Article

Changes in the physiological and numerical components of canola yield in the face of reductions in incident solar radiation

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Abstract

In this work, the period of time in which canola yield is most sensitive to changes in resource availability was identified, and the physiological and numerical components that are most affected by reductions in incident radiation at different times of the cycle were identified. cultivation. Two canola spring genotypes were planted, one short-cycle and one intermediate-cycle, which were subjected to 10-day shading treatments (14 in total) during the winter 2015 and spring 2016 agricultural cycle. The treatments (cultivar combination and shading moments) were established in an arrangement of divided plots, where the main plot was assigned to the cultivars, while the shading moments were assigned to the subplots, the latter were distributed in a randomized complete block design with three repetitions. The most significant reductions in grain yield (33%) due to the effect of shading for Bioaureo 2486 were observed from 140 °Cd up to 410 °Cd after the start of flowering, with a total of 550 °Cd. In Hyola 61 this time window presented from -45 °Cd up to 250 °Cd with a total of 295 °Cd, with a decrease in yield of up to 40%. The numerical component of yield most affected by reductions in incident radiation levels was the number of grains. On the other hand, the number of grains per pod and the number of pods per unit area largely explained the changes in the number of grains. These results will allow better orientation of the genetic improvement and agronomic management strategies tending to increase the potential yield in this crop.

Keywords: (*Brassica napus* L.), incident radiation, number of grains, yield.

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Introduction

Canola (*Brassica napus* L.) is an oil plant known worldwide because edible oil is extracted from it whose content of essential fats can prevent heart disease (Kirkegaard *et al*., 2016). Globally, the cultivated area of this crop is 37 579 575 ha, with a production of more than 75 million tons and an average yield of 1.9 t ha^{-1} (FAOSTAT, 2018). In the year 2018, 2 058 ha were harvested, with a production of 1 473 t and an average yield of 0.715 t ha^{-1} (CONASIPRO, 2019).

The most outstanding states in canola production for the 2018 cycle were Tamaulipas, State of Mexico, Tlaxcala, Hidalgo and Jalisco, Tamaulipas standing out with 91% of the planted area and production volume; however, it has presented the lowest yields (0.6 t ha^{-1}), while the state of Mexico and Hidalgo obtain 2.5 t ha^{-1} (CONASIPRO, 2019).

The expansion of canola cultivation in the main producing countries has taken place in those areas with a temperate climate in which it is well adapted, however, in marginal and drier regions, it has prospered adequately, making it a crop that is tolerant to water stress and thermal (Dreccer *et al*., 2018).

Therefore, there is a growing need to understand the effects of intensity, time and duration of different types of stress on yield determination, in order to better channel both genetic improvement strategies and those of agronomic management tending to increase crop productivity.

In grain crops, the yield is generated throughout the growing cycle; however, not all phenological stages are equally important to define it (Estrada-Campuzano *et al*., 2008). In numerous studies in other crops (maize, wheat, barley) it has been found that the number of grains is the most important numerical component for the determination of yield (Sadras, 2007; Peltonen-Sainio *et al*., 2007; Fischer, 2008), in such a way that the phenological stages where this component is being determined are very important to understand the changes in grain yield (Slafer *et al*., 2005).

Knowledge of the period of time in which the grain yield is being determined could be important for the development of strategies that allow increasing the yield, either through genetic improvement or through improvement in management practices (Slafer, 2005). Regarding canola cultivation, previous studies using shading treatments (Iglesias and Miralles, 2014; Labra *et al*., 2017) or defoliation combined with irrigation (Zhang and Flottman, 2018), have been used to understand source-demand relationships and also to analyze the plasticity of yield components.

However, defoliation or irrigation confound the effects on yield and the reported experiments used different intensities and shading times, in many cases shading treatments were extended throughout the flowering period. Recently Kirkegaard *et al*. (2018) made the determination of this crop period most sensitive to changes in resource availability, with a single canola genotype contrasting it in two different environmental conditions (localities). In this sense, given the existence of genotypes that differ in terms of plant architecture (number of branches, pods per branch, etc), it would be interesting to investigate whether the sensitivity of the genotypes depends on their architecture or length of the culture cycle.

Currently, it is known that in canola cultivation the yield generation is determined by different factors. In this sense, Sidlauskas and Bernotas (2003), observed that in the flowering stage temperatures above 27 °C have a negative effect on canola yield. On the other hand, Sinaki *et al*. (2007), observed that, among the yield components, the most sensitive to the water deficit was the number of pods, when canola plants were exposed to 20%, 50% and 75% of available water in the soil. However, the aforementioned these investigations did not aim to identify the time window during the phenological cycle where yield tends to decrease due to resource limitations.

Knowing the sensitivity of the crop to changes in the availability of resources is of great importance since the phenological stages where the main components of the yield are generated could coincide, with conditions of greater environmental supply. Based on the above, the objective of the present work was: i) to determine the changes in the yield of grain and its components in canola as a result of reductions in the levels of incident solar radiation during different phases of the ontogenic cycle.

Materials and methods

Location of experimental work

The experiment was carried out during the winter-spring 2015-2016 cycle at the Faculty of Agricultural Sciences of the Autonomous University of the State of Mexico, located in the town of El Cerrillo Piedras Blancas, Toluca, Mexico, at 19° 15’ 33’’ north latitude, 99° 39’ 38’’ west longitude, and at an altitude of 2 640 m. The predominant climate according to Garcia (1988) corresponds to a sub-humid temperate climate with rains in summer and little rainfall in winter (5% of the total in the year), annual average temperature of 12.8 ºC and annual average precipitation of 900 mm (González *et al*., 2009). The soil of the region is a pelic Vertisol of volcanic origin, it presents a mineral horizon with a low content of organic matter ranging from 1.01 to 2.36%.

Treatments and experimental design

The treatments consisted of a combination of 2 spring canola cultivars (one short; Hyola 61 and one intermediate; Bioaureo 2486) and shading treatments of 10 days duration (12 in total; including the unshaded control) applied from the appearance from the 3rd true leaf to physiological maturity. Shading was achieved by placing shade mesh 20 cm above the crop canopy, which reduced incident solar radiation by 80%. The treatments (combination of cultivars and shading periods) were established in an arrangement of divided plots, where the large plot consisted of the cultivars and the shading periods corresponded to the sub-plots (12 for each large plot), the which were distributed in a randomized complete block design with three replications.

General conditions of the experiment

The sowing was carried out in plots of five rows of 3 m in length and separated from each other at 0.30 m (4.5 m^2). A planting density of 70 seeds per m^2 was used, of which only 50 plants per m^2 were left after emergence. To achieve this, 315 seeds were distributed uniformly in each plot in the five rows of each experimental plot. The crop was kept in field capacity throughout its cycle by means of a drip irrigation system and without nutritional restrictions, so it was fertilized with the formula 150-60-30.

During the cultivation cycle, the main phenological stages, biomass production, harvest index, grain yield and their numerical components were recorded. These variables were subjected to an analysis of variance and when the F test of the analysis of variance was significant, the means test was performed using the honest least significant difference test (DMSH) at a significance level of 5 % (Dean *et al*., 2017), using the SAS statistical package version 9.0.

Results and discussion

Weather conditions

The climatic conditions during the experiment are presented in (Figure 1), for both genotypes the beginning of the reproductive period coincided with conditions of temperature (average of 13.3 °C) and radiation (daily average of 23.2 MJ m^{-2} s^{-1}) favorable. However, precipitation during the reproductive period was very low (14.8 mm between BFV and IFr), but this was not a limitation given that the crop was established under irrigation conditions (938 mm).

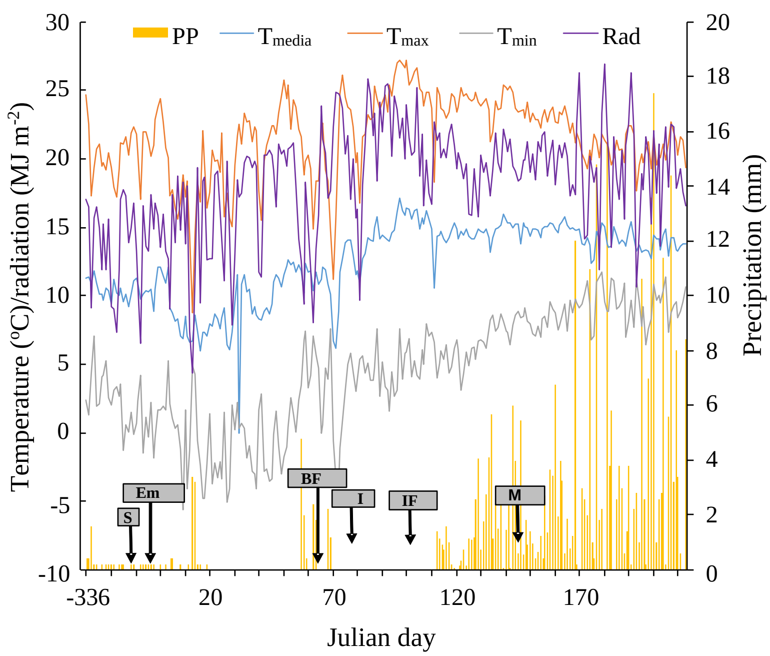

Figure 1. Agroclimatic conditions occurred during the conduct of the experimental work. (S= seeding; Eme= emergence, BFV= flower bud visible, IF= start of flowering, IFr= start of fruiting, MF= physiological maturity).

The comparison of both genotypes in the control treatment revealed that the Hyola 61 genotype outperformed Bioaureo 2486 in most of the variables, except by weight of 1 000 g. However, Bioaureo 2486 outperformed Hyola 61 by 11% in biomass production (Table 1).

Table 1. Mean values and significance of the F values for the variables of the controls of two canola genotypes, in Toluca, Mexico.

Genotypes	Biom ($g\ m^{-2}$)	Yield ($g\ m^{-2}$)	IC	NG	P1000g (g)	NS	NGPS
Hyola 61	1 630.2 b	491.9 a	30.2 a	143 371 a	3.4 a	10 257 a	13.9 a
Bioaureo 2486	1 830 a	343.8 b	18.7 b	98 761 b	3.4 a	8 295 b	11.9 b
CV (%)	10.9	8	10.8	8.7	4.6	10.1	11

Means linked by the same letter do not differ significantly to the 0.05 of the Tukey test. Biomass at maturity (Biom); grain yield (Rend); harvest index (IC); number of grains per m^2 (NG); 1000 grain weight (P1000g); number of pods per m^2 (NS); and number of grains per pod (NGPS).

The correlation between the yield and its components for the two canola genotypes is observed in (Table 2), the yield was positively and significantly correlated ($p < 0.01$) with the biomass in both genotypes and with the weight of 1000 grains ($p < 0.05$) and number of grains per pod ($p < 0.01$) in cultivar Bioaureo 2486. While in Hyola 61 this association was observed in a significant way for all variables except for weight of 1 000 grains and number of grains per pod.

Table 2. Phenotypic correlations for grain yield and its components in two canola genotypes submitted to shading treatments in Toluca, Mexico.

	Biom ($g\ m^2$)	IC	NG	P1000g (g)	NS	NGPS
Bioaureo 2486						
Yield	0.519^{**}	0.127 ns	0.921 ns	-0.094^{*}	0.25 ns	0.699^{**}
Biom		-0.739^{**}	0.433^{**}	0.074 ns	0.343^{*}	0.159 ns
IC			0.152 ns	-0.131 ns	-0.118 ns	0.252 ns
NG				-0.464^{**}	0.356^{*}	0.691^{**}
P1000G					-0.331^{*}	-0.199 ns
NS						-0.42^{**}
Hyola 61						
Yield	0.617^{**}	0.363^{*}	0.934^{**}	0.119 ns	0.735^{**}	-0.008 ns
Biom		-0.494^{**}	0.548^{**}	0.119 ns	0.763^{**}	-0.44^{**}
IC			0.379^{*}	-0.02 ns	-0.04 ns	0.441^{**}
NG				-0.234 ns	0.73^{**}	0.084 ns
P1000g					-0.038 ns	-0.25 ns
NS						-0.603^{**}

*= significant at 0.05; **= significant at 0.01 and ns= not significant; biomass to maturity (Biom); grain yield (Rend); harvest index (IC); number of grains per m^2 (NG); 1000 grain weight (P1000g); number of pods per m^2 (NS) and number of grains per pod (NGPS).

On the other hand, the biomass was negatively and significantly correlated with the IC in the two genotypes, while it correlated positively and significantly ($p < 0.01$) with the number of grains and the number of pods per unit area, while the correlation it was negative for the number of grains per pod in the Hyola 61 cultivar (Table 2). The harvest index was positively and significantly correlated with the number of grains per unit area and the number of grains per pod in the Hyola 61 cultivar. In the same way, a positive and significant association was observed between the number of grains per unit of surface with the number of pods per m^2 and the number of grains per pod for the Bioaureo cultivar, while in this cultivar the NG was negatively correlated with the weight of 1 000 grains.

On the other hand, in the Hyola 61 cultivar, only a positive association was observed between the number of grains and the number of pods per m^2. The weight of 1 000 grains was negatively and significantly correlated ($p < 0.01$) with the number of pods per unit area, and finally this variable was positively and significantly associated ($p < 0.01$) with the number of grains per pod.

Effect of shading on physiological components of yield

When analyzing the effect of the shading treatments imposed before the start of flowering, it was observed that for both genotypes the yield was explained to a greater extent by the harvest index ($r^2 = 0.77$, $p < 0.01$) (Figure 2b) than by biomass produced at physiological maturity ($r^2 = 0.32$, $p < 0.05$) (Figure 2a).

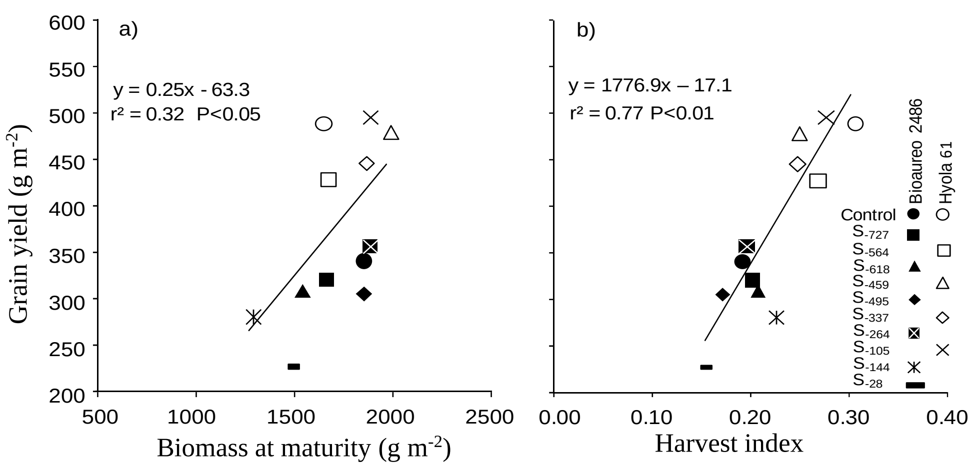

Figure 2. Relationships between grain yield with biomass at maturity (a) and harvest index; and (b) for the shading treatments applied before the start of flowering in two canola genotypes, in Toluca, Mexico.

Conversely, the shading treatments imposed after the start of flowering showed that the grain yield of each cultivar evaluated was explained to a greater extent by the production of biomass at maturity as shown in Figure 3a (Hyola 61: $r^2 = 0.52$, $p < 0.05$; Bioaureo 2486: $r^2 = 0.59$, $p < 0.05$) and not by the harvest index, since in it both genotypes were grouped in a single relationship ($r^2 = 0.37$, $p < 0.05$) (Figure 3b).

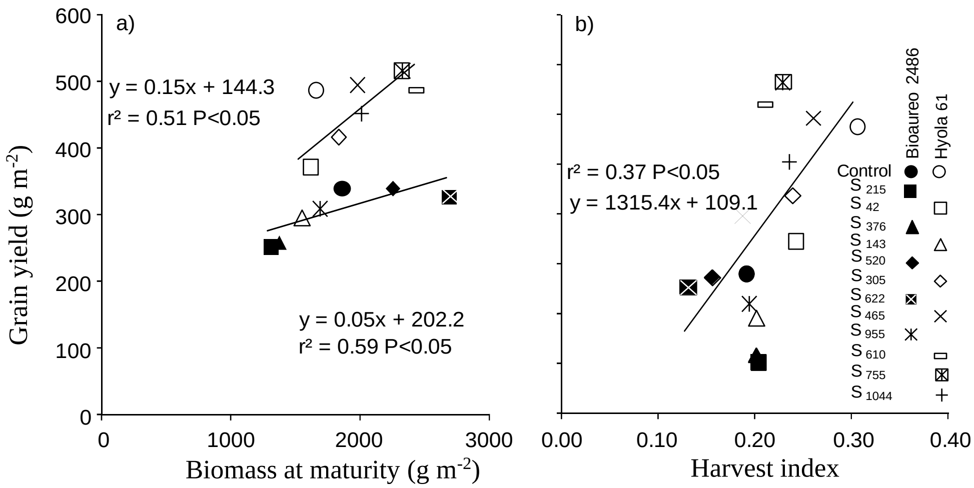

Figure 3. Relationships between grain yield with biomass at maturity (a) and with the harvest index; and (b) for the shading treatments imposed after the start of flowering, in Toluca, Mexico.

When analyzing the changes in grain yield due to the effect of shading treatments applied in pre-flowering, it could be seen that the changes in the number of grains due to the effect of shading explained 97% of the variability observed in grain yield (Figure 4a). The Hyola 61 variety obtained the highest yields (491.9 g m^{-2}, 43%) with respect to Bioaureo 2486 (343.8 g m^{-2}). In both cultivars, the shading treatments imposed before the start of flowering significantly decreased grain yield (25% on average in both cultivars).

The relationship between grain weight and number of grains was not significant, however, there were compensatory effects on grain weight, this effect being more marked in Bioaureo 2486 in treatments S_{-40} and S_{-51} (Figure 4b).

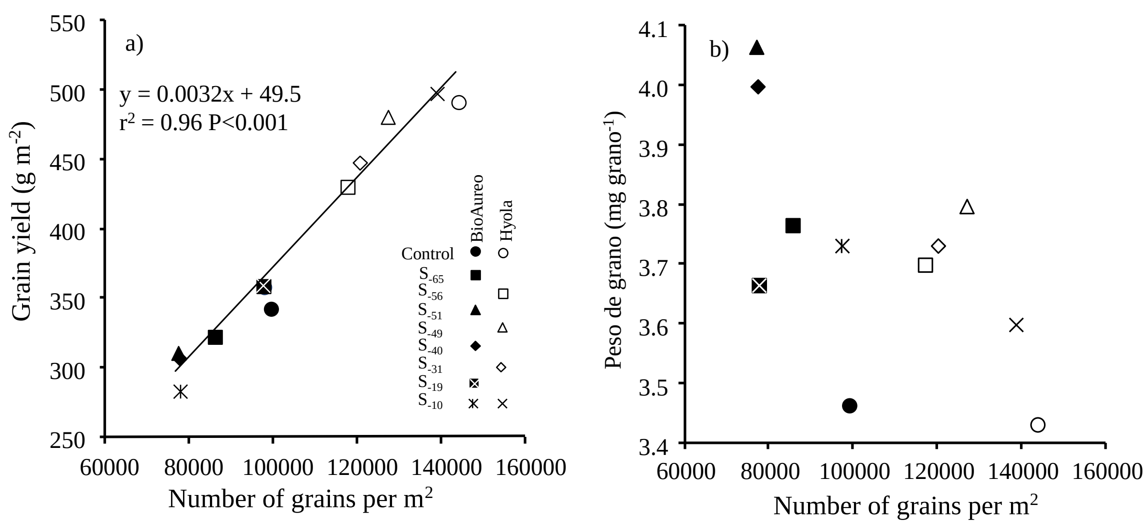

Figure 4. Relationship between grain yield with the number of grains (a) and grain weight with the number of grains; and (b) for the shading treatments imposed before the start of flowering in two canola cultivars in Toluca, Mexico.

On the other hand, the changes in the components of the grain yield as a result of the shading treatments imposed after the start of flowering, was reflected in a significant decrease in the number of grains, mainly in the S_3 and S_{22} treatments (Figure 5a) in the cultivate Bioaureo 2486 with a significant increase in grain weight in the treatments in the same treatments (Figure 5b). For the Hyola 61 genotype, the shading treatments that significantly reduced the number of grains were S_1, S_{11} and S_{21} (Figure 5a), without affecting grain weight (Figure 5b).

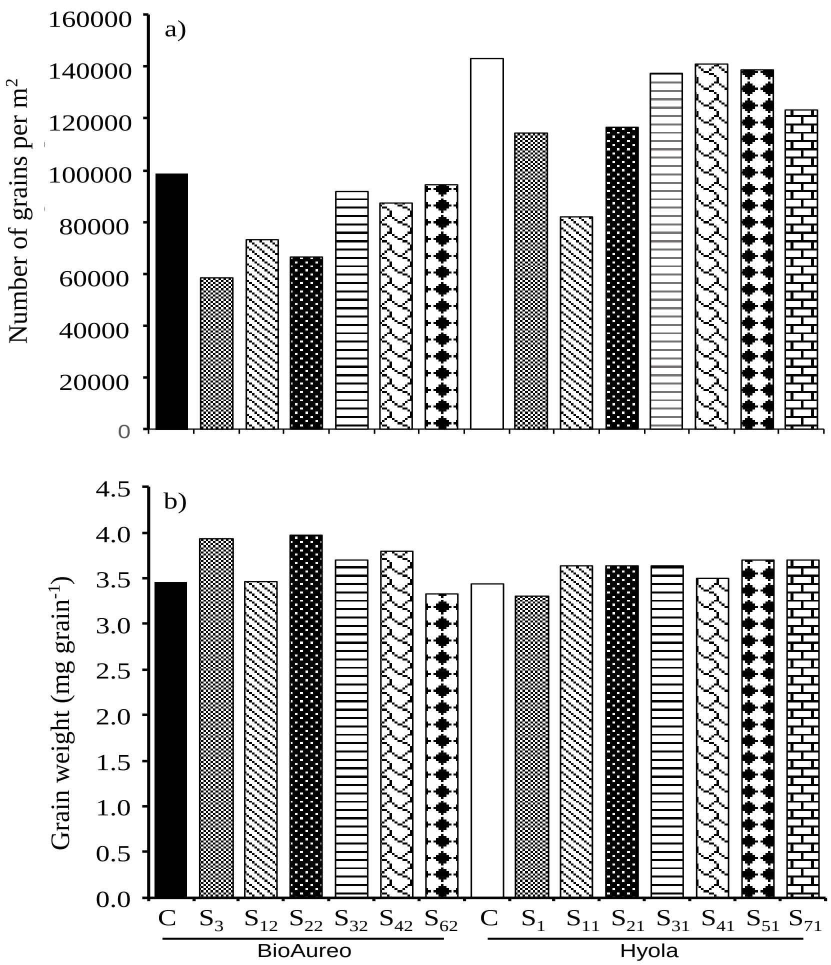

Figure 5. Relationships between the number of grains per m^2 (a) and the individual weight of grain; and (b) regarding the shading treatments imposed after the start of flowering on two canola genotypes, in Toluca, Mexico. The subscript in each shading treatment indicates the number of days since the beginning of flowering.

Grain yield and its components in relative terms

The highest sensitivity of grain yield due to the effect of reductions in assimilates for the Bioaureo 2486 genotype was observed from -140 °Cd up to 410 °Cd with a total of 550 °Cd, in this period the yield decreased significantly to 33%. While in the Hyola 61 cultivar, this period ranged from -45 °Cd up to 250 °Cd with a total of 295 °Cd, with reductions in grain yield during this period of 40% (Figure 6a).

A similar trend was observed in the relative number of grains, where Bioaureo 2486 showed a significant decrease in the number of grains of 43%, from -160 °Cd to 480 °Cd with a total of 640 °Cd. While in Hyola 61 the relative number of grains decreased by 43% from 10 °Cd to 310 °C with a duration of 320 °Cd. (Figure 6b). On the other hand, the relative grain weight for the two genotypes remained similar to the control until flowering, in which Bioaureo 2486 showed a 13% compensation with respect to the control in the shading treatment closest to the beginning of flowering (Figure 6c).

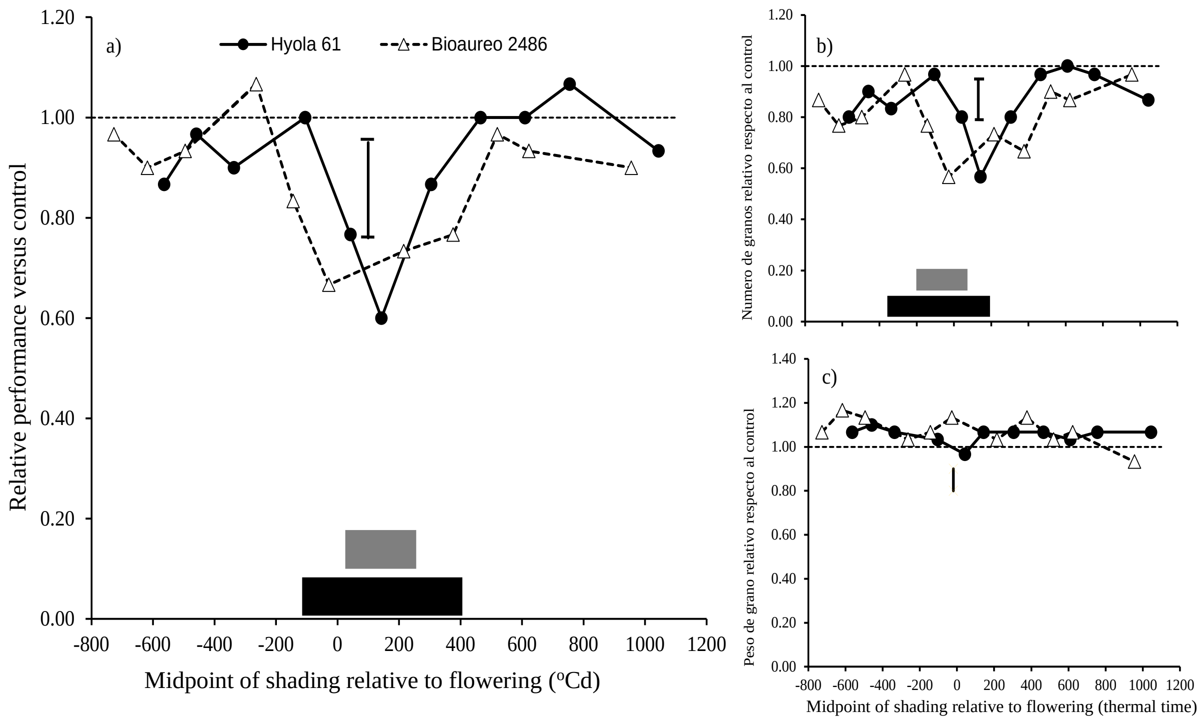

Figure 6. Relationship between the relative yield a) and its components, number of grains per relative m²; b) relative weight of grain c); and the midpoint of shading treatment from the beginning of flowering for two canola genotypes in Toluca, Mexico. The bars on the X axis indicate the length of the period in which the falls in yield, number of grains and grain weight were statistically significant for each variety (Gray: Hyola 61, Black: Bioaureo 2486).

Figure 7 shows the relationship between the relative number of grains, the number of pods per relative m^2, the number of grains per pod and the midpoint of the shading treatment where it is seen that the drop in the relative number of grains , for the Hyola 61 genotype, was mainly due to a decrease in the number of pods relative m^2 of up to 40% (Figure 7b), compared to the control in the period between 42 °Cd and up to 350 °Cd with a total of 308 °Cd, later a compensation of up to 27% was observed with respect to the control.

While for the Bioaureo 2486 genotype this variable was relatively little affected by shading treatments. On the other hand, the changes in the relative number of grains were also associated with the decrease in the number of grains per pod. For the Hyola 61 genotype, this variable only showed a decrease of 20% at 610 °C, while for the Bioaureo 2486 genotype, the number of grains per pod was reduced by 27% (Figure 7c), in the shading treatments that They were imposed around the beginning of the flowering that contemplated a period of 620 °Cd.

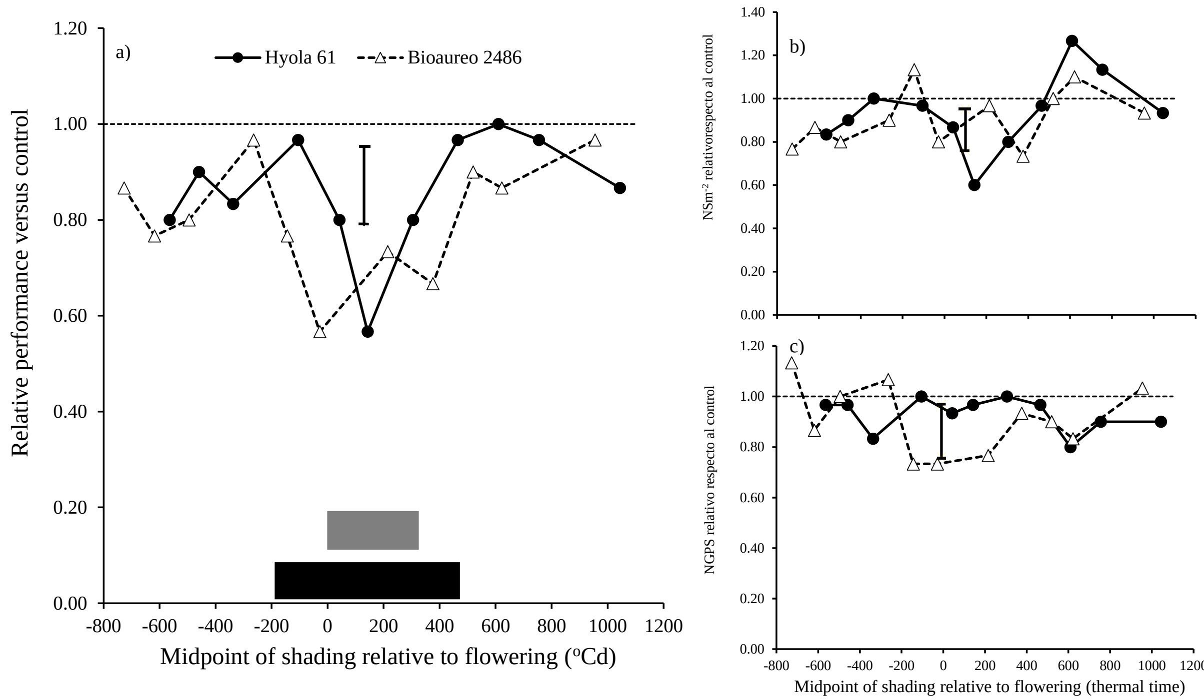

Figure 7. Relationship between the number of grains per m² relative a) and its components relative number of pods per m²; b) number of grains per relative pod; and c) the midpoint of shading treatment from the beginning of flowering for two canola genotypes in Toluca, Mexico. The bars on the X axis indicate the length of the period in which the falls in the number of grains were statistically significant for each variety (Gray: Hyola 61, Black: Bioaureo 2486).

Discussion

The yield generated by the controls was 4.9 and 3.4 t ha^{-1} for Hyola61 and Bioaureo 2486, respectively. These yields show that the work was located in suitable agro-ecological conditions. It is known that in most annual crops from flowering there is a rapid reduction in the leaf area index (IAF) (Madoni and de la Fuente, 2015), which, in the case of canola despite being partially compensated by the green area of the pods, creates an assimilation deficit for the definition of yield Schwab (2010). Based on this, it could be ensured that the shading treatments prior to this stage and consequent to it were the cause of potentiating said deficit. The time window where the canola plant was most sensitive to changes in assimilated availability and in which yield was significantly reduced was identified for: Bioaureo 2486; from -140 °C up to 410 °C with a total of 550 °C with a significant decrease in yield of up to 33%.

While in Hyola 61 this time window presented from -45 °Cd up to 250 °Cd with a total of 295 °Cd and a significant decrease in yield of up to 40%. The greater affectation in Hyola 61, could be associated to the fact that it potentially presents a smaller number of branches (data not reported) compared to Bioaureo 2486. These results coincide with those obtained by Kirkegaard *et al*. (2018) who identified the critical period with a single canola genotype at two different sites, using shading from 30 and 48 days after planting and until physiological maturity.

These authors found significant reductions in canola yield from 100 °Cd after the start of flowering (BBCH60: Biologische Bundesanstalt, Bundessortenamt and CHchemical industry) (this period comprises from 50% of plants with an open flower on the stem main until flowering ceases) and continued up to 500 °C after BBCH60, this period was the one with the greatest impact in both sites, generating a reduction of 40 to 50% in yield.

On the other hand, previous studies analyzing other environmental factors (drought and temperature) other than incident solar radiation have agreed that the period around flowering is the most sensitive for determining canola yield. For example, Champolivier and Merrien (1996) concluded that the most sensitive moment in canola to drought is the flowering phase and the grain growth stage known as G4 (period corresponding to the transition between flowering and developing pod when the final length is reached this) + 10 days. Whereas, Mc Gregor (1981) and Morrison (1993) agreed that temperatures above 27 °C during flowering cause reductions in flower fertility due to sterility of the ovaries, pollen infertility and pod abortion, which is caused by a low potential water in the stigma reducing the ability to hydrate pollen and therefore the growth of the pollen tube (Morrison, 1993). In this sense, the maximum temperatures occurred during the conduct of this work did not reach 27 ºC, therefore, it is likely that the decrease in the number of grains was mainly associated with the reduction in radiation interception during the flowering stage.

On the other hand, in terms of components of the number of grains per m^2 (number of pods per m^2 (NS) and number of grains per pod (NGPS)) the two cultivars behaved differentially, which is how in Hyola 61 the NGPS was reduced up to 20% and the NS 40%, with respect to the control and in Bioaureo 2486 the NGPS was reduced by 27% and the NSm^2 was relatively little affected (9%). These results agree with Kirkegaard *et al*. (2018), who observed reductions between 50 and 55% in the number of grains in two studied environments.

The authors attributed the reductions in the number of pods and the number of grains per pod to a smaller amount of assimilates available when the maximum number of flower buds is reached and the first flowers have opened. In this sense, the data from our study indicates that Hyola 61, being short-cycle and with little branching, bases the number of grains per unit area on the number of pods, while intermediate genotypes such as Bioaureo 2486 depend to a greater extent on the number of grains per pod.

The reductions in canola grain yield were mainly explained by reductions in the number of grains per unit area (43% for the two genotypes) with evidence of a compensation in grain weight being more notable for the Bioaureo 2486 genotype (13%). The foregoing shows that the number of grains is the yield component most sensitive to changes in the availability of resources, as occurs in most grain crops (Slafer *et al*., 2014).

The compensation in grain weight observed in our study partially coincides with the results obtained by Champolivier and Merrien (1996), who stated that water stress in flowering affected the number of grains per plant (31%) and the oil content on the contrary, they observed a compensation effect on the weight of 1 000 grains, accompanied by a significant increase in the final concentration of glucosinolate in the seeds (60%).

The two genotypes used showed different strategies in the generation of the number of pods per m^2, one of them Hyola 61 of low size and with less biomass production and whose production of pods per m^2 was mostly affected (40%) compared to Bioaureo 2486 of high size but with higher biomass production whose pod production was not affected by the shading treatments practically throughout its cycle but in the production of the number of grains per pod.

The superiority in biomass production and number of pods by the Bioaureo 2486 genotype compared to Hyola 61, may be related to a greater number of branches. This is important considering that future yield progress may be associated with increases in aboveground biomass (Shearman *et al*., 2005; Miralles and Slafer, 2007).

Conclusions

In terms of physiological components, grain yield was mainly explained by changes in the harvest index and to a lesser extent by biomass production. The time window in which the yield was affected to a greater extent by the availability of assimilates in canola was different in each of the two cultivars used. In Bioaureo 2486 the window of decrease in yield was presented from -140 °Cd up to 410 °Cd with a total duration of 550 °Cd, with reductions of up to 33%, compared to the unshaded treatment. In Hyola 61 the yield decrease window appeared from 45 °Cd up to 250 °Cd with a total duration of 295 °Cd.

Changes in grain yield due to shading were explained by the number of grains rather than by the individual grain weight. The two genotypes used differed in their strategy to generate the number of grains. Hyola 61 depended more on the number of pods, while Bioaureo 2486 did so through the number of grains per pod.

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Cited literature

Champolivier, L. and Merrien, A. 1996. Effects of water stress applied at different growth stages to (*Brassica napus* L.) var. oleifera on yield, yield components and seed quality. Eur. J. Agron. 5(3-4):153-160. doi.org/10.1016/S1161-0301(96)02004-7.

CONASIPRO. 2019. Bases de datos oleaginosas mundial y nacional 1980-2018. http://www.oleaginosas.org/cat_69.shtml#51.

Dean, D.; Raguljić, D. and Voss, D. 2017. Design and analysis of experiments. Springer International Publishing AG. Cham, Switzerland. 852 p.

Estrada, C. G.; Miralles, D. J. and Slafer, G. A. 2008. Yield determination in triticale as affected by radiation in different development phases. Eur. J. Agron. 28(4):597-605. doi.org/10.1016/j.eja.2008.01.003.

Fischer, R. A 2008. The importance of grain or kernel number in wheat: a reply to Sinclair and Jamieson. Field Crops Research. 105(1-2):15-21. doi:10.1016/j.fcr.2007.04.002.

García, E.1988. Modificaciones al sistema de clasificación climática de Köppen. Instituto Nacional de Geografía. Universidad Nacional Autónoma de México (UNAM). México. 246 p.

González, A.; Sahagún, J.; Vázquez, L. M.; Rodríguez, J. E.; Pérez, D. J.; Domínguez, A.; Franco, O. y Balbuena, A. 2009. Identificación de variedades de maíz sobresalientes considerando el modelo AMMI y los índices de Eskridge. Agric. Téc. Méx. 35(2):189-200.

Iglesias, F. M. and Miralles, D. J. 2014. Changes in seed weight in response to different sources: sink ratio in oilseed rape. Inter. J. Agric. Res. Innov. Technol. 4(1):44-52.

Kirkegaard, A. J.; Lilley, M. J.; Brill, D. R.; Ware, H. A. and Walela, K. C. 2018. The critical period for yield and quality determination in canola (*Brassica napus* L.). Field Crops Res. 222(1):180-188. doi.org/10.1016/j.fcr.2018.03.018.

Kirkegaard, A. J.; Lilley, M. J. and Morrison, M. J. 2016. Drivers of trends in Australian canola productivity and future prospects. Crop Pasture Sci. 67(4):i-ix.

Labra, M. H.; Struik, P. C.; Evers, J. B. and Calderini, D.F., 2017. Plasticity of seed weight compensates reductions in seed number of oilseed rape in response to shading at flowering. Eur. J. Agron. 84(1):113-124.

Madoni, G. A. y De la Fuente, E. B. 2015. ¿Qué se entiende por estructura del cultivo? *In*: Satorre, H; Benech A. R. L; Slafer, G. A.; de la Fuente, E. B.; Miralles, D. J.; Otegui, M. E. y Savin, R. (Eds.). Producción de granos: bases funcionales para su manejo. Facultad de Agronomía, Universidad de Buenos Aires, Argentina. 247-255 pp.

Mc Gregor, D. I. 1981. Pattern of flower and pod development in rapeseed. Canadian J. Plant Sci. 61(2):275-282. doi.org/10.4141/cjps81-040.

Miralles, D. J. and Slafer, G. A. 2007. Sink limitations to yield in wheat: how could it be reduced? J. Agric. Sci. Cambridge. 145(2):1-11. doi.org/10.1017%2FS0021859607006752.

Morrison, M. J. 1993. Heat stress during reproduction in summer rape. Can. J. Bot. 71(2):303-308. doi.org/10.1139/b93-031.

Peltonen-Sainio, P.; Kangas, A.; Salo, Y. and Jauhiainen, L. 2007. Grain number dominates grain weight in temperate cereal yield determination: Evidence based on 30 years of multi-location trials. Field Crops Res. 100(2-3):179-188.

Sadras, V. O. 2007. Evolutionary aspects of the trade-off between seed size and number in crops. Field Crops Res. 100(2-3):125-138.

Schwab, M. I. 2010. Comportamiento agronómico de Colza según fechas de siembra. Trabajo final, Universidad Católica Argentina, Facultad de Ciencias Agrarias, Argentina. http://bibliotecadigital.uca.edu.ar/repositorio/tesis/comportamiento-agronomico-colza-fechas-siembra.pdf.

Shearman, V. J.; Sylvester, R.; Scott, R. K. and Foulkes, M. J. 2005. Physiological processes associated with wheat yield progress in the UK. Crop Sci. 45(1):175-185. Doi:10.2135/cropci2005.0175.

Sidlauskas, G. and Bernotas, S. 2003. Some factors affecting seed yields of spring oilseed rape (*Brassica napus* L.) Agron. Res. 1(2):229-243.

Sinaki, J. M.; Majidi, H. E.; Shirani, R. A.; Nour, M. G. and Zarei, H. 2007.Los efectos del déficit hídrico durante las etapas de crecimiento de la canola (*Brassica napus* L.). American-Eurasian J. Agric. Environ. Sci. 2(4):417-422.

Slafer, G. A.; Araus, J. L.; Royo, C. and García del Moral, L. F. 2005. Promising eco-physiological traits for genetic improvement of cereal yields in Mediterranean environments. Annals Appl. Biol. 146(1):61-70.

Slafer, G. A.; Savin, R. and Sadras, V. O. 2014. Coarse and fine regulation of wheat yield components in response to genotype and environment. Field Crops Res. 157(1):71-83. Doi: https://doi.org/10.1016/j.fcr.2013.12.004.

Zhang, H. and Flottmann, S. 2018. Source-sink manipulations indicate seed yield in canola is limited by source availability. Eur. J. Agron. 96(1):7076. http://dx.doi.org/10.1016/j.eja.2018.03.005.