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Adaptability and stability of canola hybrids in different sowing dates[1]

Adaptabilidade e estabilidade de híbridos de canola em diferentes épocas de semeadura

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ABSTRACT - Canola is an important crop in the world market, mainly for its oil being used for human consumption and biodiesel production, being a great economical option for the farmer, which are the reasons to the increase in its cultivation in Brazil. This study aimed to evaluate the adaptability and stability of canola hybrids, depending on the sowing dates. The canola hybrids (Hyola 61, Hyola 76, Hyola 411 and Hyola 433) were evaluated in three sowing dates (04/10, 04/25 and 05/10) in the agricultural years of 2013 and 2014, under a randomized complete block design with five replications. The response variables analyzed were seed yield and oil content. Adaptability and stability of the hybrids were evaluated by three methods: Wricke's ecovalence (1962); confidence index (ANNICCHIARICO, 1992) and method of maximum ideal deviation (LIN; BINNS, 1988). The methodology proposed by Wricke (1962) highlighted as stable the hybrids Hyola 61 for seed yield and Hyola 411 for oil content. In the methodology proposed by Lin and Binns (1988) and Annicchiarico (1992), the hybrids with higher general adaptability and stability were Hyola 411 and 433. These hybrids presented the highest means for seed yield and oil content with predictable and responsive behavior to changes in sowing dates tested in the region of Maringá-PR.

Key words: *Brassica napus* L.. Oil content. Productivity.

RESUMO - A canola é uma cultura importante no mercado mundial, principalmente por seu óleo ser utilizado para consumo humano e produção de biodiesel, sendo excelente opção econômica para o agricultor, o que impulsiona o aumento de seu cultivo no Brasil. O presente trabalho objetivou avaliar a adaptabilidade e a estabilidade de híbridos de canola, em função das épocas de semeadura. Os híbridos de canola (Hyola 61, Hyola 76, Hyola 411 e Hyola 433) foram avaliados em 3 épocas de semeadura (10/04, 25/04 e 10/05) nos anos agrícolas de 2013 e 2014, sob o delineamento em blocos ao acaso com 5 repetições. As variáveis respostas analisadas foram o rendimento de sementes e o teor de óleo. A adaptabilidade e estabilidade dos híbridos foram avaliadas por três metodologias: método da ecovalência (WRICKE, 1962); índice de confiança (ANNICCHIARICO, 1992) e método do desvio do máximo ideal (LIN; BINNS, 1988). A metodologia proposta por Wricke (1962) destacou como estáveis o híbrido Hyola 61 quanto ao rendimento de sementes e Hyola 411 para o teor de óleo. Na metodologia proposta por Lin e Binns (1988) e Annicchiarico (1992), os híbridos com maior adaptabilidade geral e estabilidade foram Hyola 411 e 433. Esses híbridos apresentaram as maiores médias para o rendimento de sementes e teor de óleo, com comportamento previsível e responsivo às variações das épocas de semeadura testadas para a região de Maringá-PR.

Palavras-chave: *Brassica napus* L.. Teor de óleo. Produtividade.

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INTRODUCTION

Canola was developed by Canadian plant breeders from rapeseed (*Brassica napus* L. var. *oleifera*), belonging to the family of cruciferous and the *Brassica* gender. Today, erucic acidfree rapeseed oil with a balanced fatty acid composition is considered optimal for nutritional purposes (salad oil, margarine), and for non-food purposes: biofuel production, tensides for detergent, biodegradable plastics and hydraulic oils (FRIEDT *et al*., 2007). The meal from oilseed rape after oil extraction also provides a protein-rich animal meal for all livestock and compounds of meal (WITTKOP; SNOWDON; FRIEDT, 2009).

The production of rapeseed/canola grain in the world jumped from just over 8 million tons in the 1970s to over 60 million in the early decade of 2010 (USDA, 2014). In Brazil, this growth was just under 5 thousand tonnes in 1980 to levels close to 70 thousand tonnes in early 2010 (DE MORI; TOMM; FERREIRA, 2014). Its expansion has generated new demands on the use of this raw material for the production of oil and oil by-products such as meal and press cake. The cultivation of this oleaginous tends to increase further in Brazil due to the demand for the product in the Brazilian and European markets as well as being a good economic option for the Brazilian farmer (MARJANOVIC-JEROMELA *et al*., 2008; TOMM *et al*., 2009).

The genotype by environment interaction has been one of the principal subjects of study in breeding, allowing the generation of different methodologies for genetic improvement (ESCOBAR *et al*., 2011). These genotypic differences play an important role in crop adaptation for specific environments (GUNASEKERA *et al*., 2006).

The sowing date becomes an important agent in phenotypic characterization of plants because the plant will be affected by environmental conditions arising throughout its cycle. It is a key point in the production of this oilseed, affecting its seed yield and other agronomic characteristics for both winter canola (UZUN *et al*., 2009), as for spring canola (MELGAREJO *et al*., 2014; SHIRANI-RAD *et al*., 2014; TOBE *et al*., 2013).

Thus, it is necessary to study its relationship with genotypes, in order to better understand the phenotypic expression demonstrated by the plant in these specific environmental conditions. One of the possible alternatives to better understand it, is to identify stable cultivars with wide adaptability, through the use of adaptability and stability analyzes (CRUZ; REGAZZI; CARNEIRO, 2004).

The concept of adaptability refers to the ability of genotypes to advantageously harness environmental stimulus (CRUZ; CARNEIRO, 2003). This measure of adaptation can be performed in a general manner, comparing to the overall mean value of genotypes in the environment, or more specifically, through the partition in favorable and unfavorable environments. The term stability is conceptualized as the capacity of the genotypes to present predictable behavior in relation to environmental variations (MARIOTTI *et al*., 1976).

Studies evaluating the interaction between sowing date and canola cultivars are incipient in Brazil, and those that address adaptability and stability of the crop are scarce, with few international reports (MASHAYEKH; MOHAMADI; GHARANJICK, 2014; TAHIRA; KHAN; AMJAD, 2013).

Therefore, seeking to expand the knowledge about the agronomic potential of this crop with focus on data of oil content and seed yield, this work was carried out with aim to evaluate adaptability and stability of canola hybrids, according to sowing dates in the city of Maringá, Parana State.

MATERIAL AND METHODS

The experiments were carried out in the Iguatemi Experimental Farm (FEI) part of the Center for Agricultural Sciences, State University of Maringá (UEM), located in the city of Maringá, northwestern of Paraná State. FEI is located at latitude of 23º25’ south and longitude 51º57’ west of Greenwich, with an average altitude of 540 m.

The experimental area is on a dystrophic Red Argisol, medium texture. The soil was analyzed for chemical characteristics and fertilization was carried out in accordance with the technical recommendations for the cultivation of canola (TOMM *et al*., 2009).

Evaluated sowing dates were as follows: April 10, April 25 and the last one on May 10, in the years 2013 and 2014. Each period constitutes an environment where the hybrids Hyola 61, Hyola 76, Hyola 411 and Hyola 433, belonging to different maturity groups (Table 1), were tested.

The experimental design used in each environment was the randomized blocks with 5 replications. The experimental plots consisted of six rows of five meters in length, spaced 0.45 m apart, totaling a useful area of 3.6 m^2, in which it was received the treatments.

Cultural practices such as nitrogen and sulfur fertilization in coverage, pests, diseases and weeds control were conducted in all experimental units during the development of the crop, according to recommendations of Tomm *et al*. (2009). At the Laboratory of Seed Technology of the Applied Research Center for Agriculture (NUPAGRI) of UEM, the following response variables were quantified:

Table 1 - Characteristics of the evaluated canola hybrids

Characteristics	Canola hybrids			
	Hyola 61	Hyola 76	Hyola 411	Hyola 433
Emergence to early flowering (days)	53-77	61-81	59-65	58-67
Flowering duration (days)	28-52	24-62	30-72	28-73
Emergence to maturity (days)	123-155	120-164	120-150	120-150
Cicle	Medium	Long	Early	Early
Plant height (cm)	88-136	126-159	128-139	124-131
Reaction to the disease "blackleg" (*Leptosphaeria maculans*)	Polygenic resistance	Polygenic resistance	Polygenic resistance	Polygenic resistance

Seed yield: the water content in the seeds was measured up after harvest, on a wet basis. Subsequently, the harvested plot was extrapolated to 1 hectare, with correction of water content in wet basis to 9%, and the results were expressed in kg ha^{-1}. **Oil content:** the Soxhlet´s method was used, through the Soxhlet extractor and petroleum ether as solvent, with reflux of 6 hours (IAL, 2008). The oil content was determined by weight difference, being presented as a percentage.

The collected data were submitted to individual analysis of variance for each environment after meeting the basic assumptions for analysis. The joint analysis of variance was studied in which the effects of hybrids and environments have been considered fixed. The homogeneity of the residual square means for each environment was compared by the Bartlett's test. The hybrids were compared by Scott-Knott's test at 5% probability.

Adaptability and stability of the hybrids were evaluated by parametric methodology: Wricke's ecovalence (1962), confidence index (ANNICCHIARICO, 1992) and the non-parametric methodology: method of maximum ideal deviation (LIN; BINNS, 1988).

The Ecovalence index (ω_i) of Wricke (1962) was calculated as follows:

$$\omega_i = r\sum_j(Y_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + \bar{Y}_{..})^2 \quad (1)$$

Where, ω_i: contribution of the hybrid i in the total variance of the interaction; Y_{ij}: mean of the plot that received the hybrid i in the environment j; $\bar{Y}_{i.}$: mean of the hybrid i for all environments; $\bar{Y}_{.j}$: mean of the environment j for all hybrids; $\bar{Y}_{..}$: overall mean.

In the methodology proposed by Annicchiarico (1992), it was estimated the confidence index:

$$I_i = \hat{\mu}_i - Z_{(1-\alpha)}\hat{\sigma}_{Zi} \quad (2)$$

Where, I_i: confidence index, expressed in percentage; $\hat{\mu}_i$: mean relative to the hybrid i expressed as a percentage; Z: percentage (1-α) of the cumulative normal distribution function; α: significance level; $\hat{\sigma}_{Zi}$: standard deviation of the percentage values of the hybrid i. It was considered $Z_{(1-\alpha)}$ = 0.2734, which corresponds to the variable's value of a Z distribution, for α = 0,25.

In the Lin and Binns methodology (1988) the estimator P_i was calculated as a measure of stability and general adaptability:

$$P_i = \frac{\sum_{j=1}^{a}(Y_{ij} - m_j)^2}{2a} \quad (3)$$

Where, P_i: estimative of the stability and adaptability parameter of the hybrid i; Y_{ij}: the yield of the i^{th} - hybrid in the j^{th} environment; M_j: maximum response observed among all hybrids in the environment j; a: number of environments.

This value was partitioned into two components attributed to: genetic factors (P_{ig}) and hybrid x environment interaction factors (P_{iga}). The computational applicative in genetics and statistics GENES (CRUZ, 2013) was used in assistance to the analysis. The overall mean value of the hybrids on sowing dates for both variables was used as a measure of adaptation.

RESULTS AND DISCUSSION

The joint analysis of variance of sowing dates is presented in Table 2. It was found homogeneity of variance for the character oil content, however, was not observed for seed yield. In this case, the degrees of freedom of the error and hybrids x environments interaction were adjusted according to Cochran (1954).

The mean values analyzed for seed yield and oil content were superior than those found by Melgarejo *et al*. (2014), who observed an overall mean of 1,058.5 kg ha^{-1} and 38.2% respectively, working in Marechal Cândido Rondon city, western Paraná State. The values of coefficient of variation were 13.51% and 5.97% for seed yield and oil

Table 2 - Joint analysis of 4 canola hybrids evaluated in six different environments for the response variables seed yield (SY) and oil content in seeds (OIL)

Sources of Variation	SY (kg ha^{-1})		OIL (%)	
	DF	Mean Square	DF	Mean Square
Blocks/ Sowing dates	24	20,494.86	24	10.88
Hybrids (H)	3	117,012.19*	3	22.07*
Sowing dates (D)	5	119,695.59*	5	15.26^{ns}
H x D	12[1]	52,256.71*	15	29.79*
Error	57[1]	15,483.70	72	5.50
C.V. (%)		13.51		5.97
Overall Mean		1,081.01		39.26

[1]Adjusted degrees of freedom according to Cochran (1954); * Significant at 5% probability by the F test; ^{ns} Non Significant at 5% probability by the F test

content, respectively, and are in agreement with the values found by Kaefer *et al*. (2014).

The joint analysis showed significance (P<0.05) for hybrids and the interaction hybrids x sowing dates (H x D) of the characteristics seed yield and oil content. Considering the source of variance hybrids, it was found evidence for the existance of mean genetic differences among the analyzed hybrids. Regarding the source of variance sowing dates, these did not differ for oil content in canola seed (P>0.05), but differed for seed yield (P<0.05). This can be explained by several factors, such as small differences in cultural practices, differences among the climatic components, and among the agricultural years of 2013 and 2014. In other studies, environmental variation was the largest component of the total variation for seed yield, with examples of winter (MARJANOVIC-JEROMELA *et al*., 2011; NOWOSAD *et al*., 2016) and spring genotypes (TOBE *et al*., 2013) of canola.

The presence of H x D interaction means that the sowing dates produced a differential effect in the response of hybrids for both traits. Thus in order to identify hybrids less affected by environmental variation, the methods of adaptability and stability was used.

The results of Wricke's method (1962) are shown in Table 3. In this methodology, the ω_i is equal to the sum of squares of the hybrid x sowing dates interaction. A hybrid displays low Ecovalence when contributes little to the interaction, in other words, the hybrid shows a similar response to the mean of all the tested genotypes having more phenotypic stability.

The hybrids Hyola 61 and 76 presented lower Ecovalence, demonstrating greater stability of seed yield in the evaluated environments. For oil content, Hyola 411 showed greater stability, due to the lower contribution of the total Ecovalence. Hyola 76 contributed more to the H x D interaction, giving it low stability as response to the evaluated sowing dates. It is interesting that the characters seed yield and oil content, exhibit above average behavior in the environments, which was used as reference in this study both to the stability as to the adaptability parameter.

It is verified in Table 4, the performance of stability and adaptability of hybrids in different sowing dates, according to the Annicchiarico methodology (1992). For seed yield and oil content, the hybrids Hyola 411 and 433 indicated the top recommendation indices of general

Table 3 - Ecovalence (ω_i) for canola hybrids to seed yield (SY) and oil content in seeds (OIL) according to the Wricke's method (1962)

Canola hybrids	SY			OIL		
	Means[1] (kg ha^{-1})	Ecovalence (ω_i)	ω_i (%)	Means[1] (%)	Ecovalence (ω_i)	ω_i (%)
Hyola 61	1,048.74 A	52,881.19	8.43	38.84 A	89.80	20.10
Hyola 76	1,009.32 A	70,386.30	11.22	38.26 A	172.66	38.64
Hyola 411	1,140.66 A	142,697.87	22.76	39.97 A	36.51	8.17
Hyola 433	1,125.31 A	361,115.16	57.59	39.99 A	147.90	33.10
Total	-	627,080.51	100.00	-	446.88	100.00
Overall Mean	1,081.01	-	-	39.26	-	-

[1]Means followed by the same capital letter in the column do not differ by the Scott-Knott test at 5% probability

adaptability and stability as well as values above the overall mean in the environments.

In this methodology, the index (I_i) is generated from the mean values of the genotypes, with regards to the average of environments. It expresses the stability and also the general adaptability, with the highest values found by the genotypes that present the highest mean percent (μ_i) and the lowest deviation (σ_{zi}), which are related to the highest recommendation indices (CRUZ; CARNEIRO, 2003).

The hybrids presented good performance in evaluated sowing dates, for exhibitting acceptable confidence indices, close to 100%, which demonstrates at worst case, values 10% lower than the overall mean. Hyola 411 has a seed yield, on average, 1.06% higher than the mean environments in the most adverse conditions, with 75% confidence. Thus, these early maturing hybrids proved to be more stable, with less likelihood of failure in the farmer's choice.

Through the method of Lin and Binns (1988) the parameter P_i was obtained for the environments in general, as well as its partition in genetic parts (P_{ig}) and interaction (P_{iga}), described in Table 5. The results indicate that the smaller the value of parameter P_i, the greater the capacity of the genotype to produce minimal variation in the phenotype for the different sowing dates tested.

The hybrid Hyola 433 showed general adaptability and stability, presenting considerable genetic effect on expression of seed yield, besides obtaining mean higher than the overall mean. Hyola 411, also stood out, with the highest yield, however, its behavior was poorly explained by genetic factors. For oil content, Hyola 411 showed lower value of P_i, configuring itself as the most stable and with broad adaptation, exceeding the overall mean.

As with the Annicchiarico methodology (1992), it is mentioned once again the position of the early hybrids Hyola 411 and 433 as the most stable and with broad adaptation to the evaluated dates, setting themselves as good choices for planting in the region. Hyola 76 had the lowest seed yield and oil content adaptability and stability, compared to the sowing dates. These results disagree with the Wricke's methodology (1962) for seed yield in agreement, however, regarding the oil content.

Over time many biometric models have been proposed by researchers. The difference between methods originates from the very concepts of adaptability, stability and in the biometric procedures used to measure it (CARGNELUTTI FILHO *et al*., 2007). The existing differences in results among different methods occurs in most studies. For some authors, it brings more trust to indicate if the same results were found in different methods rather than just one (MARQUES *et al*., 2011; PELÚZIO *et al*., 2008; VASCONCELOS *et al*., 2015). Therefore, it is advisable to use methodologies for different statistical classifications, as used in this study.

Table 4 - General adaptability and stability measures of canola hybrids for seed yield and oil content according to the Annicchiarico's method (1992)

Seed yield				
Canola hybrids	Means[1] (kg ha^{-1})	$\hat{\mu}_i$(%)	$\hat{\sigma}_{Zi}$(%)	I_i[2](%)
Hyola 61	1,048.74 A	97.05	4.23	94.20
Hyola 76	1,009.32 A	93.61	4.37	90.66
Hyola 411	1,140.66 A	105.63	6.77	101.06
Hyola 433	1,125.31 A	103.71	10.12	96.88
Overall Mean	1,081.01	-	-	-
Oil content				
Canola hybrids	Means[1] (%)	$\hat{\mu}_i$(%)	$\hat{\sigma}_{Zi}$(%)	I_i[2](%)
Hyola 61	38.84 A	98.85	4.89	95.55
Hyola 76	38.26 A	97.50	6.55	93.09
Hyola 411	39.97 A	101.77	3.10	99.67
Hyola 433	39.99 A	101.88	6.16	97.72
Overall Mean	39.26	-	-	-

[1]Means followed by the same capital letter in the column do not differ by the Scott-Knott test at 5% probability. [2] α=0.25 of probability

Table 5 - General adaptability and stability measures of canola hybrids for seed yield and oil content according to the Lin and Binns' method (1988)

Seed yield					
Canola hybrids	Means[1] (kg ha^{-1})	P_i	Deviation		% (Genetic)
			Genetic (P_{ig})	Interaction (P_{iga})	
Hyola 61	1,048.74 A	18,360.41	11,322.07	7,038.35	61.67
Hyola 76	1,009.32 A	26,462.13	18,032.46	8,429.67	68.14
Hyola411	1,140.66 A	9,551.46	1,715.16	7,836.30	17.96
Hyola 433	1,125.31 A	4,508.51	2,731.52	1,776.99	60.59
Overall Mean	1,081.01	-	-	-	-

Oil content					
Canola hybrids	Means[1] (%)	P_i	Deviation		% (Genetic)
			Genetic (P_{ig})	Interaction (P_{iga})	
Hyola 61	38.84 A	4.88	2.72	2.16	55.69
Hyola 76	38.26 A	9.08	4.21	4.87	46.39
Hyola411	39.97 A	1.41	0.72	0.69	51.05
Hyola 433	39.99 A	2.09	0.69	1.40	33.04
Overall Mean	39.26	-	-	-	-

[1]Means followed by the same capital letter in the column do not differ by the Scott-Knott test at 5% probability

CONCLUSIONS

1. In the methodology proposed by Wricke (1962), the most outstanding hybrid for phenotypic stability in seed yield was Hyola 61. For oil content, the hybrid Hyola 411 was the most stable;
2. In the methodology proposed by Lin and Binns (1988) and Annicchiarico (1992), the hybrids with general adaptability and behavioral stability were Hyola 411 and 433. These hybrids showed the highest means for seed yield and oil content, with predictable behavior and responsive to changes in sowing dates tested in the region of Maringá-PR.

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