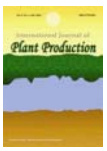

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Oil concentration in canola (*Brassica napus* L.) as a function of environmental conditions during seed filling period

A. Faraji*

Agricultural and Natural Resources Research Center of Golestan, Postal code 4915677555, Beheshti Street, Gorgan, Iran.
*Corresponding author. E-mail: abolfazlfaraji@yahoo.com

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Abstract

Oil concentration (OC) in canola (*B. napus* L.) is determined during seed filling period (SFP), and the variation in OC is greatly related to environmental conditions during that period. To determine factors affecting OC in canola, 12 field experiments were conducted at Agricultural Research Station of Gonbad, Iran, during 2000-07. The experiments were carried out under different growing conditions. The regression functions were fitted to the data of each group of genotypes, over years and experiments. Increasing SFP was a determinant factor for increasing OC. Oil concentration was affected by the duration of SFP, which was maximized when plants of both genotypes (open pollinates and hybrids) were exposed to lower temperatures. There was a linear negative relationship between air temperature during SFP and OC. High temperatures, accelerated the rate of plant development, lowered the length of SFP, and reduced OC potential. In both group of genotypes, the variation of OC was explained by rainfall during SFP, and temperature and radiation interactions during the period, as showed by photothermal quotient (PTQ). There was a positive logarithmic relationship between PTQ during SFP and OC. The relationships of OC with duration of SFP, and temperature, PTQ and rainfall during SFP over years, sowing dates and genotypes showed that these variables are generally applicable in canola OC determination.

Keywords: Oil content; Genotype; Seed yield; PTQ; Temperature.

Introduction

Canola (*Brassica napus* L.) seeds contain high-quality oil that is low in saturated fats. In fact, oil is a secondary plant metabolite that occurs naturally in Brassicaceae, a plant family that has given rise to important crops. Storage oil, in the form of triacylglycerol (TAG), is synthesized during the growth of embryos of oilseeds, and then degraded to provide carbon and energy during germination and early seedling growth (Eastmond and Graham, 2001).

Vegetable oils with a high relative amount of unsaturated fatty acids are of great significance for human health (Amiri-Oghan et al., 2009; Omidi et al., 2010). Canola is a major oil crop that also supplies proteins for the feed industry. By the past, improvement of seed quality focused on fatty acid balance and low seed glucosinolate content. Current goals include the breeding of yellow-seeded canola lines with high content of seed oil (Nesi et al., 2008).

To realize factors affecting oil yield content of *Brassica napus*, crop growth and yield must be evaluated under different environmental conditions. Determining optimum conditions can be a complex task since environmental variables interact with plant growth in a variety of ways. In agricultural fields, environmental stresses are responsible for limiting the crop productivity and quality (Pahlavani et al., 2007; Sinha, 2010). Factors such as sowing date (Adamsen and Coffelt, 2005; Faraji et al., 2009), soil moisture (Gan et al., 2004), assimilate availability (Habekotte, 1993), and temperature (Johnson et al., 1995; Morrison and Stewart, 2002) affect seed development, limiting the achievement of maximum OC. In canola, pod and seed density appear to be fully determined just after the end of flowering, but oil content to be determined in seed filling duration.

Frick et al. (1994) determined effects of N level, time of N increase, CO_2 enrichment, and plant density on *Brassica napus*. Maximum seed oil content (30 to 34%, dry weight basis) was obtained using the lowest N level. In general, an increase in seed oil content was accompanied by a decrease in seed protein. Beaudette et al. (2010) compared canola seed oil yield emissions in tree-based intercropping (TBI) and conventional monocropping (CM) systems. Each cropping system was planted with six canola cultivars, grown at four fertilizer N rates. Seed oil concentrations decreased linearly

with fertilizer N, while seed oil yields increased either linearly or following a quadratic trend. Seed oil concentrations were higher in the CM than in the TBI system, but the two systems did not differ significantly in terms of seed oil yield.

The effect of soil drying on seed yield and oil contents were studied in canola (*B. napus* L.) grown in sandy and loamy soils in lysimeters in the field (Jensen et al., 1996). By controlling irrigation, the plants were exposed to early drought (ED) during the vegetative and the flowering stage or late drought (LD) during the pod filling stage. Under low evaporative demands (2-4 mm day^{-1}) in 1991, seed and oil yields were not significantly influenced by soil drying. Under high evaporative demands (4-5 mm day^{-1}) in 1992, the ED and LD treatments on sand decreased the seed yield by 8% and 17% of the fully irrigated (FI) treatment, respectively; oil yield was significantly decreased (17% in both ED and LD treatments) on sand, only.

On the other hand, Kondra (1975) found effects of row spacing and seeding rate to be insignificant on oil content of *B. napus*. In addition, seed oil and protein contents were unaffected by seeding rate in similar experiments (Morrison et al., 1990).

High oil yield potential of canola can be better realized with understanding of oil determining processes under growing conditions, such as seed filling period. The acreage of canola (*B. napus* L.) in Golestan province, Iran, where this crop has not been traditionally grown, is increasing, due to increased awareness by farmers of benefits of good crop rotations. This study aimed at determining the effect of environmental factors during oil accumulation period in oil yield, comparing all traits in open pollinate and hybrid genotypes. In Fact, the objective of this study was to test the effects of varying environmental conditions such as photothermal quotient, temperature and rainfall during oil concentration period, time of sowing, seed rate and plant density, nitrogen level, supplemental irrigation and planting pattern on oil yield of canola genotypes, conducted during 2000-2007.

Materials and Methods

To determine factors affecting OC in OP and hybrid genotypes of canola, 12 field experiments were conducted at Agricultural Research Station

of Gonbad (45 m a.s.l., 37^{o} N, 55^{o} E), Golestan province, Iran, during 2000-2007. The experiments were carried out at different sowing dates, usually under optimal growing conditions with ample supply of nutrients in a pest, disease and weed-free environment. The region is classified as a warm and semiarid Mediterranean climate. The soil was a fine, silty, mixed, thermic typic Calcixerol. Prior to sowing, soil samples were taken, and according to soil test data, adequate amounts of N, P and K were supplied from urea, triple super phosphate and potassium sulphate, respectively. Experimental Plots were hand weeded regularly. After seedling establishment, plants were thinned to desired spacing.

Phenological stages were recorded with the Harper and Berkenkamp (1975) growth stage key. PTQ was calculated as the ratio of mean daily incident radiation to mean daily temperature in excess of 0 ^{o}C (Adamsen and Coffelt, 2005; Poggio et al., 2005). Mean temperature and PTQ were calculated as the sum of the daily temperatures and PTQs divided by the number of days during the SFP. The regression functions were fitted to the data of each group of genotypes, over years, experiments and sowing dates (SAS Institute Inc., 1996). Summary of some cultural practices in the experiments are shown in Table 1. Weather data was measured at a nearby weather station (Table 2).

Table 1. Summary of the some cultural practices in the experiments.

	Growing season	Treatments and genotypes
Exp. 1	2000-2002	Yield trail (21 OP and 2 hybrid genotypes)
Exp. 2	2000-2002	4 sowing dates, 2 row spacing and 2 genotypes (1 OP and 1 hybrid)
Exp. 3	2001-2002	3 irrigation regimes, 3 nitrogen amounts and 2 genotypes (1 OP and 1 hybrid)
Exp. 4	2001-2002	9 fertilizer treatments and 2 genotypes (1 OP and 1 hybrid)
Exp. 5	2001-2003	3 seed rates, 3 row spacing (1 OP genotype)
Exp. 6	2002-2004	Yield trail (14 OP and 4 hybrid genotypes)
Exp. 7	2002-2004	3 seed rates, 3 row spacing and 2 genotypes (1 OP and 1 hybrid)
Exp. 8	2002-2004	4 sowing dates and 4 genotypes (3 OP and 1 hybrid)
Exp. 9	2003-2005	3 sowing dates, 3 row spacing (1 OP genotype)
Exp. 10	2003-2006	Yield trail (5 OP genotypes)
Exp. 11	2004-2006	Yield trail (11 OP and 5 hybrid genotypes)
Exp. 12	2005-2007	5 sowing dates, 2 irrigation regimes and 2 genotypes (1 OP and 1 hybrid)

Table 2. Monthly weather data at Agricultural Research Station of Gonbad during 2000-2007*.

Years		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
2000-1	Tmax (°C)	23.9	17.9	15.7	12.4	17.0	20.4	24.2	31.7	34.4
	Tmin (°C)	13.7	7.3	6.3	3.1	3.7	7.3	11.8	16.2	20.9
	Precipitation (mm)	29.8	9.0	57.6	11.0	32.8	77.0	11.3	14.2	1.7
	Evap. (mm day^{-1})	2.8	1.9	1.3	1.1	1.7	2.4	3.4	5.5	6.6
2001-2	Tmax (°C)	26.0	20.5	18.2	13.0	16.1	20.4	20.5	26.8	33.6
	Tmin (°C)	13.2	9.8	6.1	3.5	4.1	7.3	10.5	14.1	19.3
	Precipitation (mm)	6.3	35.8	14.0	51.9	23.7	31.6	109.9	12.6	25.4
	Evap. (mm day^{-1})	3.5	2.3	1.7	1.0	1.4	2.4	2.1	3.9	6.9
2002-3	Tmax (°C)	29.8	20.1	11.3	13.6	12.9	13.9	18.6	27.7	31.8
	Tmin (°C)	16.7	9.3	1.3	3.7	4.5	5.2	9.0	13.0	17.7
	Precipitation (mm)	33.8	60.7	55.2	28.3	57.6	89.0	75.5	35.6	8.5
	Evap. (mm day^{-1})	3.5	1.1	0.8	1.3	1.3	1.4	1.6	4.3	6.0
2003-4	Tmax (°C)	30.0	19.4	15.8	20.8	19.4	19.5	21.7	28.1	33.8
	Tmin (°C)	15.8	8.2	6.9	8.8	8.2	7.7	8.9	15.5	20.3
	Precipitation (mm)	28.6	85.4	43.2	5.0	85.4	40.9	101.1	34.1	14.6
	Evap. (mm day^{-1})	3.1	1.8	2.0	2.6	1.8	2.6	2.8	4.7	6.4
2004-5	Tmax (°C)	27.0	21.0	12.9	12.3	12.4	18.1	22.9	28.8	33.5
	Tmin (°C)	12.8	10.0	3.7	3.5	2.4	7.6	10.2	15.8	20.4
	Precipitation (mm)	66.3	80.8	58.4	66.2	47.7	49.2	22.1	64.9	18.0
	Evap. (mm day^{-1})	2.9	1.6	0.9	1.1	1.7	1.9	2.9	4.7	5.4
2005-6	Tmax (°C)	27.6	18.8	16.7	10.2	16.5	19.3	23.4	29.7	37.5
	Tmin (°C)	14.7	7.8	6.1	0.5	4.4	6.9	11.8	15.9	21.9
	Precipitation (mm)	29.9	139.3	36.7	47.3	34.5	22.6	52.8	22.3	8.1
	Evap. (mm day^{-1})	3.1	1.7	1.1	1.0	1.5	2.2	2.9	4.1	7.6
2006-7	Tmax (°C)	29.3	19.4	12.1	15.9	15.5	15.8	19.8	29.4	30.6
	Tmin (°C)	17.0	8.5	3.8	3.5	3.7	5.4	10.3	14.5	24.2
	Precipitation (mm)	30.6	63.9	63.2	10.6	35.8	148.1	56.2	25.0	14.9
	Evap. (mm day^{-1})	3.2	1.8	0.9	2.0	1.4	3.0	2.0	4.8	5.8

* Tmax=Mean maximum temperature, Tmin=Mean minimum temperature, Rad=Radiation, Evap.=Evaporation.

Results and Discussion

In this study, increasing SFP was a good determinant factor for increasing OC (Figure 1). OC was affected by the duration of SFP (Figure 1), which was maximized when plants of both genotypes were exposed to lower temperatures during this period (Figure 2). The logarithmic relationship between OC and the duration of SFP was strong (Figure 1). The equation between OC and the duration of SFP was Y=15.16 ln (x)-15.4 in OP genotypes, and Y=12.6 ln (x)-6.1 in hybrid genotypes (Figure 1). However, the duration of SFP response linearly to the temperature experience during this period in the genotypes, increasing its duration by lower temperatures.

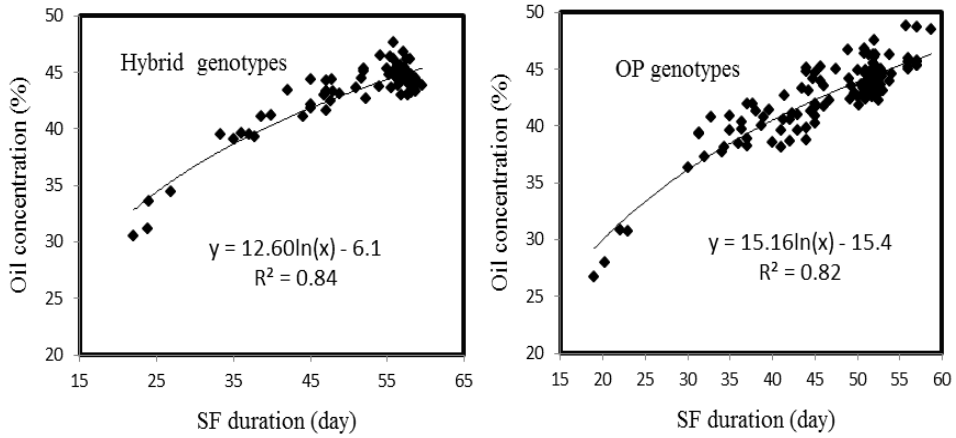

Figure 1. Relationship between seed filling duration and oil concentration in OP and hybrid genotypes.

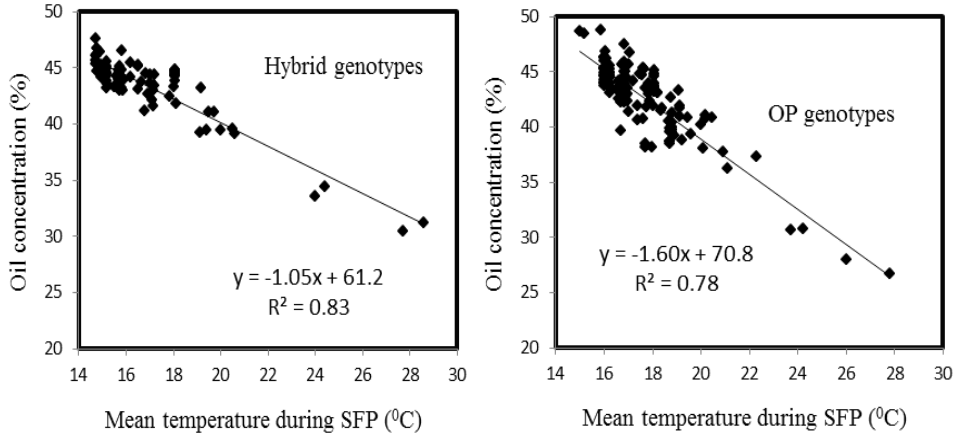

Figure 2. Relationship between mean temperature during SFP and oil concentration in OP and hybrid genotypes.

There was a linear negative relationship between mean air temperature during SFP and OC (Figure 2). For an each unit increase in mean air temperature during SFP, OC of OP and hybrid genotypes decreased 1.60 and 1.05%, respectively (Figure 2). In Golestan province, Faraji (2010) showed that, in both groups of OP and hybrid canola genotypes, there was a negative linear relationship between mean air temperature during SFP and

the duration of the period, explaining 78 and 81% of the variation of OP and hybrid genotypes, respectively. For each degree increase in mean air temperature during SFP, the duration of SFP decreased 2.36 day in OP genotypes and 2.16 day in hybrid genotypes.

Compared with OP genotypes, in hybrid genotypes, SFP occurred earlier. This resulted that, in hybrid genotypes, the duration of SFP lengthened by exposure to lower temperatures, led to a greater SFP, an increased seed weight (SW) and a higher seed yield (SY) (Table 3). SFP was lengthened by lower temperatures in both OP and hybrid genotypes. In fact, hybrid genotypes had higher SFP than OPs at all temperatures. The mean air temperature during SFP, duration of SFP, SW and SY of OP and hybrid genotypes were 17.3 and 16.8 ^{o}C, 46 and 50 day, 3.8 and 4.2 mg, and 3035 and 3332 kg ha^{-1}, respectively (Table 3).

Table 3. Mean values of the some traits of OP and hybrid genotypes over the 12 experiments*.

Genotypes	Days from emergence to SF	Days from emergence to physiological maturity	duration of SFP (day)	Mean temperature during SFP (^{o}C)	Seed weight (mg)	Seed yield (kg ha^{-1})
Open pollinates	127	173	46	17.3	3.8	3035
Hybrids	114	164	50	16.8	4.2	3332

* SF=Seed filling, SFP=Seed filling period.

However, in canola OC is determined during the SFP, and a great proportion of the variation in OC is related to environmental conditions during that period. Direct selection for longer SFP may increase yield, and i.e., selection for higher yield in many genotypes may result in longer SFP (Egli, 2004). However, lengthening SFP of canola may be the most promising avenue to higher yields.

In both group of genotypes, the variation of OC could be explained by cumulative light absorption during the critical period of SF, and in turn temperature and radiation interactions during the period, as showed by PTQ. There was a logarithmic positive relationship between PTQ during SFP and OC (Figure 3). The equation between OC and PTQ during SFP was Y=26.77 ln(x)+51.5 in OP genotypes, and Y=26.33 ln(x)+50.9 in hybrid genotypes (Figure 3).

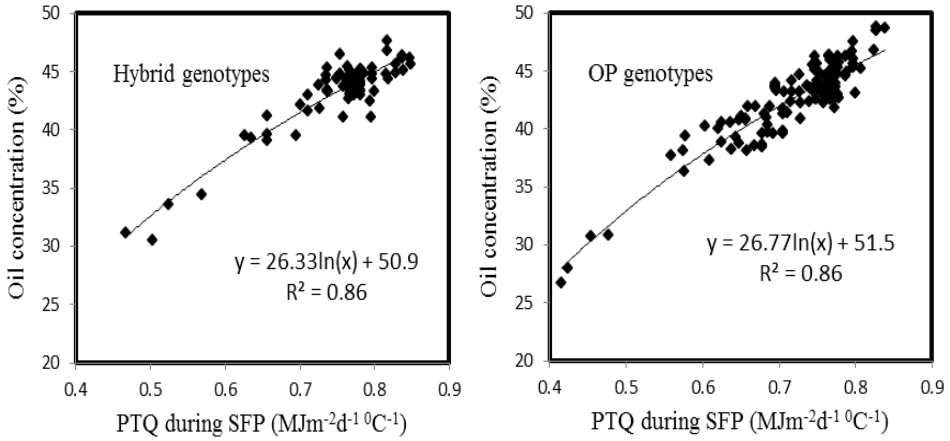

Figure 3. Relationship between PTQ during SFP and oil concentration in OP and hybrid genotypes.

Increasing rainfall during SFP was a good determinant factor for increasing OC (Figure 4). There was a logarithmic positive relationship between accumulative rainfall during SFP and OC (Figure 4). The logarithmic equation between OC and rainfall during SFP was Y=7.23 ln(x)+9.30 in OP genotypes, and Y=8.0 ln(x) +6.08 in hybrid genotypes (Figure 4).

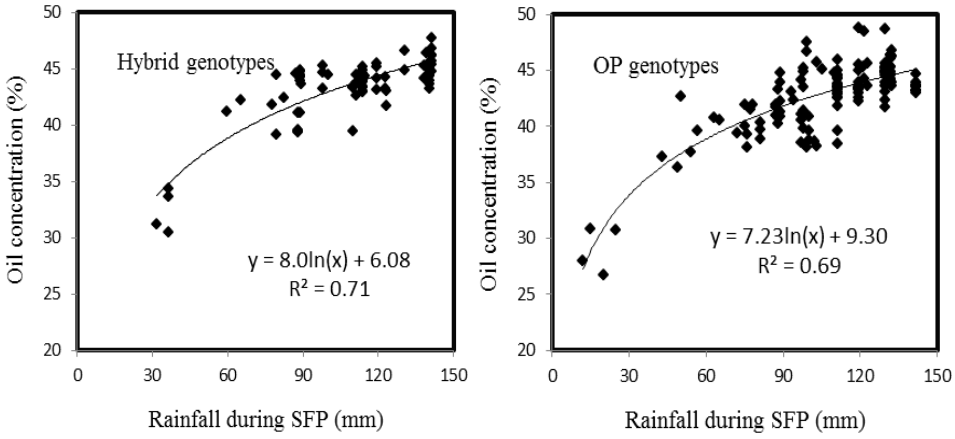

Figure 4. Relationship between rainfall during SFP and oil concentration in OP and hybrid genotypes.

Results clearly showed the importance of air temperature during SFP in determining the duration of that period and thereby OC. In both OP and hybrid genotypes, warmer temperatures increased the rate of plant development, reduced the length of the SFP, and reduced the OC potential (Figures 1 and 2). However, the direct effects of temperature depend on the genotype and its adaptability. However, lower air temperatures during SFP in hybrid genotypes, compared with OP genotypes (Table 3), appeared to be responsible for longer SFP, probably allowing more accumulation of assimilates into seeds, which resulted in heavier seeds (Faraji, 2011). This probably resulted from increased photosynthesis when SFP occurred under lower temperatures and higher PTQs, in accordance with previous reports in canola (Habekotte, 1997; Adamsen and Coffelt, 2005).

As duration of SFP in canola is a function of temperature during this period (Habekotte, 1997), increase in temperature during this period decreased its duration. High temperatures, accelerated the rate of plant development, lowered the length of SFP, and reduced the OC potential, confirmed that cooler growing conditions during SFP improved OC and SY. The fact that increase in OC was resulted from an increase in duration of SFP, and PTQ and rainfall during that period, implies that optimum weather conditions such as high radiation, moderate temperatures and assimilate production during SFP were important factors to determine OC in canola.

Conclusion

In this study, a great proportion of the variation in canola genotype OC was related to environmental conditions such as mean air temperature, radiation and rainfall during SFP. The relationships established in this study explained most of the variability in OC for both group of genotypes. Oil concentration was maximized for the genotypes when exposed to the lower temperatures during the period. In both group of canola genotypes, temperature and radiation interactions during SFP, as showed by photothermal quotient (PTQ), and rainfall during SFP well explained variation of OC. These relationships are simple tools that could be applied to simulate OC in canola under a wide range of environmental conditions. The relationships of OC with duration of SFP, and temperature, PTQ and rainfall during SFP over years, sowing dates and genotypes showed that these variables are generally applicable in canola OC determination. Hence, further increase in OC could be obtainable through improvement in one or a combination of these factors.

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