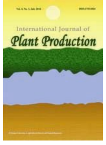

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Seed weight in canola as a function of assimilate supply and source-sink ratio during seed filling period

A. Faraji*

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

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Abstract

Understanding variation in SW (seed weigh) is of major importance in understanding SY (seed yield) variation. The objective of this study was to determine factors such as SN (seed number) per unit area, SFD (seed filling duration) and SFR (seed filling rate) and temperature, LAI (leaf area index), LAD (leaf area duration), above-ground dry matter, CGR (crop growth rate), leaf dry matter remobilization and efficiency and SSR (source-sink ratio) around SFP (seed filling period), affecting SW in canola (*Brassica napus* L.). The experiment was conducted at Agricultural Research Station of Gonbad, Iran, during 2005-7. Two cultivars of spring type canola (Hyola401 and RGS003) as subplots were grown at 5 sowing dates (SDs) as main plots, spaced approximately 30 days apart, to obtain a wide range of environmental conditions during SFP. The experiment was arranged in two conditions, i.e. supplemental irrigation (SI) and rainfed (RF). SW was influenced by the growing season rainfall and temperature. The availability of the crop to produce and to remobilize photosynthetic assimilates to developing seeds was a good determinant factor for SW. SW increased with increase in LAI, above-ground dry matter production and remobilization and SSR around SFP, leading to an increased SY, suggested that SW primarily depends on the resource availability. The relationships of SW with SFR and SFD and above-ground dry matter, LAI, leaf dry matter remobilization and efficiency and SSR around SFP, over environmental conditions, sowing dates and cultivars, showed these variables to be generally applicable in canola SW determination.

Keywords: Canola; Cultivar; Seed weight; Assimilate supply; Seed filling period.

Introduction

In canola (*Brassica napus*), final SY is determined primarily by SN per unit area (Morison, 1993; Brandt and McGregor, 1997; Angadi et al., 2000), but variation in SW does impact SY. Factors such as SD (Adamsen and Coffelt, 2005; Faraji, 2012), moisture regime (Gan et al., 2004; Pahlavani et al., 2007), assimilate availability (Habekotte, 1993; Faraji, 2010) and temperature (Johnson et al., 1995; Morrison and Stewart, 2002) affect seed development, limiting the achievement of maximum SW. SW in canola is determined during the SFP and a great proportion of the variation in SW is related to environmental conditions during the critical period when SW is being determined. Changes in environmental conditions during the SFP could potentially affect SW (Saini and Westgate, 2000). Therefore, direct selection for long SFPs may increase yield and conversely, selection for higher yield in many crops resulted in longer SFPs (Egli, 2004). However, given that lengthening the SFP may be the most promising avenue to higher yields, but new approaches to manipulate it will probably have to be devised.

SFD is regulated by the leaf's ability to supply assimilate to the developing seed and the ability of the seed to use this assimilate for continued growth. Water and high temperature stresses during SFP accelerate leaf senescence and shorten the SFP. Saini and Westgate (2000) indicated that stress conditions late in grain filling limit the duration of dry matter accumulation in cereal grains. During the SFP, SW shows a phase of fast increase during which sink demand for assimilates is strong. Assimilates used in seed filling mainly originate in current photosynthesis (Dosio et al., 2000). Source limitation during later phases of SFP decreases SW (Uhart and Andrade, 1995). Under such conditions, final SW probably relates the SSR during the effective SFP (Borras and Otegui, 2001) to a greater extent than the effective sink capacity established early in seed filling.

The mechanism by which assimilate availability might regulate canola seed development and weight, have not been established. However, less information is available about the effect of environmental conditions on SW. So as part of a two year study, the effect of assimilate supply around SFP was evaluated and factors affecting SW during this period were identified.

Materials and Methods

The experiment was conducted at Agricultural Research Station of Gonbad, Golestan province, Iran (45 m a.s.l., 37^{o} N, 55^{o} E) over two years (2005-6 and 2006-7). The region classify as 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, P and K were preplant-incorporated to supply 50 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} from triple super phosphate and potassium sulphate, respectively. N was applied at 75 kg N (as urea)/ha, that a third of this amount was applied preplant, a third of that was side-dressed at beginning of stem elongation and the rest at the beginning of flowering. The experiment was a randomized complete block design arranged in split plot with 3 replications. Two cultivars of spring canola (Hyola 401, a hybrid cultivar and RGS003, an open pollinated one) as subplots were grown at 5 sowing dates as main plots. The sowing dates were 9 Nov., 6 Dec., 5 Jan., 4 Feb. and 6 Mar. in 2005-6 and 6 Nov., 6 Dec., 5 Jan., 4 Feb. and 6 Mar in 2006-7, to have a wide range of environmental conditions during SFP.

Plots were over planted and after seedling establishment, the plants were thinned to the desired spacing between plants of 5 cm (1000000 plant ha^{-1}). Each subplot consisted of eight five-meter long rows. Main plots and subplots were 2 and 0.4 m apart, respectively. A 3-m pathway separated replicates. From each plot, above-ground dry matter, LAI and other necessary samples were taken from 10 plants of rows of 2 and 3. The area of leaves (one side lamina) was measured using a leaf-area meter (DIAS, Delta-T Devices). Leaf area duration (LAD) was calculated by the equation as: $LAD = \frac{LAI_1 + LAI_2}{2(T_2 - T_1)}$. Where LAI_1 and lAI_2 are the leaf area index between the beginning of seed filling and physiological maturity and T is the day corresponding to LAI determination (Liu et al., 2004). Leaf dry matter in remobilization was calculated from leaf dry matter at the beginning of seed filling minus that of at physiological maturity. Leaf efficiency in remobilization was calculated as the quotient of Leaf dry matter in remobilization and leaf dry matter at the beginning of seed filling.

At physiological maturity 10-plant samples were obtained from each plot to determine SN per unit area (plant density per unit area × pod number per plant × SN per pod). At harvested time (2 days after physiological maturity) rows of 5, 6 and 7 were harvested for seed yield determination. During the season, phenological stages of the beginning and end of the seed filling were recorded with the Harper and Berkenkamp (1975) growth stage key. SFD was considered as the number of days between the beginnings of seed filling to physiological maturity. A 1000-seed sub samples was weighed (with 8%

moisture content), to determine 1000-SW. Temperature and rainfall measured at a near-by weather station (Table 1). Maximum mean temperatures were calculated for the same growth phases as the sum of the daily maximum temperatures divided by the number of days during the growth phase. SSR was calculated as the quotient of LAD and SN per unit area (Ruiz and Maddonni, 2006).

Table 1. Rainfall, used water in evapotranspiration and maximum temperature during SFP.

	Rainfall during growth season (mm)	Used water in evapotranspiration during growth season (mm)		Mean maximum temperature during SFP (^{0}C)	
		Irrigated	Rainfed	Hyola401	RGS003
2005-6					
Sowing dates					
9 Nov.	213	351	300	22.3	23.1
6 Dec.	195	342	269	23.5	24.9
5 Jan.	165	321	229	25.2	25.3
4 Feb.	128	308	230	26.1	26.8
6 Mar.	95	310	170	35.7	36.1
2006-7					
Sowing dates					
6 Nov.	379	422	366	20.4	20.9
6 Dec.	334	387	322	22.0	22.9
5 Jan.	276	342	275	24.1	24.9
4 Feb.	265	352	281	29.7	30.6
6 Mar.	237	388	269	33.9	34.5

[*] SN= seed number.

In SI conditions, plots were irrigated at the beginning of stem elongation, flowering and seed filling stages. Two days before irrigation times, soil samples were dried for 24 hours at 105 °C and weighed. Then soil water content was measured and plots were reached to field capacity with irrigation. As run off was never observed in the field and drainage and capillary rise were considerd negligible, therefore total used water in evapotranspiration was identified from initial soil water content minus final soil water content, precipitation and irrigation using the following equation (Zhang et al., 1999): $TWU=P+I+\Delta W$. Where TWU= total used water in evapotranspiration during crop growth season (mm), P= precipitation or rainfall (mm), I= irrigation (mm) and ΔW= soil water content when the crop is sown minus that of at harvest for the 1.2 m depth (mm). Data were tested by the analysis of variance using SAS (SAS Institute, 1989).

Results

There were differences in rainfall, used water in evapotranspiration during crop growth season and mean maximum temperature during SFP between the two growing season of the study (Table 1), resulted the significant effect of year in the combined ANOVA (Table 2). The 2005-6 growing season was drier than 2006-7 (Table 1). The greater number of rainy days and the associated cloudiness during flowering and seed set in 2006-7, compared with 2005-6, resulted in lower SN per pod in 2006-7 (Table 3). SN per unit area in 2005-6 growing season (103740 seed per unit area) was greatly (45%) more than that of in 2006-7 (71400 seed per unit area). Also, mean 1000-SW in 2006-7 (2.95 g) was 34% more than that of in 2005-6 (3.95 g) (Table 3). Difference between irrigation and cultivars were significant (Table 3). 1000-SW was more in SI conditions than RF (Table 3), due to adequate water amount and to have a condition without water stress during the crop growth season under SI.

Table 2. Analysis of variance for yield and yield components in the combined ANOVA[1].

Source of variation	Df	Pod number per plant	SN per pod	1000-seed weight	SY
Year (Y)	1	288^{ns}	1200^{**}	28.6^{**}	1460813^{*}
Irrigation (IR)	1	2740^{ns}	94.9^{ns}	7.0^{ns}	3864994^{ns}
Y*IR	1	400^{ns}	5.2^{ns}	0.16^{ns}	383974^{ns}
Error 1	8	1859	36.5	2.4	1038007
Sowing date (SD)	4	51017^{**}	759^{**}	16.3^{*}	154969646^{**}
Y*SD	4	3085^{ns}	27.1^{ns}	2.0^{**}	373831^{ns}
IR*SD	4	1150^{ns}	14.0^{ns}	0.76^{ns}	735414^{ns}
Y*IR*SD	4	868^{ns}	23.8^{ns}	1.3^{*}	28224^{ns}
Error 2	32	10303	128	3.4	3520044
Cultivar (C)	1	1290^{ns}	102^{**}	4.4^{ns}	9702591^{ns}
Y*C	1	544^{*}	0.001^{ns}	0.78^{**}	472508^{*}
IR*C	1	72.4^{ns}	0.001^{ns}	0.02^{ns}	156241^{ns}
Y*IR*C	1	88.3^{ns}	10.6^{ns}	0.19^{ns}	2443654^{ns}
SD*C	4	9.3^{ns}	5.0^{ns}	0.07^{ns}	352734^{ns}
Y*SD*C	4	249^{ns}	5.6^{ns}	0.10^{ns}	420324^{ns}
IR*SD*C	4	415^{ns}	15.5^{ns}	0.16^{ns}	212871^{ns}
Y* IR*SD*C	4	930^{ns}	12.8^{ns}	0.06^{ns}	295088^{ns}
Error 3	40	3514	120	2.49	4121779

^{ns} non significant and * and ** significant at 5 and 1% level, respectively.

Table 3. Means of some traits of canola during two years in the experiment.

	Pod number per plant	SN per pod	1000-seed weight (g)	SY (kg ha^{-1})
		2005-6		
Irrigated	64^{a}	19.3^{a}	3.2^{a}	2567^{a}
Rainfed	50^{b}	17.1^{b}	2.7^{b}	2095^{b}
Sowing dates				
9 Nov.	77^{a}	21.1^{a}	3.2^{a}	3780^{a}
6 Dec.	70^{b}	19.2^{b}	3.0^{b}	3106^{b}
5 Jan.	58^{c}	18.6^{bc}	3.1^{b}	2460^{c}
4 Feb.	44^{d}	18.1^{c}	3.0^{b}	1724^{d}
6 Mar.	35^{e}	14.2^{d}	2.4^{c}	582^{e}
Cultivars				
Hyola401	58^{a}	19.2^{a}	3.1^{a}	2678^{a}
RGS003	56^{a}	17.3^{b}	2.8^{b}	1984^{b}
		2006-7		
Irrigated	63^{a}	12.6^{a}	4.2^{a}	2233^{a}
Rainfed	57^{b}	11.2^{b}	3.7^{b}	1987^{b}
Sowing dates				
6 Nov.	95^{a}	15.1^{a}	4.3^{a}	3543^{a}
6 Dec.	79^{b}	12.2^{bc}	4.3^{a}	2896^{b}
5 Jan.	63^{c}	14.0^{ab}	3.8^{b}	2362^{c}
4 Feb.	39^{d}	11.4^{c}	4.2^{a}	1588^{d}
6 Mar.	24^{e}	6.9^{d}	3.0^{c}	162^{e}
Cultivars				
Hyola401	65^{a}	12.8^{a}	4.2^{a}	2332^{a}
RGS003	55^{b}	11.0^{b}	3.7^{b}	1888^{b}

[*] Means followed by the same letter within each column are not significantly different according to the LSD (P=0.05). SN=seed number; SY=seed yield.

Variation in SY was closely related to SN per unit area and SW (Table 3). In both years, first SD had the highest pod number per plant, SN per pod and 1000-SW, led to highest SY. SI increased canola 1000-SW, significantly. The mean 1000-SW in SI and RF conditions was 3.2 and 2.7 g in 2005-6 and 4.2 and 3.7 g in 2006-7 (Table 3). 1000-SW was varied between 2.4 to 3.2 g in 2005-6 and 3.0 to 4.3 g in 2006-7 (Table 3). Delay in SD until 6 Mar., led to dramatically decrease in 1000-SW. There was significant SN per unit area and 1000-SW differences between cultivars in both years (Table 3). The 1000-SW of Hyola401 and RGS003 was 3.1 and 2.8 g in 2005-6 and 4.2 and 3.7 g in 2006-7, respectively. Therefore, over two years, the 1000-SW of Hyola401 was 12.3% more than that of RGS003.

SW was affected by SFD and SFR. The relationship between 1000-SW and SFD was strong, particularly for Hyola401 hybrid, explaining 79 and

70% of the variation for Hyola401 and RGS003, respectively (Figure 1 a and b). For an each day increase in SFD, 1000-SW of Hyola401 and RGS003 increased 0.094 and 0.072 g, respectively (Figure 1 a and b). Also there was a strong positive relationship between 1000-SW and SFR, explaining 78 and 81% of the variation for Hyola401 and RGS003, respectively (Figure 1 c and d). 1000-SW was maximized for the cultivars when exposed to the lowest temperatures during SFP. There was a strong negative relationship between SFD and mean air temperature during SFP, explaining 82 and 75% of the variation for Hyola401 and RGS003, respectively (Figure 2). For an each degree increase in mean air temperature during SFP, 1000-SW of Hyola401 and RGS003 decreased 1.89 and 1.56 g, respectively (Figure 2).

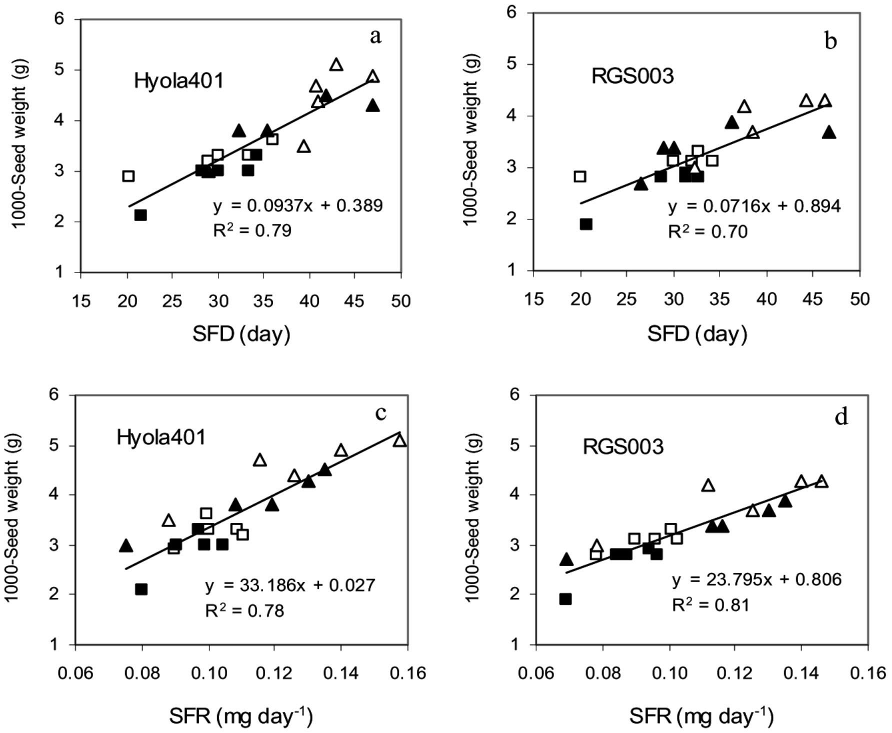

Figure 1. Relationships between 1000-SW and SFD (a and b) and 1000-SW and SFR (c and d). SFD=seed fill duration; SFP=seed filling period; SFR; seed filling rate; SW=seed weight. (□) Irrigated condition in 2005-6; (■) Rainfed condition in 2005-6; (Δ) Irrigated condition in 2006-7; (▲) Rainfed condition in 2006-7.

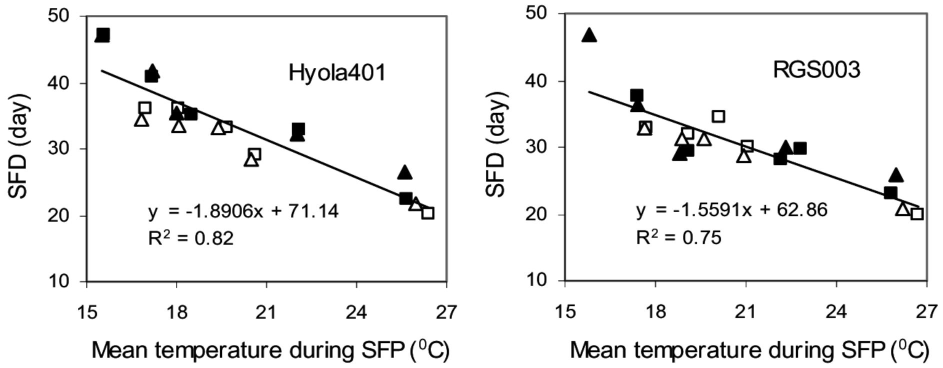

Figure 2. Relationship between SFD and mean air temperature during SFP. SFD=seed fill duration; SFP=seed filling period. (□) Irrigated condition in 2005-6; (■) Rainfed condition in 2005-6; (Δ) Irrigated condition in 2006-7; (▲) Rainfed condition in 2006-7.

The availability of the crop to produce and to remobilize photosynthetic assimilates for developing seeds was a good determinant factor for SW. Early SDs increased 1000-SW (Table 2), due to a better weather conditions during SFP (Table 1) and increase in assimilate supply. For all treatments, LAI peaked at the beginning of seed filling and then declined during SFP. In both cultivars, LAI and above-ground dry matter at the beginning of seed filling well described 1000-SW variations. There was a linear positive relationship between LAI at the beginning of seed filling and 1000-SW, explaining 74 and 72% of the variation for Hyola401 and RGS003, respectively (Figure 3 a and b). For an each unit increase in LAI, 1000-SW of Hyola401 and RGS003 increased 0.55 and 0.43 g, respectively (Figure 3 a and b). However, in both cultivars, there wasn't any significant relationship between 1000-SW and LAD during SFP.

There was a linear positive relationship between above-ground dry matter at the beginning of seed filling and 1000-SW, explaining 76% of the variation for the cultivars (Figure 3 c and d). For an each g m^{-2} increase in above-ground dry matter at the beginning of seed filling, 1000-SW of Hyola401 and RGS003 increased 0.0024 and 0.0019 g, respectively (Figure 3 c and d). LAI and above-ground dry matter at the beginning of seed filling well accounted the variation of canola 1000-SW in this study. Over years, irrigation conditions and SDs, 1000-SW of Hyola401 had a greater response to increase in LAI and above-ground dry matter at the beginning of seed filling, compared to RGS003 (Figures 1 and 2). Leaf dry matter remobilization and efficiency were good indicators of SW determination. 1000-SW was a function of leaf dry matter in remobilization and leaf efficiency in remobilization. There was a linear strong relationship between 1000-SW and leaf dry matter in remobilization, explaining 78 and 77% of the variation for Hyola401 and RGS003, respectively (Figure 4 a and b). For an each g m^{-2} increase in leaf dry matter in remobilization, 1000-SW of Hyola401 and RGS003 increased 0.0073 and 0.0065 g, respectively (Figure 4 a and b). For both cultivars, the increase in leaf efficiency in remobilization associated with increase in 1000-SW. There was a linear strong relationship between 1000-SW and leaf efficiency in remobilization, explaining 79% of the variation for the cultivars (Figure 4 c and d).

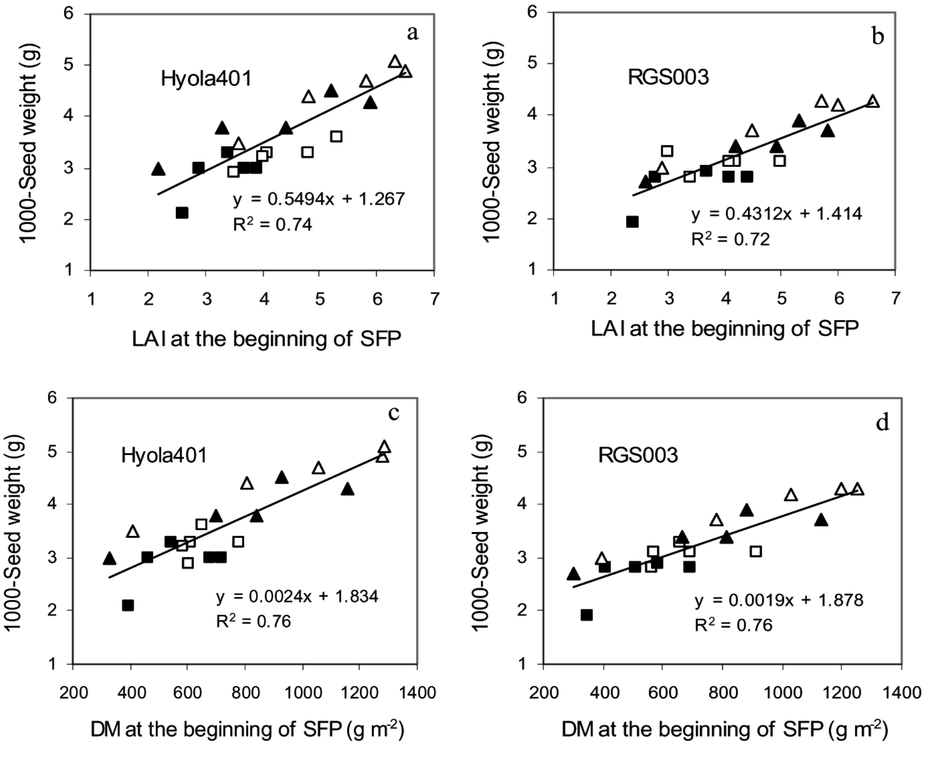

Figure 3. Relationships between 1000-SW and LAI at the beginning of SFP (a and b) and 1000-SW and above-ground dry matter at the beginning of SFP (c and d). LAI= leaf area index; SFP= seed filling period; SW= seed weight; DM= dry matter. (□) Irrigated condition in 2005-6; (■) Rainfed condition in 2005-6; (Δ) Irrigated condition in 2006-7; (▲) Rainfed condition in 2006-7.

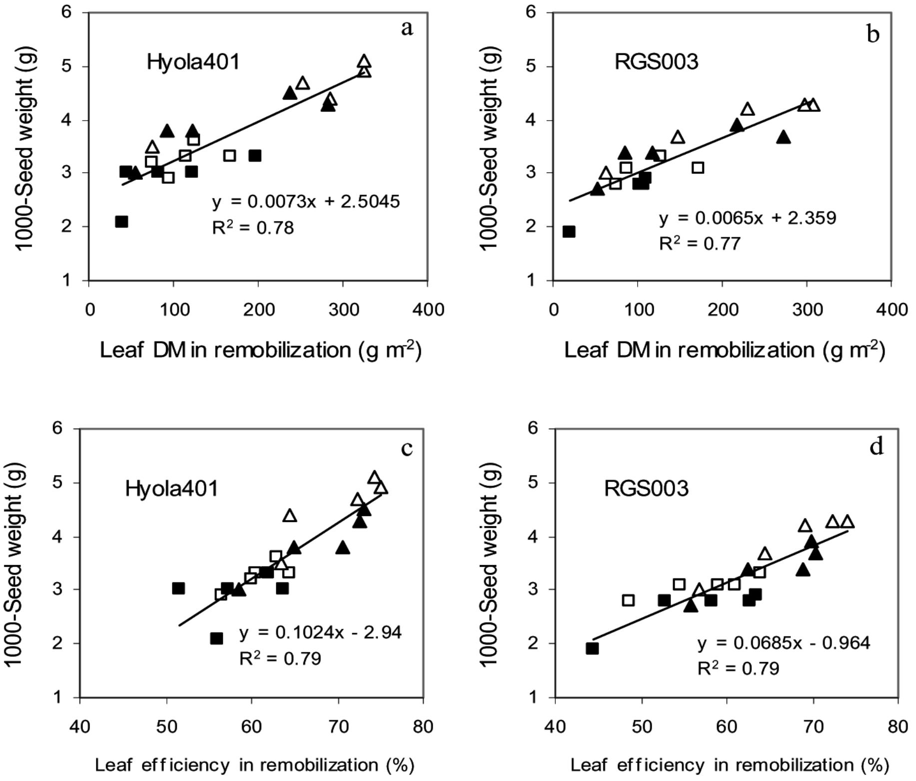

Figure 4. Relationships between 1000-SW and leaf dry matter in remobilization (a and b) and 1000-SW and leaf efficiency in remobilization (c and d). SW= seed weight; DM= dry matter. (□) Irrigated condition in 2005-6; (■) Rainfed condition in 2005-6; (Δ) Irrigated condition in 2006-7; (▲) Rainfed condition in 2006-7.

There was not any significant relationship between 1000-SW and CGR during SFP, indicating that SW was not affected by CGR during SFP. However the SSR well accounted for SW prediction. There was a strong linear relationship between 1000-SW and SSR during SFP, explaining 84 and 76% of the variation for Hyola401 and RGS003, respectively (Figure 5), indicating that a post seed filling SSR well described 1000-SW variation for both cultivars. For an each unit increase in SSR, 1000-SW of Hyola401 and RGS003 increased 29.6 and 15.0 g, respectively (Figure 5). The changes in environmental conditions during SFP over sowing dates and irrigation conditions, had no impact on the relationships of SW with SFD, SFR and LAI and dry matter production and remobilization around SFP.

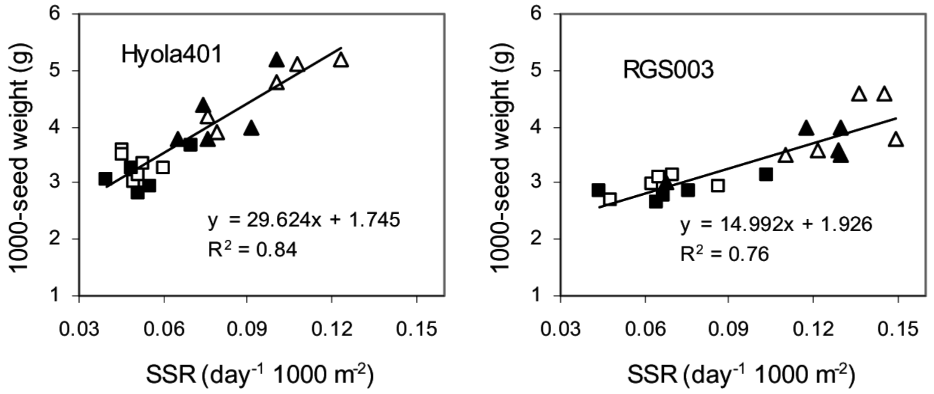

Figure 5. Relationship between 1000-SW and SSR during SFP. SSR= source-sink ratio. SW= seed weight. (□) Irrigated condition in 2005-6; (■) Rainfed condition in 2005-6; (Δ) Irrigated condition in 2006-7; (▲) Rainfed condition in 2006-7.

Discussions

The combination of years, sowing dates and irrigation conditions provided wide variation in environmental conditions during SFP. Seed yield and 1000-seed weight were influenced by growing season rainfall and temperature. 1000-seed weight was significantly higher in supplemental irrigation, compare to rainfed conditions in all two years (Table 3). The non significant relationship between SN per unit area and 1000-SW, showed that SN per unit area was not a limiting factor for seed development. In wheat, Areche and Slafer (2006) found that when the number of grains per unit area increased, a concomitant increase in the proportional contribution of grains that are constitutively smaller takes place, led to a non significant relationship between the number of grains per unit area and SW. Miralles and Slafer (1995) indicated that the reduction in the average grain weight produced by increases in grain number was not attributed to an increased competition for assimilates.

As SFD in canola is a function of temperature during SFP (Habekotte, 1997), so, in this study, increase in temperature during this period decreased SFD (Figure 2). High temperatures, due to delay in SD (Table 1), accelerated the rate of plant development, reduced the length of the SFD (Figure 2) and reduced the SW potential (Figure 1), as we can see in some species (Entz and Flower, 1991; Chimenti and Hall, 2001). Araus et al.

(2002) suggested that plant development could be genetically manipulated to lengthen phases associated with SY, even in environments where the SFP is subjected to drought stress. In this study, matching the phenology of the crop to the duration of favorable conditions by selecting the most appropriate SD to avoid periods of stress, was crucial for maximum SW and SY. Kirkland and Johnson (2000) resulted that response of SW to SD was similar to that of for SY, indicating that a portion of the positive yield response to optimum SD was associated with higher SW.

Some of the advantages with early SDs likely was associated with the avoidance of extreme growing conditions during SFP. Compared to later SDs, canola sown at mid-Nov. avoided high temperatures during critical period of seed filling and had greater amount of rainfall during crop growth season (Table 1), led to increased SN per unit area, 1000-SW and SY. SFP of the crop in late SDs coincide with high temperatures, that resulted to decrease in 1000-SW. As well as some species (Borras et al., 2003), in this study, high temperatures (Table 1) during SFP shortened the duration of the effective SFP, probably led to the natural process of desiccation to begin prematurely. Results from other studies (Nutall et al., 1992; Kirkland and Johnson, 2000) confirmed that cooler and moisture growing conditions during SFP explained improved canola SW and SY. However, ideal growing condition for canola seed development would explain why SW was greater for early SDs and irrigated conditions.

SFD generally has been found to be positively correlated with SY in wheat (Talbert et al., 2001), maize (Ottaviano and Camussi, 1981) and sunflower (Aguirrezabal, et al., 2003). The fact that increase in SW resulted from an increase in SFD and a faster SFR, implies that optimum weather conditions such as moderate temperatures, assimilate production and reserve dry matter remobilization during SFP were important factors to determine SW in canola. As pointed out by Habekotte (1997), in this study, the duration of seed filling was strongly depending on temperature regime (Figure 2). Hence, dry matter production and translocation during the SFP and thus SW were probably influenced by temperature. However, this result that the SW of canola was negatively correlated with mean air temperature during reproductive growth stages, indicated that selection for long SFD may lead to increased SW.

As showed by Royo et al. (1999), in this study, seed filling was maintained by a high contribution from assimilation before and immediately after the beginning of SFP and remobilization of vegetative reserves during seed growth. The strong relationships of 1000-SW with LAI and above-ground dry matter at the beginning of seed filling and leaf dry matter remobilization and efficiency, indicated that SW was driven by the produced cumulative carbohydrates till seed filling stage and the ability of the crop to remobilize reserved carbohydrates to developing seeds. Drought stress from anthesis to maturity, specially if accompanied by high temperatures, hastens leaf senescence, reduces the duration and rate of seed filling and hence reduces SW (Royo et al., 2000). Under different drought treatments, Zhong-hu and Rajaram (1994) found that wheat kernel weight remains relatively stable due to high remobilization of stored preanthesis assimilate. Habekotte (1993) found that canola pod density and SW were linearly related to cumulative dry matter production of the crop until the end of flowering, i.e. to total assimilate availability over that period. In Maize, Borras and Otegui (2001) indicated that final SW is a product of the sink capacity of individual kernels and the availability of assimilates to fill these sinks. In canola, Chongo and McVetty (2001) did not find any correlations between SY and leaf photosynthetic rates, but the high-yielding group displayed the highest net photosynthetic rates, utilized water more efficiency at early flowering and produced the highest total dry matter and SY, suggesting the importance of canola leaves during the early reproductive stage. Increased remobilization efficiency of reserves from leaves, or other plant parts has been suggested as a potential strategy to improve SW and SY (Wahid et al., 2007).

The stability of these relationships over a wide range of environmental conditions supports the conclusion that LAI and above-ground dry matter at the beginning of SFP are important determinants of canola SW. 1000-SW increased with increase in above-ground dry matter production and remobilization and SSR around SFP, leading to an increased SY. However, dry matter is the product of growth rate and duration of the growing period, both of which indicate the potential for improvement in SW and thereby SY. During seed set, the relation between source and sink regulates the availability of assimilates necessary for seed filling (Diepenbrock, 2000). Higher LAI and LAD under irrigated conditions and early SDs (some data not shown) probably increased the interception of solar radiation and thus a greater CO_2 fixing ability of canola plants, resulted in accumulation of more assimilates. This result in part agrees with Liu et al. (2004), who stated that achieving a high total biomass through adequate vegetative growth is an essential prerequisite for high reproductive growth and a high SW in soybean. SW response to high SSRs during SFP may be conditioned by preseed filling growing conditions. Therefore as showed by Cantagallo et al., 2004, a reduction of the assimilate availability per plant before seed filling, such as that expected in the late SDs in this study, probably reduced ovary size, conditioned final 1000-SW. Crops with adequate resource availability per seed, such as those cultivated at mid-Nov. and irrigated conditions, attained the maximum SWs. Consequently as some species (Borras et al., 2003; Ruiz and Maddonni, 2006), in this study, the SFP assimilate availability per seed conditioned SW. Ruiz and Maddoni (2006) found that a post-flowering SSR better accounted (r^2=0.69) for SW prediction than LAD (r^2=0.42). This result suggests that SW primarily depends on the resource availability, that agree with Aguirrezabal et al. (2003) in sunflower.

Conclusion

Understanding variation in SW and identifying factors that determine SW is of major importance in understanding SY variation. In this study, increase in canola SY achieved through increase in SW. A great proportion of the variation in SW was related to environmental conditions during the critical period of seed filling. The ability to match SFP of the crop to less stressful conditions was an effective means of avoiding the negative impact of temperature and drought stress. Together, growing season precipitation and temperature have been found to be good indicators of canola SW potential. Potential SW seems to be determined before the beginning of SFP, so an increase in LAI and above-ground dry matter accumulation increased final SW. A higher LAI during this critical period could be attained through early SDs, SI and improvement cultivars. Variation in SSR during SFP better accounted for 1000-SW variability than variation in SFP source size. In treatments with contrasting LAD and SN per unit area, the SSR improved SW prediction. The relationships established in this work explained most of the variability in SW for both cultivars. They help to explain the low SW that is often found in the Mediterranean type conditions of the area, when SD is delayed. These relationships are simple tools that could be applied to simulate SW in canola under a wide range of environmental conditions. The relationships of SW with above-ground dry matter and LAI at the beginning of seed filling, leaf dry matter remobilization and efficiency, SSR, SFD and SFR over environmental conditions, sowing dates and cultivars, showed these variables to be generally applicable in canola SW determination.

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