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Winter camelina seed yield and quality responses to harvest time

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ABSTRACT

Winter camelina [*Camelina sativa* (L.) Crantz] is an winter-annual oilseed crop that offers the potential for producing a second crop in the Upper Midwest. However, little is known about changes in oil, fatty acid (FA) composition and protein content as seeds mature in the field, nor the best harvest time to maximize winter camelina seed yield and quality. Therefore, a study was conducted in 2016–2017 at two locations Morris and Rosemount, Minnesota, to determine the changes in seed yield and quality from the beginning of seed-set to full maturity in winter camelina. Plant growth, seed yield and seed quality traits were evaluated over eight harvest dates ranging from early June through early July. Seed yield and oil content at both locations did not change significantly after mid-June corresponding to 1200–1300 °C d cumulative growing degree days, which resemble closely with maximum seed carbon and protein content. As the harvest date progresses, contents of seed linoleic, oleic and palmitic acids declined, while that of linolenic and eicosenoic acids increased, reaching their stable levels by physiological maturity. At maximum seed mass (*i.e.*, physiological maturity), moisture content was estimated to be 410 g kg^{-1}, which could be used as an indicator of when to swath or desiccate to hasten harvest. Results indicated that seed yield and oil content of winter camelina maximized by mid-June, before the crop reached physiological maturity in Minnesota. However, an additional 150–250 °C d was required to dry seed enough for ease of harvesting.

1. Introduction

Corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr] dominate the landscape of the Upper Midwest and demand for alternative land use to increase food and fuel production have increased in recent years (Sindelar et al., 2017). One opportunity created by this demand is the implementation of winter annual crops, such as winter camelina [*Camelina sativa* (L.) Crantz], to temporally expand the use of land already in production (Martinelli and Galasso, 2011; Gesch and Archer, 2013; Heaton et al., 2013). It is estimated that 27 million ha used for corn and soybean production in the Upper Midwest can be temporally intensified; this land use change can provide additional income to growers as well as ecologic and environmental services to the community at large (Heaton et al., 2013; Johnson et al., 2015; Sindelar et al., 2017). Winter camelina is of particular interest as it has a short growing season, requires low nutrient inputs, tolerant to drought, and can survive the harsh Upper Midwestern winters to produce both food- and industrial- grade oil (Zubr, 1997; Martinelli and Galasso, 2011; Moser, 2012; Zanetti et al., 2013; Allen et al., 2014).

Prior research demonstrated that winter camelina can provide a suite of environmental benefits including nitrogen sequestration, pollinator habitat and forage. For instance, a study by Johnson et al. (2017) demonstrated that winter camelina significantly reduced nitrogen in the soil profile up to 60 cm in comparison to a soybean crop alone. Mitigating nutrient loss from agricultural fields during spring is a key issue in the Upper Midwest (Randall et al., 1997) and the implementation of winter camelina could help to decrease some of the risk associated with fallow land in early spring (Carpenter et al., 1998).

Winter camelina not only provides ecological benefits, but also has the potential to increase farm economic viability as its seed can be used to produce both food- and industrial-grade oil (Zubr, 1997; Moser, 2012; Zanetti et al., 2013; Allen et al., 2014). Alternative biodiesel feedstocks, like winter camelina, have gained interest due to their low costs, compatibility with existing equipment and the ability to integrate them into current agronomic systems (Moser et al., 2009; Sindelar et al., 2017). Moreover, fuel properties of camelina-based biodiesel are

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*Abbreviations:*CGDD, cumulative growing degree days

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similar to those of soybean-based biodiesel, thus indicating its acceptability for use as a biodiesel source (Moser, 2012).

Although camelina has been cultivated since 4000 BCE, recent interest in its oil, particularly omega-3 fatty acids and seed meal, has spurred research in this crop (Zubr, 1997; Berti et al., 2016). Furthermore, recent research (Berti et al., 2017) has indicated that winter camelina can be double- or relay-cropped with forage or food crops leading to improvements in yield per area and energy balance, while also providing several ecosystem services. Although winter camelina shows great promise as a winter annual crop, it still has some issues that need to be addressed. For instance, a study by Sintim et al. (2015) showed that camelina grain yield was reduced by 24% when seed pods were harvested at 90% maturity as opposed to 50% maturity. Seed loss that occurs due to mechanical and environmental disturbances often can be correlated to low plant moisture (Vera et al., 2007; Sintim et al., 2016). This indicates that physiological maturity in camelina occurs prior to full plant ripening and thus, waiting until the plant has fully matured can impact overall yield negatively, likely due to seed shedding and/or avian predation (field observations).

No information exists with respect to (1) the seed moisture content at physiological maturity of winter camelina in the Upper Midwest and (2) changes in seed storage oil and fatty acid composition while maturing in the field under variable environmental conditions. Previous studies have addressed the physiological development of camelina seed but under controlled environment conditions (Pollard et al., 2015) or done elsewhere (Rodríguez-Rodríguez et al., 2013). Therefore, the objectives of this study were to determine (1) the best harvest time to optimize seed yield and quality, (2) the changes in fatty acid composition as seeds grow and mature under field conditions, and (3) seed moisture content at physiological maturity. Determining when physiological maturity occurs in field-grown winter camelina will help target when to apply desiccants to hasten its harvest, thus allowing rapid subsequent planting of the second crop in double-crop systems in the Upper Midwest to improve overall production and economics.

2. Materials and methods

2.1. Cultural practices

The experiments were conducted at two locations *i.e.* USDA-ARS Swan Lake Research Farm near Morris, MN (45°35′ N, 95°54′ W, elevation 345 m) and University of Minnesota Rosemount Research and Outreach Center near Rosemount, MN (44.41 °N, 93.4 °W, elevation 311 m) during the year 2016–2017. The soil type in Morris was a Barnes loam soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll) and in Rosemount was a Lindstrom silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludoll). At the Morris and Rosemount sites, soil pH was 7.4 and 5.9 (Watson and Brown, 1998), total nitrogen was 1.87 and 1.94 g kg^{-1} (high temperature combustion; Nelson and Sommers, 1996) and organic matter was 42 and 44 g kg^{-1} in the upper 0.6 m (loss on ignition method).

Monthly total precipitation and mean air temperature during the study period can be found in Table 1. The weather variables (minimum, maximum and average air temperature at 2 m above ground and daily precipitation) were recorded by an automated weather station at the Swan Lake Research Farm, Morris, MN and from a weather station located < 16 km from the Rosemount experiment station, Rosemount, MN.

Plot size for each treatment was 3.1 by 1.5 m at both locations. The treatments (*i.e.*, harvest date; see below) in both experiments were arranged in a randomized complete block design with four replications. At Morris, the seedbed was prepared by two passes of a no-till seed drill (approximately 3.8 cm deep soil disturbance) for minimal tillage and level the seed bed. On the second pass, 1.13 kg a.i. ha^{-1} of trifluralin was incorporated for weed control. Winter camelina (‘Joelle’) was sown at a rate of 9.5 kg ha^{-1}. The seed was sown on 13 September 2016, following a spring wheat (*Triticum aestivum* L.) crop. Seeds were sown at a depth of 1.5 cm with 19 cm row spacing with a no-till drill (InterSeeder Technologies LLC., Woodward, PA). Fertilizer was broadcasted at a rate of 78-34-34 kg ha^{-1} of N-P-K soon after the soil had thawed on 30 March 2017.

At Rosemount, winter camelina was seeded at a slightly higher rate of 11.2 kg ha^{-1} on 27 September 2016 following a stand of alfalfa (*Medicago sativa*), which was terminated on 14 September 2016 with 1.78 kg a.i. ha^{-1} glyphosate. In contrast to Morris, the overall weed pressure at Rosemount was low, so trifluralin was not applied. The field was cultivated on 26 September to create a level seed bed, like in Morris, one day prior to sowing camelina. Winter camelina was sown at a depth of 2 cm with 19 cm row spacing with a John Deere 8300 grain drill, then packed with a Brillion seeder in a final pass. The sowing depth was different by 0.5 cm between locations which might have resulted in yield differences among two locations. However, previous research (Gesch et al., 2017) has shown that seed yields of camelina did not differ significantly between the two sowing depths (1 and 2 cm). Fertilizer was broadcasted on 5 May 2017 in Rosemount at the same rate as was applied in Morris.

2.2. Treatments and plant sampling

Treatments consisted of eight harvest dates spaced at about 4-day intervals starting on 5 June 2017 and ending on 5–6 July 2017. Harvest sampling started at principal growth stage 74, when more than 50% of the silicles (fruit) had reached their final size according to the extended BBCH scale up to two-digit (Martinelli and Galasso, 2011). The sampling period was designed to encompass seed filling from beginning to full maturity to target maximum seed yield and quality and optimum harvest time. Accumulated growing degree days (CGDD; °C d) were calculated using daily maximum air temperature (T_{max}), daily minimum air temperature (T_{min}) and base temperature (T_{base}) for which 4 °C was used (Eq. (1); Gesch and Cermak, 2011).

$$CGDD = \sum\left(\frac{T_{max} + T_{min}}{2}\right) - T_{base} \tag{1}$$

Each plot was harvested manually for yield and quality attributes using clippers by taking a 1 m^2 area from the center of each plot. Within each plot, a separate seed sample was taken at harvest just outside the harvest area to record the seed moisture after drying at 65 °C to constant mass. Harvested plants were bagged and dried in a forced air oven at 65 °C to constant weight, after which, the seed was threshed manually using roller pins, cleaned of chaff (using small column air separator, Matu International Inc., Corvallis, OR), and weighed. All the treatments were harvested and handled in the same manner. Seed used for harvest calculations were tested for moisture after drying subsamples at 65 °C for 48 h, and yields were adjusted to a moisture content of 80 g kg^{-1}. The crop harvest index was calculated as dry seed weight divided by dry weight of total aboveground biomass at harvest.

2.3. Seed oil content and profile

Oil content was measured by pulsed nuclear magnetic resonance (NMR) (Bruker Minispec mq-10, Bruker, The Woodlands, TX, USA) using 5 g of seed from each replicated plot (n = 4). Prior to measurement, seeds were dried for 3 h at 130 °C and then cooled in a desiccator for 30 min. The NMR was calibrated with pure camelina oil and values of oil contents were reported as g kg^{-1}. The same seed samples were ground to a powder using a coffee grinder and approximately 200 mg of the powder was used to determine total C and N by combustion (model LECO TRU SPEC, LECO Corp., St. Joseph, MI). Seed crude protein was calculated by multiplying percent N content by 6.25.

Fatty acid methyl ester (FAME) profiles of winter camelina seed oil were analyzed by gas chromatography–mass spectroscopy (GC–MS) (Agilent 7890B GC and Agilent 5977B Networked MS) using a method