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Planting methods affect emergence, flowering and yield of spring oilseed crops in the U.S. central High Plains

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ABSTRACT

Alternative types of planting methods can alter seed placement, and seedling growing conditions. These factors can affect establishment and seed yield of spring oilseed crops, evaluated in six growing environments of the U.S. central High Plains. Seeding with a hoe drill (HD) resulted in the best emergence and stand ratings, and earlier flowering. Emergence and stand ratings for seeding with a no-till drill (NT) were better than ratings for broadcast seeding (BC). Canola (*Brassica napus* L.) had better stand rating and earlier flowering than Indian mustard (*Brassica juncea* (L.) Czernj. & Cosson) and *Camelina* (*Camelina sativa* (L.) Crantz), which were similar. Oilseed yield was limited by available water or heat stress at all experimental sites. At Colby, with good growing conditions in 2005, canola provided greatest yield (2180 kg ha^{-1}). Relative productivity of the oilseed species shifted from canola to *Camelina* with warmer and drier growing conditions. Adapting spring oilseed germplasm to the U.S. central High Plains can focus on cold tolerance for emergence, intensive water extraction to avoid water stress, heat tolerance during flowering and increased harvest index and oil content.

1. Introduction

Spring oilseed crops develop over a reduced growing season and provide diversity to wheat-based cropping systems in Northern Great Plains (Johnston et al., 2002). The extracted oil can be food grade, provide an industrial feedstock or serve as biofuel (Pavlista et al., 2011a); oilseed meal can be used as livestock feed. An adapted, early short-season oilseed crop could add diversity and serve as a transition crop following corn or grain sorghum, prior to drilling wheat in the central High Plains (Johnston et al., 2002; Baltensperger et al., 2004; Boyles et al., 2006). Developing baseline data on seeding methods for oilseed cultivars can help growers evaluate the commercial feasibility of spring oilseed production in temperate semiarid regions.

Nielsen (1997) demonstrated agronomic feasibility of canola in the central High Plains and forecast yields for spring canola in the range of 600–1700 kg ha^{-1} for 80% of growing seasons in NE Colorado. Nielsen (1998) reported water productivity of canola equivalent to 7.72 kg ha^{-1} for each mm of water used, after a yield threshold of 160 mm of water use; similar yield response to water use was observed in S. Africa (Tesfamariam et al., 2010). Gunasekera et al. (2006) concluded Indian mustard had potential for oilseed production in semiarid regions due to stress tolerance traits and superior biomass productivity relative to water use and utilization of sunlight. However, oilseed productivity was less for Indian mustard than canola due to a larger oilseed fraction of above-ground biomass (harvest index) for canola. *Camelina* is a potential oilseed crop for semi-arid cropping systems with reduced growing season duration (Pavlista et al., 2011b; Pileram et al., 2007; Robinson 1987). Stand establishment for spring oilseed crops is hampered by small seed size, need for shallow seed placement and temporal variation in near-surface conditions. In semi-arid regions, inadequate moisture can limit germination; when emerged, seedlings can be vulnerable to dry conditions. Alternative types of planting methods can alter seed placement, soil and growing conditions; these factors can affect crop establishment and seed yield. Floral development, seed set and seed fill can be impaired by heat stress and water deficits. Our objective was to determine effects of planting

Abbreviations: BC, broadcast; DAP, days after planting; GDD, growing degree days; HD, hoe drill; NT, no-till.

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Table 1
Growing conditions at six environments for spring oilseed crop planted in six growing environments (AK 05 = Akron, CO, 2005; CB 05 = Colby, KS, 2005; LN 05 = Lingle, WY, 2005; SN 05 = Sidney, NE, 2005; CB 06 = Colby, KS, 2006; and SN 06 = Sidney, NE, 2006).

Environment	Planting date	Harvest date	CumGDD[a] 21 DAP (°C-d)	Precip 3/1–7/15 (mm)	Flowering ± 4 wks[b]	
					Precip (mm)	T_{max} (°C)
AK 05	3/29	7/19	227	233	121	21.6
CB 05	3/30	7/7–16	293	323	162	23.9
LN 05	4/27	7/22–8/1	154	243	187	28.8
SN 05	3/29	8/5	224	301	220	24.8
CB 06	4/18	7/7–26	306	212	134	31.9
SN 06	4/5	7/31	278	185	114	29.1

[a] Growing degree days (GDD) calculated as average of daily temperature extremes, with base temperature of 5 °C. Cumulative growing degree days (CumGDD) calculated as the sum of GDD for the 21 days following planting (days after planting, DAP).
[b] Cumulative precipitation and average daily maximum temperature (T_{max}) are calculated for the eight-week time interval centered on average 50% bloom date for the growing environment.

method on stand formation, bloom date and yield of spring oilseed crops under semi-arid, rain-fed conditions.

2. Material and methods

Field studies evaluating oilseed planting methods were conducted at four locations: Akron, CO in 2005, Lingle, WY in 2005, Colby, KS in 2005 and 2006 and Sidney, NE in 2005 and 2006. These sites span a range of growing conditions in the central High Plains (Table 1, also find planting and harvest dates). The three planting methods were: no till (NT, double-disk opener) where seeds were drilled at row spacings of 0.25 m (Akron), 0.19 m (Colby) and 0.2 m (Lingle and Sidney); broadcast (BC) where seeds were planted with the same drill as NT but with the hoses disconnected and drag chains attached for incorporation, and hoe drill (HD) where seeds were planted following primary tillage with a tandom disc and drilled at comparable row spacing. Target planting depth was 20 mm. Oilseed cultivars included canola cv. 'Hyola 401', Indian mustard cv. 'Arid' and *Camelina* cv. 'Boa'. Seed from these cool-season oilseed species were planted in four replicated plots of 31 m^2 (Akron), 65 m^2 (Colby), 32 m^2 (Lingle) or 9 m^2 (Sidney) with a targeted plant population density of approximately 2 million seeds ha^{-1}, 10.5, 6.5 and 2.2 kg ha^{-1} for canola, Indian mustard and *Camelina*, respectively. Previous crop was wheat for Colby in 2005 and 2006, Proso millet for Akron in 2005 and for Sidney in 2006, and corn for Sidney in 2005; previous crop for Lingle, 2005 was not recorded. Soil fertility was amended with 50–0–0 (kg ha^{-1} of N–P–K) at Akron, 2005; 15–17–0 at Sidney, 2005; 75–34–0 at Colby, 2005; 109–34–0 at Colby 2006 or none (Lingle, 2005 and Sidney, 2006). Glyphosate (0.9 L ha^{-1}) was applied pre-plant for weed suppression. Trifluralin (784 g a.i. ha^{-1}) was also applied pre-plant at Sydney (2005 and 2006) and incorporated by rotary hoe; at Akron ethalfluralin (0.931 L a.i. ha^{-1}) was applied pre-plant, but incorporated with primary tillage for HD treatment only. Pesticides applied early post-emergence to suppress insects include zeta-cypermethrin (0.10 L a.i. ha^{-1}, Akron, 2005), bifenfrin (0.0326 L a.i. ha^{-1}, Colby 2005 and 2006) and lambda cyhalothrin (0.025 L a.i. ha^{-1}, Sidney, 2005). Field observations included emergence and stand ratings (visual ratings based on scale of 0 = no stand and 10 = excellent) and 50% bloom date, from which days after planting (DAP) were calculated. Seed was machine-harvested (entire plot length), cleaned and analyzed for yield. Reported yields from Colby were adjusted to 13% moisture content, at other locations yields are reported on a field moisture basis. Harvest data collected from Akron in 2005 were not included in the analysis due to effects of a hailstorm, severe drought and inadequate weed control in NT and BC treatments. Field observations were incomplete at some locations, in 2005: emergence ratings and bloom date were not recorded at Sidney, stand ratings were not recorded at Lingle and bloom date was not recorded at Akron. Statistical analysis were conducted (SAS 9.13, PROC GLM) with each site year as an environment (whole plot effect) with planting method (split effect) and oilseed species (split–split effect) as treatment design; environment and planting method effects were declared random. Experimental design was randomized complete block within each environment. Main effects were evaluated by Tukey's protected honestly significant difference (HSD); interacting effects were evaluated by linear contrasts, as suggested by results, and tested using Scheffe's procedure (Milliken and Johnson, 2009). Within environment comparisons were evaluated by HSD for bloom DAP, as linear contrasts were not estimable.

Table 2
Analysis of variance for emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments (AK 05 = Akron, CO, 2005; CB 05 = Colby, KS, 2005; LN 05 = Lingle, WY, 2005; SN 05 = Sidney, NE, 2005; CB 06 = Colby, KS, 2006; and SN 06 = Sidney, NE, 2006). Values represent the probability of observing a greater '*F*' value due to chance alone (Type III mean squares).

Effect	Emergence	Stand	50% bloom (DAP)	Yield (kg ha^{-1})
Environment	0.0035	<0.0001	<0.0001	<0.0001
Planting method	<0.0001	0.0002	0.0005	0.6885
Env × PM	<0.0001	<0.0001	<0.0001	0.5407
Species	<0.0001	<0.0001	<0.0001	<0.0001
Env × Sp	<0.0001	<0.0001	<0.0001	<0.0001
PM × Sp	<0.0001	0.1931	<0.0001	0.0790
Env × PM × Sp	0.0244	0.0588	0.0015	0.0690
Mean	4.03	6.12	57.1	630
RMSE	1.06	1.25	2.25	204

3. Results

Growing environment, planting method, oilseed species and their interactions affected crop emergence, stand, 50% bloom DAP and yield (Table 2). Main effect means are presented for environment (Table 3), planting method (Table 4) and species (Table 5). Interacting effect means are presented for environment and planting method (Table 6), environment and species (Table 7) and planting method and species (Table 8). These results are summarized in the following sections.

3.1. Emergence and stand

Emergence ratings were poor to adequate. Linear contrasts suggested by results were not significant, using Scheffe's procedure, therefore main effects are discussed. Poorest emergence ratings

Table 3
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments (AK 05 = Akron, CO, 2005; CB 05 = Colby, KS, 2005; LN 05 = Lingle, WY, 2005; SN 05 = Sidney, NE, 2005; CB 06 = Colby, KS, 2006; and SN 06 = Sidney, NE, 2006). Results are averaged over oilseed species (canola, Indian mustard, *Camelina*) and planting methods (no-till drill, broadcast or hoe drill).

Environment	Emergence[a,b]	Stand[c]	50% bloom (DAP)	Yield (kg ha^{-1})
AK 05	2.9 d	3.1 d	–	
CB 05	4.4 b	8.3 a	53.7 c	1580 a
LN 05	5.4 a	–	52.3 c	450 c
SN 05	–	6.8 b	–	620 b
CB 06	3.6 cd	7.3 b	58.2 b	130 e
SN 06	3.9 bc	5.1 c	67.3 a	300 d
HSD	0.69	0.82	1.4	134

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Means in a column with the same letter are not statistically different according to Tukey's HSD mean separation test at $\alpha = 0.05$.
[c] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth.

Table 4
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments. Results are averaged over growing environments (Akron, CO, 2005; Colby, KS, 2005 and 2006; Lingle, WY, 2005; Sidney, NE, 2005 and 2006) and oilseed species (canola, Indian mustard, *Camelina*).

Planting method	Emergence[a,b]	Stand[c]	50% bloom (DAP)	Yield (kg ha^{-1})
NT drill	4.5b	6.3b	57.2b	620b
Broadcast	1.9c	5.1c	58.7a	640a
Hoe drill	5.7a	7.0a	55.4c	630b
HSD	0.46	0.54	1.1	88

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Means in a column with the same letter are not statistically different according to Tukey's HSD mean separation test at $\alpha = 0.05$.
[c] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth.

occurred at Akron (2005) due to dry spring conditions, while best ratings were recorded at Lingle, 2005. Best emergence and stand ratings resulted from seeding with the HD (Table 4); poorest emergence and stand ratings were recorded for seeding with BC; at Akron (2005), stand failure occurred with BC (Table 6). The best emergence and stand ratings occurred for canola (Table 5). Relative stand ratings for oilseed species differed among environments: ratings for Indian mustard exceeded those for *Camelina* at Colby in 2005 and 2006 (Table 7); however, ratings for *Camelina* exceeded those for Indian mustard at Sidney in 2006. Thermal conditions likely did not limit emergence. Nykiforuk and Johnson-Flanagan (1994) reported that canola lines required 8–12 days for germination at 10 C, corresponding to 40–60 GDD (base 5 C). At all locations, an equivalent GDD exceeded this range of values, at 21 days after planting (Table 1). Johnston et al. (2002) reported that NT seeding improved canola establishment in the northern Great Plains. In this study, the HD provided the best seeding environment, canola resulted in the best stands and poorer emergence occurred under dry conditions.

Table 5
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments. Results are averaged over growing environments (Akron, CO, 2005; Colby, KS, 2005 and 2006; Lingle, WY, 2005; Sidney, NE, 2005 and 2006) and planting methods (no-till drill, broadcast or hoe drill).

Species	Emergence[a,b]	Stand[c]	50% bloom (DAP)	Yield (kg ha^{-1})
Canola	4.8a	6.8a	56.4b	750a
Indian mustard	4.3b	5.9b	57.5a	510c
Camelina	3.0c	5.6b	57.5a	640b
HSD	0.46	0.54	1.1	88

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Means in a column with the same letter are not statistically different according to Tukey's HSD mean separation test at $\alpha = 0.05$.
[c] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth.

3.2. Flowering

Planting methods affected flowering (50% bloom DAP) differentially among the growing environments (Table 6); these interactions were analyzed within each growing environment, as linear contrasts were not estimable. At Colby, in 2006, HD resulted in earlier flowering; also, BC delayed flowering at Colby in 2005 and 2005, relative to HD. No significant planting method effects were detected in Lingle, 2005 nor in Sidney, 2006. Canola and Indian mustard flowered earlier than *Camelina* in 2005 and 2006 at Colby (Table 7). At Lingle, in 2005, Indian mustard and *Camelina* flowered later than canola. No differences were detected in Sid-

Table 6
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments. Results are averaged over oilseed species (canola, Indian mustard, *Camelina*).

Environment	Planting method	Emergence[a]	Stand[b]	50% bloom[c] (DAP)	Yield (kg ha^{-1})
Akron 05	NT drill	4.2	4.2		
Akron 05	Broadcast	0	0.2		
Akron 05	Hoe drill	4.5	4.8		
Colby 05	NT drill	4.2	7.8	52.9b	1590
Colby 05	Broadcast	3.2	8.0	55.5a	1630
Colby 05	Hoe drill	6.0	9.2	52.7b	1520
Lingle 05	NT drill	7.6		52.9a	410
Lingle 05	Broadcast	2.4		52.6a	410
Lingle 05	Hoe drill	6.1		51.5a	520
Sidney 05	NT drill		7.3		560
Sidney 05	Broadcast		6.7		670
Sidney 05	Hoe drill		6.2		640
Colby 06	NT drill	3.2	7.3	59.2b	100
Colby 06	Broadcast	1.8	6.2	62.3a	30
Colby 06	Hoe drill	5.7	8.5	53.2c	200
Sidney 06	NT drill	3.1	4.8	67.1a	320
Sidney 06	Broadcast	2.2	4.3	67.2a	280
Sidney 06	Hoe drill	6.5	6.2	67.4a	290

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth. Refer to text for analysis of interacting effects.
[c] Statistical differences were not detected for means followed by the same letter, within a growing environment.

Table 7
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted in six growing environments. Results are averaged over planting methods (no-till drill, broadcast or hoe drill).

Environment	Species	Emergence[a]	Stand[b]	50% bloom[c] (DAP)	Yield (kg ha^{-1})[d]
Akron 05	Canola	3.8	3.9		
Akron 05	Indian mustard	3.2	2.6		
Akron 05	*Camelina*	1.7	2.8		
Colby 05	Canola	5.8	9.5	52.8b	2180
Colby 05	Indian mustard	5.0	8.7	53.2b	1560
Colby 05	*Camelina*	2.5	6.8	55.0a	1000
Lingle 05	Canola	5.8		49.7b	400
Lingle 05	Indian mustard	4.9		54.1a	240
Lingle 05	*Camelina*	5.4		53.2a	700
Sidney 05	Canola		7.6		770
Sidney 05	Indian mustard		6.0		480
Sidney 05	*Camelina*		6.7		610
Colby 06	Canola	3.9	7.7	55.0b	110
Colby 06	Indian mustard	4.0	8.3	56.3b	20
Colby 06	*Camelina*	2.8	6.0	63.3a	340
Sidney 06	Canola	4.9	5.3	68.0a	240
Sidney 06	Indian mustard	4.4	4.1	66.4a	270
Sidney 06	*Camelina*	2.5	5.9	69.0a	370

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth.
[c] Statistical differences were not detected for means followed by the same letter, within a growing environment.
[d] Refer to text for analysis of interacting effects.

Table 8
Emergence and stand ratings, days from planting to 50% bloom and oilseed yield for spring oilseed crop planted by three methods (no-till drill, broadcast or hoe drill). Results are averaged over growing environments.

Plantingmethod	Species	Emergence[a]	Stand[b]	50% bloom[c] (DAP)	Yield (kg ha^{-1})
No till	Canola	5.4	7.3	55.4b	800
No till	Indian mustard	4.6	6.2	58.8a	490
No till	*Camelina*	3.4	5.5	57.5a	580
Broadcast	Canola	2.4	5.4	58.8a	680
Broadcast	Indian mustard	1.7	5.0	59.4a	510
Broadcast	*Camelina*	1.6	4.9	57.6a	770
Hoe drill	Canola	6.8	7.8	54.9b	770
Hoe drill	Indian mustard	6.6	6.7	54.4b	550
Hoe drill	*Camelina*	3.8	6.5	57.5a	570

[a] Emergence ratings (0 = no emergence; 10 = 100% emergence) taken 21 days after planting.
[b] Stand ratings (0 = no stand; 10 = 100% stand) taken during mid-vegetative growth.
[c] Statistical differences were not detected for means followed by the same letter, within a planting method.

ney, 2006. Oilseed species responded differentially to planting methods (Table 8); these interactions were analyzed within each planting method, as linear contrasts were not estimable. Under NT, canola flowered earlier than Indian mustard and *Camelina*. With HD, *Camelina* flowered later than canola and Indian mustard. No differences were detected with BC. Averaging over planting method and species, flowering (Table 3) occurred earliest at Lingle (2005) and Colby (2005) and latest at Sidney (2006). Earliest flowering resulted from HD seeding, averaged over environments and species (Table 4). Differences in flowering, due to planting method, is likely an indicator of relative emergence. Earlier flowering with HD seeding supports the observation of improved seeding environment for the HD method. Averaged over environments and planting methods, canola flowered slightly earlier than Indian mustard and *Camelina*, which were similar (Table 5). In contrast, under Mediterranean conditions, Gunasekera et al. (2006) found Indian mustard flowered earlier than canola.

3.3. Seed yield

Relative yields of oilseed species differed among growing environments (Table 7). Canola yields exceeded that of *Camelina* in Colby, 2005 and Sidney, 2005; in contrast, *Camelina* yields exceeded canola yields in Lingle, 2005; Colby, 2006 and Sidney, 2006. Canola produced relatively more in cool and wet environments (Table 1), while *Camelina* was relatively more productive under warmer growing environments. Averaged over species and planting methods, oilseed yields (Table 3) were greatest in Colby (2005) and least at Colby (2006), corresponding with in-season precipitation and heat stress (Table 1, see also Section 4). No differences were detected due to planting methods (Table 4). Averaged over environments and planting methods, canola yields were greatest, Indian mustard yields were least and *Camelina* yields were intermediate (Table 5).

4. Discussion

There was no correspondence between emergence and stand responses to planting methods with that of seed yield. These crops have a high degree of plasticity and furthermore the seeding rate in these trials exceeded the optimal rate for highest yields. In Canada, canola showed no significant change in yield when increasing the population from 40 to 80 plants m^{-2} (Angadi et al., 2003). The seeding rate in our trials was 200 seed m^{-2}; therefore, a 40% stand would still give optimal yield under the conditions. In Lithuania in 2009, *Camelina* yields were not affected by seeding rates between 110 and 220 plants m^{-2} (Koncius and Karcauskiene, 2010). *Camelina* was seeded, in our trials, at 200 seed m^{-2}, indicating seeding rates should not be yield-limiting. A possible influence in the Brassica species used in this study could be shading due to over-planting, which could reduce yield (Shekhawat et al., 2012). Many regions do not use the HD for small seeded oil crops because of the risk of seedling burial with a heavy rain. However, our data indicate that in the harsher environments of the High Plains, the HD may provide beneficial seedling protection and improved seed-zone moisture conditions.

Oilseed yields can be limited by heat and water stress which occurs during flowering and early seed set (Tesfamariam et al., 2010; Champolivier and Merrien, 1996). Gunasekera et al., 2006 reported that harvest index increased slightly with mild water stress, relative to that of no stress or severe water stress, which were similar. However, Nielsen (1997) failed to detect differences in yield responses of canola to timing of water use when water supply matched average precipitation at the semi-arid site. Angadi et al. (2000) found that heat stress conditions of 35 C were more injurious when occurring at flowering rather than at pod developmental stage. Daily maximum temperature matched or exceeded 35 C on 12 days at Colby, 2006, 2 days at Colby, 2005 and 2 days at Sidney, 2006 during the period four weeks prior to and four weeks following flowering. Greater heat stress during flowering, at Colby in 2006, could account for smaller yields than recorded at Sidney in 2006, despite the drier conditions at Sidney. Nuttall et al. (1992) reported a yield decline for canola which was equivalent to 147 kg ha^{-1} per degree (C) increased temperature (average daily maximum temperature, four weeks prior to and following anthesis, 21–24 C range). In the present study, yields were likely limited by water deficits and/or heat stress at each of the sites.

Opportunities to develop adapted cultivars should focus on emergence, water use and stress tolerance traits. Nykiforuk and Johnson-Flanagan (1994) reported differences in germination rates, among canola lines, which were related to mobilization of lipid and protein reserves; indicating opportunity for genetic improvement in cold tolerance for germination. Vigil et al. (1997) reported similar thermal requirements for germination for three spring canola cultivars, but greater requirements for emergence of winter canola cultivars. Gunasekera et al. (2006) reported that Indian mustard had greater potential for stress tolerance than canola, as indicated by greater water use efficiency (biomass-based) and radiation use efficiency—attributed to greater osmotic adjustment. However, the yield advantage of canola resulted from a larger harvest index. Authors identified the need to improve harvest index and oil content of Indian mustard to combine yield potential with stress tolerance.

5. Conclusion

The HD was beneficial for seedling emergence and stand development while NT seeding resulted in adequate stands. No differences were detected in yield response to planting method. Earlier flowering with HD seeding, and for canola likely resulted from improved emergence. Oilseed yields were likely limited by water deficits and/or heat stress at all experimental sites. Relative productivity shifted from canola to *Camelina* for warmer and drier growing conditions. Opportunities for genetic gain leading to adapted cultivars include cold tolerance for germination, heat tolerance at flowering, osmotic adjustment to avoid water deficits, and increases in harvest index and oil content.

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References

Angadi, S.V., Cutforth, H.W., Miller, P.R., McConkey, B.G., Entz, M.H., Brandt, S.A., Volkmar, K.M., 2000. Response of three *Brassica* species to high temperature stress during reproductive growth. Can. J. Plant Sci. 80, 693–701.

Angadi, S.V., Cutforth, H.W., McConkey, B.G., Gan, Y., 2003. Yield adjustment by canola grown at different plant population under semiarid conditions. Crop Sci. 43, 1358–1366.

Baltensperger, D.D., Lyon, D.J., Burgener, P.A., Hein, G.L., Harveson, R.M., Yonts, C.D., Margheim, J.F., Frickel, G.E., Foster, G.J., 2004. Brown Mustard Production. Univ. Nebraska Coop, Circ #EC04-183A.

Boyles, M., Peeper, T., Stamm, M., 2006. Great Plains Canola Production Handbook. Kansas State University, MF-2734.

Champolivier, L., Merrien, M., 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. Argon. 5, 16–153.

Gunasekera, C.P., Martin, L.D., Siddique, K., Walton, G.H., 2006. Genotype by environment interactions of Indian mustard (*Brassica juncea* L.) and canola (*Brassica napus* L.) in Mediterranean-type environments. I. Crop growth and seed yield. Eur. J. Agron. 25, 1–12.

Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Nielsen, D.C., Lafond, G.P., Riveland, N.R., 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.

Koncius, D., Karcauskiene, D., 2010. The effect of nitrogen fertilizers: sowing time and seed rate on the productivity of *Camelina sativa*. Zemdirbyste Agric. 97, 37–46.

Milliken, G.A., Johnson, D.E., 2009. Analysis of messy data. Designed Experiments, vol. 1. CRC Press, Boca Raton, FL, pp. 48–49.

Nielsen, D.C., 1997. Water use and yield of canola under dry land conditions in the Central Great Plains. J. Prod. Agric. 10, 307–313.

Nielsen, D.C., 1998. Comparison of three alternative oilseed crops for the central Great Plains. J. Prod. Agric. 11, 336–341.

Nuttall, W.F., Moulin, A.P., Townley-Smith, L.J., 1992. Yield response of canola to nitrogen phosphorus, precipitation, and temperature. Agron. J. 84, 765–768.

Nykiforuk, C.L., Johnson-Flanagan, A.M., 1994. Germination and early seedling development under low temperature in canola. Crop Sci. 34, 1047–1054.

Pavlista, A.D., Isbell, T.A., Baltensperger, D.D., Hergert, G.W., 2011a. Planting date and development of spring-seeded irrigated canola, brown mustard and *Camelina*. Ind. Crops Prod. 33, 451–456.

Pavlista, A.D., Santra, D.K., Isbell, T.A., Baltensperger, D.D., Hergert, G.W., Krall, J., Mesbach, A., Johnson, J., O'Neil, M., Aiken, R., Berrada, A., 2011b. Adaptability of irrigated spring canola oil production to the US High Plains. Ind. Crops Prod. 33, 165–169.

Pileram, A.L., Sands, D.C., Boss, D., Dale, N., Wichman, D., Lamb, P., Lu, C., Barrows, R., Kirkpatrick, M., Thompson, B., Johnson, D.L., 2007. *Camelina sativa*, a Montana omega-3 and fuel crop. In: Janick, J., Whipkey, A. (Eds.), Issues in New Crops and New Uses. ASHS Press, Alexandria, VA, pp. 129–131.

Robinson, R.G., 1987. *Camelina*: a useful research crop and a potential oilseed crop. Minn. Agric. Exp. Sta. Bull. 579 (item no. AD-SB-3275).

Shekhawat, K., Rathore, O.P., Premi, B.K., 2012. Advances in agronomic management of Indian mustard (*Brassica juncea* (L.) Czernj. Cosson): an overview. Int. J. Agron., 14, http://dx.doi.org/10.1155/2013/408284, Article ID 408,284.

Tesfamariam, E.H., Annandale, J.G., Steyn, J.M., 2010. Water stress effects on winter canola growth and yield. Agron. J. 102, 658–666.

Vigil, M.F., Anderson, R.L., Beard, W.E., 1997. Base temperature and growing-degree-hour requirements for the emergence of Canola. Crop Sci. 37, 844–849.