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Increased growing temperature reduces content of polyunsaturated fatty acids in four oilseed crops

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ABSTRACT

Environmental temperature directly influences the lipid profile produced by oilseeds. If growing temperatures increase, as is predicted by current models, the precise profile of lipids produced are likely to change. This paper develops models to predict lipid profiles as a function of growing temperature. Data relating to lipid profiles of soybean (*Glycine max*), spring canola (*Brassica napus*), spring camelina (*Camelina sativa*), and sunflower (*Helianthus annuus*) were gathered from the literature and evaluated to examine the influence of temperature on relative production of oleic, linoleic, and linolenic acid. For each crop, a set of linear regressions was used to correlate temperature during the grain fill, defined as 30 days before harvest, with the molar percentages of oleic, linoleic, and linolenic acid present. An increase in temperature from 10 to 40 °C resulted in an increase in the production of oleic acid and a decrease in the production of linoleic and linolenic acid in soybeans, canola, and sunflowers. Over the range of data available, the lipid profile of camelina was temperature insensitive. To test the validity of the correlations, the four crops were grown in a field study in Manhattan, Kansas simultaneously, in the same environment, in 2011. The correlations accurately predicted the field data for soybean, canola, and camelina but not for sunflower. The correlation for sunflower under-predicted the molar amount of oleic acid and over-predicted the molar amount of linoleic acid. This study indicates increasing growing temperatures from 10 to 40 °C will result in more monounsaturated oils and less polyunsaturated oils in soybean, canola, and sunflower.

1. Introduction

Plant lipids are important because of their use as food, fuel, and chemicals. Lipids also have uses as starting materials for surfactants, lubricants, epoxides, coatings, inks, polymers, and other products in the chemical industry (Metzger and Bornscheuer, 2006). The lipid profile of a seed can affect its end use. In oils for human consumption, linoleic acid is valued for its health benefits but linolenic acid results in oil having a poor oxidative stability and shortened shelf life (Singh et al., 2010). For biodiesel production, it is desirable to have a lipid profile that is highly saturated to minimize oxidation of double bonds because oxidized methyl esters can form polymers that plug fuel filters and damage engine performance (Monyem and Gerpen, 2001). Specific lipid profiles also influences reactivity. Multiply unsaturated lipids have been shown to have a higher reactivity than monounsaturated species (Singh et al., 2009, 2011).

Fatty acid profiles are influenced by plant type, genotype, temperature, environmental conditions, and agricultural practices (Harris et al., 1978). Several studies have examined the effect of temperature on fatty acid composition of the grain (Canvin, 1965; Aksouh et al., 2001; Ren et al., 2009). Many studies examining how temperature influenced the resultant seed lipid profile were performed in greenhouses but greenhouses can only approximate growing conditions in the field and cannot give a complete picture of how crops will respond to different temperatures (Canvin,

Abbreviations: Oleic acid=, C18:1; Linoleic acid=, C18:2; Linolenic acid=, C18:3; Gas Chromatography or Gas Chromatograph=, GC; Flame ionization detector=, FID.

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1965; Aksouh et al., 2001; Ren et al., 2009). Conversely, data from field studies only encompass a relatively narrow temperature range (Nagao and Yamazaki, 1983; Putnam et al., 1991; Gugel and Falk, 2006; Gao et al., 2009). Most studies found that as temperatures rise, the percentage of polyunsaturated lipids, linoleic (C18:2) and linolenic (C18:3) in particular, decreases while the percentage of oleic acid (C18:1) increases. Yet each of the prior studies is limited in scope, typically including only one crop grown in a handful of locations, resulting in growing conditions across a limited temperature range. The general consensus from these studies is that growing temperature and genotype are the main factors contributing to the large variation within a crop's lipid profile (Lajara et al., 1990).

In the current work, the literature was reviewed to determine if temperature is the single dominant factor influencing lipid composition. In this paper, 25 studies of oil profiles for crops grown in fields and greenhouses were compiled with temperatures ranging between 10 and 40 °C to provide a more complete understanding of how lipid profiles are affected by temperature. Temperature during the grain fill, defined as 30 days before harvest, was correlated with the percentage of major lipids contained in soybean, canola, camelina and sunflower. Then the oilseed crops were grown and the lipid profile of their seeds was determined and compared to the literature to demonstrate the validity of the determined correlations.

Oilseed crops were chosen for their ability to grow in the Midwest and their potential for use as a feedstock for production of biodiesel or other biochemicals. Soybean (*Glycine max*) is the most valuable oilseed crop in United States in terms of production and economic value as it accounts for over 90% of US production of biodiesel and is a dominant food product (Gao et al., 2009). Over 50 million metric tons of canola (*Brassica napus*) is produced annually, making it the world's third most important oilseed crop behind palm and soybean (Downey, 1990). Camelina (*Camelina sativa*) is a relatively new oilseed crop that because of its low agricultural inputs and ability to grow on marginal lands, could play an important role in food and fuel production in the future (Budin et al., 1995). Sunflower (*Helianthus annuus*) is one of the five largest oilseed crops in the world with over 1.5 million acres of sunflower planted in USA in 2011 ("Economic Research Service, USDA. 'Table 20: Sunflowerseed: Acreage planted, harvested, yield, production and value, U.S., 1980–2011'," 2012). Compared to previous multi-crop studies on seed oil compositions, the current study is distinct in that it includes camelina with the traditional crops (Werteker et al., 2010).

Our objectives were to gather literature data on lipid profiles over a large range of growing temperatures and correlate the temperature during the grain fill to the molar amount of lipid contained in the seeds. The correlations were compared to field studies to demonstrate their validity.

2. Materials and methods

2.1. Collecting lipid profiles from literature

For field studies, literature was included in this review if the study included the location where the crops were grown and harvest date (or sufficient data with which to make a reasonable estimate of the date of harvest). If only the planting date was given, the harvesting date was assumed to be the average of the recommended days to allow the plant to grow in the field. For soybean the assumed harvest date was 100 days after planting while for the short season crops, canola, camelina, and sunflower, the assumed harvest date was 92 days after planting. The mean monthly maximum temperature for each location was found in the National Oceanic and Atmospheric Administration's National Climatic Data Center. If the grain filling days spanned two months, the average mean maximum temperature of that period was calculated, accounting for the days of grain filling in each month. For greenhouse studies, literature was included in this review if temperature data was given. A list of the literature included in this review can be found in Table 1.

Table 1
Published data included in this study.

Citation, author (year)	Location	Plants grown
Aksouh et al. (2001)	Greenhouse	Canola
Aksouh-Harradj et al. (2006)	Greenhouse	Canola
Angelini et al. (1997)	Central Italy	Camelina
Bhardwaj and Hamama (2008)	Virginia	Canola
Budin et al. (1995)	Minnesota	Camelina
Canvin (1965)	Greenhouse	Sunflower
Gao et al. (2009)	Michigan	Soybean
Gugel and Falk (2006)	Saskatoon and Scott, Saskatchewan and Beaverlodge, Alberta	Camelina
Iqbal et al. (2011)	Greenhouse	Canola
Larson et al. (2002)	Greenhouse	Canola
Lu and Kang (2008)	Greenhouse	Camelina
Maestri et al. (1998)	Cordoba, Argentina	Soybean
Martınez-Force et al. (1998)	Greenhouse	Sunflower
Nagao and Yamazaki (1983)	Okayama, Japan	Sunflower
Putnam et al. (1991)	Rosemount, MN	Soybean, canola, camelina
Rao et al. (1998)	Fort Valley, GA	Soybean
Ren et al. (2009)	Greenhouse	Soybean
Rennie and Tanner (1989)	Greenhouse	Soybean
Robertson et al. (1971)	Tifton, GA, Baton Rouge, LA, College Station, TX	Sunflower
Shafiullah et al. (1994)	Islamabad, Pakistan	Sunflower
Tremolieres et al. (1982)	Greenhouse	Canola and sunflower
Unger and Thompson (1982)	Bushland, TX	Sunflower
Vantoai et al. (2012)	Columbia and Portageville, MO	Soybean
Wolf et al. (1982)	Greenhouse	Soybean
Zubr and Mattha (2002)	Mullhein, Paderborn, Carlow, Germany and Uppsala, Sweden	Camelina

Genotype has been documented to have an effect on the oilseed profile, so an attempt was made to control for genotype in the collected literature. Only literature studies with genotypes that matched the oilseed crops grown as validation studies were used. Since few studies specifically articulated the genotype of the seeds, categorization strategies were employed. Soybean cultivars have been considerably modified due to genetic engineering and can have a wide variety of lipid profiles. Studies with more oleic acid than linoleic acid were neglected because soybean in the field studies had twice as much linoleic acid than oleic. The commercial canola evaluated is significantly different from the wild *B. napus* varieties. By definition, canola is a *B. napus* hybrid or variety with less than 5% erucic acid, therefore *B. napus* oils with more than 5% erucic acid were neglected. Because it has not yet reached use maturity, camelina has experienced limited genetic modifications, thus all data from the literature was included. Commercially available sunflower hybrids have a wide variety of lipid profiles and are classified by percentage of oleic acid. The sunflower hybrid used in this study was classified as a mid-oleic line with oleic acid percentages between 55 and 75% and linoleic acid percentages between 20 and 42% (Grompone,