Canola and Mustard Response to Short Periods of High Temperature and Drought Stresses at Different Growth Stages

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Abstract

Brassica crops grown on the semiarid Canadian prairie are often subject to heat and water stress during the period of flowering. A growth chamber study was conducted at Swift Current to understand the effects of short periods of high temperature stress and/or water stress at different developmental stages on the seed yield formation of different *Brassica* species. Two advanced breeding lines of canola quality *Brassica juncea* (PC98-44 and PC98-45) along with a canola cv. Quantum (*B. napus* L.) and a mustard cv. Cutlass (*B. juncea* L.) were grown under 20/18 °C day/night temperature. High (35/18 °C) and low (28/18 °C) temperature stresses were imposed for 10 days at bolting, flowering or pod formation stages in two separate growth cabinets. At the same time, low (90% available water) or high (50% available water) water stress was imposed on half of the plants in each of the temperature treatments. All yield components were affected by temperature stress, while water stress had no effect on most yield components. The severe reduction of pods main shoot^{-1} (75%), seeds pod^{-1} (25%), and seed weight (22%) by 35/18 °C, reduced main stem seed yield of by 87% in all *Brassica* cultivars. However, seed yield reduction per plant by the same stress was 51%, indicating recovery from the stress treatments by *Brassica* species. Delaying exposure to stress to pod development stage reduced the chance of the plant to recover from the stress. The low water stress was to encouraging better recovery at 28/18 °C stress. In the controlled growth chamber, B. juncea cultivars responded to heat stress by increasing pod production but ignoring filling pods, while B. napus maintained a better seed fill. Under field conditions where plant-to-plant competition is strong, B. juncea may produce more pods with higher seed yield than canola; this needs to be confirmed with further field trials.

Introduction

In the short growing season of the Canadian prairies, early maturing canola is a better fit than other oilseed crops like sunflower and safflower. Canola is a cool season crop and suffers from high temperature stress (Angadi et al. 2000). Recent success in developing new lines of *B. juncea* with oil quality similar to canola has renewed interest in this species in the semiarid prairie.

Temperature and water stress are the two most important abiotic factors limiting productivity of crop plants. Temperature stress can reduce seed yield directly through infertile pollen, fertilization failure, and floral bud abortion, and indirectly through reducing photosynthetic source by shedding leaves or by reducing length of growing period. Water stress influences seed yield indirectly through hydraulic and non-hydraulic processes. In the semiarid Canadian prairie, heat and water stress occur simultaneously during the growing season. However, little information is available on the combined effect of temperature and drought stress on crop yield in canola.

Heat and drought stress can reduce plant yield by affecting both source and sink. Therefore, plant response to abiotic stresses depends on the developmental stage. Canola and mustard are indeterminate crops and exhibit substantial recovery from the stress (Mendham and Salisbury, 1995). As a result, many studies have reported reproductive stage as the most susceptible stages for stresses (Hall 1992; Paulsen 1994). Canola yield compensation comes from both increased branching and increased efficiency of pod retention. Therefore, understanding the critical stage for heat and water stress, the nature of the heat injury and ability to recover from heat stress will help in making management decisions.

The objectives of the current study were to determine the effect of heat and water stress, alone or in combination, on the yield formation and seed yield of canola and mustard, and to assess whether canola quality *Brassica juncea* is more tolerant to high temperature and drought stress than other *Brassica* species. Finally, the *Brassica* species were evaluated for their stress susceptibility and for their ability to recover from heat and water stress applied at different growth stages.

MATERIALS AND METHODS

The growth chamber experiment was conducted at the Semiarid Prairie Agricultural Research Centre (SPARC), Agriculture and Agri-Food Canada (AAFC), Swift Current, Canada during 2001. Two canola quality Brassica juncea breeding lines ‘PC98-44' and ‘PC98-45' developed by Saskatchewan Wheat Pool, Saskatoon, Canada, along with a oriental mustard cv. Cutlass (B. juncea) and a canola cv. Quantum (B. napus) were used for the study. All plants were grown in a controlled environment chamber (Model GR 96, CONVIRON, Control Environment Ltd., Winnipeg, Canada) at 20/18 °C day/night temperature until the high temperature treatments were imposed. Day night cycles of 16 hrs day and 8 hrs night were used. Stress treatments were imposed at three different growth stages; bud (stage 5.0), flower (stage 6.0) and pod (7.0 stage). Temperature stress at 28/18 °C day/night (low stress) and 35/18 °C day/night (high stress) were imposed for 10 d in separate growth cabinets. Water stress treatments were imposed simultaneously with temperature treatments. Every day morning half of the plants in each temperature treatment were watered to 90% of available water (low stress), while the rest were watered to 50% of available water (high stress). To avoid extreme stress, the water was added twice, a small amount in the night and replenishing the water deficit during the daytime. Data from the trial was analyzed using GLM procedure of SAS (SAS Institute Inc., Cary, NC).

Results and Discussion

Yield Formation

Plants grown under the 28/18 °C and 35/18 °C stress conditions, compared to control at 20/18 °C, reduced the number of pods on main shoot by 39 and 76%, respectively (Table 1). Short periods of water stress had no effect on pod production. As the heat stress increased, the number of fertile pods decreased. Plants grown at 35/18 °C produced only 25% of fertile pods compared to those at 20/18 °C. Flowering was the most sensitive stage for heat stress, followed by bud formation and pod formation stages. Due to susceptibility of pollen development, anthesis, and fertilization (asynchrony of stamen and gynoecium development) to heat stress, flowering stage was most sensitive stage (Hall, 1992). The lowest number of pods plant^{-1} in plants stressed at pod formation stage was due to shortest opportunity to recover from heat stress.

Canola quality Brassica juncea plants produced more pods compared to canola or mustard cultivars. Under 28/18 °C stress condition, the B. juncea lines PC98-44 and PC98-45 produced 5 and 60% higher pods compared to Cutlass and Quantum, respectively, while under 35/18 °C it was 28% and 44%, higher, respectively. This can play a vital role in yield formation under short periods of stress. Flowers produced under the 35/18 °C stress condition failed to produce any pods for all cultivars. Therefore, recovery is very important, where cultivars with higher pod numbers can recover better than those with lower pod numbers.

Heat stress reduced seeds pod^{-1} and seed weight significantly. The reduction in seeds pod^{-1} was more pronounced in mustard cultivars (up to 44%) compared to canola (up to 20%). The reduction was observed in 28/18 °C stress also. These observations on yield formation indicate that B. juncea cultivars adopt a different strategy to respond to heat stress compared to canola cultivar. Under stress, B. juncea reduces focus on filling their pods and seeds, and focuses on producing new sinks (pods).

Seed Yield

Main shoot seed yield decreased by 54 and 87%, respectively, with the 28/18 and 35/18 °C stress treatments, but yield was not affected by water stress. Canola produced highest seed yield on main shoot, while the lowest was by mustard cv. Cutlass. Crop development stage had a significant influence on susceptibility of main shoot to heat damage. Flowering stage was the most susceptible to heat stress with seed yield reduction ranging from 78% with 28/18 °C stress to 96% with 35/18 °C stress, compared to control. Contrary to our hypothesis, stressing *Brassica* species earlier than flowering stage had smaller effect. For example, heat stress at bud formation stage reduced seed yield by 50% with 28/18 °C and 72% with 35/18 °C, compared to control. The severe yield reduction with 35/18 °C stress was similar in all species, suggesting recovery from this effect is important for adaptability of Brassica species in semiarid conditions.

Heat and water stress combination contributed to the differences in seed yield plant^{-1}. Lower water stress, with the heat stress of 28/18 °C, helped canola and mustard to recover from the stress, while no such effect was observed when heat stress increased to 35/18 °C for 10 days (Fig. 1). Seed yield plant^{-1} decreased by 18% with 28/18 and by 50% with 35/18 °C heat stress for 10 days. Plants stressed at earlier growth stages usually recover by producing more branches. In this controlled environment study, *Brassica juncea* focused on branching and pod formation, but not on pod filling. Under field conditions, *B. Juncea* with the capacity to build up sink quickly may recover better than canola. Further studies, using field growth habit may help better understand this response.

Summary

Short periods of heat stress reduced seed yield of canola and mustard significantly. Developmental stage influenced heat stress effect. Relative to heat stress, short period of water stress was less significant in affecting seed yield. Heat stress had both direct and indirect effects on reproductive growth, while water stress had indirect (source/sink relationship) effect. In general, both mustard and canola responded similarly to stresses under the growth-chamber conditions where there is no plant-plant-competition. Severe heat stress (35/18 °C) for 10 days aborted all flowers that produced at all growth stages. Therefore, recovery plays a significant role in adaptability of oilseed crops. Unrestricted branching in the current study failed to imitate field conditions where stronger plant-to-plant competition may limit branching. Under field conditions, B. juncea species may be more capable of maintaining great sink strength, producing more branches, and thereby higher seed yield, than conventional canola species. This needs to be confirmed.

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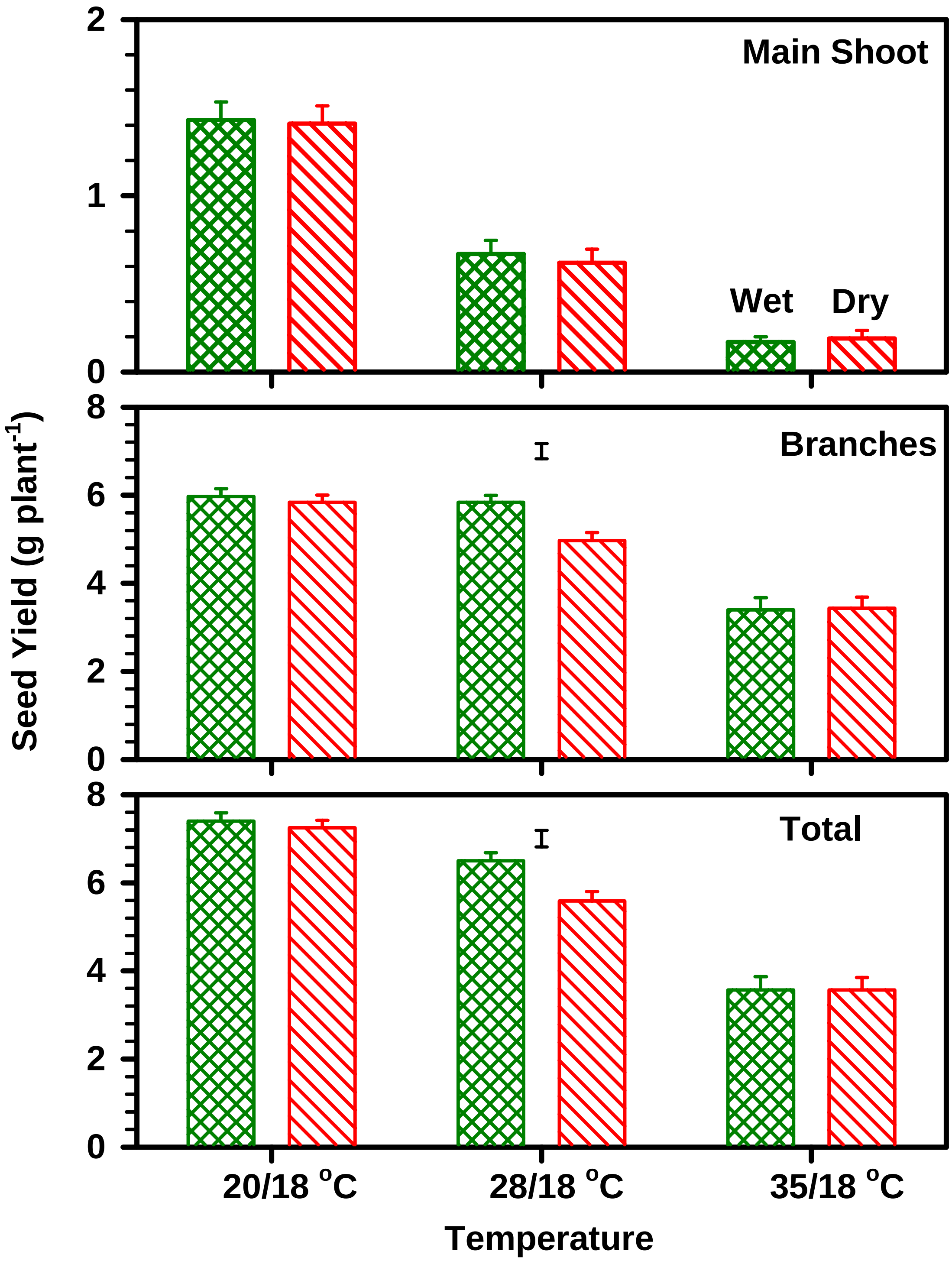

Fig. 1. Effect of short periods of heat and water stress on main shoot, branch total seed yield of *Brassica* oilseeds. LSD values are presented when interactions effects are significant.

Table 1. Mean number of pods $plant^{-1}$ (on main shoot, branches and total), seed yield (on main shoot, branches and total), seeds pod^{-1} and seed weight for different heat and water stress treatments at different growth stages and different *Brassica* cultivars.

Crops	Number of Pods $Plant^{-1}$			Seed Yield (g $Plant^{-1}$)			Seeds	Seed Weight
	Main shoot	Branches	Total	Main shoot	Branches	Total	Pod^{-1}	g 1000^{-1}
Crops/Cultivars								
Cutlass	17	202	219	0.46	5.20	5.59	8.7	2.85
PC98-44	23	227	250	0.61	4.42	5.03	6.6	3.00
PC98-45	25	206	230	0.74	4.87	5.60	7.8	3.05
Quantum	27	130	157	1.24	5.15	6.37	13.6	3.10
LSD (0.05)	0.7	4.2	4	0.04	0.10	0.10	0.2	0.05
Developmental Stage								
Bud	22	198	220	0.73	5.62	6.38	9.5	3.31
Flower	20	194	215	0.69	4.71	5.40	9.1	2.98
Pod	26	183	210	0.80	4.41	5.16	8.9	2.72
LSD (0.05)	0.7	3.6	3.7	0.03	0.08	0.09	0.2	0.04
Temperature								
20/18 C	36	183	219	1.42	5.91	7.33	11.19	3.21
28/18 C	24	229	253	0.65	5.41	6.04	7.82	3.31
35/18 C	9	166	175	0.18	3.41	3.57	8.36	2.50
LSD (0.05)	0.7	3.7	4	0.03	0.08	0.09	0.18	0.04
Water								
Low Stress (90 %)	23	193	216	0.76	5.06	5.81	9.24	3.05
High Stress (50 %)	23	191	214	0.75	4.75	5.47	9.04	2.97
LSD (0.05)	ns	ns	ns	ns	0.07	0.07	ns	0.03