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Camelina Growing Degree Hour and Base Temperature Requirements

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ABSTRACT

Oilseed crops show potential as biofuel feedstocks that can diversify spring wheat (*Triticum aestivum* L.) rotations in the northern Great Plains. Camelina (*Camelina sativa* L.) is a relatively new oilseed crop, with limited emergence information available. A 70-d incubator study investigated the impact of temperature (0, 2, 4, and 16°C), seeding depth (3 and 6 mm), and cultivar (Blaine Creek, Calena, Celine, Ligena, and Suneson) on camelina emergence. After 68 d, camelina emergence at 0°C approached 100%. Base temperature averaged −0.70°C for the five cultivars tested and was 19% lower for the 6- than the 3-mm seeding depth, although emergence was 11% sooner for the 3- than the 6-mm seeding depth. About 1150 growing degree hours were required for 50% emergence, which corresponds to 29 March for camelina planted on 10 March, the earliest date when the average daily temperature exceeds the base temperature according to long-term weather records for Sidney, MT. These results suggest that camelina emerges at temperatures below the freezing point of water and that early planting in spring would probably be limited by field access due to wet soil rather than the base temperature requirement. Although camelina emerges at temperatures below freezing under laboratory conditions, further investigation is warranted to confirm emergence under field conditions and determine the frost tolerance of camelina subsequent to germination.

There is an increasing need to diversify crop production systems in the Northern Great Plains (NGP) of North America, where the traditional system of spring wheat–fallow results in inefficient use of soil water and plant nutrients, increased soil erosion potential, and reduced economic return (Greb et al., 1970; Janzen, 1987; Wienhold et al., 2006; Allen et al., 2011). As a result, adoption of alternative crops such as oilseeds and pulses has increased in the NGP. For instance, oilseed production acreage in northeastern Montana and northwestern North Dakota increased from 72,000 ha in 1990 to >334,000 ha in 2010 (Hansen et al., 2012). Camelina is an oilseed crop that has recently received interest as a low-input cropping alternative in the semiarid NGP. Little information is available for production and management of this new crop, however. For example, Lenssen et al. (2012) investigated the suitability of three crucifer oilseeds, including camelina, in place of fallow in 2-yr rotations with durum wheat (*Triticum durum* Desf.).

Seeding date is an important consideration for oilseed crops because this affects plant vegetative and reproductive growth, yield, and the quality of yield components (Gan et al., 2004; Adamsen and Coffelt, 2005; Chen et al., 2005; Urbaniak et al., 2008; Pavlista et al., 2011; Gesch and Cermak, 2011). Timely seeding helps avoid uneven emergence, heat stress during reproductive stages, and hastened maturity. For example, research in Montana showed that, with planting dates from mid-March to late April, earlier planting dates were linked to increased camelina seed yields compared with the later seeding dates (McVay and Lamb, 2008). However, spring temperatures vary by year, and a more consistent approach could be to adjust planting dates based on accumulated heat units (Vigil et al., 1997). Determining the base temperature and heat units required for germination of camelina is important to identify the appropriate time frame for seeding.

Seeding depth is also an important consideration for camelina emergence. For production in Montana, McVay and Lamb (2008) recommended that camelina should be seeded no deeper than 6.4 mm, with some seed visible on the soil surface. Other reports have shown camelina seeding depths ranging from 0 (broadcast) to 50 mm below the soil surface, while most camelina is typically seeded between 0- and 20-mm depths (Urbaniak et al., 2008; Francis and Campbell, 2003; Pavlista et al., 2011; Gugel and Falk, 2006; Enjalbert and Johnson, 2011; Lafferty et al., 2009).

Allen (2011) suggested that camelina planted to a depth deeper than 6 mm decreased plant density and crop competiveness with weeds in a 2-yr study in northeastern Montana that was direct seeded with four seeding depths that ranged from 6 to 25 mm.

The lack of published data and need for improved management practices justify further investigation of camelina emergence rate as affected by temperature and planting depth. The objective of this study was to determine the

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Abbreviations: ERPD, emergence rate per day; GDH, growing degree hour; NGP, Northern Great Plains.

Table 1. Emergence rate per day (ERPD) at 50% emergence for different cultivars, seeding depths, and incubation temperatures of camelina.

Parameter	ERPD
	no. d^{-1}
Cultivar	
Suneson	7.25 a†
Blaine Creek	7.04 ab
Ligena	6.96 b
Calena	6.80 b
Celine	6.51 c
Seed depth, mm	
3	7.3 a
6	6.5 b
Temperature, °C	
16	18.9 a
4	4.4 b
2	2.8 c
0	1.5 d
Significance	*P* value
Cultivar (V)	***
Seed depth (D)	**
Temperature (T)	***
V × D	**
V × T	**
D × T	***
V × D × T	**

† Means followed by a different letter within a column and source of variation are significantly different at $P \leq 0.05$.
** Significant $P \leq 0.01$.
*** Significant $P \leq 0.001$.

base temperature and heat unit requirements for camelina emergence. A secondary objective was to determine the impact of camelina seeding depth on the base temperature and heat unit requirements for seedling emergence.

MATERIALS AND METHODS

Emergence of five spring camelina cultivars seeded at two depths was determined in an incubator experiment. Blaine Creek and Suneson (Montana State University releases) and Calena, Celine, and Ligena (European cultivars) were planted in pots at a depth of 3 or 6 mm and incubated at 0, 2, 4, or 16°C. Williams loam (a fine-loamy, mixed, superactive, frigid Typic Argiustoll) soil for this pot study was collected from the surface 10 cm at a USDA-ARS research farm located near Culbertson, MT. The soil was passed through a 2-mm sieve and then pasteurized at 70°C for 30 min to sterilize weed seeds (Nelson, 2003).

Clear, 0.5-L plastic containers were partially filled with 198 g of moist soil at 0.18 g g^{-1} soil water that was equivalent to 168 g of oven-dry soil. The soil was packed to a bulk density of 1.2 Mg m^{-3}. Then 20 seeds from a given camelina cultivar were placed in each pot and spaced in an equidistant pattern. The seeds were covered to either a 3- or 6-mm planting depth with 35 or 70 g of moist soil, described above, and tamped to a bulk density of 1.2 Mg m^{-3}. Each plastic pot was covered with a perforated plastic snap-on lid to reduce evaporative water loss yet maintain adequate gas transfer (Vigil et al., 1997).

A total of 160 pots were prepared (five cultivars, four temperatures, two depths, and four replications) in a complete factorial arrangement and placed into separate Percival Intellus environmental controller units (Percival Scientific) without lights set to the appropriate temperatures.

The number of emerged seeds was recorded twice daily for the first 24 d after planting and then once daily thereafter. A visible hypocotyl just above the soil surface represented an emerged seedling, which once recorded was removed gently with tweezers so as not to disturb the surrounding soil. Total emergence was determined 70 d after planting. Fifty percent emergence was based on linear interpolation of total emergence. Growing degree hour requirements for 50% emergence were estimated with a nonlinear regression procedure in Sigma Plot (SPSS Inc.) similar to the Hill equation:

$$\text{Emerg} = \frac{A\left(\text{GDN}^{n}\right)}{\text{GDH}^{n} + B^{n}} \quad [1]$$

where Emerg is the emergence percentage at growing degree hour GDH^{n}, A is the estimated maximum emergence, GDH is the growing degree hours as described above, B is a fitted slope parameter that represents GDH at 50% emergence, and n is the Hill coefficient that functions as a shape factor to determine the response curve (Heidel and Maloney, 1999). The emergence rate per day (ERPD) was calculated by dividing 50 by the number of days to reach 50% emergence and then regressing on temperature:

$$\text{ERPD} = \beta_0 + \beta_1(\text{TEMP}) \quad [2]$$

where β_0 and β_1 are fitted constants, and TEMP is the temperature (°C). The base temperature was determined by solving for TEMP with ERPD = 0 using simple linear regression, considering that estimates were near 0°C (Vigil et al., 1997):

$$\alpha = \frac{-\beta_0}{\beta_1}$$

where α is the base temperature estimate. Differences between regression parameter estimates were determined in SAS (SAS Institute, 2008).

RESULTS AND DISCUSSION

All tested camelina cultivars emerged at 0°C, the lowest temperature tested in this study. The percentage of seed that emerged ranged from 89 to 100%, with an overall average of 97%. Differences ($P < 0.05$) in emergence percentage were not detected for cultivars, seeding depth, temperature, or interactions between any of those variables (data not shown). The time required to emergence was inversely related to the incubation temperature (Table 1). Averaged across cultivar and seeding depth, 50 and 100% emergence occurred at 32 and 68, 18 and 44, 11 and 49, and 3 and 8 d after planting at 0, 2, 4, and 16°C, respectively (data not shown).

In a controlled temperature chamber experiment with NEB C-1 camelina, Russo et al. (2010) reported that 100% germination at 4, 10, and 16°C occurred within 9, 5, and 2 d after placing seed on moistened filter paper in petri dishes.

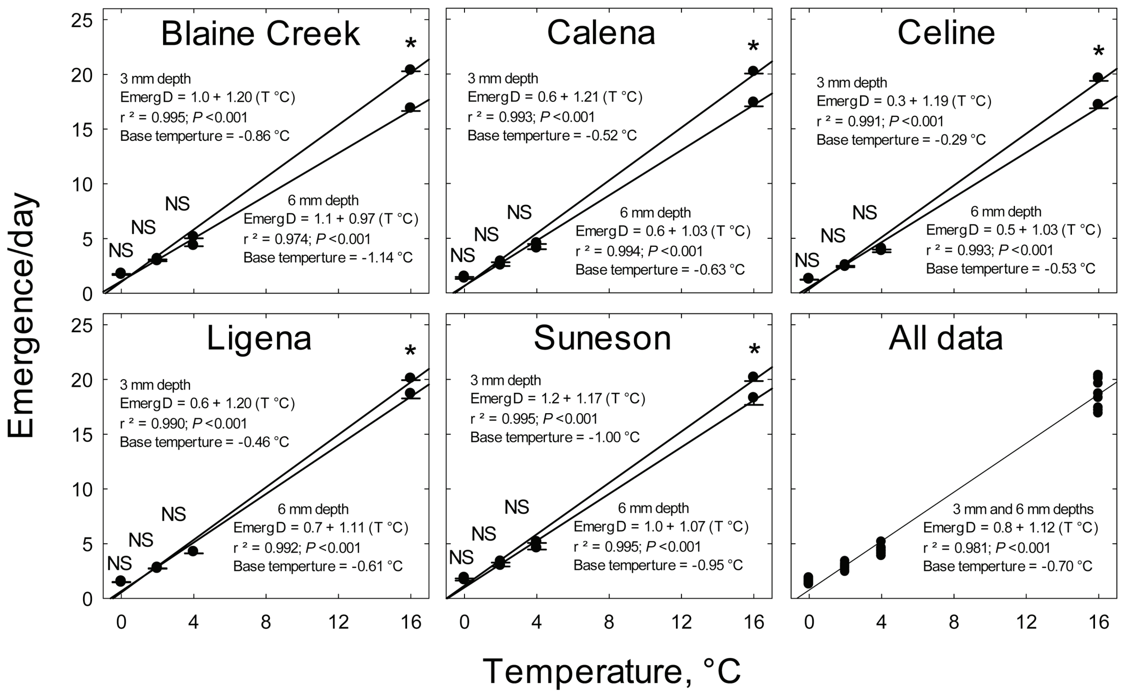

Fig. 1. Emergence rate (at 50% emergence) of camelina at different seeding depths and incubation temperatures. Data points are the means of four treatment replicates. *Significant differences between seeding depths ($P \leq 0.05$) for emergence per day; NS is not significant.

Other research has recognized the cold tolerance of camelina. In a field experiment near Lind, WA, with little to no snow cover, Calena camelina survived temperatures that dropped to –23°C and stayed below 0°C for 12 h (Karow et al., 2009). Robinson (1987) reported frost injury to mustard (*Sinapis alba* L.), rape (*Brassica napus* L.), and flax (*Linum usitatissimum* L.) with –2°C temperature, but camelina was not affected.

The ERPD differences between cultivars, seeding depths, and incubation temperatures were significant at the 0.001 level (Table 1; Fig. 1). The ERPD among cultivars ranged from 6.5 to 7.3%. Suneson exhibited higher ERPD than Ligena and Calena, while Blaine Creek was similar to those three cultivars. Celine showed significantly lower ERPD than all other cultivars.

Seeding depth affected the emergence rate, where the ERPD (averaged across cultivars and incubation temperatures) for the 3-mm depth was 7.3% compared with 6.5% for the 6-mm depth (Table 1). As expected, the ERPD was inversely related to the incubation temperature and ranged from 1.5% at 0°C to 18.9% at 16°C (Table 1). The three-way and all two-way interactions were significant ($P < 0.01$; Table 1). Most notable was the cultivar × depth interaction, where Celine seeded at the 3-mm depth had as low as or lower ERPD than two other cultivars seeded at the 6-mm depth (data not shown).

Table 2. Base temperature (based on emergence rate at 50% emergence) for five camelina cultivars.

Cultivar	Base temperature	SE	Regression equation†	R^2	$P > F$
	°C				
Blaine Creek	–1.00 a‡	0.06	emergence = 1.07 + 1.08T (°C)	0.977	<0.001
Calena	–0.57 b	0.05	emergence = 0.64 + 1.12T (°C)	0.982	<0.001
Celine	–0.41 b	0.06	emergence = 0.44 + 1.11T (°C)	0.983	<0.001
Ligena	–0.53 b	0.06	emergence = 0.61 + 1.16T (°C)	0.987	<0.001
Suneson	–0.98 a	0.06	emergence = 1.09 + 1.12T (°C)	0.986	<0.001
Seed depth					
3 mm	–0.63 b	0.07	emergence = 0.74 + 1.19T (°C)	0.990	<0.001
6 mm	–0.77 a	0.06	emergence = 0.79 + 1.04T (°C)	0.987	<0.001
Significance					
Cultivar (C)	***				
Depth (D)	*				
V × C	ns				

* Significant at $P \leq 0.05$; ns, not significant.
*** Significant $P \leq 0.001$.
† T is the incubation temperature.
‡ Means followed by a different letter within a column and source of variation are significantly different at $P \leq 0.05$.

Table 3. Estimated growing degree hours (GDH) requirements for camelina emergence at 50% emergence with mean values for 3- and 6-mm seeding depths using nonlinear regression.

Cultivar	Temperature	Parameter estimates			R^2	SE
		GDH	A†	B‡		
	°C	°C h	no.	°C h		
Blaine Creek	2	1061	99	18.8	0.9997	0.84
	4	1200	103	11.8	0.9974	2.25
	16	1071	99	11.7	0.9998	0.47
Calena	2	1204	100	15.5	0.9992	1.26
	4	1315	98	15.6	0.9992	1.34
	16	1068	98	12.0	0.9989	0.80
Celine	2	1309	98	17.3	0.9995	1.03
	4	1407	100	15.9	0.9997	0.80
	16	1108	102	12.5	0.9999	0.79
Ligena	2	1171	100	17.8	0.9994	1.11
	4	1329	100	17.2	0.9989	1.57
	16	1042	99	14.3	0.9999	0.32
Suneson	2	1027	99	15.4	0.9994	1.09
	4	1156	99	15.6	0.9993	1.09
	16	1042	99	13.1	0.9983	1.23
All data	2	1149	99	12.1	0.9423	10.9
	4	1280	100	12.5	0.9671	8.30
	16	1065	99	12.7	0.9925	2.50

† A is the estimated maximum emergence.

‡ B is a fitted slope parameter that represents GDH at 50% emergence.

The base temperature (BT) based on the emergence rate at 50% emergence ranged from −1.00 to −0.41°C and averaged −0.70°C for the five cultivars tested (Table 2; Fig. 1). Blaine Creek and Suneson had a lower ($P < 0.001$) BT than the other three cultivars (Table 2). The BT also differed ($P < 0.05$) between seeding depths, with values of −0.63 and −0.77°C for the 3- and 6-mm depths, respectively (Table 2). The cultivar × depth interaction for BT was not significant (Table 2).

The estimated GDH required for 50% emergence ranged from 1027 to 1407 and averaged 1167 across incubation temperatures, seeding depths, and cultivars (Table 3). Relating this to long-term (30-yr average) weather records for Sidney, MT (Western Regional Climate Center, 2012) indicated that the dates for accumulated GDH needed for 50% emergence range between 28 March (1027 GDH) to 31 March (1407 GDH), with an overall average of 1167 GDH corresponding to 29 March. Shifting camelina planting to an early date could also help alleviate workload demands during the typically busy period of planting in the spring wheat cropping systems of the NGP. The likely limiting factor for early camelina planting will not be accumulated heat units, as with many other crops, but rather field conditions suitable for planting operations. From a practical standpoint, camelina planting could be reasonable just after spring thaw when the soils are dry enough to prevent compaction from planting operations.

CONCLUSION

Camelina is an oilseed crop that could potentially contribute to biofuel feedstocks and diversify spring wheat rotations in the northern Great Plains; however, little management information is available regarding emergence with temperature and seeding depth. Our work showed that after 68 d, camelina emergence at 0°C approached 100%, and that the average base temperature was −0.70°C for the five cultivars tested in a controlled climate incubation study. Camelina emergence was 11% quicker at the 3- than the 6-mm seeding depth, although base temperature estimates were 19% lower for the 6- than the 3-mm depth. On average, about 1150 GDH were required for emergence, which for Sidney, MT, corresponds to 29 March according to long-term weather records, with camelina planted on 10 March the earliest date when the average daily temp (−0.53°C) rises above the BT of −0.70°C. These laboratory results suggest that camelina emergence is very tolerant of cold conditions and that early planting in the spring would probably be limited by field access due to wet soil rather than the base temperature requirement. However, further investigation is warranted to confirm the cold-tolerant emergence of camelina under field conditions and to determine frost tolerance subsequent to germination.

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