol, occurring at the site of the experiment, the daily sequential water balance was performed by the Thornthwaite & Mather (1955) method, allowing the quantification of relative evapotranspiration, in other words, the ratio between the actual and reference evapotranspiration (ETR ETo^{-1}). The thermal sum for canola, for the different periods of sub development and overall crop cycle was determined by considering a base temperature of 5.0 °C (Thomas, 2003; Luz et al., 2012) and calculating values of the thermal constants from the phenology performed on site.

The effect of weather conditions on the productive and qualitative variables of grain and oil was evaluated by regression analysis in each sub-period (rosette sowing, elongation, flowering and filling-maturation) and throughout the cycle. The environmental variables evaluated were T, TM, Tm, TM – Tm and the relative evapotranspiration (ETR ETo^{-1}). Since $0 \leq ETR\ ETo^{-1} \leq 1$, we assumed that ETR $ETo^{-1} < 0.8$ was limiting for the potential development of the plants, depending on the number of days with ETR $ETo^{-1} < 0.8$ in each sub-period. This analysis was performed using the "stepwise" procedure from the statistical software R (R Core Team, 2013), seeking to identify which sub-periods were more sensitive to these variables and which environmental variables showed significant effect on agronomic variables at the 5% level of error probability ($p \leq 0.05$).

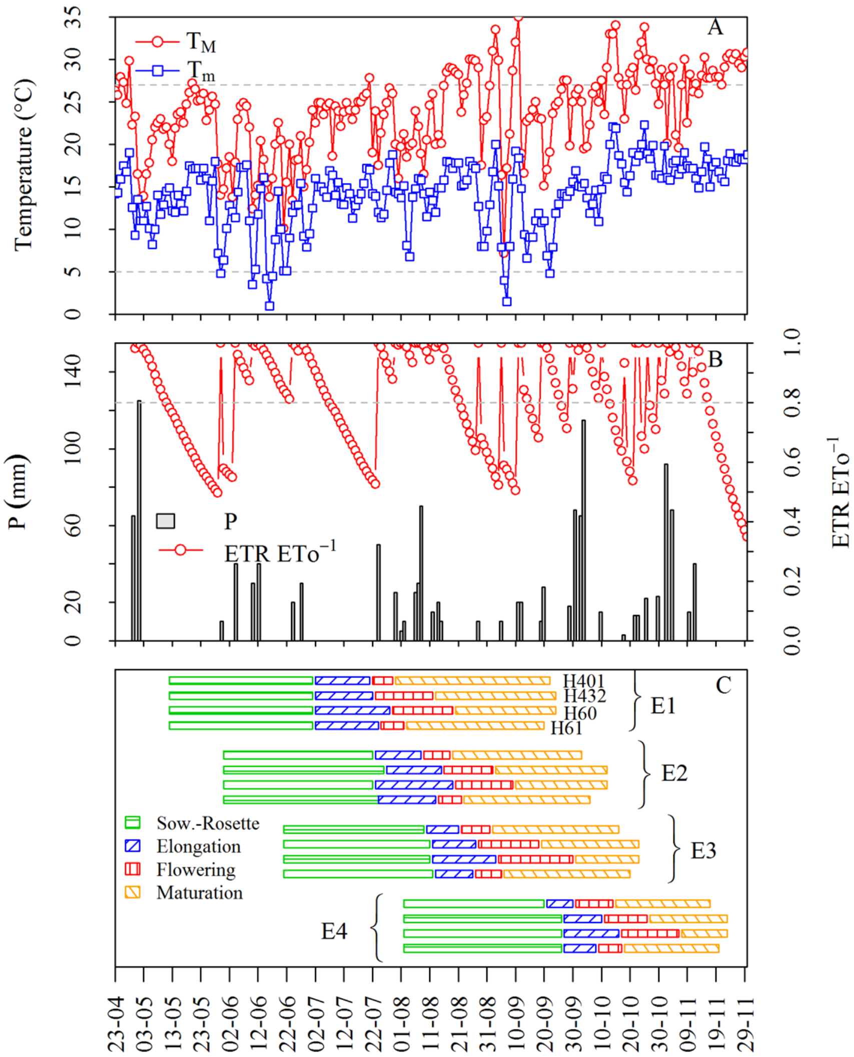
Before conducting the analysis of variance (ANOVA), a descriptive analysis and verification of normal errors was carried out. The comparison of means was performed by the Tukey test at significance level of 5%. For variables that did not present normal distribution of errors, data transformations were performed using the Box-Cox procedure, wherein data processing and analysis were performed with the software R (R Core Team, 2013).

Results and Discussion

Environmental conditions

During the trial period, there was a tendency of decreasing air temperatures until June 2008 with a subsequent increase starting in July (Fig. 1A). The maximum air temperature ranged from 7.2 °C to 35.0 °C and the minimum between 1.0 °C and 22.3 °C (Fig. 1A). These values reveal the intense variation of air temperature during the trial period, with minimum values below 5.0 °C [average base temperature of the canola cycle (Thomas, 2003)] on days 05/30, 06/10, 15, 16 and 17 and 09/6, 7 and 22 and a maximum over 27 °C on 65 days, occurring with increased frequency from 08/16 to 09/11 and 09/27 until the end of the experiment. According to Thomas (2003), air temperatures above 27 °C promote flower abortion, especially if associated with water deficit. In the short period from 02 to 12/09, the air temperatures presented extensive amplitude, ranging from 1.5 °C to 35.0 °C. Based on the data from the automatic weather station belonging to the National Institute of Meteorology in Marechal Candido Rondon (24° 19' 15" S; 54° 00' 40" W; 392 m), which is located about 35 km west of the experiment site, the daily solar radiation presented significant oscillations, with several periods of up to 7 days with high cloud cover (data not shown). The high values of air temperature generally coincided with low average daily values of relative humidity (around 50%), such as on day 09/03, when a maximum air temperature of 33.5 °C and 33.0% of

Figure 1 – Daily variation of the maximum (TM) and minimum (Tm) daily air temperature (A), relative evapotranspiration ETR ETo^{-1} and daily pluvial precipitation P (B), and length of the main phenological subperiods of canola (C), in sowings E1 (5/12/2008), E2 (5/31/2008), E3 (6/21/2008) and E4 (8/2/2008). The horizontal bars in panel C are ordered from top to bottom, in the sequence of the canola hybrids Hyola 401 (H401), Hyola 432 (H432), Hyola 60 (H60) and Hyola 61 (H61).



average daily relative air humidity was recorded.

In Figure 1B, one can observe that the rain was poorly distributed during the crop cycle, with periods of hydric deficiency for canola between 05/15 and 06/03, between 07/07 and 23 and between 08/22 and 09/11, albeit less intense due to the small rainfalls which occurred in the period. This resulted in relative evapotranspiration below 0.80 (ETR ETo^{-1}). Extreme precipitation events occurred on 04/29 and 05/01, totaling 190 mm, in the period from 04/01 to 10, totaling 248 mm, and finally from 11/02 to 04 with 160 mm. Despite these rainy periods, there was probably no oxygen deficiency in the soil due to good drainage, as a result of it being a relatively deep Latosol.

Yield and quality of the grain

For most of the evaluated variables, there was a significant interaction ($p < 0.05$) between the effects of the sowing date and the hybrids, except for the protein content in which only the sowing date factor presented a significant effect.

For the grain yield (Table 1), the largest value occurred at sowing E1, followed by E2, E3 and E4, with the last sowing presenting a significantly smaller grain yield than the others among the studied hybrids. Notably, hybrid Hyola 401 presented higher grain yield compared to the others assessed in this study, with no significant difference between sowing E1 and E2 and between sowing E2 and E3.

In the sowings E1, E2 and E3, even though Hyola 61 presented higher yield than Hyola 432, no significant difference between them was detected, both presenting intermediate values compared to the other genotypes. On the other hand, Hyola 60 presented the lowest grain yield and the highest sensitivity to sowing dates, due to its greater variability of response. Only hybrids Hyola 61 and Hyola 432 presented difference in grain yield between sowing E3 and E4, indicating that both exhibited greater sensitivity to less favorable environmental conditions than Hyola 401, i.e. the later sowings. The observed results corroborate with those obtained by Ávila et al. (2004) and Melgarejo et al. (2014), in which canola sowings in April and May, in the Maringá-PR and Marechal Cândido Rondon-PR region presented the greatest grain yields, and between various canola hybrids evaluated by Ávila et al.

Table 1 – Results of the test of average productivity comparison, weight of 1000 grains (P1000), oil and protein content, index of acid and oil productivity of the canola hybrids Hyola 60, Hyola 61, Hyola 401 and Hyola 432 sown in the sowing periods E1, E2, E3 and E4 in Toledo-PR.

Periods	Hybrids				Average
	Hyola 60	Hyola 61	Hyola 401	Hyola 432	
Productivity (kg ha^{-1})					
E1	1421 A c	1958 A ab	2206 A a	1593 A bc	1794
E2	831 B c	1874 A ab	2111 AB a	1519 A b	1584
E3	698 B c c	1347 B ab	1687 B a	1028 B bc	1190
E4	305 C a	356 C a	610 C a	384 C a	414
Average	814	1384	1653	1131	
P1000 (g)					
E1	3.57 A a	3.51 A a	3.75 A a	3.59 A a	3.61
E2	2.70 B c	3.06 B bc	3.51 A a	3.30 A ab	3.14
E3	2.83 B b	3.03 B b	3.57 A a	3.47 A a	3.22
E4	2.22 C b	1.95 C b	2.02 B b	2.78 B a	2.24
Average	2.83	2.89	3.21	3.29	
Oil content (%)					
E1	36.19 A a	36.16 B a	32.92 A a	36.24 A a	35.38
E2	29.42 B c	37.84 B a	32.78 A bc	35.49 A ab	33.88
E3	31.39 AB a	30.91 A a	33.00 A a	31.81 A a	31.78
E4	26.77 B a	27.98 A a	28.27 A a	25.95 B a	27.24
Average	30.94	33.22	31.74	32.37	
Protein content* (%)					
E1	27.98	28.85	26.24	27.11	27.55 AB
E2	25.24	25.41	26.21	27.17	26.01 B
E3	28.77	27.63	27.13	27.18	27.68 A
E4	27.75	28.00	26.11	28.67	27.63 A
Average	27.44	27.48	26.42	27.53	
Acid value* (g oleic ac: (100 g of oil)$^{-1}$)					
E1	1.66 A a	2.31 A a	1.64 A a	1.94 A a	1.86
E2	2.87 ABa	2.22 A a	1.77 A a	2.47 A a	2.28
E3	2.53 ABa	2.52 A a	2.16 A a	2.70 A a	2.46
E4	4.79 B b	1.92 A a	1.97 B a	2.76 A ab	2.57
Average	2.66	2.23	1.87	2.43	
Oil productivity (kg ha^{-1})**					
E1	513.20 A b	706.27 A ab	725.60 A a	575.77 A ab	630.21
E2	243.18 B b	709.82 A a	691.60 A a	539.14 A a	545.93
E3	219.52 B b	414.21 B a	553.45 A a	327.02 B b	378.55
E4	78.69 C a	98.39 C a	171.57 B a	95.65 C a	111.08
Average	535.56	384.40	263.65	482.17	

The same uppercase letters in the column and same lowercase letters in the line do not differ among themselves in accordance with the Tukey test at a significance level of 5%. E1, E2, E3 and E4 represent, respectively, the sowing dates 5/12/08, 5/31/08, 6/21/08 and 8/2/08. *Means obtained from transformation $x^{0.5}$; ** Means obtained from transformation $x^{0.7}$.

(2004), the largest grain yields occurred with Hyola 401.

The mass of 1000 grains (P1000, Table 1) showed no significant difference between the hybrids in the E1 sowing, where for sowings E2 and E3, the hybrids Hyola 401 and Hyola 432 exhibited similar values of P1000 and Hyola 61 and Hyola 60 were significantly lower than the other genotypes. For all hybrids, the E4 sowing resulted in a significant decrease in P1000, conceivably being a cause for grain yield reduction.

The effect of the sowing date on the oil content was less pronounced than in the grain yield, whereas the hybrid Hyola 401 showed no significant difference in lipid content between sowings, while Hyola 432 presented significant difference and lower lipid content in sowing E4, in relation to the other dates (Table 1). The hybrids Hyola 61 and Hyola 60 were more sensitive to environmental conditions, given that for Hyola 61 significant differences occurred between sowings E3 and E4 in relation to sowings E1 and E2. Interestingly, there was a slight increase in oil content for Hyola 60 at sowing E3 in relation to E2, which may be related to determination errors, and it did not differ in the other sowing periods. The average values of the hybrids ranged from 30.94% to 33.22%. Kutcher et al. (2005) and Hocking et al. (1997) found average levels of oil even higher than 40%, a difference that can be related to the variability of environments. Gunasekera et al. (2006) evaluated canola hybrids sown in May, June and July in Australia and verified a reduction of oil content in the grain with delayed sowing, which is what occurred in this study, especially in the E4 sowing with hybrids Hyola 60, Hyola 61 and Hyola 432. Melgarejo et al. (2014) observed a significant reduction in oil content of hybrids Hyola 433 and Hyola 61 with late sowing, with values ranging from about 40% to around 34%. In relation to other works, the average content of oil obtained in this study was smaller, which, in addition to environmental differences, may be related to the methodology used, since for the extraction process, it was necessary to grind the grains in a grinder and subsequently grind manually with the aid of a crucible, which may have caused non-uniformity in the grinding due to the occurrence of badly crushed grains.

Unlike the oil content, the protein content was not clearly influenced by environmental conditions. Only in the E2 sowing were protein levels slightly lower (Table 1) than the others, differing from those found in sowings E3 and E4. The average protein values ranged from 26.01% to 27.68%. Among the evaluated hybrids, there was no significant difference in protein levels, with average values within a range observed by Kutcher et al. (2005), ranging from 18.6% to 28%. Gunasekera et al. (2006) observed that with canola sowing delay from May to July, in three locations in Australia, the grain protein content increased, presenting on average 24.5%, 27.2% and 28.3% in Merredin, Mullewa and Newdegate, respectively, in 2000. Murakami et al. (1997) found 23.61% of protein.

The lowest acidity values in the oil were observed for the hybrid Hyola 401, although it did not significantly differ from the other hybrids (Table 1). Though insignificant, there was a slight tendency of higher acidity level in the oil with delayed sowing for hybrids Hyola 401 and Hyola 432, whereas Hyola 60 presented significant elevation compared to the other hybrids. Hyola 61 presented higher values of acidity in sowing E3, oscillating at lower values in the remaining sowings, albeit not presenting any significant difference compared to the other sowing dates. Among the hybrids, there were significant differences only in sowing E4 for Hyola 60, which had higher values of acidity, when compared with the other hybrids.

The acid value observed in the oil of hybrids Hyola 60, Hyola 401 and Hyola 432 in the E1 sowing was within the maximum limit established by the current legislation, which is 2 g of oleic acid (100 g of oil)$^{-1}$, according to ANVISA (1999). Hybrid Hyola 401 presented the lowest levels of oil acidity in all the sowings, indicating its superiority for consumption as food. On the other hand, hybrid Hyola 61 presented acceptable acidity for consumption only in sowing E4, at which time the other hybrids tended to present higher values. According to Angelucci et al. (1987), the high acidity obtained from the crude oil increases the loss of neutralization, in addition to being an indicator for low quality grains, improper handling and storage or poor processing. All hybrids presented acidity values above that recommended (ANVISA, 1999) for all the sowings and, when within the accepted values, the levels were close to the maximum acceptable value. Since storage and processing conditions were suitable, the high acidity values indicate that the grains produced were not of good quality for food. It should be emphasized that the non-occurrence of significant differences in most cases is likely related to the high value obtained in Hyola 60 in sowing E4. These results clearly show that the sowing of canola in western Paraná should take place by May, considering that later dates result in grain yield and oil quality losses.

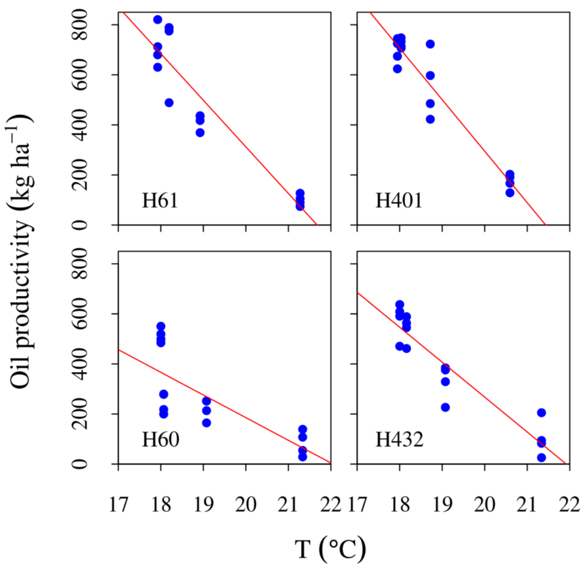
In terms of oil yield per hectare (kg of oil ha^{-1}), obtained by association of grain yield and oil content, there was a similar tendency for grain yield (Table 1), this being the main determinant of oil yield. The biggest oil yields were obtained in all sowing seasons by the hybrids Hyola 61 and Hyola 401 and, although not significantly different, with higher productivity in Hyola 401. The first two sowings resulted in levels of higher oil yield, with the exception of hybrid Hyola 60 when compared to the rest, which as with the grain yield, presented a significant decrease in sowing E2. Hybrid Hyola 401 presented greater stability of oil yield, exhibiting significant reduction only in sowing E4. Additionally, although not significantly different, in sowing E4, hybrid Hyola 401 presented oil yields well above the other hybrids.

The effect of the genetic factor can be observed by comparing hybrids Hyola 61 and Hyola 432, which presented the highest levels of oil in the most productive sowings (E1 and E2), although under less favorable environmental conditions there was a significant decrease for Hyola 432, whereas Hyola 401 kept levels that did not present significant difference among sowings (Table 1). Comparing the most productive hybrids, Hyola 401 and Hyola 61, we observed that the mass of 1000 grains in Hyola 401 was significantly higher than in Hyola 61, indicating that, in order for there not to be any significant difference in oil yield, Hyola 61 produced the largest number of grains under the least favorable environmental conditions. On the other hand, the grain yield of hybrid Hyola 432 was significantly lower than that of Hyola 401, while the mass of the grains was indifferent (Table 1), i.e., Hyola 432 produced fewer grains. These results reveal that the hybrids present important genetic differences and adopt different strategies under non-ideal environmental conditions. Under the study conditions, Hyola 401 tended to maintain the highest grain quality in the different sowings, as can be noted by observing the oil yield results (Table 1), in which stable levels were kept in the four sowings, while Hyola 61 presented a decreasing trend of oil yield in sowings E3 and E4. Hybrid Hyola 432 was less productive than Hyola 401, especially in sowings E3 and E4, demonstrating that it is more sensitive to environmental conditions. The main factor related to the affected grain yield was the number of grains, considering that the 1000 grain mass did not differ in Hyola 401, which was even higher in sowing E4. With the exception of sowing E3, the oil content did not differ from the other canola hybrids evaluated.

Regression analysis was used in order to identify how the environmental factors [air temperature and relative evapotranspiration (ETR ETo^{-1})] influenced canola grain yield and grain oil yield. In Figure 1, it is possible to observe that in some periods, there were values of ETR $ETo^{-1} < 0.8$. Separately, when there was a significant effect, it was incoherent, seeing that negative angular coefficients occurred, although a positive effect would have been the logical outcome, taking into account that ETR ETo-1 ≈ 1 indicates good moisture condition in the soil, results that differ from Bilibio et al. (2011), that found significant reduction on growth parameters of canola under water irrigation of 30% of evapotranspiration. The number of days with ETR $ETo^{-1} < 0.8$ also had little importance in defining the canola grain yield. The ETR ETo^{-1} had significant and consistent effect only at the filling-maturation stage, which is possibly associated with low relative humidity values in periods with high air temperatures, more frequent as of September, which hit mainly the sowings E3 and E4. The water deficit, coupled with low relative humidity and high air temperatures result in stomatal closure, which reduces photosynthesis and increases respiration, reducing photosyn-thetic accumulation in grains. On the other hand, a drought occurred in the sowing-rosette subperiod of the sowing test, which delayed the development of plants even under relatively high air temperatures. Stress due to the drought was important as it replaced the cold, inducing the ramification of the inflorescences, considering that after the rainfall there was pronounced ramification and flowering. In this case, the effect of the drought can be considered positive.

In multiple regression analyses, ETR $ETo^{-1}{}_{fill.mat}$ showed no significant effect at the 5% probability level, likely due to the correlation with $T_{fill.mat}$. On the other hand, the high air temperature significantly affected the yield of grain and canola oil. The average temperature of the air during the cycle of hybrids in each sowing had a significantly negative effect on the hybrids evaluated. Despite regression being linear, the distribution of points (Fig. 2) indicates an average maximum temperature of 18.5 °C where there seems to be no negative effect of air temperature on the grain yield and oil content in canola grains. Analyzing the effect of the air temperature at each development stage of the crop, a negative effect was observed until the end of the rosette stage, with a negative exponential relationship for hybrids Hyola 401 and Hyola 61, and a sharp downward trend of grain yield and oil content in grain, with average values above 16 °C. In the stem elongation stage, there was a negative relationship only for Hyola 60, represented by the second-degree polynomial function, with the average air temperature at the maximum point of 18.9 °C. This relationship was of high significance ($p < 0.01$) with a coefficient of determination equal to 0.92, indicating that there was no major impact of air temperature on this hybrid in the elongation period. During flowering, the increase in the average air temperature resulted in significant reduction in grain yield indicators, although this relationship is less clear in some hybrids. For hybrids Hyola 401 and Hyola 432 it was very evident the negative exponential effect of the average air temperature increase on production (respectively, $R^2 = 0.93$ and $R^2 = 0.70$), however, for hybrids Hyola 61 and Hyola 60 this effect was much clearer on the last date of sowing. The subperiod of the crop in which the average air temperature had greater effect on grain yield was the grain filling-maturation subperiod (Fig. 3), in which all the hybrids studied suffered negative impact of high air temperature ($R^2 \geq 0.78$). The delay in the canola sowing, in southern Brazil, results in the exposure of the crop to higher air temperatures. At the beginning of the cycle (rosette), the high temperature reduces the emission of ramifications in the inflorescences, which implies fewer siliques and grains produced. During flowering and filling-maturation, several notable events take place such as the shortening of this period (Berry & Spink, 2006), the impact of high air temperature by the abortion of flowers and siliques, higher incidence of disease and pest attacks, such as the whitefly and the Trigona spinipes bee, which is of high ecological importance.

Figure 2 – Regression analysis between oil productivity (kg ha^{-1}) and average air temperature over the cycle (T; °C) for the hybrids, Hyola 61 (H61), Hyola 401 (H401), Hyola 60 (H60) and Hyola 432 (H432). Regression equations are y = 4037.20 – 186.25 x, R^2 = 0.87 for the Hyola 61 hybrid; y = 4408.13 – 205.66 x, R^2 = 0.92 for the Hyola 401; y = 1996.04 – 90.53 x, R^2 = 0.58 for the Hyola 60; y = 3057.72 – 139.51 x, R^2 = 0.87 for Hyola 432.



Case Studies

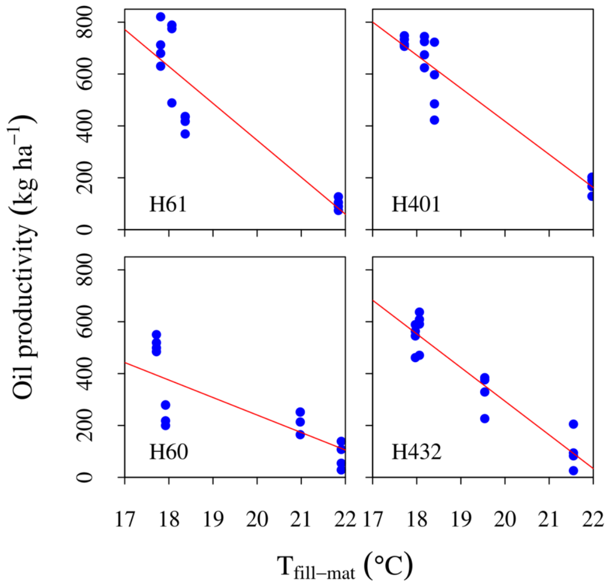
The elongation and flowering stages were, in some cases, only about a week long, i.e., short stages to show the effect of the environment on the production variables. This can be a low correlation factor with the air temperature and soil moisture. However, the filling-maturation sub-period is marked by the filling of the grains in addition to the concurrent issuance of new flowers, thus occurring increased exposure organs that are determinant of grain yield and very sensitive to environmental pressure, such as high air temperature, which causes silique and flower abortion, along with the major activity of pests and diseases. Added to this, the high thermal sum, as a result of the higher air temperatures, can drastically speed up this sub-period, which is aggravated by the existence of water deficiency, resulting in higher leaf temperature. In this short sub-period, there is not enough time for the accumulation of photosynthates in the grains, resulting in low grain yield (Berry & Spink, 2006; Krüger et al., 2014).

Analyzing the environmental conditions throughout the cycle of the hybrids (Fig. 1B), we observed a period of drought from 07/10 to 24, reaching the stages of elongation in the E1 sowing and rosette subperiod in sowings E2 and E3 (Fig. 1C). As discussed earlier, the drought can be beneficial in the rosette subperiod, therefore not being a probable cause for the grain yield reduction in E3. In E1, drought struck the elongation stage, although it was the sowing in which the highest grain yields and oil content were obtained in canola grains. On the days 08/31 to 09/11, the air temperature fluctuated from 1.5 °C to 35.0 °C. According to Thomas (2003), the canola base temperature is 5 °C, resulting in a halt of development on 09/6 and 7. Likewise, on days 09/1 to 4 and 9 to 11, the maximum air temperature was higher than 27 °C, a critical value above which the air temperature causes the abortion of flowers and fall of newly formed siliques. Between 09/1 and 11/1, the hybrid Hyola 60 was in full bloom (Fig. 1C), which may explain the significant reduction in grain yield and oil content in sowing E2, while the other hybrids exhibited grain yields and oil content in grains equivalent those in sowing E1. In addition to the high thermal amplitude, there was a drought from 08/22 to 09/11, with ETR ETo^{-1} values of 0.50. Therefore, without a doubt there was an effect associated with the lack of water in the soil and high air temperature during this period, which was more significant for hybrid Hyola 60.

Furthermore, hybrid Hyola 60 has a longer cycle than the others, exposing itself even more to the obstacles of the environment. However, the reduced impact of the high and low air temperature, associated with water deficiency in the other hybrids, indicates that Hyola 60 is the most sensitive to environmental pressures. Notwithstanding, in sowing E4 we observed significant reduction in grain yield also in the other hybrids. In percentage terms relative to the oil yield in sowing E1, in sowing E4, Hyola 60 produced just 11% of oil, followed by Hyola 61 (13%), Hyola 432 (16%) and Hyola 401 (23%). This sharp reduction in canola grain yield, in the E4 sowing, occurred mainly due to high air temperatures (Fig. 1A), which affected the crop from the flowering up until the grain filling stages.

One interesting aspect is that hybrid Hyola 401, in its earliest maturity, had its flowering in a milder period in terms of air temperature, which may likely be the cause of greatest relative grain yield (E4/E1 = 0.23), in relation to the other hybrids (Fig. 1). Hybrid Hyola 401 features, among the hybrids studied, rapid flowering development, abundant and quick branching of inflorescences and reasonable tolerance to adverse environmental conditions. In this experiment, Hyola 401 was more capable due

Figure 3 – Analysis of the relationship between the total oil production and the average temperature of the filling-maturation phase ($T_{fill\ mat}$; °C) for the canola hybrids Hyola 61 (H61), Hyola 401 (H401), Hyola 60 (H60) and Hyola 432 (H432). The regression equations obtained in each panel are y = 3192.30 – 142.4 x, R^2 = 0.78 for Hyola 61; y = 2968.86 – 127.56 x, R^2 = 0.89 for Hyola 401; y = 1598.30 – 67.45 x, R^2 = 0.60 for Hyola 60; and y = 2888.64 – 129.75 x, R^2 = 0.90 for Hyola 432.



to having stages sensitive to hydric and thermal stress (flowering and grain filling) in periods with milder air temperature and lower water deficiency, which made it the most productive hybrid in late sowings, such as sowings E3 and E4. These data clearly demonstrate the interaction between genetic aspects of the crop with environmental aspects and indicate that high air temperature is the main cause of reduced canola grain yield in this region.

Conclusion

The results revealed that hybrids Hyola 401 and Hyola 61 are the most productive, especially in the best environmental conditions, whereas the least productive is Hyola 60. Hyola 401 presents the best quality indicators in the four sowing dates. There is a downward trend in the productivity and quality of the grains with delayed sowing. The average air temperature is the main environmental factor affecting production and quality, especially in the grain filling-maturation subperiod and throughout the cycle, with reduced production when air temperatures increased.

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Influência de épocas de semeadura na produtividade e qualidade de óleo de canola

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RESUMO

Avaliou-se o efeito ambiental na produtividade e na qualidade dos grãos dos híbridos Hyola de canola Hyola 60, Hyola 61, Hyola 401 e Hyola 432, semeadas em 12/05/08, 31/05/08, 21/06/08 e 02/08/08, mais uma semeadura teste com os híbridos Hyola 401 e Hyola 61 (18/04/08). O experimento, em blocos ao acaso, em esquema fatorial 4x4 (4 datas de semeadura e 4 híbridos). Mediu-se a temperatura e a umidade relativa do ar e a precipitação pluvial e calculou-se a evapotranspiração real e de referência, diárias. O efeito da umidade do solo foi avaliado pela razão de evapotranspiração. Os resultados foram submetidos à análise da variância e, se F significativo a 5% de significância, aplicou-se o teste de Tukey para comparação das médias. O efeito ambiental foi avaliado através de análise de regressão. O híbrido Hyola 401 é superior em produtividade e qualidade, enquanto que o Hyola 60 tem pior desempenho produtivo. Há tendência de redução da produtividade e qualidade dos grãos com o atraso da semeadura. A temperatura média do ar é o principal fator ambiental que afeta a produtividade e qualidade dos grãos, tanto ao longo do ciclo total da cultura, como no subperíodo enchimento-maturação, com redução da produtividade e qualidade dos grãos sob maiores temperaturas do ar.

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