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Oil productivity and composition of sunflower as a function of hybrid and planting date

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A B S T R A C T

Sunflower (*Helianthus annuus* L.) is a potential cash crop for the southeastern United States for production of cooking oil or biodiesel. Two years (2006 and 2007) of experiments were conducted at each of five locations in Mississippi to evaluate the effect of planting date (April 20, May 20, and June 20), and hybrid (DKF3875, DKF2990, DKF3510, DKF3901, PR63M80, PR62A91, PR63A21, PR63M91, and PR64H41) on seed yield, oil content, and oil composition of sunflower. Seed oil concentration varied from 25 to 47%. The oleic acid concentration in the oil was greater than 85% for DKF3510 and PR64H41, above 65% for PR63M80 and PR63M91, and intermediate for the other hybrids. Total saturated fatty acids (TSFA) concentration in the oil (the sum of palmitic, stearic, arachidic, behenic, and lignoceric acids) ranged from 6.3 to 13.0%, with DKF3510, PR63M91, and PR64H41 having lower concentration of TSFA than the other hybrids. Mean seed yields ranged from 997 to 2096 kg ha^{-1} depending on location. Mean oil yields at the five locations ranged from 380 to 687 kg ha^{-1}, and calculated biodiesel production ranged from 304 to 550 kg ha^{-1}. Seed and oil yields in this study suggest sunflower in Mississippi should be planted by the last week of May. Later planting (20 June) may significantly decrease both seed and oil yields in the non-irrigated system in Mississippi and in other areas of the southeastern United States with similar environmental conditions.

1. Introduction

Sunflower (*Helianthus annuus* L.) is not commonly grown in the southeastern United States, although previous research has shown feasibility of growing sunflower as a cash crop for the region (Zheljazkov et al., 2008). Currently, North American sunflower production is concentrated in North Dakota, South Dakota, Colorado, Kansas, Minnesota, Nebraska, and Texas (Johnston et al., 2002; National Agricultural Statistics Service, 2006) and in Canada (Angadi and Entz, 2002a,b; Johnston et al., 2002). Sunflower is usually grown in rainfed systems because it is relatively drought tolerant (Robinson, 1978; Lindstrom et al., 1982; Stone et al., 2002) and utilizes soil nutrients efficiently (Connor and Hall, 1997; Valchovski, 2002) due to its well-developed and deeply penetrating root system (Jaafar et al., 1993; Nielsen, 1998; Angadi and Entz, 2002a,b; Stone et al., 2002).

Sunflower oil is one of the world's major vegetable oils; it is used in the food industry and in various commercial products, and it has been shown to have significant potential for biodiesel production (Arkansas Bio-Fuels Enterprises, 2007; National Sunflower Association, 2009). Previous research has demonstrated that the fatty acid (FA) composition of sunflower oil depends on genetic and environmental conditions (Robertson et al., 1978; Lajara et al., 1990; Miller and Vick, 1999; Sobrino et al., 2003). In general, the FA profile of vegetable oils determines their nutritional properties and specific uses (Warner et al., 2003; Burton et al., 2004). Usually, sunflower oil comprises up to 90% unsaturated FAs (combined oleic and linoleic) and approximately 10% saturated FAs (palmitic and stearic) (Steer and Seiler, 1990). Sunflower hybrids can be divided into three major groups: (i) traditional sunflower with oleic acid content of 14–39% of the oil; (ii) mid-oleic acid sunflower (42–72% oleic acid content, also called NuSun in the United States); and (iii) high-oleic acid sunflower (75–91% oleic acid) (Codex Alimentarius

Abbreviations: FA, fatty acid; TSFA, total saturated fatty acids.

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Committee, 2005). Sunflower oils with high oleic acid content are considered healthy (Jing et al., 1997; Krajcovicova-Kudlackova et al., 1997), and they have high stability during frying and extended shelf life, which makes them preferable for the 3 billion kg year^{-1} frying oil market in the United States (Warner et al., 2003). Sunflower breeders have responded to the market demand and have recently developed several hybrids with high oleic acid content (Hardin, 1998; Kleingartner, 2002; Burton et al., 2004).

Sunflower can also be grown for biodiesel production (National Sunflower Association, 2009). The USDA has stated that biodiesel offers environmental, economic, and national security benefits (Kurki et al., 2007). For the period from 1999 to 2006, biodiesel demand in the United States increased over 400 times (National Sunflower Association, 2009). Hence, farmers in the southeastern United States have been interested in sunflower as a potential biodiesel crop. Sunflower was evaluated in the 1970s and 1980s in Florida for biodiesel production (Green et al., 1980, 1981, 1982). Overall, Green et al. (1981) found the open-pollinated Russian varieties Peredovik 66 and Sputnik 71 to provide the highest yields among the varieties they tested; however, a number of new sunflower hybrids have been developed since then to meet specific market requirements for fatty acid composition. Recent research in Mississippi demonstrated the potential for sunflower to be grown as a cash crop for production of vegetable oil or biodiesel (Zheljazkov et al., 2008).

With the advent of new sunflower hybrids with different FA composition, growth characteristics, and vegetation period, there is a need to evaluate their potential productivity, oil content, and FA profile when grown at different latitudes in the southeastern US. The objective was to evaluate the effect of hybrid, and planting date as well as their interaction on yield, oil content, and oil composition of sunflower in five locations in Mississippi, representing four different latitudes.

2. Materials and methods

2.1. Field experiments

A split-plot design field experiment was conducted during the 2006 and 2007 cropping seasons at five locations in Mississippi: Beaumont, Newton, Starkville, and two locations in Verona, Verona 1 and 2. The factors were (i) planting date (April 20, May 20, and June 20), and (ii) hybrid (DKF3875, DKF2990, DKF3510, DKF3901, PR63M80, PR62A91, PR63M91, PR63A21, and PR64H41). Certified seed for the nine sunflower hybrids was provided by Monsanto Co. (St. Louis, MO) and Pioneer (Pioneer Hi-Bred International Inc., Woodland, CA).

The five locations for the experiment were chosen to represent major growing areas from south to north Mississippi, four different latitudes (Fig. 1), and different soil types (U.S. Department of Agriculture, 2001). The soils at the five locations were McLaurin sandy loam (Beaumont), Prentiss fine sandy loam (Newton), Marietta fine sandy loam (Starkville), Catalpa silty clay loam (Verona 1), and Quitman sandy loam (Verona 2). The soil at the five locations was tilled and prepared following the procedure for row crops soil preparation in the region. Land preparation included disking and formation of raised beds at 97–102 cm center to center at the beginning of April. The herbicide Treflan [trifluralin, 2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine] at 4.5–5.6 kg ha^{-1} (preplant incorporated, right after the formation of raised beds) was applied to improve weed control at the five locations. Individual experimental plots were 6 by 4 m, with four rows in every plot. Sunflower planting at the five locations was done using a cone planter at 3.8 cm depth, at 97–102 cm interrow space, and a seeding rate that provided 6.4 seed m^{-1} of row.

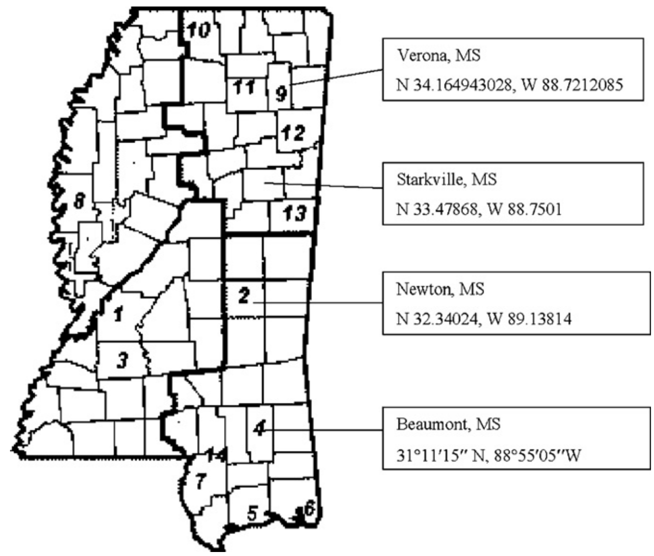

Fig. 1. Map of Mississippi with indication of the counties and the Mississippi Agriculture and Forestry Experiment Stations (MAFES) (1–14). The field experiments with the nine sunflower hybrids were conducted at the MAFES research stations in Beaumont (4), Newton (2), Starkville, and Verona 1 and Verona 2 (9).

During the two growing seasons, several pests were identified. The major pest was blackbirds (red-winged blackbirds, *Agelaius phoeniceus* L.; common grackles, *Quiscalus quiscula* L. and some other blackbird species), which were controlled using propane cannons. Other pests included stem weevil (*Cylindrocopturus adspersus* LeConte) and head clipping weevil (*Haplorhynchites aeneus* Boh.), which were found at the two Verona locations only and controlled with a single application of Sevin (80% carbaryl [1-naphthalenyl methylcarbamate]) at 1.4 kg ha^{-1}. Head rot (caused by *Rhizopus* sp.) incidence was low and did not require control.

Harvesting was done when all plants in a given treatment reached harvesting maturity, after physiological stage R-9 (Schneiter and Miller, 1981), by harvesting the two inner rows in each plot. Sunflower seeds were threshed on a stationary thresher (Almaco, LPR-E, Nevada, IA), and seed moisture was determined by a stationary electronic grain-moisture tester (Model GAC2000, Dickey-John, Auburn, IL) using a 500-g sample from each plot. Sunflower seed subsamples (around 100 g from each plot) were further cleaned by hand to remove any broken seed or impurities, placed overnight in a freezer at −20 °C to prevent disease development and eliminate living insects, and then stored in a refrigerator at 4 °C to await further analysis.

2.2. Soil nutrient analyses

Representative soil samples were taken from the five experimental sites prior to planting, air-dried at room temperature, ground to pass through a 1-mm sieve, and extracted using the Lancaster soil test method (Cox, 2001) at the Mississippi State University Soil Testing and Plant Analyses Laboratory. The nutrient concentration of soil samples was determined by an inductively coupled argon plasma spectrometer (Thermo Jarrell Ash, Franklin, MA). Phosphorus (P) and potassium (K) fertilizers were broadcasted and incorporated following the soil analyses and recommendations at each location. One half of the nitrogen (N) fertilizer was applied prior to planting and the second half as side dressing at the V-4 growth stage (Schneiter and Miller, 1981) to provide a total of 134 kg N ha^{-1} over the growing season. Added fertilizer was based on literature data and recent research on sunflower in the region (Zheljazkov et al., 2008, 2009). The fertility blanket was designed

Table 1
Analysis of variance *P* values for the fixed effects of the model, namely location (Loc), planting date (PD) nested in Loc, hybrid, and PD × hybrid nested in Loc on seed and oil yield, oleic acid, oil content, total saturated fatty acid (TSFA) and linoleic (polyunsaturated fatty acid; PUFA) in Mississippi.

Source of variation	Seed yield	Oil yield	Oleic acid	Oil content	TSFA	PUFA
Loc	0.001[a]	0.001	0.001	0.001	0.001	0.001
PD(Loc)	0.001	0.001	0.007	0.001	0.001	0.001
Hybrid	0.001	0.001	0.001	0.001	0.001	0.001
PD × hybrid(Loc)	0.001	0.065	0.001	0.140	0.001	0.001

[a] Significant effects that need multiple means comparison are underlined.

to provide understanding of sunflower yield response to planting date, and hybrid, without confounding effects due to limited N, P, or K.

2.3. Analysis of sunflower FA composition and seed oil content

The sunflower subsamples from every plot were extracted and analyzed for FA composition on a Hewlett-Packard Model 5890 gas chromatograph as described previously (Zheljazkov et al., 2008). Seed oil content was determined from a 40-mL sample of cleaned, weighed seed from each plot using a Maran Ultra Resonance NMR instrument (Resonance Instruments Ltd., Witney, UK), following the American Oil Chemists' Society Official Methods and Recommended Practices, AK4-95 (American Oil Chemists' Society, 1994) and as described previously (Zheljazkov et al., 2008). Because seed from different hybrids had various moisture contents, oil contents were adjusted to 0 and to 10% moisture content. We report the oil content based on 0% moisture content.

2.4. Statistical methods

In 2006 and 2007, within each of the five locations (Beaumont, Newton, Starkville, Verona 1, and Verona 2), the experimental field had blocks, and each block was partitioned into three and randomly assigned to the three planting dates (1, 2, and 3), and within each planting date the nine hybrids (DKF2990, DKF3510, DKF3875, DKF3901, PR62A91, PR63A21, PR63M80, PR63M91 and PR64H41) were completely randomized. For each location, this layout makes the design split-plot design with planting dates (PD) as the whole-plot treatments and the hybrids as the sub-plot treatments. The two factors of interest (PD, and hybrid) were considered as fixed, and block (with combination of the two years and the four blocks giving a total of eight blocks) was considered as random. In order to compare the five locations, one complete ANOVA was done for each of the two yield and four fatty acid composition responses. Since the PDs used at the five locations were not exactly the same, but similar; and since the 9 hybrids tested at each location were exactly the same, the main effect of location was added on the split-plot design model and the effects of PD and PD × hybrid were nested within location. The ANOVA was completed using the Mixed Procedure of SAS (SAS Institute Inc., 2003), and further multiple means comparison was completed for significant ($P < 0.05$) and marginally significant ($0.05 < P < 0.1$) effects by comparing the least squares means of the corresponding treatment combinations using the lsmeans statement of Proc Mixed. Letter groupings were generated using a 1% level of significance when the two-factor interaction effect was significant, and using a 5% level of significance when a main effect was significant. For each response, the validity of model assumptions was verified by examining the residuals as described in Montgomery (2009).

3. Results and discussion

3.1. Main and interaction effects of planting date and hybrid on measured responses

Location had a significant effect on seed yield, oil yield, oleic acid concentration, oil content, and on TSFA and PUFA (poly unsaturated fatty acids, in this case it is linoleic acid) (Table 1). Planting date nested within location and hybrid had significant effects on oil content, whereas the planting date by hybrid interaction nested within location had significant effect on the five responses but not on oil content (Table 1).

3.2. Seed and oil yields, oleic acid concentration, oil content, TSFA, and PUFA in different locations

Overall, mean seed yields at the five locations ranged from 997 to 2096 kg ha^{-1} and were as follows: Beaumont > Verona 1 > Verona 2 > Newton > Starkville (Table 2). Mean oil yields ranged from 380 to 687 kg ha^{-1}, with mean yields in Beaumont and Verona 1 being the highest, oil yields at Verona 2 were lower, and oil yields in Newton and Starkville were the lowest. Mean oleic acid concentration was within the 56–65% range, with the highest mean concentration obtained in Starkville and the lowest in Newton. The mean oil content was 38–42.6%; the oil content was higher in Starkville and Verona 1, and lower in the other three locations. The mean TSFA was 9.1–9.9%; TSFA was higher in Newton, lower in Beaumont and Verona 2, and lowest in Verona 1. The mean PUFA (linoleic acid) concentration was 24–33%, and the highest was in Newton, the lowest in Starkville, and intermediate in the other locations (Table 2).

Seed yields within the five locations and depending on the treatments ranged between 217 and 2889 kg ha^{-1} (Table 3). Our yields were consistent with a previous study using four hybrids in Mississippi (Zheljazkov et al., 2008). In most instances, average yields from the first and second planting dates were within the range of sunflower hybrids in various locations across the United States (National Sunflower Association, 2009). Overall, seed yields in Newton, Verona 1, and Verona 2 were higher from the first and

Table 2
Mean seed yield, oil yield, oleic acid, oil content and TSFA at the five locations in Mississippi.

Location	Seed yield (kg ha^{-1})	Oil yield (kg ha^{-1})	Oleic acid (%)	Oil content (%)	TSFA (%)	PUFA (%)
Beaumont	2096 a[a]	687 a	59.0 b	38.0 b	9.47 b	29.2 b
Newton	1186 d	389 c	56.0 c	38.2 b	9.88 a	32.6 a
Starkville	997 e	380 c	65.0 a	42.6 a	9.35 bc	24.4 c
Verona 1	1859 b	685 a	59.8 b	42.0 a	9.12 c	29.4 b
Verona 2	1430 c	512 b	59.4 b	39.4 b	9.56 b	29.5 b

[a] Means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.

Table 3
Mean seed yield from the different combinations of planting dates (PD) and hybrid at the five locations in Mississippi.

PD	Hybrid	Beaumont (kg ha^{-1})	Newton (kg ha^{-1})	Starkville (kg ha^{-1})	Verona 1 (kg ha^{-1})	Verona 2 (kg ha^{-1})
1	DKF2990	2509 abc	1491 a–d	528 e	2000 def	2066 abc
1	DKF3510	2373 a–d[a]	1651 abc	713 cde	2815 ab	2369 ab
1	DKF3875	1924 de	1606 abc	885 b–e	2503 a–e	1956 a–d
1	DKF3901	1903 de	1532 abc	1260 abc	2191 c–f	1847 b–e
1	PR62A91	1542 efg	1258 b–e	605 de	2281 b–e	1799 cde
1	PR63A21	1148 g	781 efg	1074 a–d	1028 hi	820 hij
1	PR63M80	2420 a–d	1848 a	1151 a–d	2889 a	2473 a
1	PR63M91	2101 b–e	1788 ab	913 b–e	2743 ab	1605 c–f
1	PR64H41	2506 abc	1593 abc	1105 a–d	2558 a–d	2379 ab
2	DKF2990		1166 cde	1097 a–d	2154 c–f	1440 d–g
2	DKF3510		1833 a	1592 a	2494 a–e	1454 d–g
2	DKF3875		1618 abc	1105 a–d	2283 b–e	1340 e–h
2	DKF3901		1626 abc	1140 a–d	2101 def	1445 d–g
2	PR62A91		990 def	680 de	1974 ef	1574 c–f
2	PR63A21		812 ef	540 e	1709 fg	1127 f–i
2	PR63M80		1669 abc	1440 a	2663 abc	1581 c–f
2	PR63M91		1613 abc	779 cde	2463 a–e	1738 cde
2	PR64H41		1950 a	1343 ab	2742 ab	1695 cde
3	DKF2990	2045 b–e	578 fg		923 hi	510 j
3	DKF3510	2071 b–e	687 efg		1106 hi	998 g–j
3	DKF3875	2579 ab	455 fg		819 hij	826 hij
3	DKF3901	2511 abc	675 efg		1147 ghi	920 g–j
3	PR62A91	1716 ef	217 g		704 ij	849 hij
3	PR63A21	1229 fg	251 g		334 j	624 ij
3	PR63M80	2777 a	679 efg		1286 gh	1034 g–j
3	PR63M91	1980 cde	771 efg		1277 gh	1128 f–i
3	PR64H41	2396 a–d	871 ef		1004 hi	1023 g–j

Within each locations, means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.
[a] a–d represents abcd.

second planting dates and lower from the third (Table 3). However, seed yields in Beaumont from the first and third planting dates were quite similar, whereas the second planting date at this location was unsuccessful due to poor emergence caused by drought. Overall, seed yields in Starkville were lower than in the other locations, and planting date 3 was not successful in that location due to drought (Table 3). These results are consistent with general understanding that early planting of sunflower may produce higher yields (Baros et al., 2004; Flagella et al., 2002; Soriano et al., 2004).

Table 4
Mean oil yield from the different combinations of planting dates (PD) and hybrid at the five locations in Mississippi.

PD	Hybrid	Beaumont (kg ha^{-1})	Newton (kg ha^{-1})	Starkville (kg ha^{-1})	Verona 1 (kg ha^{-1})	Verona 2 (kg ha^{-1})
1	DKF2990	906 ab	584 abc	229 ef	879 b–f	898 abc
1	DKF3510	731 abc	677 ab	302 def	1154 abc	976 ab
1	DKF3875	669 bcd	585 abc	353 c–f	1003 a–e	809 a–d
1	DKF3901	502 cde	626 ab	712 a	946 b–f	838 a–d
1	PR62A91	470 cde	428 b–e[a]	224 ef	951 b–f	669 b–e
1	PR63A21	417 de	252 efg	231 ef	405 hij	309 h–m
1	PR63M80	837 ab	699 ab	415 b–e	1389 a	1110 a
1	PR63M91	724 abc	741 a	396 b–f	1242 ab	697 b–e
1	PR64H41	840 ab	656 ab	396 b–f	1101 a–d	1065 a
2	DKF2990		345 c–f	503 a–d	811 c–f	536 d–i
2	DKF3510		625 ab	566 abc	915 b–f	485 e–j
2	DKF3875		536 a–d	367 c–f	820 c–f	424 e–k
2	DKF3901		583 abc	474 a–d	720 efg	559 d–h
2	PR62A91		351 c–f	235 ef	750 d–g	521 d–i
2	PR63A21		306 def	198 f	635 fgh	382 f–l
2	PR63M80		604 abc	646 ab	1101 a–d	560 d–h
2	PR63M91		547 a–d	301 def	962 b–f	625 c–g
2	PR64H41		633 ab	547 abc	1039 a–e	645 b–f
3	DKF2990	673 bcd	177 fgh		312 ij	166 m
3	DKF3510	705 abc	203 fgh		317 ij	327 h–m
3	DKF3875	849 ab	127 gh		292 ij	274 j–m
3	DKF3901	858 ab	226 efg		385 hij	301 i–m
3	PR62A91	499 cde	76 h		208 jk	246 klm
3	PR63A21	331 e	68 h		93 k	194 lm
3	PR63M80	1054 a	195 fgh		487 ghi	346 h–m
3	PR63M91	724 abc	292 efg		486 ghi	368 g–l
3	PR64H41	815 ab	236 efg		416 hi	342 h–m

Within each locations, means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.
[a] b–e represents bcde.

Table 5
Mean oleic acid concentration from the different combinations of planting dates (PD) and hybrid at the five locations in Mississippi.

PD	Hybrid	Beaumont (%)	Newton (%)	Starkville (%)	Verona 1 (%)	Verona 2 (%)
1	DKF2990	53.1 c	46.5 de	58.6 cde	53.7 d	55.6 c
1	DKF3510	84.1 a	87.2 a	88.7 a	87.6 a	87.8 a
1	DKF3875	37.8 f	39.9 e–h[a]	49.8 fgh	44.7 efg	43.4 def
1	DKF3901	38.7 ef	45.1 def	56.4 def	50.0 de	47.2 d
1	PR62A91	36.5 f	33.8 ghi	44.2 h	41.1 fg	45.3 de
1	PR63A21	43.8 def	37.8 f–i	62.6 cd	46.5 d–g	46.6 d
1	PR63M80	68.7 b	64.9 bc	71.9 b	71.5 b	70.3 b
1	PR63M91	63.0 b	60.8 bc	64.7 bc	62.5 c	65.6 b
1	PR64H41	86.0 a	88.1 a	88.0 a	87.9 a	88.6 a
2	DKF2990		48.8 d	60.3 cd	53.9 d	50.3 cd
2	DKF3510		86.7 a	88.3 a	86.5 a	86.1 a
2	DKF3875		41.4 d–g	48.7 gh	39.7 g	37.5 f
2	DKF3901		47.0 de	56.8 def	48.1 def	47.1 d
2	PR62A91		40.9 e–h	53.0 efg	44.5 efg	45.3 de
2	PR63A21		47.1 de	51.7 efg	48.6 def	45.7 de
2	PR63M80		67.5 b	71.0 b	68.7 bc	65.3 b
2	PR63M91		64.9 bc	65.2 bc	62.2 c	68.2 b
2	PR64H41		89.6 a	90.1 a	88.3 a	87.4 a
3	DKF2990	46.7 cd	37.1 ghi		49.9 de	47.0 d
3	DKF3510	88.1 a	85.6 a		86.9 a	85.5 a
3	DKF3875	43.4 def	32.4 i		42.7 efg	38.9 ef
3	DKF3901	48.6 cd	39.0 f–i		47.5 def	42.5 def
3	PR62A91	45.6 de	36.2 ghi		42.1 fg	44.0 def
3	PR63A21	52.7 c	33.5 hi		39.7 g	45.2 de
3	PR63M80	70.5 b	64.9 bc		70.5 b	66.2 b
3	PR63M91	66.7 b	59.3 c		61.6 c	65.5 b
3	PR64H41	88.4 a	86.5 a		87.4 a	86.0 a

Within each locations, means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.

[a] e–h represents efgh.

3.3. Oil yields

Generally, oil yields from the first and second planting dates in Newton, Verona 1, and Verona 2 were greater than oil yields from the third planting date (Table 4). Oil yields from the first and second planting dates at these locations varied from 198 kg ha^{-1} (PR63A21 planting date 2 in Starkville) to 1389 kg ha^{-1} (PR63M80 planting date 1 in Verona 1). Seed and oil yields in this study suggest sunflower in Mississippi should be planted by the end of May; later planting (20 June) may significantly decrease both seed and oil yields under a non-irrigated system in Mississippi.

3.4. Oleic acid

The concentration of oleic acid varied widely among the hybrids and was also affected by location (Table 5). Generally, DKF3510 and PR64H41 have very high oleic acid concentration, in most instances greater than 85%, and are characterized as high oleic acid hybrids (Codex Alimentarius Committee, 2005; National Sunflower Association, 2009). The oleic acid concentration in PR63M80 and PR63M91 (both mid-oleic NuSun hybrids) was greater than 65%, while the rest of the hybrids had around 45% concentrations of oleic acid.

3.5. Seed oil content

Seed oil content based on 0% moisture content varied from 25% (PR63A21 third planting Newton) to 47% (PR63M80, first planting in Verona 2) (data not shown). Mean seed oil content decreased from the first to the second planting date in Starkville, Verona 1 and Verona 2 locations, but decreased in the third planting date in Newton (Table 6). In Beaumont, the third planting provided higher oil content than the first planting. The seed oil content in different hybrids ranged from 37–38% (PR62A91, PR63A21, DKF3875) to 41–43% (PR64H41, DKF2990, PR63M91, PR63M80) (Table 7). Later plantings in Newton and Verona 2 decreased the content of seed oil relative to the first planting. Overall, the seed oil content in this study was comparable to previous reports from Mississippi (Zheljazkov et al., 2008) and from other countries (De la Vega and Hall, 2002; Valchovski, 2002) and was within the range for seed oil concentration of hybrids tested across the United States (National Sunflower Association, 2009). Sunflower producers in the United States may often be paid premiums by oil crusher facilities for seed that is greater than 40% oil (National Sunflower Association, 2009).

3.6. Total saturated fatty acids (TSFA)

Total saturated fatty acid (palmitic, stearic, arachidic, behenic, and lignoceric acids combined) ranged from 6.3% (PR64H41 third

Table 6
Mean oil content from the different planting dates at the five locations in Mississippi.

Planting date	Beaumont (%)	Newton (%)	Starkville (%)	Verona 1 (%)	Verona 2 (%)
1	35.0 de[a]	41.0 bc	45.7 a	46.3 a	43.5 ab
2	NA	39.1 bcd	39.5 bcd	40.7 bc	38.5 cde
3	41.0 bc	34.5 e	NA	38.9 bcd	36.1 de

[a] Across planting dates and locations, means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.

Table 7
Mean oil content from the different hybrids.

Hybrid	Oil content (%)
DKF2990	41.4 ab[a]
DKF3510	39.0 cd
DKF3875	38.0 d
DKF3901	40.4 bc
PR62A91	37.3 d
PR63A21	37.9 d
PR63M80	42.3 a
PR63M91	42.9 a
PR64H41	41.2 ab

[a] Means followed by the same letter are not significantly different. All pairwise differences were tested using the pdiff option of the lsmeans statement of Proc Mixed.

planting in Beaumont) to 13.0% (DKF3901 first planting in Beaumont) (data not shown). This is a wider range for TSFAs than previously reported for four sunflower hybrids (Zheljazkov et al., 2009). Generally, DKF3510, PR63M91, and PR64H41 had lower concentrations of TSFA than the rest of the hybrids.

The mean PUFA (linoleic acid) concentration varied in contrast to the variations in oleic acid concentration; hybrids with high oleic acid and factors increasing oleic acid had correspondingly lower or decreasing concentrations of PUFA (data not shown). Overall, PUFA ranged from 0.8% (PR64H41 second planting in Starkville) to 50.2% (PR62A91 first planting in Beaumont); however, DKF3510 and PR64H41 consistently gave below 5% in all locations and planting dates. The mean concentration of MUFA (the combined concentrations of oleic and gondoic acids) varied the same way as oleic acid (Table 5), because the concentrations of gondoic acid were very small, ranging from 0.13 to 0.34% (Min = 0.13 m Q1 = 0.19, mean = 0.225, Q3 = 0.263, Max = 0.34%), whereas the values of oleic acid averaged 60%.

4. Concluding remarks

This and the previous studies in Mississippi (Zheljazkov et al., 2008) and in other countries (Lajara et al., 1990; Valchovski, 2002) confirm that the FA composition of sunflower oil depends not only on hybrid, but also on environment. Planting dates have a significant influence on sunflower FA composition in Mississippi, which was demonstrated earlier for Texas (Unger, 1980; Jones, 1984). Ultimately, planting dates result in different temperatures during the initial and later stages of sunflower development, and temperature has been shown to be a major modifier of sunflower FA composition (Fernandez-Moya et al., 2002; Izquierdo et al., 2006; Sobrino et al., 2003). Previous research demonstrated that sunflower grown in southern locations may have higher accumulation of oleic acid (Robertson et al., 1978; Zheljazkov et al., 2008) compared to more northern latitudes. High oleic acid and low TSFA cooking oils are preferred by consumers due to the proven nutritional and health benefits (Kleingartner, 2002; Krajcovicova-Kudlackova et al., 1997; Hu et al., 2001).

Our results suggest that a second planting date and in some instances a third can provide seed yields, oil content, and FA composition within the range of sunflower hybrids across the United States (National Sunflower Association, 2009). While the results suggest that an earlier planting date may result in better crop establishment and higher yields, later planting has the advantage of having sunflower as a second crop, perhaps after winter crops such as winter mustard (*B. cretica* Lam.). Our preliminary trials showed winter mustard reaches technical maturity and can be harvested beginning in June (Zheljazkov et al., submitted for publication), at a time between the second and third planting dates in this study. This opens the possibility for double cropping of winter canola or winter mustard and sunflower in Mississippi and possibly in other states of the southeastern United States. Double cropping of oilseed crops would increase the economic and environmental sustainability of crop production in the southeastern United States. Also, double cropping of winter canola or mustard with sunflower may produce up to four times higher biodiesel yield per area compared with soybean [*Glycine max* (L.) Merr.].

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References

American Oil Chemists' Society, 1994. Official Methods and Recommended Practices of American Oil Chemists' Society, 4th ed. Am. Oil Chem. Soc. Press, Champaign, IL.
Angadi, S.V., Entz, M.H., 2002a. Root system and water use patterns of different height sunflower cultivars. Agron. J. 94, 136–145.
Angadi, S.V., Entz, M.H., 2002b. Water relations of standard height and dwarf sunflower cultivars. Crop Sci. 42, 152–159.
Arkansas Bio-Fuels Enterprises, 2007. Crop Yields in Gallons, Available at http://home.earthlink.net/~arkansasbiofuels/id33.html (accessed April 2007; verified 11 May 2010).
Baros, J.F.C., Carvalhoa, M., de Bascha, G., 2004. Response of sunflower (*Helianthus annuus* L.) to sowing date and plant density under Mediterranean conditions. Eur. J. Agron. 21, 347–356.
Burton, J.W., Miller, J.F., Vick, B.A., Scarth, R., Holbrook, C.C., 2004. Altering fatty acid composition in oil seed crops. Adv. Agron. 84, 273–306.
Codex Alimentarius Committee, 2005. Codex Standard for Named Vegetable Oils. Codex-Stan 210, p. 2 http://www.codexalimentarius.net/download/standards/336/CXS_210e.pdf (accessed 11 May 2010).
Connor, D.J., Hall, A.J., 1997. Sunflower physiology. In: Schneiter, A.A. (Ed.), Sunflower Technology and Production. ASA, Madison, WI, pp. 113–182, Agron. Series No. 35.
Cox, M.S., 2001. The Lancaster soil test method as an alternative to the Mehlich 3 soil test method. Soil Sci. 166, 484–489.
De la Vega, A.J., Hall, A.J., 2002. Effect of planting date, genotype, and their interactions on sunflower yield. II. Components of oil yield. Crop Sci. 42, 1202–1210.
Fernandez-Moya, V., Martinez-Force, E., Garces, R., 2002. Temperature effect on high-stearic acid sunflower mutant. Phytochemistry 59, 33–37.
Flagella, Z., Rotunno, T., Tarantino, E., Di Caterina, R., De Caro, A., 2002. Changes in seed yield and oil fatty acid composition of high oleic sunflower (*Helianthus annuus* L.) hybrids in relation to the sowing date and the water regime. Eur. J. Agron. 17, 221–230.
Green Jr., V.E., Roath, W.W., Robertson, J.A., Zimmerman, D.C., Yang, S.M., Genung, W.B., 1982. Oilseed Sunflower Research in Florida 1981. Agron. Res. Rep. AG-82-1. Inst. of Food and Agric. Sci., Univ. of Florida.
Green Jr., V.E., Robertson, J.A., Bailey, B.A., Simone, G.W., Simone, F.A., Johnson, F.A., Genung, W.B., 1980. Oilseed Sunflower Research in Florida 1979. Agron. Res. Rep. AG-80-4. Inst. of Food and Agric. Sci., Univ. of Florida.
Green Jr., V.E., Robertson, J.A., Simone, G.W., Dunn, R.A., Genung, W.B., Yang, S.M., 1981. Oilseed Sunflower Research in Florida 1981. Agron. Res. Rep. AG-81-3. Inst. of Food and Agric. Sci., Univ. of Florida.
Hardin, B., 1998. Mid-oleic acid sunflower hybrids debut. Agric. Res. 46, 14–15.
Hu, F.B., Manson, J.E., Willett, W.C., 2001. Types of dietary fat and risk of coronary heart disease: a critical review. J. Am. Coll. Nutr. 20, 5–19.
Izquierdo, N.G., Aguirrezábal, L.A.N., Andrade, F.H., Cantarero, M.G., 2006. Modeling the response of fatty acid composition to temperature in a traditional sunflower hybrid. Agron. J. 98, 451–461.
Jaafar, M.N., Stone, L.R., Cordrum, D.E., 1993. Rooting depth and dry matter development of sunflower. Agron. J. 85, 281–286.
Jing, M., Folsom, A.R., Lewis, L., Eckfeldt, J.H., Ma, J., 1997. Relation of plasma phospholipid and cholesterol ester fatty acid composition of carotid artery intima-media thickness: The Artherosclerosis Risk in Communities (ARIC) study. Am. J. Clin. Nutr. 65, 551–559.
Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Nielsen, D.C., Lanfond, G.P., Riveland, N.R., 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.
Jones, O.R., 1984. Yield, water-use efficiency and oil concentration and quality of dryland sunflower grown in the southern High Plains. Agron. J. 76, 229–235.
Kleingartner, L.W., 2002. NuSun sunflower oil: redirection of an industry. In: Janick, J., Whipkey, A. (Eds.), Trends in New Crops and New Uses. ASHS Press, Alexandria, VA, pp. 135–138.

Krajcovicova-Kudlackova, M., Simoncic, R., Bederova, A., Klvanova, J., 1997. Plasma fatty acid profile and alternative nutrition. Ann. Nutr. Metab. 41, 365–370.

Kurki, A., Hill, A., Morris, M., 2007. Biodiesel: The Sustainability Dimensions. National Sustainable Agriculture Information Service, Butte, MT, Available at http://attra.ncat.org/attra-pub/biodiesel_sustainable.html (accessed June 2009; verified 11 May 2010).

Lajara, J.R., Diaz, U., Quidiello, R.D., 1990. Definite influence of location and climatic conditions on the fatty acid composition of sunflower oil. J. Am. Oil Chem. Soc. 67, 618–623.

Lindstrom, M.J., Warnes, D.D., Evans, S.D., 1982. A water use comparison between corn and sunflowers. J. Soil Water Conserv. 37, 362–364.

Miller, J.F., Vick, B.A., 1999. Inheritance of reduced stearic and palmitic acid content in sunflower seed oil. Crop Sci. 39, 364–367.

Montgomery, D.C., 2009. Design and Analysis of Experiments, 7th ed. Wiley, New York.

National Agricultural Statistics Service, 2006. Acreage. Agricultural Statistics Board, U.S. Department of Agriculture, Available at: http://usda.mannlib.cornell.edu/usda/nass/Acre/2000s/2006/Acre-06-30-2006.pdf (accessed June 2007; verified 11 May 2010).

National Sunflower Association, 2009. http://www.sunflowernsa.com (accessed October 2009; verified 11 May 2010).

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

Robertson, J.A., Chapman, J.R., Wilson, J.R., 1978. Relation of days after flowering to chemical composition and physiological maturity. J. Am. Oil Chem. Soc. 55, 266–269.

Robinson, R.G., 1978. Production and culture. In: Carter, J.F. (Ed.), Sunflower Science and Technology. Agron. Monogr. 19. ASA, CSSA, and SSSA, Madison, WI, pp. 89–143.

SAS Institute Inc., 2003. SAS OnlineDoc, Version 9.2. SAS Institute Inc., Cary, NC.

Schneiter, A.A., Miller, J.F., 1981. Description of sunflower growth stages. Crop Sci. 21, 901–903.

Sobrino, E., Tarquis, A.M., Diaz, M.C., 2003. Modeling the oleic acid content in sunflower oil. Agron. J. 95, 329–334.

Soriano, M.A., Orgaz, F., Villalobos, F.J., Fereres, E., 2004. Efficiency of water use of early plantings of sunflower. Eur. J. Agron. 21, 465–476.

Steer, B.T., Seiler, G.J., 1990. Changes in fatty acid composition of sunflower (*Helianthus annuus*) seeds in response to time of nitrogen application, supply rates and defoliation. J. Sci. Food Agric. 51, 11–26.

Stone, L.R., Goodrum, D.E., Schlegel, A.J., Jaafar, M.N., Khan, A.H., 2002. Water depletion depth of grain sorghum and sunflower in the central high plains. Agron. J. 94, 936–943.

Unger, P.W., 1980. Planting date effects on growth, yield, and oil of irrigated sunflower. Agron. J. 72, 914–916.

U.S. Department of Agriculture, 2001. Official Soil Series Descriptions. USDA-Soil Survey Division, Natural Resources Conservation Service, Available at http://soils.usda.gov/technical/classification/osd/index.html (accessed 7 March 2006; verified 11 May 2010).

Valchovski, I., 2002. Influence of heavy rate of nitrogen fertilizer on oil content and fatty acid composition of different varieties and hybrids. Rasteniev'dni Nauki 39 (5/6), 338–341.

Warner, K., Vick, B.A., Kleingartner, L., Isaac, I., Doroff, K., 2003. Composition of sunflower NuSun (mid-oleic sunflower), and high-oleic sunflower oils. In: Proc. Sunflower Res. Workshop, Fargo, ND, 16–17 January 2003. National Sunflower Assoc., Mandan, ND, Available at http://www.sunflowernsa.com/research/research-workshop/documents/107.PDF.

Zheljazkov, V.D., Vick, B.A., Baldwin, B.S., Buehring, N., Astatkie, T., Johnson, B., 2009. Oil content and saturated fatty acids in sunflower as a function of planting date, nitrogen, and hybrid. Agron. J. 101, 1003–1011.

Zheljazkov, V.D., Vick, B.A., Ebelhar, M.W., Buehring, N., Baldwin, B., Astatkie, T., Miller, J.F., 2008. Yield, oil content, and composition of sunflower (*Helianthus annuus* L.) grown at multiple locations in Mississippi. Agron. J. 100, 635–642.

Zheljazkov, V.D., Vick, B.A., Ebelhar, M.W., Buehring, N., Astatkie, T., submitted for publication. Effect of N on seed and oil yields and fatty acid composition of winter canola and mustard. Agron. J.