Oil Content and Saturated Fatty Acids in Sunflower as a Function of Planting Date, Nitrogen Rate, and Hybrid

Valtcho D. Zheljazkov,* Brady A. Vick, Brian S. Baldwin, Normie Buehring, Tess Astatkie, and Billy Johnson

ABSTRACT

The fatty acids (FA) composition of sunflower (*Helianthus annuus* L.) determines its uses and health effects on humans, while oil content determines the price paid to producers. The hypothesis of this study was that agronomic factors (genotype, planting date, and N rate) will affect total saturated fatty acid (TSFA) concentration and oil content of sunflower. Additionally, Mississippi-grown sunflower will have a different FA composition than the original seeds produced in more northern latitudes and used for planting. A field experiment was performed in four locations in Mississippi (Newton, Starkville, and two locations in Verona) to assess the effect of planting date (20 April, 20 May, and 20 June), N application rate (0, 67, 134, and 202 kg N ha⁻¹) and genotype (hybrid, DKF3875, DKF2990, DKF3510, and DKF3901) on sunflower seed oil content and composition. The TSFA and oil content were significantly affected by planting date, hybrid, and N rate. Overall, later planting dates increased TSFA relative to the first planting, and in most instances TSFA concentrations in sunflower from the third planting was higher than in seeds from the second. Generally, the first planting date provided the highest oil content of the four hybrids, the second planting reduced oil content, while the third was not different from the second. Our results suggest that an earlier planting date may reduce the TSFA and increase oil content of sunflower in Mississippi. Regarding individual FA, overall, palmitic (16:0) and stearic acid (18:0) concentrations in sunflower seed grown in Mississippi from the first planting were reduced relative to the respective concentrations in the original seed. Later planting tended to increase these two acids relative to the first planting and relative to the original seed. The three minor saturated fatty acids (SFA), arachidic (20:0), behenic (22:0), and lignoceric acid (24:0) followed a similar pattern. This study demonstrated that agricultural factors such as planting date, hybrid, and N rate may significantly modify FA composition and oil content of sunflower grown in Mississippi, suggesting that these could be used as management tools for decreased TSFA and increased oil content.

**S**unflower is one of the major oilseed crops in the world, grown on some 22 million ha (Skoric et al., 2008). Based on the final product and uses, contemporary sunflower hybrids are characterized as either oil type or confectionery type. The oil type is distinguished with small seeds, high oil content, with various fatty acid compositions and is used as high-quality edible vegetable oil for human consumption, or for biodiesel production (Arkansas Biofuel Enterprises, 2007; National Sunflower Association, 2009). The confectionery type is characterized by large, striped hull seeds, and is used either for confectionery or birdseed (National Sunflower Association, 2009).

The concentration of FA in various sunflower hybrids is important with respect to its final uses and market price (Warner et al., 2003; Burton et al., 2004; National Sunflower Association, 2009). In general, sunflower oil contains both saturated and unsaturated FA, either mono- or polyunsaturated. Unsaturated FA comprise approximately 900 g kg⁻¹ of the oil and include oleic acid (18:1, or 18-carbon FA with one double bond) and linoleic acid (18:2). Saturated FA such as palmitic acid (16:0) and stearic acid (18:0) may constitute another 70 to 110 g kg⁻¹ of the oil (Steer and Seiler, 1990; Friedt et al., 1994; Pierson, 1994; Skoric et al., 2008). Other saturated FA of sunflower oil are minor constituents and include arachidic (20:0), behenic (22:0), and lignoceric (24:0).

Consumption of oils with high concentration of unsaturated FA has been found to have a positive effect on human health (Jing et al., 1997; Krajcovicova-Kudlackova et al., 1997; Hu et al., 2001). Increased consumption of saturated FA leads to higher concentrations of total and LDL cholesterol in humans, which in turn significantly increases risks of heart attack and stroke, America’s number one and number three killers (American Heart Association, 2009). Hence, it is important to reveal agricultural factors that may reduce or increase the concentration of TSFA (combined concentration of palmitic, stearic, arachidic, behenic, and lignoceric) of sunflower. Studies by Vick et al. (2004) have shown that environment plays a

**Abbreviations:** FA, fatty acids; ICAP, indicatively coupled argon plasma spectrometer; NMR, nuclear magnetic resonance; PPI, preplant incorporated; TSFA, total saturated fatty acids.
significant role in the relative proportion of TSFA in sunflower grown in the northern plains. However, to date there are no reports on the effects of agronomic or environmental factors that could be used to reduce the TSFA of sunflower grown in the southeastern United States.

Furthermore, starting in the 1970s, breeders have been developing sunflower cultivars and hybrids with high concentrations of monounsaturated FA and decreased TSFA (Soldatov, 1976; Hardin, 1998; Kleingartner, 2002; Vick et al., 2003; Burton et al., 2004; Vick et al., 2007; Skoric et al., 2008). Many selection and breeding efforts throughout the world produced sunflower hybrids with increased monounsaturated FA composition; however, some of these hybrids had reduced oil content relative to the traditional sunflower cultivars and hybrids. Agricultural factors that may increase oil content of sunflower are definitely of interest to producers, due to the fact that current sunflower prices at crushing plants are determined based on oil content (National Sunflower Association, 2009).

In 1977 in the United States, public health recommendations were to reduce fat intake, and much progress has been made in this aspect. However, the reduced fat intake also resulted in increased consumption of carbohydrates (German and Dillard, 2004), which caused other health problems in humans. The 2004 public health recommendations in the United States are to reduce significantly the intake of SFA, trans fats, and cholesterol (German and Dillard, 2004). Increased consumption of vegetable oils (such as palm oil) with high TSFA has been linked to increased cardiovascular diseases such as heart attack while unsaturated oils [such as soybean, Glycine max (L.) Merr., and sunflower] were not (Kabagambe et al., 2005). Elevated beyond recommended rates consumption of TSFA has been linked to health problems in humans. In addition, high concentration of individual saturated FA could also have deleterious measurable effects. For example, palmitic acid has long been shown to be hypercholesterolemic in humans (Temme et al., 1996). While palmitic acid and high glucose levels in human cultured islets may induce β-cell apoptosis (the process of normal or “programmed” cell death (PCD), monounsaturated FA appears to prevent such deleterious effects (Maedler et al., 2003). In vitro experiments suggested a possible role of increased consumption of saturated FA to reproductive abnormalities in obese women (Mu et al., 2001). Even minor saturated FA (not usually reported in sunflower research papers) may affect human health. For example, behenic acid is one of the saturated long-chain fatty acids of sunflower oil (Cater and Denke, 2001; Salas et al., 2005). Although this acid is poorly absorbed by animals or humans, it has been shown to act as a cholesterol-raising agent in humans (Cater and Denke, 2001).

Increased temperature may increase the concentration of behenic acid in sunflower oil (Izquierdo and Aguirrezábal, 2008). Hence, sunflower grown in Mississippi might accumulate higher concentrations of behenic acid relative to the same hybrids grown in more northern latitudes.

Sunflower is considered a promising high-value crop for the southeastern United States, however, there is insufficient research on agronomic factors that may alter TSFA or oil content of modern sunflower hybrids. The hypothesis of this study was that genotype, planting date, and N rate will have an effect on TSFA and oil content of sunflower. Furthermore, the concentration of individual FA in sunflower seeds grown in Mississippi may be altered relative to the original seed used for planting and produced in more northern latitudes.

**MATERIALS AND METHODS**

**Field Experiments**

The field experiment was conducted in 2007 at four locations in Mississippi: Newton, Starkville, and two locations in Verona. The three experimental factors were planting date (20 April, 20 May, and 20 June), hybrid (DKF3875, DKF2990, DFK3510, DFK3901), and N rate (0, 67, 134, and 202 kg N ha$^{-1}$). At Starkville, the third planting was not successful. DFK3875 is a traditional type; DFK2990 is traditional, downy mildew resistant; DFK3510 is mid-oleic acid (NuSun), downy mildew resistant; and DFK3901 is traditional, downy mildew resistant (DeKalb, 2007). Certified seeds of the four hybrids used in this study were produced in Woodland, northern California, and provided by Monsanto (Monsanto Co., St. Louis, MO). The four locations represented distinct growing areas from south to north Mississippi and different soil types (USDA, Soil Survey Division, Natural Resources Conservation Service, 2001) (Table 1). The fertilizers applied and the sunflower degree days are also provided in Table 1.

**Soil Nutrient Analyses, Land Preparation, Planting, and Nitrogen Application**

The concentration of phyto-available nutrients was determined before tillage by an inductively coupled argon plasma spectrometer (ICAP) (Thermo Jarrell Ash, Franklin, MA) following extraction using the Lancaster method (Cox, 2001). Phosphorus and K fertilizers were broadcasted and incorporated at each location following the soil analysis and specific recommendations. Nitrogen [as urea-ammonium nitrate solution (UAN) 320 g kg$^{-1}$ N] was knifed in on either side of the row (20–25 cm from row) and was applied in 67 kg N ha$^{-1}$ increments: the first 67-kg increment was applied at planting and the side dressing was applied a month later at the V-4 growing stage (Schneiter and Miller, 1981).

Land preparation at the four locations included disking and formation of raised beds at 97 to 102 cm center to center at the beginning of April. Weeds were controlled with preplant incorporated trifluralin, (2.33 L ha$^{-1}$). Experimental plots were 6 by 4 m. Sunflower was planted using a cone planter at 3.8 cm depth, at 97- to 102-cm interrow space, and a seed rate of 6.4 seed m$^{-1}$ of linear row. All plants were incorporated trifluralin, (2.33 L ha$^{-1}$). Experimental plots were 6 by 4 m. Sunflower was planted using a cone planter at 3.8 cm depth, at 97- to 102-cm interrow space, and a seed rate of 6.4 seed m$^{-1}$ of linear row. All plants were harvested at maturity, after physiological stage R-9 (Schneiter and Miller, 1981). Sunflower heads were threshed on a stationary thresher (Almaco, LPR-E, Nevada, IA) and seed moisture was determined by an electronic grain-moisture tester (Model GAC2000, Dickey-John, Auburn, IL).

**Analysis of Sunflower Fatty Acid Composition**

One hundred gram sunflower subsamples from every plot (cleaned to remove broken seeds and impurities) were ground in a coffee grinder. A subsample (0.15–0.25 g) was treated with a solution of hexane-chloroform-0.5 mol L$^{-1}$ sodium methoxide in methanol (Sigma, St. Louis, MO) (75:20:5, v/v/v), vortexed for 2 to 5 s, and the mixture settled for 10 min.
The supernatant was transferred to a 2-mL autosampler vial and injected into a Hewlett-Packard Model 5890 gas chromatograph (GC), with a DB-23 capillary column (30 m x 0.25 mm, J&W Scientific, Folsom, CA). The temperature was held at 190°C for 4 min, then increased to 220°C at 15°C/min, held at 220°C for 1 min, then increased to 240°C at 25°C/min, and finally held at 240°C for 1.0 min, for a total run time of 8.8 min. The concentration of individual FA in the sunflower seed samples is given as percent by weight of the total FA in the oils from every plot. For the purpose of data analysis, the FA (g kg\(^{-1}\)) concentrations are expressed as adjusted FA (g kg\(^{-1}\)), which is the FA (g kg\(^{-1}\)) in the harvested seed less the FA (g kg\(^{-1}\)) in the corresponding original, planted hybrid seed.

### Analysis of Seed Oil Content

Seed oil content was determined on a 40-mL subsample from each plot of cleaned, weighed seed on a Maran Ultra Resonance NMR instrument (Resonance Instruments Ltd., Witney, UK), following the American Oil Chemists’ Society (1994) Official Methods and Recommended Practices, AK4–95. Oil seed content was adjusted to standard seed moisture of 100 g kg\(^{-1}\).

### Statistical Methods

Within each of the four locations (Newton, Starkville, Verona 1, and Verona 2), the experimental field had three blocks, and each block was partitioned into three and randomly assigned to the three planting dates (1, 2, and 3). Within each planting date the 16 combinations of Hybrid (DKF2990, DKF3510, DKF3875, and DKF3901) and N Rate (0, 67, 134 kg N ha\(^{-1}\)) were completely randomized. For each location, this layout made the design a split-plot factorial with planting date by hybrid by N rate interaction effect at the two Verona locations. At Newton, oil content in the 67, 134, and 202 kg N ha\(^{-1}\) were completely randomized. For each location, the validity of model assumptions on the error terms was verified by examining the residuals as described in Montgomery (2005) and appropriate transformations were applied on responses with violated assumptions.

### RESULTS AND DISCUSSION

#### Fatty Acid Composition of the Original Seed Used in this Study

The seed oil of the four hybrids had different fatty acid profiles (Table 2). Based on oleic acid concentration, DKF3510 is a high-oleic sunflower, DKF3875 and DKF2990 are the traditional class of sunflower with high polyunsaturated fatty acid (linoleic), whereas DKF3901 belongs to a mid-oleic acid sunflower, intermediate in both oleic and linoleic acid compared with the high/low values in other hybrids (Codex Alimentarius Committee, 2005; Canadian Food Inspection Agency, 2007). However, according to the classification of the National Sunflower Association (www.sunflowers.com), DKF3875, DKF2990, and DKF3901 are characterized as traditional, while DKF3510 is characterized as high-oleic (National Sunflower Association, 2009).

#### Seed Oil Content

Analysis of variance results for the main and interaction effects of planting date, hybrid, and N rate on seed oil content (adjusted for 100 g kg\(^{-1}\) seed moisture content) shown in Table 3 indicated a significant planting date by hybrid interaction effect at Newton and Starkville, a significant N rate effect at Newton, a significant hybrid by N rate interaction effect at Starkville, and a significant planting date by hybrid by N rate interaction effect at the two Verona locations.
kg N ha$^{-1}$ rates were equal (324 g kg$^{-1}$), but lower than that at the 0 kg N ha$^{-1}$ rate (341 g kg$^{-1}$) (data not shown). This result is consistent with previous reports indicating decrease in oil content with increasing N rates (Tonev, 2006; Montemurro and Giorgio, 2005; Valchovski, 2002; Zheljazkov et al., 2008). Also at Newton, oil content was highest in the seeds from the first planting date, and lower from the second planting date followed by the lowest oil content from the third planting date (Table 4). However, the rate of reduction was not uniform among the hybrids; with DKF3510 giving lower oil content than the other three hybrids in the first planting date, and DK3875 giving the lowest oil content in the second and third planting date.

Similarly, oil content at Starkville from the first planting was higher than that from the second planting date (Table 4). Also similar to the Newton results, oil content within the first planting was lower in DKF3510 and higher in the other hybrids, while within the second planting, oil content of DKF3875 was lower than in the other hybrids. Also at Starkville, N application at 134 and 202 kg N ha$^{-1}$ reduced oil content of DKF3875 relative to the 0 kg N ha$^{-1}$ treatment (Fig. 1). All N applications reduced oil content of DKF2990 relative to the 0 kg N ha$^{-1}$ rate. Nitrogen application rates did not change oil content of DKF3510 and DKF3901.

Generally, at Verona 1 location, hybrids produced more oil at the first planting and less at the second and the third planting within all N rates (Fig. 2). Furthermore, DKF3875 produced less oil at the third planting than at the second planting within 0.67, and 134 kg N ha$^{-1}$. Hence, DKF3875 produced less oil than the other hybrids at the third planting and within all N rates. A similar pattern was also observed at the Verona 2 location (Fig. 3). Our results confirm prior reports that have shown greater oil content with earlier planting dates (Goksoy et al., 1998).

Generally, oil content of sunflower grown in Mississippi was similar to the results from 2007 sunflower hybrid trials in the United States. For example, the average oil content of 36 sunflower hybrids in Brandon, CO in 2007 was 387 g kg$^{-1}$, the average oil content of 74 hybrids in Casselton, ND was 399 g kg$^{-1}$, the average oil content of 54 hybrids in Colby, KS for the same year was 432 g kg$^{-1}$, the oil content of 32 hybrids in Cheyenne, NE was 376 g kg$^{-1}$ (National Sunflower Association, 2009). Surely, in some of the sunflower trials the average oil content was higher, up to 460 g kg$^{-1}$ (National Sunflower Association, 2009).

### Table 2. Fatty acid concentration of the original certified seed of the four sunflower hybrids grown at four locations in Mississippi.

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Palmitic</th>
<th>Stearic</th>
<th>Oleic</th>
<th>Linoleic</th>
<th>Arachidic</th>
<th>Gondoic</th>
<th>Behenic</th>
<th>Lignoceric</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKF2990</td>
<td>67.8</td>
<td>53.9</td>
<td>262.0</td>
<td>561.0</td>
<td>3.1</td>
<td>1.7</td>
<td>7.0</td>
<td>1.8</td>
</tr>
<tr>
<td>DKF3510</td>
<td>41.4</td>
<td>43.1</td>
<td>862.0</td>
<td>31.0</td>
<td>4.0</td>
<td>2.4</td>
<td>10.5</td>
<td>3.6</td>
</tr>
<tr>
<td>DKF3875</td>
<td>65.3</td>
<td>40.3</td>
<td>402.0</td>
<td>459.0</td>
<td>3.3</td>
<td>1.4</td>
<td>8.3</td>
<td>2.6</td>
</tr>
<tr>
<td>DKF3901</td>
<td>62.0</td>
<td>64.6</td>
<td>328.0</td>
<td>509.0</td>
<td>4.7</td>
<td>1.3</td>
<td>10.3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Table 3. Analysis of variance results for seed oil content at four locations in Mississippi.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Newton</th>
<th>Starkville</th>
<th>Verona 1</th>
<th>Verona 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting date (PD)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Hybrid</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>PD × hybrid</td>
<td>0.001†</td>
<td>0.014</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>N rate</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>PD × N rate</td>
<td>0.376</td>
<td>0.725</td>
<td>0.054</td>
<td>0.182</td>
</tr>
<tr>
<td>Hybrid × N rate</td>
<td>0.801</td>
<td>0.038</td>
<td>0.030</td>
<td>0.193</td>
</tr>
<tr>
<td>PD × hybrid × N rate</td>
<td>0.756</td>
<td>0.308</td>
<td>0.069</td>
<td>0.002</td>
</tr>
</tbody>
</table>

† Significant effects that need multiple means comparison are underlined.

### Table 4. Seed oil content for three planting dates and four hybrids at Newton and Starkville, MS.

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Locations</th>
<th>20 April</th>
<th>20 May</th>
<th>20 June</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newton</td>
<td>413 a†</td>
<td>346 cd</td>
<td>253 f</td>
</tr>
<tr>
<td>DKF2990</td>
<td>Starkville</td>
<td>441 a</td>
<td>342 c</td>
<td></td>
</tr>
<tr>
<td>DKF3510</td>
<td></td>
<td>376 b</td>
<td>351 c</td>
<td></td>
</tr>
<tr>
<td>DKF3875</td>
<td></td>
<td>399 a</td>
<td>315 e</td>
<td></td>
</tr>
<tr>
<td>DKF3901</td>
<td></td>
<td>394 a</td>
<td>330 de</td>
<td></td>
</tr>
</tbody>
</table>

† Within each location, means followed by the same letter are not significantly different at P < 0.01.

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**Fig. 1.** Oil content for the four sunflower hybrids and four N rates grown at the Starkville location. Means sharing the same letter are not different at the 0.01 level of significance.

**Fig. 2.** Oil content for four sunflowers grown at three planting dates and four N rates (kg N ha$^{-1}$) at the Verona 1 location. Means sharing the same letter are not different at the 0.01 level of significance.
Association, 2009). Various hybrids in the above sunflower trials had different oil content.

**Total Saturated Fatty Acids Concentration**

The TSFA (combined concentration of palmitic, stearic, arachidic, behenic, and lignoceric) in sunflower seed grown in Mississippi was significantly affected by planting date and by hybrid at Starkville, by the interaction of planting date and hybrid at Newton and the two Verona locations, by N rate at Newton and Starkville, and by the interaction of hybrid by N rate at the Verona 1 location (Table 5).

At Newton, N applications increased TSFA relative to the 0 kg N ha$^{-1}$ rate (Table 6). At Starkville, N rates at 134 and 202 kg N ha$^{-1}$ increased TSFA relative to the 0 and 67 kg N ha$^{-1}$ (Table 6), and the second planting date increased TSFA relative to the first planting date (data not shown). Also at Starkville, the four hybrids had distinct TSFA concentration in the seed; DKF3901 had the highest TSFA (116 g kg$^{-1}$), next was DKF3875 (110 g kg$^{-1}$), followed by DFK2990 (98 g kg$^{-1}$), and the lowest TSFA was found in DKF3510 (85 g kg$^{-1}$), which is also the highest oleic acid hybrid of the four. At the Verona 2 location, the 202 kg N ha$^{-1}$ treatment had higher TSFA relative to the 67 or 134 kg N ha$^{-1}$, but was not different from 0 kg N ha$^{-1}$ (Table 6). In general, the third planting date (and in some instances the second planting) at Newton, Verona1, and Verona 2 locations increased TSFA relative to the first planting date (Fig. 4). Hence, our results indicate that earlier planting date may reduce the TSFA of sunflower in Mississippi. At the Verona 1 location, DKF3875 and DKF3901 had greater TSFA at all N rates than DKF2990, whereas DKF3510 had the lowest TSFA at all N rates (Table 7).

Reducing the TSFA in sunflower oil would improve its dietary properties, would result in higher oxidative stability, and may benefit both consumers and producers (Miller and Vick, 1999; Flagella et al., 2002). Previous research has demonstrated that FA composition of sunflower oil may be affected by genetic (Miller and Vick, 1999; Burton et al., 2004; Izquierdo and Aguirrezábal, 2008; Skoric et al., 2008) and environmental conditions (Robertson et al., 1978; Lajara et al., 1990; Steer and Seiler, 1990; Flagella et al., 2002; Sobrino et al., 2003; Izquierdo and Aguirrezábal, 2008; Zheljazkov et al., 2008).

**Palmitic Acid**

With respect to palmitic acid concentration in sunflower seed, the interaction of planting date and hybrid and the

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**Table 5. Analysis of variance for total saturated fatty acids at four locations in Mississippi.**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Newton</th>
<th>Starkville</th>
<th>Verona1</th>
<th>Verona2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting date (PD)</td>
<td>0.001†</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Hybrid</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>PD × hybrid</td>
<td>0.001</td>
<td>0.137</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>N rate</td>
<td>0.036</td>
<td>0.004</td>
<td>0.045</td>
<td>0.039</td>
</tr>
<tr>
<td>PD × N rate</td>
<td>0.740</td>
<td>0.974</td>
<td>0.370</td>
<td>0.100</td>
</tr>
<tr>
<td>Hybrid × N rate</td>
<td>0.411</td>
<td>0.744</td>
<td>0.032</td>
<td>0.606</td>
</tr>
<tr>
<td>PD × hybrid × N rate</td>
<td>0.364</td>
<td>0.697</td>
<td>0.567</td>
<td>0.450</td>
</tr>
</tbody>
</table>

† Significant effects that need multiple means comparison are underlined.

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**Table 6. Total saturated fatty acids concentration for four N application rates at Newton, Starkville, and Verona 2, MS.**

<table>
<thead>
<tr>
<th>N rate</th>
<th>Newton</th>
<th>Starkville</th>
<th>Verona 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg N ha$^{-1}$</td>
<td>g kg$^{-1}$</td>
<td>g kg$^{-1}$</td>
<td>g kg$^{-1}$</td>
</tr>
<tr>
<td>0</td>
<td>107.3 b†</td>
<td>100.1 b</td>
<td>113.3 ab</td>
</tr>
<tr>
<td>67</td>
<td>109.9 a</td>
<td>100.0 b</td>
<td>112.2 b</td>
</tr>
<tr>
<td>134</td>
<td>110.5 a</td>
<td>104.2 a</td>
<td>112.9 b</td>
</tr>
<tr>
<td>202</td>
<td>110.8 a</td>
<td>104.1 a</td>
<td>115.3 a</td>
</tr>
</tbody>
</table>

† Within each location, means sharing the same letter are not significantly different at the 0.01 level of significance.

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**Table 7. Total saturated fatty acids (TSFA) for four N rates and four hybrids at Verona 1, MS.**

<table>
<thead>
<tr>
<th>N rate</th>
<th>DKF2990</th>
<th>DKF3510</th>
<th>DKF3875</th>
<th>DKF3901</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg N ha$^{-1}$</td>
<td>g kg$^{-1}$</td>
<td>g kg$^{-1}$</td>
<td>g kg$^{-1}$</td>
<td>g kg$^{-1}$</td>
</tr>
<tr>
<td>0</td>
<td>9.3 c†</td>
<td>8.0 d</td>
<td>11.2 a</td>
<td>11.0 a</td>
</tr>
<tr>
<td>67</td>
<td>9.6 bc</td>
<td>8.0 d</td>
<td>10.8 a</td>
<td>11.1 a</td>
</tr>
<tr>
<td>134</td>
<td>9.8 b</td>
<td>8.2 d</td>
<td>11.3 a</td>
<td>11.1 a</td>
</tr>
<tr>
<td>202</td>
<td>9.5 bc</td>
<td>8.2 d</td>
<td>11.3 a</td>
<td>11.2 a</td>
</tr>
</tbody>
</table>

† Within each hybrid, means followed by the same letter are not significantly different at the 0.01 level of significance.
interaction of planting date and N rate were significant at the two Verona locations. Hybrid by N rate was also significant at Verona 1, and the three way interaction of planting date, hybrid, and N rate was significant at Newton and Starkville. At Newton, within the first planting date, 134 kg N ha\(^{-1}\) increased palmitic acid concentration only in DKF3510 relative to the other N rates (Fig. 5). Within the second planting date, DKF2990 had higher palmitic acid concentration with 202 kg N ha\(^{-1}\) than with 0, 67 or 134 kg N ha\(^{-1}\), which all yielded the same concentration (Fig. 5). Within the third planting date, while the hybrids differed in their palmitic acid concentration, N application rates did not alter the concentration of this acid in any of the hybrids (Fig. 5). Thus, within each planting date at Newton, most N rates had little effect on palmitic acid concentration relative to the respective original seed. However, later planting dates resulted in slightly increased palmitic acid concentration, likely due to environmental differences during seed maturation (Fig. 5).

At Starkville, within the first planting date, N applications did not alter the palmitic acid concentration of the hybrids. However, all four hybrids had less palmitic acid than the original seed, with DKF2990 having the lowest (Fig. 6). Within the second planting date, N applications did not alter palmitic acid concentration of DKF2990, DKF3510, and DKF3875. However, in DKF3901, 67 kg N ha\(^{-1}\) decreased this acid relative to 0 and 202 kg N ha\(^{-1}\) (Fig. 6). Unlike the first planting date, the palmitic acid relative to the original seed was lower only for DKF2990 within the second planting date.

At the two Verona locations, the first planting date resulted in the lowest palmitic acid concentration relative to the original seed. The concentration of this acid increased in most treatments with the second, and further with the third planting date. At the Verona 2 location, the third planting date had greater palmitic acid concentration relative to the original seed (Fig. 7). Generally, at both locations, the lowest palmitic acid concentration was in DKF2990 (Fig. 7 and 8). At Verona 1, but not Verona 2, increased N application rates within the first and the second planting dates decreased palmitic acid concentration relative to the 0 kg N ha\(^{-1}\) or the original seed, but not within the third planting date (Fig. 8). At both locations, the first planting dates resulted in lower palmitic acid concentration relative to the second and especially to the third planting date. In addition, the first planting had the largest decrease in palmitic acid concentration relative to the original seed (Fig. 8). At the Verona 1 location, DKF2990 had the lowest palmitic acid relative to the original seed, but it took 202 kg N ha\(^{-1}\) to decrease it further (Fig. 9). Furthermore, N rates of 134 and 202 kg N ha\(^{-1}\) in DKF3901 and 67, 134, and 202 kg N ha\(^{-1}\) in DKF3875 decreased the concentration of this acid relative to that of the 0 kg N ha\(^{-1}\) rate (Fig. 9).

Stearic Acid

The concentration of stearic acid was affected by the interaction of planting date and hybrid at all four locations, by N rate alone at the Newton and Starkville locations, and by the interaction of planting date and N rate at the Verona 1 location (Table 8). At Newton, the 0 kg N ha\(^{-1}\) rate, and at Starkville, the 0 and 67 kg N ha\(^{-1}\) rates resulted in the greatest decrease in stearic acid relative to the original seed (–14, –16, and
tivity, respectively) (data not shown). This result is consistent with previous report (Valchovski, 2002).

Overall, stearic acid in all hybrids and locations increased with later planting dates (the second or the third) relative to the first early planting (Fig. 10). All planting dates reduced stearic acid levels relative to the original planted seed except for DKF3875 at the third planting date and at the Newton and Verona 2 locations. The two hybrids DKF2990 and DKF3901 (which originally had higher stearic concentration than the other hybrids) had the greatest decrease of stearic acid concentration relative to the original seed (Fig. 10). At the Verona 1 location, the first planting resulted in lower stearic acid concentrations than the other planting dates, and the greatest decrease (up to \(-28 \text{ g kg}^{-1}\)) relative to the original seed. The third planting date resulted in the highest stearic acid concentration, but was still below the original seed. There were no prior reports on the effect of planting dates on palmitic or stearic acid concentrations.

**Arachidic, Behenic, and Lignoceric Acids**

Statistical analyses were conducted on the interaction effects of planting date, hybrid, and N rate on arachidic, behenic, and lignoceric acid concentrations. However, these are minor saturated fatty acid constituents in sunflower oil and small changes in their concentrations would not significantly affect the sunflower oil quality. Our results (data not shown) indicated that these three fatty acids were affected similarly as palmitic and stearic acids by N rate and date of planting. Increasing N rates resulted in slight (< 0.2% units) or no increase in the concentration of each fatty acid. Later planting dates also led to slight increases in the three minor fatty acids (< 0.3% units).

The results from this study support current understanding that sunflower FA composition is modified by the environment. For example, research in Spain (a major sunflower-producing country) also demonstrated an effect of geographic location on FA composition of sunflowers (Lajara et al., 1990). Also, locations affected linoleic and stearic acid, but not palmitic acid. In general, linoleic acid tended to increase in more northern latitude (Lajara et al., 1990). Earlier studies in Texas found that linoleic acid concentration in sunflower increased with later planting dates (Unger, 1986; Jones, 1984).

Research has shown temperature dependence of the sunflower FA profile (Unger, 1980, 1986; Robertson et al., 1978; Fernandez-Moya et al., 2002; Izquierdo et al., 2002; Izquierdo et al., 2006; Izquierdo and Aguirrezabal, 2008; Zheljazkov et al., 2008). The current understanding is that higher night temperatures in the 100 to 300°C day after flowering (Izquierdo and Aguirrezabal, 2008), or growing sunflower in more

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Newton</th>
<th>Starkville</th>
<th>Verona 1</th>
<th>Verona 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting date (PD)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
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<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>PD × hybrid</td>
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<td>0.001</td>
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<tr>
<td>N rate</td>
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<td>0.001</td>
<td>0.001</td>
<td>0.001†</td>
</tr>
<tr>
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<td>0.665</td>
<td>0.001</td>
<td>0.111</td>
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<tr>
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<td>0.521</td>
<td>0.141</td>
</tr>
<tr>
<td>PD × hybrid × N rate</td>
<td>0.607</td>
<td>0.885</td>
<td>0.818</td>
<td>0.176</td>
</tr>
</tbody>
</table>

† Significant effects that need multiple means comparison are underlined.

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Fig. 8. Adjusted palmitic fatty acid, averaged across four sunflower hybrids planted at three planting dates at the Verona 1 and Verona 2 locations. Within each location, means sharing the same letter are not significantly different at the 0.01 level of significance.

Fig. 9. Adjusted palmitic fatty acid for four sunflower hybrids and four N rates at the Verona 1 location. Means sharing the same letter are not significantly different at the 0.01 level of significance.

Fig. 10. Adjusted stearic fatty acid for four sunflower hybrids planted at three planting dates at four locations. Within each location, means sharing the same letter are not significantly different at the 0.01 level of significance.
CONCLUSIONS

This study demonstrated that planting date, hybrid, and N application rates can alter fatty acid composition and oil content of modern sunflower hybrids grown in Mississippi. The TSFA was affected by planting date, hybrid, N rate, or their interactions, partially confirming our hypothesis. Overall, later planting dates increased TSFA relative to the first planting, and in most instances TSFA concentrations in sunflower from the third planting were higher than the second. Generally, the first planting date provided the highest oil content of the four hybrids, the second planting reduced oil content, while the third was not different from the second. Our results suggest that an earlier planting date may reduce the TSFA and in addition, may increase oil content of sunflower in Mississippi.

Overall, palmitic and stearic acid concentrations in sunflower seed grown in Mississippi from the first planting were reduced relative to the respective concentrations in the original seed, which was produced in California. Later planting tended to increase these two acids relative to the first planting and relative to the original seed. Overall, increasing N rates and later planting tended to increase the arachidic, behenic, and lignoceric acid concentrations in the four hybrids. The agricultural factors such as planting date, hybrid, and N rate may modify FA composition and oil content of sunflower grown in Mississippi. These agronomic factors could be used to produce sunflower seed with decreased TSFA and increased oil content.

REFERENCES


