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Influence of genotype and sowing date on camelina growth and yield in the north central U.S.

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A R T I C L E I N F O

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A B S T R A C T

Camelina (*Camelina sativa* L.) has gained considerable attention in North America as a potential oilseed feedstock for advanced biofuels and bioproducts. Progress has been made towards characterizing camelina's production potential for the western U.S. and Canada. However, little has been done to evaluate its potential for the north central region of the U.S. The objectives of the following study were to evaluate plant stand establishment, growth, and yield of 10 camelina cultivars and target the optimum sowing time for spring seeding in the northern Corn Belt. The study was conducted over three growing seasons between 2008 and 2010 in west central Minnesota, on a Barnes loam soil. Eight cultivars were evaluated in 2008, 10 cultivars in 2009, and four cultivars in 2010. Sowing dates ranged from 16 April to 15 June over the three-year study. Plant population density, time to 50% flowering, seed yield, and oil content were affected by sowing date, tending to decline with delayed sowing. Seed yield was significantly affected by cultivar only in 2009, whereas oil content was consistently affected by cultivar all three years. Across cultivars, seed yields were as high as 2300 kg ha^{-1} to as low as 743 kg ha^{-1} and were generally greatest for sowings between mid-April to mid-May. Across sowing dates and cultivars, oil content ranged from about 36 to 43% (wt wt^{-1}) and declined with delayed sowing. Generally, seed yield and oil content differences tended to be small between most genotypes in the study. Results indicate that the best time to sow spring camelina in west central Minnesota is from about mid-April to mid-May. Further research is needed to optimize other agricultural inputs for camelina production in the northern Corn Belt.

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1. Introduction

In recent years camelina (*Camelina sativa* L.) has gained considerable attention in the United States and Canada as a potential oilseed feedstock for advanced biofuels and bioproducts. Although camelina has a long history as a cultivated oilseed crop in northern Europe and Scandinavia (Zubr, 1997), it is a relatively new crop to North America. The seed oil content of camelina typically ranges from about 35 to 45% (wt wt^{-1}) and has been found suitable for making biodiesel (Fröhlich and Rice, 2005), and recently has been shown to serve as an excellent feedstock for renewable aviation fuel (Shonnard et al., 2010).

Due to the high production cost of biofuels relative to petroleum-based fuels, which largely is a consequence of high feedstock cost (Demirbas, 2006), a major attraction of camelina is its relatively low agricultural input requirements (Robinson, 1987; Putnam et al., 1993; Gesch and Cermak, 2011) thus, keeping its production cost low compared to other feedstock. In North America, camelina is being developed primarily as an industrial crop and therefore, should not directly compete in the market place with commodity food, feed, and fiber crops. Moreover, camelina is resilient to limited soil moisture and freezing temperatures (French et al., 2009; Gugel and Falk, 2006) making it a good candidate to be produced on lands where high valued food crops such as maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] may not be economically viable. Additionally, autumn-sowing winter annual types of camelina can allow potential for double-cropping with certain food and feed crops (Gesch and Archer, 2013) making it possible to produce biofuel and food on the same land in a single season with camelina serving as a "cash" cover crop.

Considerable effort has been made to characterize camelina's agronomic potential for the western and Great Plains regions of the U.S. (McVay and Khan, 2011; Pavlista et al., 2011; Schillinger et al., 2012; Lenssen et al., 2012) and Canada (Gugel and Falk, 2006; Blackshaw et al., 2011; Urbaniak et al., 2008a), but little attention has been given to its performance in the northern Corn Belt region of the U.S. Robinson (1987) was one of the first to report results of several field experiments conducted in the U.S. during the

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1960s and early 70s to evaluate the effects of various management practices on camelina including sowing date. Robinson compared camelina seed yields to those of other *Brassicaceae* oilseeds including *Brassica napus* and *B. juncea* and found in most cases that yields were comparable with fewer inputs, and also showed that early spring (mid-April) was a good time to sow camelina in central Minnesota. However, sowing date was not extensively tested and only one genotype was used.

With regard to camelina sowing date studies, results have varied. For instance, Urbaniak et al. (2008a) found no affect of sowing date on either seed yield or oil content for camelina grown in eastern Canada and Pavlista et al. (2011) found that yields were greatest when sown in late-March to late-April in the Nebraska Panhandle, U.S., although oil content was unaffected. In a three-year study conducted across four field sites in the Pacific Northwest, U.S., using the cultivar Calena sown between mid-October to mid-April at all sites, Schillinger et al. (2012) reported that yield responded to sowing date but that the response pattern varied at each of the four sites. Gesch and Cermak (2011) reported that seed and oil yields for the winter annual camelina cultivars Joelle and BSX-WG1 were optimal when sown in early October. These studies highlight the importance of characterizing the optimum sowing time of camelina for a given region as well as genotype.

Only a few studies have addressed the effect of cultivar on camelina seed yield and oil content. Among 30 camelina accessions evaluated by Vollmann et al. (2007) across three environments in Austria, seed yield was found to range from 1574 to 2248 kg ha^{-1} and oil content ranged from 40.5 to 46.7% depending on cultivar. In a study evaluating 19 camelina accessions across three field sites in western Canada, Gugel and Falk (2006) reported that yields ranged from 962 to 3320 kg ha^{-1} and oil content ranged from 38 to 43%. Urbaniak et al. (2008b) evaluated nine cultivars across three environments in eastern Canada and found seed yields significantly varied in the range of 552–2568 kg ha^{-1} with oil content ranging from 36.2 to 40.1%.

Establishing best management practices, including sowing date, and selecting the most productive genotype(s) for a given region or environment will aid in optimizing camelina productivity while reducing feedstock cost for biofuel production. To date, no extensive evaluation of camelina germplasm or optimum sowing date has been made for summer annual production of camelina in the northern Corn Belt region of the U.S. Therefore, the present study was designed to evaluate the growth and yield of 10 camelina cultivars and target the optimum sowing time in west central Minnesota, U.S.

2. Materials and methods

2.1. Cultural practices

The present study was conducted over three growing seasons during 2008, 2009, and 2010 at the USDA-ARS Swan Lake Research Farm located 24 km northeast of Morris, Minnesota (45°35′N, 95°54′W). The soil was a Barnes loam soil (fine-loamy, mixed, superactive, frigid calcic hapludoll). The pH of soil at the study site is generally 7.2–7.3 and total organic and inorganic carbon ranges from 34.4 to 27.9 g kg^{-1} in the surface to 0.6 m soil depth (Johnson et al., 2010). The experimental design was a split-plot randomized complete block replicated four times. The main plots consisted of sowing date and subplots consisted of cultivar. The size of subplots in 2008 was 1.8 m by 4.6 m and in 2009 and 2010 it was 3.7 m by 7.6 m. The smaller size in 2008 was due to a limited amount of seed for sowing. Bulk seed collected for each cultivar grown in 2008 was used for sowing the trials in 2009 and 2010. All camelina cultivars were sown at a rate of 4.5 kg ha^{-1} on 30 cm spaced rows using a Wintersteiger plot drill (Model PDS 12R) with double-disk openers and using a seeding depth of approximately 1.0 cm.

Ten camelina cultivars were evaluated in the study. In 2008, Blaine Creek, Calena, CO46, CO54-97, Gold of Pleasure, Ligena, Robinson, and Suneson were grown. In 2009, the same cultivars were grown with the addition of Celine and Galena, and in 2010 only Calena, CO46, Blaine Creek, and Suneson were evaluated. All seeds used for the study were initially obtained from the North Dakota State University Extension Service (Fargo, North Dakota, USA). The genotype labeled Gold of Pleasure is likely a landrace that originated from Europe and was used in early breeding work in the U.S. The germination rate of seed used in the study was ≥90%. Sowing dates were targeted for as early as possible in the spring (typically mid-April to early-May in west central Minnesota, depending on field conditions) and then for early- to mid-May and late-May to early-June. Sowing dates were 23 April and 14 May in 2008; 4 May, 15 May, 29 May, and 15 June in 2009; and 16 April, 3 May, and 26 May in 2010. Only two dates could be sown in 2008 due to a limited amount of seed. In all three years of the trial, the previous crop was hard red spring wheat (*Triticum aestivum* L.). Prior to sowing camelina, the soil was chisel plowed in the autumn and in spring 90, 34, 45, 34 kg ha^{-1} of N, P, K, S was incorporated into the soil by shallow disking. Urbaniak et al. (2008b) reported camelina yields did not respond significantly to N fertilizer above 60–80 kg ha^{-1}. The fertilizer rates used in the present study were such to try and eliminate fertility as a limiting factor. At the same time the fertility was added, trifluralin at a rate of 1.1 kg ai ha^{-1} was also incorporated into the soil for weed control. Additional weeding was done by hand when necessary, but was minimal throughout the study.

2.2. Plant sampling and measurements

Seedling emergence and plant population density at harvest were measured on the same 1 m of row that was randomly selected and marked after sowing within the area used for harvest. This same 1 m of row was used for measuring the date when 50% of plants showed an open flower. Plant lodging was measured visually at the time of harvest using a scale of 0– 5 with 0 being fully erect and 5 being parallel to the ground. Growing degree days (GDD) were calculated as: $\mathrm{GDD} = \sum(T_{\max} + T_{\min}/2) - T_{\text{base}}$, where $T_{\max}$ and $T_{\min}$ are daily maximum and minimum air temperature, respectively, and T_{base} is base temperature of which a value of 5 °C was used (Blackshaw et al., 2011). Weather data including air temperature and precipitation were collected at a permanent weather station located at the study site.

Camelina was mechanically harvested with a plot combine. In 2008, due to the narrow plot width, the entire plot was harvested for yield. In 2009 and 2010, 5 rows from the center of each 12-row plot were harvested for yield. For a given sowing date, all cultivars were harvested at the same time after reaching full maturity, judged by when >90% of silicles had dried and turned brown and most seed was reddish-brown in color. Harvest dates were 28 July and 5 August for the first and second sowing dates in 2008; 4, 11, and 18 August and 1 September for the first, second, third and fourth sowing dates in 2009; and 16 and 27 July and 9 August for the first, second, and third sowing dates in 2010. Seed yield samples were dried in mesh bags in a forced air oven at 43 °C for 48–72 h before being screen cleaned. Moisture content of seed was determined immediately after cleaning by drying a subsample at 65 °C for 48 h and seed yields were adjusted to moisture content of 10%.

Seed oil content was measured by pulsed NMR (Bruker Minispec pc120, Bruker, The Woodlands, TX) as previously described by Gesch et al. (2005). Calibration of the instrument was performed with pure camelina oil. A subsample of approximately 5 g of seed of each replicate was used for analysis. Moisture content was