OIL AND FATTY ACID PROFILES OF SOYBEANS

(MATURITY GROUPS IV, V, AND VI)

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CHAPTER I

INTRODUCTION

Soybeans are a global commodity used as feed for livestock, as a source of protein and oil for people, and in the industrial manufacturing of thousands of products. In the U.S. only about 5% of total production is processed for human food with the majority crushed for oil and animal feed (Nwokola, 1996). Soybean oil is a major source of the five essential fatty acids for humans (palmitic, stearic, oleic, linoleic, and linolenic) (Firestone, 1999). A lack of the daily requirements of these fatty acids can lead to serious health problems. For example, symptoms associated with linoleic (C18:2) fatty acid deficiency are diminished growth, diminished skin pigment, fatty livers, kidney degeneration, and the loss of muscle tone (Chapkin, 1992).

SOYBEAN OIL COMPOSITION

Soybean oil is composed of approximately 16% saturated fatty acids (palmitic [C16:0] and stearic [C18:0]), 24% monounsaturated fatty acids (oleic [C18:1]), and 60% polyunsaturated fatty acids (linoleic [C18:2] and linolenic [C18:3]). It is because of the

high percentage of these polyunsaturated fatty acids that soybeans are considered to be unstable (Neff and List, 1999).

SEED DEVELOPMENT INFLUENCES ON FATTY ACID COMPOSITION

Seed maturation is associated with considerable increase in the size and weight of the various tissues of the seed. In oil crops much of this weight increase is due to the accumulation of lipids in the endosperm or embryo of the seed. In dicotyledonous plants, such as soybean, the principal site of storage is the cotyledon. The major change in fatty acid composition of the triglycerides occurs during the first 52 days after flowering. During this period, C18:3 decreases from 34% to 12% of the total lipid content of the seed. The percentages of C18:2 and C18:1 increase, while C18:0 remains fairly constant and C16:0 decreases slightly (Smith, 1984). Sangwan et al. (1986) examined the extent of variability in fatty acid composition of soybean cultivars at different stages of seed development. Pod samples were taken from seven soybean cultivars (Alankar, Ankur, Black tar, Bragg, Cobb, HM-1, and SH-3) at 10 day intervals from the 45^{th} day to the 75^{th} day after flowering or when the plant had matured. The total free fatty acids were estimated by titrating the oil samples against standard alkali (AOAC method No. 28.032) and the methyl esters were separated with a gas chromatograph. They found that the saturated fatty acids, C16:0 and C18:0, decreased as the seed matured in all of the cultivars except Bragg and SH-3. Both showed slight increases in C16:0 during the advanced stages of maturity. In three of the cultivars (Alankar, Ankur, and Black tar), C18:1 showed a slight increase at the initial stages of maturity and then decreased in the

later stages. In the other cultivars (Bragg, Cobb, HM-1, and SH-3), the C18:1 content decreased progressively as seed development occurred. C18:2 increased in all cultivars as seed development advanced. The same was true for C18:3 except in the cultivars Alankar and Ankur. In Alankar, C18:3 initially increased and later, in maturation, it began to decrease. In Ankur, C18:3 remained almost unchanged throughout development. Sangwan et al. (1986) compared their results to studies that had been done up to the time of this study. The results of decreasing C18:1 levels and increasing C18:3 levels, as seed matured, were in contrast to previous findings (Rubel et al., 1972). The decrease in levels of C16:0 and C18:0 along with an increase in C18:2 with seed maturity were in agreement with observations from other studies (Kannangara et al., 1973). They concluded that the oil of the mature seed was superior to that of immature seed because it contained lower amounts of free fatty acids and higher amounts of the essential unsaturated fatty acids, mainly C18:2 and C18:3.

ENVIRONMENTAL INFLUENCES ON FATTY ACID COMPOSITION

The environment plays a critical role in oil content and fatty acid development. Seed-fill is the most critical growth stage for environmental effects and temperature is the primary factor. Oil begins to accumulate in developing seeds 15-20 days after flowering. The most rapid deposition occurs 20-40 days after flowering and continues until 70 days after flowering (Rose, 1988). When temperatures are above the optimum for growth (22ºC) an accumulation of C18:1 appears to result (Holmberg, 1973). This is at the expense of C18:2 and C18:3, but C18:0 is unaffected (Smith, 1984). At temperatures

lower than the optimum 22ºC, a higher proportion of polyunsaturated fatty acids are present. The variations in fatty acid composition are generally confined to C18:1, C18:2, and C18:3. Temperature has little effect on the proportion of saturated fatty acids; these are primarily determined by the genotype of the plant.

Cherry et al. (1985) compared the fatty acid profiles of six genotypes grown for one year in both Indiana and Mississippi. They found that genotypes grown in the southern environment had an increased oil content and C18:1 percentage and a decrease in C18:3 percentages. This led them to conclude that the environmental sensitivity of fatty acid profiles needed to be considered when producing soybean genotypes outside their area of adaptation.

Another environmental condition that affects soybean oil is moisture stress. Rose (1988) looked at early maturing, indeterminate soybean lines for five years comparing dryland and fully irrigated plots. Moisture stress effects on yield, seed weight, and oil and protein content of the seeds were evaluated. Rose found that 57-68% of the seed weight loss was attributed to changes in weight per seed of oil and protein. When compared to the irrigated treatments, the oil and protein percentages of the dryland seed varied. This variation was dependant upon the balance between reduction in seed weight and response of the oil or protein to the pattern of stress. In one season, Rose reported that when a severe stress occurred in early pod fill, the percentage of protein decreased, while the oil percentage increased. In the three other years, the percentage of protein increased on dryland plots while oil percentage decreased. They determined that there was no significant increase in either protein or oil percentages during the high rainfall season.

GENETIC MODIFICATION OF FATTY ACID COMPOSITION

Soybean oil and the fatty acids, which make up the oil, are quantitative traits that are influenced by many environmental and genetic factors. Oil composition is primarily determined by the genotype of the maternal parent (Brim, 1973). Significant progress has been made to improve soybean oil quality through genetic modification of fatty acid composition. This has led to the development of "value-added" soybean oils, with novel combinations of fatty acids, for innovative food and industrial uses. Realizing that the lack of a natural product with oxidative stability and a high monounsaturated/polyunsaturated (M/P) ration would have a negative impact on future utilization and market share of soybean oil, the American Soybean Association initiated support for research in 1978 to develop germplasm exhibiting genetically altered oil composition. The initial challenge was to develop a soybean genotype having a 3% C18:3 content, a typical level for hydrogenated soybean oil (Wilson, 1991). Historically, hydrogenation was used to reduce the amount of C18:3 and increases the monosaturated/polyunsaturated fatty acid ratio of soybean oil. Commercial soybean varieties have relatively high levels of C18:3 (8-10%). However this process is expensive and it generates *trans* isomers of unsaturated fatty acids. *Trans* isomers pose a health risk, as they are associated with an increased risk of coronary disease (Hammond and Fehr, 1983; Hardin, 1989). Initial studies utilized conventional breeding methods along with available germplasm to develop these low C18:3 lines. Mutations in certain soybean genes led to further alteration in fatty acids composition (Wilson, 1991).

Oils with a higher saturated fatty acid content (C18:0) have increased melting temperatures. Interesterified oils, high in C18:0, can be processed into softer margarines that have suitable spreadability, sensory characteristics, and acceptable oil-off properties. Such products are favorable when low *trans* acid contents are required (List et al., 2001). Treating soybean seed with ethyl methanesulfonate (EMS), to induce mutations, has developed several soybean lines with low C18:3 content. These lines have been found to have about half the C18:3 content of most soybean cultivars. In one line, C1640, the low C18:3 content was controlled by one major allele; while in another line, A5, C18:3 content was controlled by the same allele with the addition of minor genes that modified its expression (Hammond and Fehr, 1983). Graef et al. (1985) recovered a mutant (A6) from sodium azide treated seeds of FA8077 that had a high C18:0 percentage. Previous soybean lines produced between 2.2 to 7.2% C18:0, whereas A6 contains about 28% C18:0. After studying some of the crosses made between A6 and its parent line FA8077, they determined that the mutation influencing C18:0 content in A6 was controlled by a recessive allele at one locus. The allele in A6 was designated fas^a, and the alleles from two other mutant lines, FA41545 and A81-606085, were designated fas^b and *fas*, respectively (Graef et al., 1985). Bubeck et al. (1989) crossed four high C18:0 mutants (ST1, ST2, ST3, and ST4) with A6 and found that the allele controlling high C18:0 content for three of the four mutants was the same as the one controlling A6. Rahman et al. (1997) performed a study to determine the genetic control of the high C18:0 mutants KK-2 and M25. KK-2 had two times the amount of C18:0 compared to 'Bay', which was one of the parents of KK-2. Reciprocal crosses were made between each mutant and 'Bay', and then between the two mutants. It was determined that the high C18:0 content

of the two lines was controlled by recessive alleles at a single locus. When the seed from the cross of the two mutants was evaluated, they found F_2 seed with C18:0 content lower than the seeds of KK-2 and higher than those of M25. This demonstrated that different alleles, at different loci, control the C18:0 content in these two mutants. They designated KK-2 as $st_1st_1St_2St_2$ and M25 $St_1St_1st_2st_2$. They also found that the allele in KK-2 was partially dominant to the allele in M25. They were able to produce a line with a C18:0 content greater than 30%, but it was not possible to further develop the line because the irregular seeds failed to grow after germination.

Lowering the C18:3 content of soybeans, because of its association with flavor instability, has brought about much interest and research. Decreasing the percentage of C18:3 and/or increasing the percentage of C18:0 can enhance frying stability of the oil. New genetically altered soybean lines have increased C18:0 or C16:0 or they have decreased C18:3 levels. Soybean oil with a high percentage of C18:0 has significantly greater oxidative stability than does normal soybean oil (White, 2000). Researchers have developed soybean breeding lines that may be the forerunners for varieties specially suited for making salad oils. These oils could be stored at room temperature for two to three months longer than the soybean oils of today. Another approach to genetically modifying soybeans to preserve oil freshness is to breed them to have little to none of the enzyme (lipoxygenase) that breaks down C18:3 and other polyunsaturated lipids. During the 1940's significant research within the soybean oil industry led to the development of standardized oil processing equipment. During this same time, scientists found that off-flavors and objectionable odors, which developed in aging soybean oil, were mostly associated with the breakdown of C18:3 (Hardin, 1989).

An increase in C18:0, along with a decrease in C18:3, is another way to improve the stability of the soybean oil. White and Miller (1988) looked at the oxidative stability of soybean oil that had low C18:3 and high C18:0 contents, comparing the oil from three common commercial lines and two mutant lines. They used the mutant line A5, which is a low C18:3 line (2.9%), and the mutant line A6, which is a high C18:0 line (28%) (Hammond and Fehr, 1983; Graef et al., 1985). They cold pressed the seeds, refined the oil, and then they deodorized the oil without the use of any additives. They stored the oil samples at two different temperatures, 28°C and 60°C. They then compared the five oils based on peroxide values, conjugated dienoic acid values, and sensory panel. It was determined that: 1) A5 and A6 lines were more stable than the commercial varieties, as measured by the peroxide values and the conjugated dienoic acid values, but sensory panel data were inconclusive; 2) oils with similar C18:3 contents did not have similar rates of oxidation; 3) that the differences fatty acid content of the five oils were not as distinct in the 60°C test as they were in the 28°C test.

Several researchers have studied the inheritance and gene action of modified fatty acid levels (Fehr et al., 1991a, Fehr et al., 1991b, Graef et al., 1998, and Rahman et al., 1997). Stojšin et al. (1998) developed the soybean line RG10 through the use of EMS, which had a C18:0 content of less than 2.5%. After developing the RG10 soybean they determined the number of loci and gene action associated with the inheritance of reduced C18:3 content in RG10. They looked at the F_2 and F_3 progenies of the crosses RG10 X C1640 and RG10 X 'Century'. Using chi-square analyses on the F_2 seeds and F_3 families from the RG10 X C1640 cross and F_3 families from the RG10 X 'Century' cross, they observed frequency distributions that fit a 1:2:1 ratio. These results indicated that the low

level of C18:3 in RG10 was controlled by a mutant allele at the *Fan* locus. Because of the simple inheritance of the low C18:3 allele in this line, they considered it an ideal parent for breeding programs where the objective is to improve oil quality.

These types of results have also been seen in the other inheritance studies conducted on the genes that control fatty acid quantity. Researchers determined that lowering the C16:0 content of soybean oil improves the nutritional quality of the oil (Wilcox et al., 1994). Researchers also found that at least three major genes condition reduced C16:0 content (Erickson et al., 1988; Wilcox et al., 1994). Since oil is just one of the characteristics of a soybean plant and seed, it may be valuable to know if a change in a fatty acid level affects the agronomic or seed characteristics of the plant. Rebetzke et al. (1998a) performed a study in which they tried to determine if genes for reduced C16:0 content found in N87-2122-4 were associated with changes in agronomic and seed characteristics. In lines that were homozygous for the major C16:0 reducing genes, a significant decrease in yield was observed when compared to the normal C16:0. They also found that the C18:1 and C18:3 contents increased significantly for the reduced C16:0 lines. One cross did provide a significant increase in seed oil content. To examine the influence of selection for C16:0 modifiers, genetic correlations were established. They found that C16:0 was significantly negatively correlated with changes in C18:1 and significantly positively correlated with changes in C18:3 content. They also found that genetic modifiers conditioning for C16:0 content seemed independent of genes controlling seed yield, suggesting that selection for reduced C16:0 lines homozygous for the C16:0 genes may be achieved with no reduction in seed yield.

USES FOR OILS WITH SPECIFIC FATTY ACID COMPOSITIONS

The development of targeted fatty acid profiles, to help expand the use of soybean oil for edible and industrial applications, has become a high priority (Wilson, 1998). The three specific phenotypes that were targeted were: frying oils, baking oils, and industrial oils. Miller and White (1988) studied the stability of low C18:3/ high C18:0 soybean oils under high temperature conditions. They used mutant lines A5, a low C18:3 line, and A6, a high C18:0 line, along with two commercial varieties. They tested these oils for stability during intermittent heating and the frying of bread cubes using sensory panel evaluations, peroxide test, and conjugated dienoic acid values. Each oil was heated to 185°C in a mini fryer. At the beginning of heating, bread cubes were fried. Half of the bread cubes were stored at -10°C to preserve freshness and the other half was stored at 60°C for 14 days. Once the bread cubes had been fried, the heating continued for 10 hr/day for four days. After 40 hours of additional heating, more bread cubes were fried. The oils, from the A5 and A6 mutant lines, were more stable than those of the commercial varieties for the sensory panel evaluations of the fried cubes, peroxide values of the oil extracted from the cubes, and conjugated dienoic acid values of the oil. Small differences did occur in the flavor and the oxidative stability of the cubes fried after the 40 hours of heating the oil. Large differences between the A5 mutant line, the A6 mutant line, and the commercial varieties occurred after storage of the bread cubes for 14 d.

One of the newest uses for soybean oil is as a fuel additive, mainly with diesel fuel (*Biodiesel*, 2002). Since the oil embargo of 1973, by the Organization of Petroleum Exporting Countries (OPEC), a significant amount of research on biodiesel and other

domestically produced fuels has been conducted. The viscosity of vegetable oils is 10-20 times that of diesel fuel. When used as a fuel, the oil causes injector fouling and other engine problems. But, when the oil is mixed with methanol in the presence of a catalyst, glycerin and biodiesel (chemically called methyl esters) are yielded. The methyl or sometimes ethyl esters of vegetable oils have viscosities approximately twice those of diesel fuels. Therefore, the biodiesel can be used directly or as blends with diesel fuels in a diesel engine. Biodiesel is biodegradable and it is a renewable fuel. It puts no net carbon dioxide or sulfur into the atmosphere and it emits less gaseous pollutants than normal diesel. Because of these properties, the U.S. Environmental Protection Agency has registered biodiesel as a pure fuel or fuel additive, and they have made it a legal fuel for commerce (*Biodiesel*, 2002; Lang et al., 2001).

SOYBEAN OIL QUALITY

Once the affects of genetically modifying one fatty acid were studied, the next approach was to look at the affects of genetically modifying two or more fatty acids within a soybean line. By altering more than one fatty acid, advancements in soybean oil quality could be accomplished faster. Neff and List (1999) looked at how soybean lines that were genetically modified for high C16:0 and high C18:0, changed the oxidative stability of natural and randomized oils. Randomization is the process of blending different vegetable oils together. They found that one way to improve the oxidation stability of soybean oil was to genetically modify the fatty acid composition so that there was a decrease in the polyunsaturated acids (C18:2 and C18:3) and an increase in

monosaturated (C18:1) and saturated fatty acids (C16:0 and C18:0). This increase in saturated fatty acids must be watched though. Medical studies have shown that diets high in saturated acyl components (C16:0 and C18:0 fatty acids) may contribute to increased blood serum cholesterol. Food and Drug Administration regulations require that a "low saturated" vegetable oil must contain less than 7% total saturates. Although soybean oil is relatively low in total saturates, a reduction may be needed at some point to enhance the utility of soybean oil in the health food market (Rebetzke et al., 1998b).

MATURITY EFFECT ON FATTY ACID COMPOSITION

Kane et al. (1997) evaluated the grain quality of cultivars in Maturity Groups (MG) 00 through IV using late April, mid-May, early June, and late June planting dates in the southern U.S. They found that across years and cultivars, delayed planting increased C18:3 percentage and decreased both oil and C18:1 percentages. The higher seed-fill temperatures associated with early planting were strongly correlated with increased oil content and C18:1 levels and reduced C18:3 percentages. The reduced C18:3 percentage, for all six cultivars, was closely associated with increased seed-fill temperatures. However, the C18:1 response to seed-fill temperatures was strongly dependant upon cultivar maturity. They found the C16:1 percentage of early-maturing cultivars was more sensitive to seed-fill temperatures than was that of later maturing cultivars. They concluded that while the overall effects of environment on grain quality characteristics might be relatively small, perhaps the abilities of new low C18:3 cultivars

could be amplified by growing them under the warmer conditions of the southeastern U.S.

CHAPTER II

This dissertation chapter is to be submitted to the journal Crop Science for publication. The format conforms to the style of this journal.

Oil and Fatty Acid Profiles of Soybeans (Maturity Groups IV, V, and VI)

ABSTRACT

Soybean oil contains 14 fatty acids and five of them, C16:0, C18:0, C18:1, C18:2, and C18:3, are considered essential fatty acids for proper human nutrition. Increasing the oil content and improving the ratio of the various fatty acids in soybeans is a goal for many breeding programs. The objective of this research was to evaluate the relationship between grain yield, oil content, and fatty acid composition in soybean cultivars and experimental lines grown in Oklahoma. Yield, oil content, and fatty acid composition was determined in trials conducted at three locations in 2000 and 2001. In 2000, temperatures were above the optimum for seed development and severe drought stress occurred at the non-irrigated locations. These soybeans had a high C18:1 content and low C18:2, C18:3, and total oil content. Negative correlations between C18:2/C18:0, C18:2/C18:1, and C18:3/C18:1 were also observed in all tests. In 2001, temperatures were still above optimum, but there was no drought stress during seed development; this led to the fatty acid compositions being within their expected ranges, but oil percentages were still low.

INTRODUCTION

Soybeans [*Glycine max.* (L.) Merr] are used for livestock feed, as a source of protein and oil for humans, and in the industrial manufacturing of products such as liquid shortenings, margarines, non-dairy creamers, and confectionery products (*Manufactured products and soy*, 2000). A recent use of soybean oil is as a fuel additive, mainly with diesel fuel (*Biodiesel*, 2002; Lang et al., 2001; Lee et al., 1996). Soybean acreage in the U.S. has increased approximately 20% over the past decade. Soybean acreage in Oklahoma doubled between 1991 and 1999, but then declined by 17% between 1999 and 2001 (Agricultural Statistics CD-ROM, 2000; *Oklahoma State Statistics,* 2000).

Soybean oil is the most widely used edible oil in the world because of its widespread use in processed food. In 1999, soybean oil accounted for 28% of the world's vegetable and marine oil consumption (*World soybean production*, 2001). As a food, soybean use varies from country to country. Only about 5% of the soybeans produced in the U.S. are processed for human food. The majority of it is crushed for oil and animal feed (Nwokola, 1996).

Soybean oil contains 14 fatty acids (Table 1). Five of these fatty acids, palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3), are considered essential fatty acids because they must be obtained in our diet. A lack of the daily requirements of these fatty acids leads to serious health problems (Chapkin, 1992). Many healthcare professionals recommend replacing saturated fats with unsaturated fats. Soybean oil is popular because it has approximately 16% saturated fatty acids (C16:0 and C18:0) and approximately 84% unsaturated fatty acids (C18:1, C18:2, and C18:3) (Neff and List, 1999; *Soybean oil – nutritional analysis*, 2001).

Significant progress has been made to improve soybean oil through genetic modification of the fatty acid composition. Genetic studies (Bubeck et al., 1989; Erickson et al., 1988; Fehr et al., 1991a; Fehr et al., 1991b; Graef et al., 1998; Rahman et al., 1997; Stojšin et al., 1998; Wilcox et al., 1994) have led to the development of "value-added" soybean oils with novel combinations of fatty acids for innovative food and industrial uses (Wilson, 1991). Historically, soybean oil went through a process known as hydrogenation. This reduced the C18:3 content and increased the monounsaturated/polyunsaturated ratio (Wilson, 1991). Lowering the C18:3 content is also desired because of the association of C18:3 content with flavor instability in soybean oil (White, 2000). However, hydrogenation is expensive and generates *trans* isomers of unsaturated fatty acids, which pose a health risk (Hammond and Fehr, 1983). Today improved soybean oil is obtained through the genetic manipulation of soybean to modify the fatty acid composition.

Conventional breeding methods have been used with a variety of different germplasm to create soybean lines with modified fatty acid compositions (Wilson, 1991). Mutations can also lead to the development of germplasm with altered fatty acid content (Wilson, 1991). X-rays and chemical mutagens have been used to create genotypes that contain altered fatty acid composition (Hammond and Fehr, 1983; Rahman et al., 1997; Stojšin et al., 1998). A more stable and desirable soybean oil can be achieved by altering one or a combination of fatty acids (Carver et al., 1984; Neff and List, 1999: White, 2000; Wilcox et al., 1994)

Soybean oil content and composition are quantitative traits with the genotype of the maternal parent being the primarily determinant (Brim, 1973). Because these are

quantitative traits, the environment also has a large influence. Seed-fill is the most critical stage at which the environment affects oil composition, and temperature is the primary factor during this time (Rose, 1988). At temperatures lower than what are considered optimum for growth, a higher proportion of polyunsaturated fatty acids are present. An accumulation of C18:1 appears to result when temperatures are above the optimum for growth. This is at the expense of C18:2 and C18:3, but C18:0 is unaffected (Smith, 1984). Moisture stress is another environmental condition that affects soybean oil. Rose (1988) reported that when sever stress occurred early in pod fill, the percentage of protein decreased while the oil percentage increased. Rose also found no significant increase in either protein or oil percentages during a season of high rainfall.

The objective of this research was to evaluate grain yield, oil content, and fatty acid composition in soybean cultivars and experimental lines grown in Oklahoma and to evaluate the relationship between these traits.

MATERIALS AND METHODS

Four soybean trials were evaluated for two years (2000-2001). These were the Full Season Maturity Group VI Soybean Variety Test, which contained 18 entries (Appendix A), the Uniform Maturity Group IV-S Soybean Yield Test (Appendix B), which contained 16 entries, the Uniform Maturity Group V Soybean Yield Test (Appendix C), which contained 34 entries, and the Uniform Maturity Group VI Soybean Yield Test (Appendix D), which contained 24 entries. The data for the three locations of the Full Season Maturity Group VI Soybean Variety Tests were combined . The Uniform tests were part of the Uniform Soybean Test for the Southern Region.

The experimental design for each trial was a randomized complete block design with three replications at each location. Data were collected at three locations: the Vegetable Research Station at Bixby, OK (Wynona silty clay loam) (Combined FS-GVI, U-GIV, U-GV, and U-GVI), the Eastern Research Station at Haskell, OK (Taloka silt loam) (FS-GVI) and the South Central Research Station at Chickasha, OK (Dale silt loam) (FS-GVI). Plots at Bixby and Haskell were planted in four 76 cm rows that were 6 m in length. In 2000, plots at Chickasha were planted on 102 cm rows to accommodate irrigation. In 2001, plots at Chickasha were planted in four 76 cm rows due to a change in plot location. These rows were also 6 m long. One of the center rows was harvested at maturity from each plot, air dried, and weighed.

The oil content for the three replications was determined by using the Soxtec extraction system (Bhatty, 1985). The fatty acid profiles were determined by using the AOCS Official Method Ce2-66 for sampling and analysis of commercial fats and oils (AOCS, 1997). Fatty acid methyl esters were analyzed by gas chromatography using a DB225 column, 30m x 0.25mm, with a 0.15μm film thickness (J&W Scientific, Folsum, CA) on an HP 5890 Series II GC equipped with an HP 7673 autosampler (Hewlett Packard, Sunnydale, CA). Peak areas were recorded using ChemStation software (Hewlett Packard, Sunnydale, CA).

All statistical analyses were performed using SAS, version 8.2 (SAS Institute, 1999). All tests of significance were performed at the nominal 0.05 level. SAS/MIXED was used in the mixed model analysis of the fixed effects of genotype and random effects of location and genotype by location for the response variables grain yield, oil percentage, and fatty acid percentages. When there was a significant genotype effect,

means separation was performed using the Dunnett-Hsu multiple comparison method (Kuehl, 2000) where genotypes were compared to the optimal performing genotype for that response variable. The Dunnett-Hsu procedure was selected due to the number of genotypes studied and because only genotypes with the best or optimal response values are of interest. SAS/CORR was used to calculate Pearson correlations between grain yield, oil content, and the fatty acid percentages.

Specific fatty acid levels were looked for when determining the optimal genotype that would be used in the Dunnett-Hsu procedure. High C18:0 percentages were used because these oils have a greater oxidative stability than normal soybean oil (White, 2000). Also, oils with a higher saturated fatty acid content (C18:0) have increased melting temperatures (List et al., 2001). A high C18:1 content was optimal because genotypes high in this fatty acid were found to be less susceptible to oxidative changes during refining, storage, and frying (Carver et al., 1984). A high grain yield and high oil content were also determined optimal for the Dunnett-Hsu procedure. A low C16:0 content was used because it was determined that genotypes low in C16:0 content have improved nutritional quality (Rebetzke et al., 1998a). Low C18:2 and C18:3 contents were also used because these oils have a low polyunsaturated fat content, which makes the oil more stable (Neff and List, 1999; White, 2000).

RESULTS AND DISCUSSION

Combined Full Season Maturity Group VI

2000 Agronomic Results

The mean grain yield for the 2000 Combined Full Season Maturity Group VI test was 456.9 kg ha^{-1} (Table 2). Oil content averaged well below the recommended standard

of 18% determined by Updaw and Nichols (1980). The C16:0 and C18:3 mean compositions were found to be within their standard percentages of 9.7-13.3 and 5.5-9.5, respectively (Table 1). The C18:2 mean was below its standard percentage and C18:0 and C18:1 were above their 3.0-5.4 and 17.7-28.5 ranges, respectively (Table 1 and 2).

2000 Multiple Comparison Results

Grain yield, C16:0, C18:0, C18:1, C18:2 and C18:3 all showed significant genotype effects. Boggs (yield), OK895618 (C16:0), OK915605 (C18:1), OK895806, OK915605 (C18:2), and Soyola (C18:0, C18:2 and C18:3) were used as the optimal genotype for their respective variables in the Dunnett-Hsu multiple comparison test (Table 2). Soyola was the genotype that optimized the most response variables: grain yield, C16:0, C18:0, C18:1, C18:2, and C18:3. That is, it produced a high grain yield, a low C16:0, C18:2, and C18:3 content, and it produced a high C18:0 and C18:1 content (Table 2). Other genotypes that merited further consideration were OK915605, OK926524, OK935907, and Prolina. They were shown to be optimal for five of the six variables. OK926524 had a high grain yield, low C16:0 and C18:2 content, and it had a high C18:0 and C18:1 content. The other three genotypes had a high grain yield, a low C16:0, C18:2 and C18:3 content, and they also had a high C18:1 content (Table 2). Musen had the poorest performance as it was the only genotype to be significantly different from the genotypes in the optimal group for all responses.

2000 Phenotypic Results

The development of targeted fatty acid profiles to help expand the use of soybean oil for edible and industrial applications has become a high priority (Wilson, 1998). The focus of this type of research has been on three different oil phenotypes (Wilson, 2004).

These three phenotypes are frying oils, baking oils, and industrial oils. The results of these trials were evaluated using these phenotypic options. For all the traits that were evaluated the importance of their results being high or low was determined by what the end use will be. A high grain yield is always desirable, so it was included in each of the three phenotypes that were evaluated.

The first phenotype that was evaluated was frying oil. Genotypes that fit into this category have a high C18:1 content and low C16:0 and C18:3 contents. High C18:1 content makes the oil less susceptible to oxidative changes during refining, storage, and frying (Carver et al., 1984). A low C16:0 content improves the nutritional quality of the oil and a low C18:3 content means enhanced frying stability (Table 2) (Rebetzke et al., 1998a; White, 2000). There were five genotypes that satisfied the characteristics looked for in this phenotype. OK915605, OK935907, OK935917, Prolina, and Soyola all produced high grain yields, a high C18:0 content and low C16:0 and C18:3 contents (Table 2). Other genotypes possessed one or two of the four characteristics.

The second phenotype that was evaluated was baking oil. As with the first phenotype, a low C16:0 content is recommended because it improves the nutritional quality of the oil and a combined low C18:2 and C18:3 content means a low polyunsaturated fatty acid content, thus making the oil more stable (Table 2) (Rebetzke et al., 1998a; Neff and List, 1999). Again, OK915605, OK935907, OK935917, Prolina, and Soyola were found to exhibit the needed characteristics (Table 2). These genotypes produced high yields along with oils that were low in C16:0 and low in polyunsaturated fatty acids.

The final phenotype that was evaluated was industrial oil. The specific industrial use evaluated was Soy-diesel or biodiesel. For this use a high C18:1 level was used because this increased the cetane index and a low C16:0 level was used because it improved the cold-flow of the diesel fuel. These conditions help overcome ignition problems and poor performance in cooler climates (Dunn et al., 1996). There were nine genotypes that satisfied the needed characteristics for this phenotype (Table 2).

2000 Pearson Correlation Results

There were five correlations found to be significant in these data (Table 3). Negative correlations were found between C18:0/Yield, C18:2/C18:0, C18:2/C18:1 and C18:3/C18:1. The negative correlations between C18:2/C18:1 and C18:3/C18:1 were anticipated because C18:1 is a precursor for C18:2 and C18:3. Thus as C18:1 increased the percentage of the other two fatty acids would decrease and vice versa. A positive correlation was also found between C18:3/C18:2 (Table 3). This correlation is surprising because C18:2 is the precursor for C18:3. Thus you would expect these two fatty acids to be negatively correlated.

2001 Agronomic Results

The mean yield for the Combined Full Season Group VI tests in 2001 (2284.5 kg ha^{-1}) (Table 4) was higher than the mean yield in 2000 (463.6 kg ha^{-1}) (Table 2). Oil did increase, but the average of 11.0% was still well below the recommended 18% (Updaw and Nichols, 1980). The fatty acids all performed within their expected ranges.

2001 Multiple Comparison Results

C16:0, C18:0, C18:1, C18:2, and C18:3 were the variables that produced a significant genotype effect (Table 4). OK895618 (C16:0), OK895608 (C16:0 and

C18:0), OK935907 (C18:1 and C18:2), and Soyola (C18:3) were the genotypes for these five fatty acids. In this year's results, OK935907 was the genotype that was most consistent when looking at the five significant variables (Table 4). It produced a high C18:0, C18:1, and C18:2 content, and it produced a low C18:3 content. OK935907 was also the top genotype for the variables C18:1 and C18:2 (Table 4). Soyola also deserves consideration because of its performance. Soyola produced a high C18:0 and C18:1 content as well as a low C18:3 content; it was the preferred genotype for these variables. Choska was the poorest entry as it was the only entry to be significantly different from the optimal genotype in all five response variables.

2001 Phenotypic Results

The genotypes were again evaluated using the frying, baking, and industrial oil phenotypes. This year's results were in great contrast to the previous year because a smaller number of genotypes showed no notable difference from the optimal genotype. For the frying oil phenotype, in 2000 (Table 4) there were five genotypes that met the needed characteristics. In 2001, only two genotypes, OK935907 and Soyola, met two of the characteristics for this phenotype, and the remaining genotypes only met one of the characteristics. The same is true for the baking oil phenotype with the exception of Soyola, which only met one of the needed characteristics. In the industrial oil phenotype, of the nine genotypes that met the characteristics in 2000, six genotypes met one of the three characteristics needed to be considered useful for this phenotype; the remaining genotypes met none of the characteristics

2001 Pearson Correlation Results

Four correlations were found in this data. The negative correlations between C18:2/C18:0, C18:2/C18:1, and C18:3/C18:1 that were found in 2000 were again found in 2001 (Table 5). A positive correlation between C18:1/C18:0 was found. This correlation is new and does require further investigation to determine its validity. The negative correlation that was found between C18:0/Yield and C18:3/C18:2 was not found in this year's data.

Summary of the Combined Full Season Maturity Group VI test

OK935907 and Soyola showed that they were the top genotypes in the Combined Full Season Maturity Group VI test. In 2000, OK935907 produced a high grain yield and a high C18:1 content. It also produced low C16:0, C18:2, and C18:3 contents (Table 2). In 2001, it repeated its performance for C18:1, C18:2, and C18:3. This time it was the preferred genotype for both C18:1 and C18:2 (Table 4). Soyola was optimal for all six significant response variables in 2000. It was also the preferred genotype for three of those variables (C18:0, C18:2, and C18:3) (Table 2). In 2001, Soyola produced high C18:0 and C18:1 contents and a low C18:3 content. As it was in 2000, it was the preferred genotype for C18:3 in 2001 (Table 4).

OK935907 can also be called the most consistent performer when looking at the phenotypic results. In 2000, OK935907 met all of the needed characteristics for all three phenotypes that were evaluated. It was found to be useful for the frying oil, baking oil, and industrial oil phenotypes. However, in 2001, OK935907 only met two of the four needed characteristics for frying and baking oil phenotypes and it only met one of the characteristics for the industrial oil phenotype. Soyola was also one of the consistent

performers in the phenotypic results. As with OK935907, Soyola met all the needed characteristics for all three of the phenotypes that were evaluated in 2000. And as did OK935907 in 2001, Soyola performed below its previous year results. It met two of the four needed characteristics for the frying oil phenotype and then it met only one of the characteristics for the baking and industrial oil phenotypes.

UNIFORM MATURITY GROUP IV

2000 Agronomic Results

The mean grain yield and oil contents were very low for the Uniform Maturity Group IV test conducted at Bixby, OK (Table 6). C16:0 and C18:0 both performed within their expected ranges of 9.7-13.3 and 3.0-5.4, respectively. C18:1 (17.7-28.5) had a mean that was higher than its standard percentage and C18:2 (49.8-57.1) and C18:3 (5.5-9.5) were lower than expected (Table 6).

2000 Multiple Comparison Results

Grain yield and C16:0 were the only variables that demonstrated a significant genotype effects. V94-0198 and V94-0552 were shown to be the preferred genotypes for grain yield and C16:0, respectively. There were 11 genotypes that produced both a high grain yield and a low C16:0 content (Table 6). Three genotypes were significantly different for grain yield; two genotypes were significantly different for C16:0.

2000 Phenotypic Results

Because there were only two variables shown to have significant genotypic effects all three oil phenotypes had the same outcome. Eleven genotypes exhibited two of the four characteristics for the frying and baking oil phenotypes; and they exhibited one of the three characteristics for the industrial oil phenotype (Table 6).

2000 Pearson Correlation Results

As in the 2000 Combined Full Season Maturity Group VI test, negative correlations between C18:2/C18:0, C18:2/C18:1, C18:3/C18:1, and a positive correlation between C18:3/C18:2 were found (Table 3). Two new correlations were also found. A negative correlation between C18:3/C18:0 and a positive correlation between C18:1/C18:0.

2001 Agronomic Results

The Uniform Maturity Group IV test had a high mean grain yield (Table 7). Mean oil content was 16.0% and this was much closer to the recommended standard of 18% determined by Updaw and Nichols (1980). The mean percentages for C16:0, C18:0, C18:1, C18:2, and C18:3 were all within their expected ranges (Table 7).

2001 Multiple Comparison Results

Only one response variable, C16:0, out of the seven examined showed a significant genotype effect (Table 7). K1401 was shown to produce the lowest C16:0 content. Of the 16 genotypes, there were two genotypes, TN95-268 and TN96-63 that were found to be significantly different from K1401.

2001 Phenotypic Results

Because only one response variable showed a significant genotypic difference the genotypes in this test were not evaluated using the three oil phenotypes (Table 7).

2001 Pearson Correlation Results

Only one significant correlation was found in this test, a negative correlation between C18:2/C18:1 (Table 5). This correlation was also exhibited in 2000. Again, this correlation was anticipated because of the relationship between C18:1 and C18:2.

Summary of the Uniform Maturity Group IV test

Looking at both years of the Uniform Maturity Group IV test, 13 genotypes optimized C16:0 content in both years of the study (Table 6 and Table 7). TN96-63 was found to be optimal in 2000, but not in 2001 and V94-0436 was found to be optimal in 2001, but not in 2000.

UNIFORM MATURITY GROUP V

2000 Agronomic Results

The Uniform Maturity Group V test performed similar to the Uniform Maturity Group IV test (Table 6). Grain yield was high and oil content was still low with a mean of 10.0%. C16:0 performed within its standard range of 9.7-13.3 percent (Table 8). C18:0 (5.6%) and C18:1 (31.4%) both had means above their standard ranges and C18:2 (46.4%) and C18:3 (4.9%) were again below their standard ranges (Table 1).

2000 Multiple Comparison Results

All response variables showed a significant genotypic effect (Table 8). TN93-99 (Grain yield), V93-3114 (Oil), S96-2692 (C16:0), DT98-6840 (C18:0), and R96-1471 (C18:1, C18:2, and C18:3) were the optimal genotypes. K1425, K1466, Manokin, N96-556, P9594, and V95-0016 were the genotypes that optimized all seven response variables (Table 8). R96-1417 and eight other genotypes merited further consideration because they optimized six of the seven response variables. R96-1417 produced a high yield, a low C16:0, C18:2, and C18:3 content, and a high C18:0 and C18:1 content. It was also found to be the preferred genotype for C18:1, C18:2, and C18:3 (Table 8).

2000 Phenotypic Results

For the frying oil phenotype, 12 genotypes exhibited all characteristics needed for this phenotype (Table 8.). There were thirteen genotypes that demonstrated three of the characteristics. For the baking oil phenotype, there were 10 genotypes that demonstrated all four characteristics. Nine genotypes demonstrated three of the four phenotypic characteristics. For the industrial oil phenotype, there were 14 genotypes that demonstrated the three characteristics needed for this phenotype (Table 8). K1425, K1466, Manokin, N96-556, P9594, R96-1471, S96-2692, and V95-0016 were the only genotypes to meet all the needed characteristics for all three phenotypes.

2000 Pearson Correlation Results

Four correlations, the negative correlations between C18:2/C18:0, C18:2/C18:1 and C18:3/C18:1 and the positive correlation between C18:3/C18:2, which were observed in 2000 Combined Full Season Maturity Group VI test and the 2000 Uniform Maturity Group IV test, were observed in this test (Table 3). The negative correlation between C18:3/C18:0 that was observed in the 2000 Uniform Maturity Group IV test data was also observed here.

2001 Agronomic Results

The Uniform Maturity Group V test had a mean grain yield of 1478.2 kg ha^{-1} and a mean oil content of 13.3% (Table 9). These were both higher than the previous year's means. All the fatty acids had means within their expected ranges (Table 1).

2001 Multiple Comparison Results

Oil, C18:0, C18:1 and C18:3 had significant genotypic effects by the MIXED procedure (Table 9). N96-556 (Oil), K1424 (C18:0), S96-2692 (C18:1), and S97-1688

(C18:3) were the preferred genotypes for these four response variables. Nine genotypes are recommended based on two of the four response variables. A5547, DT96-6840, and TN93-99 were observed to be optimal for C18:0 and C18:3. Hutcheson, K1463, N96-556, and R96-1471 were observed to be optimal for oil and C 18:0; while N96-7211 and S96-2692 were observed to be optimal for C18:0 and C18:1. There were also 17 genotypes found to be optimal for one of the four response variables (Table 9).

2001 Phenotypic Results

For the frying oil phenotype, S97-1688 was the only genotype to demonstrate two of the four characteristics for the phenotype. In the baking oil phenotype, A5547, DT96-6840, S97-1688, and TN93-99 were the only genotypes to meet one of the four characteristics for this phenotype. Four genotypes exhibited one of the three characteristics for the industrial oil phenotype (Table 9).

2001 Pearson Correlation Results

Two correlations were observed in these data (Table 5), a negative correlation between C18:3/C18:1. This correlation was also observed in the Combined Full Season Maturity Group VI test. A positive correlation between C18:3/C18:2 was also observed.

Summary of the Uniform Maturity Group V test

Six genotypes were recommended based on all seven response variables in 2000. In 2001, N96-556 was the only genotype recommended. It produced a high grain yield, a low C16:0, C18:2 and C18:3 content and a high C18:1 content in 2000; and in both years it produced a significant oil percentage and a high C18:0 content. Manokin and V95-0016 produced a significant C18:0 content in both years of the study. P9594 produced a significant C18:1 content in both years also. Another genotype that merits further

consideration is R96-1471. It produced a low C16:0, C18:2 and C18:3 content, and a high C18:1 content in 2000 (Table 8). In both 2000 and 2001 it also produced a high C18:0 content along with being the recommended genotype for C18:1, C18:2 and C18:3 in 2000 (Table 8). According to these results, R96-147 was also a recommended genotype in the Uniform Maturity Group V test.

There was a large difference between the phenotypic results of 2000 and 2001. Eight genotypes in 2000 exhibited all the characteristics for all three phenotypes (Table 8). In 2001, S97-1688 was the only genotype to exhibit more than one of the characteristics for any of the phenotypes. The remaining genotypes exhibited one of the characteristics or less. In total there were only six genotypes to exhibit at least one of the needed characteristics in more than one phenotype in 2001; in 2000, all of the genotypes did this. The change in weather conditions from 2000 to 2001 had a major impact on this trial.

UNIFORM MATURITY GROUP VI

2000 Agronomic Results

The averages for grain yield and oil were low for the Uniform Maturity Group VI test. C16:0 and C18:3 had mean percentages that were within their expected ranges (Table 1). C18:2 was below its expected range and the means for C18:0 and C18:1 were above their normal ranges (Table 10).

2000 Multiple Comparison Results

There were six variables that had significant genotype effects. These variables were grain yield, oil content, C18:0, C18:1, C18:2, and C18:3 (Table 10). TN91-220-53 (Yield), R96-1559 (oil), N97-3525 (C18:0, C18:1, and C18:2), and OK935907 (C18:3)

were determined to be the preferred genotypes. N97-3525 was the genotype that most consistently optimized the response variables oil, C18:0, C18:1, C18:2, and C18:3. It produced a high oil percentage, a low C18:2 and C18:3 content, and a high C18:0 and C18:1 content (Table 10). It was also the preferred genotype for C18:0, C18:1, and C18:2. There were five other genotypes that also merit consideration since they too optimized five of the six response variables. Those genotypes were Dillon, N97-61, N97-9812, OK926524, and OK935907 (Table 10). R96-1559 and R96-1939 may also deserve some consideration because they optimized four of the six significant response variables

2000 Phenotypic Results

Although there were no genotypes that completely satisfied all of the characteristics for the three phenotypes, some genotypes did exhibit some of the needed characteristics. N97-61, N97-9812, OK926524, R96-1939, and TN93-142-17 had three of the four characteristics needed for the frying oil phenotype. For the baking oil phenotype five genotypes exhibited three of the four characteristics. There were also five genotypes that exhibited two of the needed characteristics. Lastly, there were six genotypes that met two of the three industrial oil characteristics.

2000 Pearson Correlation Results

Five significant correlations exhibited in the other three trials of this study were also exhibited here (Table 3). These were the negative correlations between C18:2/C18:0, C18:2/C18:1, C18:3/C18:1, C18:3/C18:0 and a positive correlation between C18:1/C18:0 (Table 4). Two significant correlations that had not been observed in the other three trials were also found. These were a negative correlation between C18:1/C16:0 and a positive correlation between C18:2/yield.

2001 Agronomic Results

The mean grain yield for the Uniform Maturity Group VI test was high at 2177.0 kg ha^{-1} (Table 11). The mean oil content was again lower than the standard set by Updaw and Nichols (1980). All the fatty acids had averages that were within the ranges expected (Table 1).

2001 Multiple Comparison Results

The five fatty acids were the only variables to have a significant genotype effect (Table 11). N97-61 was the preferred genotype for C18:0 and C18:2 and N97-3525 was the preferred genotype for C16:0, C18:1, and C18:3. AU94-507, G95-179, and SC95-1070 optimized all five significant response variables. They produced low C16:0, C18:2, and C18:3 contents as well as high C18:0 and C18:1 contents (Table 11). There were also 10 genotypes that optimized four of the six response variables.

2001 Phenotypic Results

There were six genotypes that exhibited three of the four frying oil phenotype characteristics. Fourteen genotypes exhibited two of the four characteristics. Nineteen of the 21 tested genotypes exhibited three of the four baking oil phenotypic characteristics. The other two genotypes exhibited two of the four characteristics. There were 12 genotypes that exhibited two of the three industrial oil phenotypic characteristics and nine genotypes that exhibited only one characteristic (Table 11).

2001 Pearson Correlations

Four negative correlations were observed in this test (Table 5). The negative correlations between C18:2/C18:0, observed in the 2001 Combined Full Season Maturity Group VI test, and C18:3/C18:1, observed in the 2001 Combined Full Season Maturity

Group VI test and the 2001 Uniform Maturity Group V test, were observed in this test. Significant negative correlations were observed between C18:1/C16:0 and C18:3/C16:0. The correlation between C18:3/C16:0 was not observed in the 2000 U-GVI trail.

Summary of the Uniform Maturity Group VI test

N97-3525 was the optimal genotype of this test. In 2000, it produced low C18:2 and C18:3 contents and high oil, C18:0, and C18:1 contents. In 2001, it again produced a low C18:3 content as well as a low C16:0 content and it produced a high C18:1 content. Other genotypes that deserve merit include Dillon, N97-61, N97-9812, OK926524, and OK935907. They were optimal for five of the six response variables in 2000 (Table 10) and between four and three of the five response variables in 2001 (Table 11).

Although there were no genotypes that met all of the characteristics for any of the three phenotypes, the two years did have some genotypes that showed some promise. For the frying oil phenotype, there was a slight increase in the number of genotypes that met three of the characteristics when you compare 2000 to 2001. There were three genotypes that produced two of the four characteristics in both years. The same is true for the second phenotype. For the baking oil phenotype there was a larger number of genotypes that possess three of the four characteristics in 2001 when compared to 2000; five of these genotypes did meet three of the four characteristics in both years. For the industrial oil phenotypes the two years results were similar. In 2000, three genotypes did not possess any of the characteristics for this phenotype, but in 2001 all of the genotypes possessed at least one characteristic. Dillon was the only genotype in this phenotype to meet two of the three characteristics in both years.

2000 Overall Summary

The results from 2000 confirm some of the correlations that have been reported in previous literature. The low correlation between yield/oil cited by Burton (1987) held true; none of the trials showed a significant yield/oil correlation. The negative correlations between C18:2/C18:1 and C18:3/C18:1 that were determined by Carver et al. (1984) were found in all four trials in 2000. Also, a negative correlation between C18:2/C18:0 was found in all four trials. The negative correlation between C18:1/C16:0 that was discussed by Rebetzke et al. (1998a) was only found in the Uniform Maturity Group VI test. Other significant correlations were found in three or less of the trials and those correlations may need further investigation. In 2000, some experimental lines had desirable fatty acid characteristics. OK915605 exhibited significantly low C16:0, C18:2, and C18:3 contents and a high C18:1 content along with a high yield (Table 2). The environmental conditions under which these soybean lines were developed could be the cause for these fatty acid combinations. Cherry et al. (1985) and Howell and Collins (1957) found that oil and C18:1 percentages increased while C18:2 and C18:3 percentages decreased in warmer temperatures. These trials were in agreement with these findings except that all of the trials in this report had oil percentages much lower than expected. These low oil percentages could be the result of the combination of warm temperatures during seed development and the lack of rainfall during plant growth. As Smith (1984) stated, when temperatures during seed-fill are high an accumulation of C18:1 occurs while C18:2 and/or C18:3 levels drop. It was also shown that many of the experimental lines exhibited characteristics that fit into the phenotypic profiles of frying oils, baking oils, and industrial oils (Wilson, 1998). Many of the experimental lines

demonstrated many, if not all, of the fatty acid characteristics that made up these three oil phenotypes.

2001 Overall Summary

The results of 2001 were very different from those in 2000. Grain yields were much higher and the fatty acid contents were closer to expected ranges. What set the second year apart from the first was that the trials received rainfall in August at each location. The trials received 4.8 to 8.6 cm of rain depending upon the location (Table 12). Also, temperatures were closer to optimal for seed development (Holmberg, 1973). During seed-fill, temperatures were still above the optimum, but they were not as high as in 2000. Also, there were only a few days during this period when temperatures were 38°C or higher (*Oklahoma Mesonet,* 2003).

With the better growing conditions in 2001, yields were much higher than they were in 2000. Oil percentages were higher, but all trials still produced averages well below what is expected. These low percentages could again be attributed to the combination of warm temperatures during seed development and low rainfall amounts during plant development. Even though temperatures were not as high in 2001 as they were in 2000, rainfall did occur during August. As in 2000, there was no significant correlation between yield/oil in any of the trials. The negative correlation between C18:2/C18:0 was found in two of the four trials. The negative correlations discovered by Carver et al. (1984) between C18:2/C18:1 and C18:3/C18:1 were found in two of the four trials and three of the four trials, respectively. The positive correlation between C18:3/C18:2 was found in only one of the four trials in 2001. Also the negative

correlation found by Rebetzke et al. (1998) between C18:1 and C16:0 was found to be significant in one of the four tests.

CONCLUSIONS

It was determined that year had the largest effect on traits evaluated in this study because of the differences in rainfall and temperature in 2000 and 2001. In 2000, temperatures were above what was considered optimal for seed development and drought stress was present for all locations except Chickasha. In the month of August there was no recorded rainfall at any of the three locations (Table 12). This was combined with temperatures reaching the 37.8°C + mark 10 times at Bixby, 17 times at Haskell, and 31 times at Chickasha. In these conditions, the soybeans had high C18:1 content and low C18:2 and C18:3 content. All soybeans grown at the three locations during 2000 had low oil content when compared to the recommended standard 18%. In 2001, temperatures were still above optimum, but there was no drought stress during seed development. During August 4.8 to 8.6 cm of rainfall was recorded at the three locations (Table 12). And temperatures reached the 37.8°C + mark three times at Bixby, five times at Haskell, and nine times at Chickasha. This led to the fatty acid compositions being normal, but oil percentages were still low. Negative correlations were found between C18:2/C18:0, C18:2/C18:1, and C18:3/C18:1 as expected.

Although oil was low in both years of this study there were three genotypes that were not significantly different from the top oil genotype in both years. All three of those genotypes were found in the Uniform Maturity Group V test conducted at Bixby. Eight genotypes exhibited low C16:0 characteristics in both years of this study. The majority of these coming from the Combined Full Season GVI tests (Table 13). Fourteen

genotypes exhibited high C18:0 characteristics in both years. Six of the thirteen came from the Uniform GV tests at Bixby (Table 13). There were nine genotypes that exhibited the high C18:1 characteristic and nine genotypes that exhibited low C18:2 characteristics. For both variables the majority of those genotypes came from the Uniform GVI tests at Bixby (Table 13). There were 12 genotypes that exhibited the low C18:3 characteristic. Again, the majority of those genotypes came from the Uniform GVI tests at Bixby. A few genotypes were found to exhibit desirable fatty acid characteristics for multiple fatty acids. OK935907, Dillon (Uniform Maturity Group VI test), and N97-3525 exhibited a combination of high C18:1 and low C18:2 and C18:3 contents in both years (Table 13).

This study has provided genotypes that can be considered for both production in Oklahoma and be used as germplasm in a breeding program. The goal of many breeding programs is to develop soybean lines with specific fatty acid content and this study has shown that there are many possibilities available to breeders to produce these types of lines that will grow and flourish in Oklahoma growing conditions.

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Table 1. Fatty acid composition and percentages for soybean oil[*].

Fatty acid	Carbon: Double bond ratio	Percent content
Lauric	C12:0	0-0.1
Myristic	C14:0	0-0.2
Palmitic[†]	C16:0	9.7-13.3
Palmitoleic	C16:1	0-0.2
Stearic[†]	C18:0	3.0-5.4
Oleic[†]	C18:1	17.7-28.5
Linoleic[†]	C18:2	49.8-57.1
Linolenic[†]	C18:3	5.5-9.5
Arachidic	C20:0	0.1-0.6
Gadoleic/ Gondoleic	C20:1	0-0.3
Eicosadienoic	C20:2	0-0.1
Behenic	C22:0	0.3-0.7
Docosenoic	C22:1	0-0.3
Lignoceric	C24:0	0-0.4

† Essential Fatty Acid

[*] Firestone, David (ed). 1999. Physical and chemical characteristics of oils, fats, and waxes. U.S. FDA, Washington D. C.

Table 2. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2000 Combined Full Season Maturity Group VI tests.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	kg ha^{-1}	%					
[††]Boggs$_I$	**860.0**[*]	10.1	**10.1**	4.8	**30.1**	**48.7**	6.1
Brim	**524.1**	9.3	11.1	**5.9**	**28.1**	**47.9**	6.5
Bryan	134.4	8.9	**10.3**	5.2	27.7	49.8	6.7
Choska	**786.1**	10.6	11.1	4.0	26.9	51.8	6.2
Dillon$_I$	**725.7**	10.3	**10.5**	4.8	**28.2**	50.2	6.2
Leflore	282.2	9.0	**10.6**	5.2	27.7	**49.0**	7.2
Musen	235.2	9.2	11.3	5.5	23.7	51.3	8.0
OK895606	**463.6**	10.4	10.9	**6.1**	**28.7**	**48.1**	6.0
OK895608	**416.6**	8.7	**10.0**	**6.1**	26.3	50.3	6.9
OK895618$_I$	**443.5**	10.5	**9.9**[*]	5.5	**29.4**	**48.7**	6.1
OK895806	**678.6**	9.7	11.4	5.5	**30.0**	**47.5**[*]	**5.3**
OK896101	275.5	8.8	10.9	5.4	**28.4**	**48.7**	6.2
OK915605$_{FBI}$	**537.5**	10.6	**10.7**	5.7	**31.1**[*]	**47.5***	**4.9**
OK926524$_I$	**577.8**	10.0	**10.5**	**5.9**	**30.2**	**47.6**	5.6
OK935907$_{FBI}$	**819.7**	10.3	**10.5**	4.6	**30.7**	**48.9**	**5.1**
OK935917$_{FBI}$	**584.6**	10.8	**10.5**	4.8	**29.0**	50.0	**5.3**
Prolina$_{FBI}$	**557.7**	10.3	**10.8**	5.6	**29.9**	**48.0**	**5.1**
Soyola$_{FBI}$	**362.8**	8.3	**10.7**	**6.5**[*]	**30.8**	**47.5***	**4.5**[*]
Mean	456.9	9.8	10.6	5.5	29.0	48.7	5.9

[†] Bixby: planted: June 14, 2000; Harvested: November 29, 2000; Haskell: planted: June 1, 2000; Harvested: November 21, 2000; Chickasha: planted: June 7, 2000; Harvested: December 4, 2000.

[††] F,B, or I indicates whether the entry meets the characteristics for the Frying, Baking, or Industrial phenotype, respectively.

[*] LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 3. Pearson correlations for yield, oil, and fatty acids for soybean trails conducted in Oklahoma during 2000.

	Combined FS-GVI**	U-GIV	U-GV	U-GVI
C18:0/Yield	-0.58*			
C18:1/C16:0				-0.52
C18:1/C18:0		0.66		0.50
C18:2/Yield				0.50
C18:2/C18:0	-0.67	-0.70	-0.63	-0.48
C18:2/C18:1	-0.84	-0.97	-0.64	-0.79
C18:3/C18:0		-0.63	-0.56	-0.49
C18:3/C18:1	-0.78	-0.84	-0.55	-0.56
C18:3/C18:2	0.53	0.82	0.84	

* All correlations listed are significant.

** Combined FS-GVI - Full season maturity group VI soybean trial conducted at Bixby, Haskell, and Chickasha, OK.

U-GIV - Uniform maturity group IV soybean trial conducted at Bixby, OK.

U-GV – Uniform maturity group V soybean trial conducted at Bixby, OK.

U-GVI – Uniform maturity group VI soybean trail conducted at Bixby, OK.

Table 4. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2001 Combined Full Season Maturity Group VI tests.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	Kg ha^{-1}	%					
Boggs	2633.8	13.1	**10.2**	4.3	22.9	52.0	9.0
Brim	2472.6	10.0	10.7	**5.1**	23.2	51.0	8.9
Bryan	2324.8	10.6	**10.0**	4.4	22.6	52.4	9.4
Choska	2358.4	10.1	10.6	4.2	21.9	53.8	8.4
Dillon	2217.3	13.4	**10.1**	4.5	22.4	53.1	8.6
Leflore	2358.4	10.2	10.9	**4.6**	23.7	51.3	9.0
Musen	2385.2	10.5	10.9	**4.9**	19.1	53.7	10.6
OK895606	2210.6	10.9	10.4	**5.4**	23.0	52.3	8.1
OK895608	2392.0	12.4	**9.9**	**5.5**[*]	21.0	54.0	8.9
OK895618	2533.1	10.3	**9.9**[*]	**4.9**	23.8	51.9	8.3
OK895806	2197.1	10.4	11.0	**4.8**	24.1	51.0	8.1
OK896101	2385.2	10.2	10.7	**4.5**	21.7	53.2	9.1
OK915605	1881.3	9.9	10.6	**5.1**	24.5	51.9	7.3
OK926524	2365.1	13.4	10.9	**5.3**	21.8	52.9	8.2
OK935907	1921.6	11.9	10.6	**5.2**	**28.5**[*]	**48.9**[*]	**6.4**
OK935917	2351.7	9.8	**10.2**	4.4	22.9	54.6	7.6
Prolina	1787.3	12.4	10.6	**4.9**	24.2	52.4	7.3
Soyola	2351.7	9.8	10.6	**5.3**	**25.1**	52.6	**5.2**[*]
Mean	2284.5	11.0	10.6	4.9	23.1	52.2	8.2

[†] Bixby: planted: June 13, 2001; Harvested: December 7, 2001; Haskell: planted: June 7, 2001; Harvested: November 21, 2001; Chickasha: planted: June 6, 2001; Harvested: December 6, 2001.

[*] LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 5. Pearson correlations for yield, oil, and fatty acids for soybean trials conducted in Oklahoma during 2001.

	Combined FS-GVI**	U-GIV	U-GV	U-GVI
C18:1/C16:0				-0.49*
C18:1/C18:0	0.53			
C18:2/C18:0	-0.61			-0.56
C18:2/C18:1	-0.82	-0.84		
C18:3/C16:0				0.50
C18:3/C18:1	-0.76		-0.61	-0.80
C18:3/C18:2			0.55	

* All correlations listed are significant.

** Combined FS-GVI - Full season maturity group VI soybean trial conducted at Bixby, Haskell, and Chickasha, OK.
U-GIV - Uniform maturity group IV soybean trial conducted at Bixby, OK.
U-GV – Uniform maturity group V soybean trial conducted at Bixby, OK.
U-GVI – Uniform maturity group VI soybean trail conducted at Bixby, OK.

Table 6. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2000 Uniform Maturity Group IV test conducted at Bixby, OK.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	Kg ha^{-1}	%					
K1401	**503.9**	9.2	**11.8**	5.3	30.8	46.1	4.5
K1423	**497.2**	10.5	**11.2**	5.4	28.9	48.1	5.4
KS4694	362.8	10.2	**12.2**	5.0	29.5	47.6	4.5
MD94-5332	356.1	10.0	**12.2**	6.4	32.8	43.8	3.9
MD94-5396	**571.1**	13.4	**12.3**	4.9	30.2	46.3	4.7
MD96-5275	**631.6**	9.7	**12.0**	5.4	30.8	46.0	4.3
MD96-5696	**416.6**	8.4	**11.3**	4.7	29.1	48.6	4.7
Manokin	**490.5**	10.9	**11.7**	5.7	34.2	43.3	4.1
TN93-87	**456.9**	10.4	**12.3**	5.3	31.5	45.2	4.6
TN95-268	**611.4**	10.1	13.4	5.1	29.5	46.8	4.1
TN96-63	**624.9**	10.0	**11.9**	5.6	31.1	46.1	4.3
V94-0198	**752.5**[*]	10.5	**11.4**	5.2	31.7	45.0	5.3
V94-0436	**638.3**	10.9	12.8	5.6	31.9	44.4	4.2
V94-0552	376.3	14.6	**11.0**[*]	5.4	29.5	47.2	5.5
V96-0332	**718.9**	10.8	**12.3**	5.6	31.0	45.4	4.7
V96-2543	**409.9**	9.2	**12.4**	5.1	27.2	49.2	5.5
Mean	524.1	10.6	12.0	5.3	30.7	46.1	4.6

[†] Planted: June 14, 2000; Harvested: November 21, 2000

[*] LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 7. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2001 Uniform Maturity Group IV test conducted at Bixby, OK.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	Kg ha^{-1}				%		
K1401	1679.8	17.1	**11.0**[*]	4.1	24.5	52.0	7.3
K1423	1975.4	17.6	**11.1**	4.8	23.4	51.7	7.2
KS4694	2190.4	14.1	**11.3**	4.8	25.4	50.6	7.1
MD94-5332	2062.7	16.2	**11.1**	4.9	24.3	51.3	6.9
MD94-5396	1390.8	12.9	**11.1**	4.0	24.6	51.1	7.4
MD96-5275	1901.5	15.7	**11.6**	5.1	25.5	50.9	7.2
MD96-5696	1753.7	16.4	**11.4**	4.6	25.3	50.2	7.4
Manokin	1343.8	14.4	**11.3**	4.6	24.7	51.0	7.0
TN93-87	1706.6	16.7	**11.2**	4.4	24.9	50.8	7.0
TN95-268	2707.8	15.3	11.9	4.6	23.7	51.3	7.1
TN96-63	1437.9	14.3	11.8	4.4	23.9	51.2	4.2
V94-0198	1841.0	18.1	**11.3**	4.5	24.3	51.6	7.9
V94-0436	1841.0	14.4	**11.1**	4.4	25.1	50.7	7.7
V94-0552	1901.5	19.3	**11.1**	4.3	24.7	51.3	7.6
V96-0332	2284.5	15.6	**11.8**	4.8	22.5	52.5	7.1
V96-2543	1753.7	17.1	**11.3**	4.5	24.1	51.7	6.9
Mean	1861.2	16.0	11.3	4.5	24.4	51.2	7.2

[†] Planted: June 13, 2001; Harvested: October 26, 2001.

[*] LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 8. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2000 Uniform Maturity Group V test conducted at Bixby, OK.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	kg ha^{-1}	%					
A5547	**772.7**	**11.0**	12.3	**6.0**	28.2	47.1	5.3
DT96-6840	**853.3**	**10.8**	**11.6**	**6.7**[*]	29.0	46.5	5.2
DT97-6308	799.6	8.7	**11.7**	4.9	28.3	49.1	5.2
Hutcheson	**1041.4**	**13.1**	12.4	**5.9**	29.1	46.5	**5.0**
K1424	712.2	**9.7**	**11.7**	**5.4**	26.7	50.1	5.3
[††]K1425 $_{FBI}$	**940.7**	**9.1**	**10.9**	**5.7**	**32.5**	**45.8**	**5.6**
K1463	745.8	**10.0**	**10.4**	**5.4**	**36.1**	**42.8**	**4.7**
K1466 $_{FBI}$	**940.7**	**9.8**	**11.8**	**5.4**	**32.4**	**45.1**	**4.8**
LS96-1631	**1115.4**	**11.8**	**11.3**	**5.6**	29.9	47.5	5.2
MD95-5260	584.6	9.5	**11.3**	**5.8**	31.7	46.4	**4.8**
Manokin $_{FBI}$	**900.3**	**12.2**	**11.1**	**6.0**	**34.6**	**43.7**	**4.1**
N96-180	**927.2**	**10.6**	12.4	**6.0**	**33.1**	**43.7**	**4.3**
N96-556 $_{FBI}$	**806.3**	**12.2**	**10.9**	**6.5**	**32.6**	**44.9**	**4.6**
N96-7211	**1135.5**	7.8	**11.6**	**6.0**	26.1	50.3	5.6
OK926508	685.3	8.7	**11.0**	**6.0**	30.7	46.9	5.1
OK967006	**987.7**	**11.2**	**11.2**	**5.3**	30.6	47.1	5.3
P9594 $_{FBI}$	**1128.8**	**10.4**	**11.0**	**5.3**	**34.1**	**44.3**	**4.7**
R95-2210 $_{F}$	**1290.0**	**9.7**	**10.8**	**6.2**	30.8	46.6	**4.8**
R96-1471 $_{FBI}$	**772.7**	8.9	**11.5**	**6.0**	**36.5**[*]	**41.8**[*]	**3.8**[*]
R96-3444	**1330.4**	8.4	12.2	**5.7**	**32.0**	**45.2**	**4.9**
R96-864 $_{BI}$	**1202.7**	**10.2**	**11.2**	5.1	**33.1**	**45.6**	**4.6**
S96-2641 $_{BI}$	**947.4**	**9.5**	**10.1**	5.0	**33.1**	**45.9**	**4.8**
S96-2692 $_{FBI}$	**799.6**	8.7	**9.9**[*]	**5.5**	**35.9**	**43.2**	**5.0**
S96-3418	**1068.3**	7.9	**11.3**	4.8	29.5	48.4	**5.0**
S97-1688 $_{I}$	**1175.8**	8.8	**10.7**	5.3	**31.3**	46.9	**4.9**
TN93-99	**1417.7**[*]	**12.0**	**11.0**	5.2	28.7	48.8	5.5
TN94-213	**987.7**	**10.5**	12.9	5.2	26.8	48.6	5.4
TN96-58	**1068.3**	**10.6**	**11.5**	4.7	25.8	51.6	6.0
TN96-64	**927.2**	7.6	13.6	4.6	27.0	49.2	5.6
TN96-68 $_{FI}$	**1095.2**	**10.6**	**11.1**	**6.2**	**33.2**	44.9	**4.2**
V93-3114 $_{FI}$	**1364.0**	**13.5**[*]	**11.1**	**6.0**	**33.9**	47.0	**4.8**
V95-0016 $_{FBI}$	**947.4**	**10.1**	**11.1**	**6.4**	**33.1**	**43.9**	**5.0**
V95-0242	745.8	9.5	12.2	**6.2**	30.8	**45.4**	**4.9**
V95-0391 $_{FI}$	**967.5**	**9.8**	**11.3**	**5.4**	**31.3**	46.9	**4.6**
Mean	974.3	10.0	11.4	5.6	31.4	46.4	4.9

[†] Planted: June 14, 2000; Harvested: December 5, 2000.

[*] LSMEANS top genotype.

[††] F,B, or I indicates whether the entry meets the characteristics for the Frying, Baking, or Industrial phenotype, respectively.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 9. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2001 Uniform Maturity Group V test conducted at Bixby, OK.

Entries[†]	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	kg ha^{-1}	%					
A5547	1243.0	12.4	11.2	**5.2**	21.4	51.8	**8.9**
DT96-6840	1720.1	13.9	11.5	**4.9**	20.2	53.0	**8.9**
DT97-6308	1384.1	13.6	10.6	**5.0**	23.7	52.8	7.0
Hutcheson	651.7	**13.3**	10.7	**5.1**	21.2	53.4	8.4
K1424	1726.8	--	10.8	**5.6**[*]	21.1	52.8	5.3
K1425	1458.0	16.8	11.1	3.9	21.7	54.0	7.7
K1463	1014.6	**13.5**	10.8	**4.2**	22.4	52.6	8.4
K1466	1572.2	13.5	11.4	4.3	20.8	53.7	8.4
LS96-1631	1155.7	13.8	11.3	**5.0**	21.1	53.2	8.2
MD95-5260	1001.1	**14.6**	11.2	4.2	22.7	52.9	7.5
Manokin	1565.5	12.5	11.4	**5.0**	23.6	51.6	7.0
N96-180	1565.5	12.4	11.3	3.9	21.2	53.4	8.4
N96-556	2331.5	**12.8**[*]	10.4	**4.9**	23.3	52.3	7.8
N96-7211	1128.8	12.7	7.9	**4.8**	**19.7**	54.6	8.4
OK926508	1706.6	13.6	10.5	**4.8**	22.6	52.9	7.9
OK967006	1316.9	15.3	10.4	**4.6**	20.6	54.1	8.8
P9594	1961.9	13.7	9.5	2.9	**19.2**	45.5	6.6
R95-2210	1632.7	14.1	10.9	**4.7**	22.1	52.8	8.1
R96-1471	732.4	**13.0**	10.7	**5.3**	24.2	50.8	7.6
R96-3444	1175.8	12.3	11.6	**4.9**	22.6	51.7	8.0
R96-864	1155.7	13.3	10.5	4.5	23.0	52.6	7.9
S96-2641	1847.7	13.1	10.4	4.2	23.6	52.9	7.8
S96-2692	1390.8	12.1	10.3	**4.8**	**24.8**[*]	50.7	8.0
S96-3418	2271.0	12.8	11.3	4.2	22.1	53.5	7.6
S97-1688	1196.0	12.3	10.7	3.9	24.3	52.6	**6.9**[*]
TN93-99	1249.7	16.2	10.8	**4.9**	20.2	53.7	**9.0**
TN94-213	1343.8	12.4	11.3	**4.7**	21.0	52.8	8.8
TN96-58	1861.2	14.7	11.6	4.3	24.1	51.5	7.0
TN96-64	1639.4	14.1	11.7	3.8	**20.1**	54.8	8.3
TN96-68	1451.3	11.1	10.9	**4.6**	23.8	53.1	7.2
V93-3114	2197.1	11.9	10.7	**4.9**	22.9	52.1	7.9
V95-0016	1518.5	11.3	10.7	**4.7**	23.4	51.7	7.9
V95-0242	1914.9	14.7	11.1	**4.8**	23.2	52.0	7.9
V95-0391	1263.2	11.7	11.3	4.1	21.0	54.3	7.9
Mean	1478.2	13.3	10.8	4.6	22.1	52.6	7.9

[†] Planted: June 13, 2001; Harvested: December 7, 2001.

[*] LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 10. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2000 Uniform Maturity Group VI test conducted at Bixby, OK.

Entries†	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	kg ha^{-1}	%					
AU94-507	**907.1**	**11.6**	11.7	4.6	26.8	50.0	5.8
AU96-1353	--	**10.1**	10.2	**6.3**	**31.1**	46.0	6.4
Boggs	483.8	**11.2**	10.2	5.4	**31.5**	**45.1**	6.1
Dillon	**551.0**	**12.3**	10.7	5.4	**31.9**	**45.8**	**5.1**
G95-179	--	7.5	11.5	**5.8**	28.1	46.1	6.8
N96-6783	**544.2**	10.0	11.4	4.4	24.9	52.2	6.0
N96-6800	**598.0**	9.4	11.3	5.1	27.3	49.5	5.8
N97-3525	315.8	**11.5**	9.0	**7.2***	**34.1***	**43.8***	**4.8**
N97-61	**544.2**	**11.3**	9.3	**7.1**	**31.7**	49.2	**4.7**
N97-9812	**685.3**	9.0	11.1	**6.1**	**31.8**	**45.2**	**4.7**
OK926524	**665.2**	9.5	10.6	**6.3**	**31.7**	**45.0**	**5.0**
OK935907	**772.7**	**13.2**	11.1	5.7	**33.4**	**44.7**	**4.5***
R96-1559	**759.2**	**14.0***	11.6	5.6	30.2	**46.7**	**4.9**
R96-1939	**725.7**	**11.7**	12.2	**6.2**	26.8	48.2	**5.2**
R96-3538	**618.1**	**11.7**	10.7	5.6	29.2	47.7	5.8
SC94-1075	**584.6**	**13.2**	11.4	5.3	**31.2**	**44.9**	5.9
SC95-1070	309.1	**12.1**	10.7	5.4	29.7	47.7	**5.0**
TN91-220-53	**947.4***	**11.4**	10.3	5.5	28.2	48.9	5.7
TN93-142-17	**503.9**	**10.7**	11.4	**6.0**	28.6	48.1	**5.5**
VS95-154	369.5	8.9	11.3	**6.0**	27.6	47.2	6.4
VS95-78	--	--	10.3	**5.6**	**28.7**	47.0	6.9
Mean	604.7	11.1	10.9	5.7	29.6	47.3	5.5

† Planted: June 14, 2000; Harvested: December 8, 2000.

* LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 11. Means for yield, oil, and fatty acid compositions for soybeans grown in the 2001 Uniform Maturity Group VI test conducted at Bixby, OK.

Entries†	Yield	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
	kg ha^{-1}			%			
AU94-507	1552.1	15.4	**10.9**	**4.0**	20.8	**54.2**	**8.7**
AU96-1353	2808.5	10.2	**11.0**	5.1	21.1	**52.2**	**9.1**
Boggs	3016.8	10.7	**10.2**	**3.9**	**22.5**	**52.7**	**8.1**
Dillon	2197.1	11.8	**11.6**	4.7	21.5	**53.4**	**8.3**
G95-179	2418.8	12.4	**11.5**	**3.8**	18.6	**54.8**	**9.8**
N96-6783	1901.5	11.9	**10.8**	4.9	20.6	**54.3**	**8.5**
N96-6800	2096.3	12.7	**11.1**	4.3	21.8	**52.9**	**8.2**
N97-3525	1726.8	12.0	**5.4***	4.5	**25.7***	59.0	**5.4***
N97-61	2338.2	--	**11.0**	**5.6***	**23.4**	**51.1***	7.6
N97-9812	1585.7	16.0	**12.3**	4.4	**21.9**	**52.6**	**8.1**
OK926524	2701.0	14.3	**10.5**	5.1	**22.3**	**52.7**	**8.0**
OK935907	2465.9	14.6	**10.3**	**4.2**	**22.4**	**53.9**	**7.7**
R96-1559	2271.0	--	**11.0**	4.4	20.1	**54.6**	**8.4**
R96-1939	2042.6	14.4	**11.4**	4.5	19.1	**54.6**	**8.7**
R96-3538	1841.0	14.9	**10.1**	4.9	**22.6**	**53.0**	**7.8**
SC94-1075	2056.0	--	**10.5**	3.8	**22.0**	**53.8**	**8.2**
SC95-1070	1666.3	10.7	**10.6**	**5.0**	21.5	**52.4**	**9.1**
TN91-220-53	2627.1	13.9	**10.2**	4.4	21.3	**54.2**	**8.7**
TN93-142-17	2351.7	--	**9.8**	4.7	**22.1**	**54.2**	**7.8**
VS95-154	2170.2	17.3	**11.1**	4.5	**21.8**	**53.8**	7.4
VS95-78	1713.3	13.0	**11.0**	5.0	21.2	**53.1**	**8.8**
Mean	2217.3	12.8	**10.0**	4.7	**21.1**	**51.7**	**8.7**

† Planted: June 13, 2001; Harvested: December 10, 2001.

* LSMEANS best genotype.

BOLD means indicate genotypes not significantly different from the best genotype.

Table 12. Rainfall and average temperature for Bixby, Haskell, and Chickasha, OK in 2000-2001 during the soybean growing season[*].

	Rainfall			Temperature		
Month	Historical Average	Total Precipitation		Historical Average	Monthly Average	
		2000	2001		2000	2001
	cm			°C		
			Bixby			
June	11.2	6.1	7.9	24.4	23.2	24.8
July	7.4	3.8	0.5	27.7	26.7	29.3
August	7.4	0.0	4.8	26.8	28.6	28.3
September	11.9	2.8	7.1	22.3	22.9	21.4
October	9.1	11.7	9.1	16.1	17.7	15.5
November	7.6	13.5	9.9	9.6	6.3	12.4
			Haskell			
June	10.7	7.6	6.6	24.9	22.8	24.7
July	6.6	2.5	0.0	27.8	26.4	29.2
August	7.1	0.0	6.4	27.1	28.7	28.4
September	11.4	7.9	6.1	22.9	23.2	21.4
October	10.9	13.5	17.5	16.7	17.5	15.4
November	8.9	11.4	15.2	10.3	6.5	14.1
			Chickasha			
June	9.4	5.6	1.5	25.8	23.9	25.2
July	5.3	1.8†	1.3‡	28.3	28.1	30.0
August	7.1	0.0†	8.6‡	27.3	30.4	28.2
September	9.7	6.6	6.4	23.1	24.2	21.6
October	8.4	27.7	4.1	17.2	17.9	16.1
November	5.1	8.4	2.8	10.4	6.3	12.4

† Flood irrigated on 7-20, 8-4, 8-17, and 8-28.

‡ Flood irrigated on 7-10, 7-17, 7-27, and 8-8.

[*] *Monthly Summaries*. URL:http://climate.ocs.ou.edu/monthly_summary.html. [21 February 2002].

Table 13. Genotypes that exhibited desirable fatty acid characteristics in both 2000 and 2001.

Entries	Test[†]	Oil	Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
Boggs	CFSMGVI		X				
Brim				X			
Bryan			X				
Dillon			X				
OK895606				X			
OK895608			X	X			
OK895618			X				
OK926524				X			
OK935907					X	X	X
OK935917			X				
Soyola					X		X
K1401	UMGIV		X				
TN96-63			X				
Hutcheson	UMGV	X					X
K1424				X			
K1425				X			
K1463		X					
K1466				X			
MD95-5260				X			
N96-180				X			
N96-556		X					
P9594				X	X		
S96-2692					X		
S97-1688							X
V95-0391				X			
AU96-1353	UMGVI				X		
Boggs						X	
Dillon					X	X	X
G95-179				X			
N97-3525					X	X	X
N97-61				X			
N97-9812						X	X
OK926524						X	X
OK935907				X		X	
R96-1559						X	X
R96-1989							X
SC94-1075						X	
SC95-1070					X		X
TN93-142-17							X
VS95-78					X		

[†]CFSMGVI – Combined Full Season Maturity Group VI soybean tests
UMGIV – Uniform Maturity Group IV soybean test
UMGV – Uniform Maturity Group V soybean test
UMGVI – Uniform Maturity Group VI soybean test

APPENDIXES

Appendix A. Genotypes and pedigrees for entries in the Combined Full Season Maturity Group VI soybean variety test.

Varieties	State	Pedigree
Boggs	Georgia	G81-152 x Coker 6738
Brim	North Carolina	Young x N73-1102
Bryan	Georgia	Centennial x Bedford
Choska	Oklahoma	Dyer x Bragg
Dillon	South Carolina	Centennial x Young
Leflore	Mississippi	Centennial x J74-47
Musen	South Carolina	Hutcheson x Leflore
OK895606	Oklahoma	Bedford x Mitchell
OK895608	Oklahoma	Bedford x Mitchell
OK895618	Oklahoma	Coker 156 x Essex
OK895806	Oklahoma	Bethel x Essex
OK896101	Oklahoma	Tracy x Centennial
OK915605	Oklahoma	Essex x Sohoma
OK926524	Oklahoma	Miles x Lee 74
OK935907	Oklahoma	Sohoma x Forrest
OK935917	Oklahoma	Sohoma x Forrest
Prolina	North Carolina	N/A†
Soyola	North Carolina	N87-2117-3 x Brim

†Information was not available.

Appendix B. Genotypes and pedigrees for entries in the Uniform Maturity Group IV soybean yield test.

Varieties	State	Pedigree
K1401	Kansas	Delsoy 4710 x KS4694
K1423	Kansas	Manokin x LS86-1922
KS4694	Kansas	Sherman x Toano
Manokin	Missouri	L70-L3048 x D74-7824
MD94-5332	Maryland	Clifford x Corsica
MD94-5396	Maryland	Ripley x Clifford
MD96-5275	Maryland	Ky 88-4080 x Manokin
MD96-5696	Maryland	Ky 88-4080 x Corsica
TN93-87	Tennessee	TN85-55 x TN82-268
TN95-268	Tennessee	Cordell x Hutcheson
TN96-63	Tennessee	N85-578 x Manokin
V94-0198	Virginia	DP 415 x Manokin
V94-0436	Virginia	DP 415 x C1747
V94-0552	Virginia	Hutcheson x Manokin
V96-0332	Virginia	Hutcheson x Clifford
V96-2543	Virginia	V85-5344 x C1747

Appendix C. Genotypes and pedigrees for entries in the Uniform Maturity Group V soybean yield test.

Varieties	State	Pedigree
A5547	N/A†	N/A†
DT96-6840	Mississippi	Hutcheson x P9641
DT97-6308	Mississippi	Hutcheson x A5979
Hutcheson	Virginia	V68-1034 x Essex
K1424	Kansas	Hutcheson x A4715
K1425	Kansas	Hartwig x KS4895
K1463	Kansas	S88-1934 x N90-516
K1466	Kansas	Manokin x HC89-2170
LS96-1631	Illinois	Gateway511 x Hutcheson
Manokin	Missouri	L70-L3048 x D74-7824
MD95-5260	Maryland	S88-1855 x Manokin
N96-180	North Carolina	N87-298 x Cook
N96-556	North Carolina	N87-298 x NRS5Y
N96-7211	North Carolina	Holladay x N91-8006
OK926508	Oklahoma	Miles x Forrest
OK967006	Oklahoma	Forrest x R85-3280
P9594	N/A†	N/A†
R95-2210	Arkansas	Manokin x A6297
R96-1471	Arkansas	A5403 x Manokin
R96-3444	Arkansas	PIO 9592 x KS4895
R96-864	Arkansas	A6297 x PIO 9592
S96-2641	Missouri	P9591 x S91-1839
S96-2692	Missouri	Manokin x S91-1839
S96-3418	Missouri	S92-1666 x NKS59-60
S97-1688	Missouri	S91-1381 x H5810
TN93-99	Tennessee	Hutcheson x (TN85-88 x TN5-85)
TN94-213	Tennessee	S85-1009 x Hutcheson
TN96-58	Tennessee	Hutcheson x TN89-39
TN96-64	Tennessee	Holladay x Manokin
TN96-68	Tennessee	Holladay x Manokin
V93-3114	Virginia	FFR544 x Hutcheson
V95-0016	Virginia	KS5292 x Accomac
V95-0242	Virginia	Hutcheson x V85-1195
V95-0391	Virginia	V85-1729 x V84-1354W

†Information was not available.

Appendix D. Genotypes and pedigrees for the entries in the Uniform Maturity Group VI soybean yield test.

Varieties	State	Pedigree
AU94-507	Alabama	Dillon x N85-492
AU96-1353	Alabama	Carver x N90-516
Boggs	Georgia	G81-152 x Coker 6738
Dillon	South Carolina	Centennial x Young
G95-179	Georgia	G86-1434 x G86-1267
N96-6783	North Carolina	N91-7202 x N90-7199
N96-6800	North Carolina	N90-7202 x N90-7199
N97-3525	North Carolina	N93-132 x [Brim (2) x (N88-143(2) x N35-2-19)]
N97-61	North Carolina	N90-541 x N90-1101
N97-9812	North Carolina	N90-7199 x N91-7254
OK926524	Oklahoma	Miles x Lee 74
OK935907	Oklahoma	Sohoma x Forrest
R96-1559	Arkansas	A6297 x A5403
R96-1939	Arkansas	Hutcheson x Coker 6955
R96-3538	Arkansas	A5403 x Dillon
SC94-1075	South Carolina	Coker 6847 x G83-198
SC95-1070	South Carolina	NK'S S83-30 x Manokin
TN91-220-53	Tennessee	Hutcheson x TN5-85
TN93-142-17	Tennessee	Hutcheson x (TN85-55 x TN83-26)
VS95-154	Virginia	[PI 159319 x Essex (2)] x [PI 96089 x Essex (2)]
VS95-78	Virginia	[PI 96089 x Essex (2)] x [L760132 x Essex (2)]

VITA

Luke Aaron Farno

Candidate for the Degree of

Doctor of Philosophy

Thesis: OIL AND FATTY ACID PROFILE OF SOYBEAN (MATURITY GROUPS IV, V,AND VI)

Major Field: Crop Science

Biographical:

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Education: Graduated from National Trail High School, New Paris, Ohio in June 1992; received Bachelor of Science in Agriculture with Agronomy option and minor in Chemistry from Eastern Kentucky University, Richmond, Kentucky in December of 1996; received Master of Science degree with a major in Crop Science from Oklahoma State University, Stillwater, Oklahoma in May, 1999. Completed the requirements for the Doctor of Philosophy degree with a major in Crop Science at Oklahoma State University in July of 2005.

Experience: Raised on a farm in Eaton, Ohio; employed by Eastern Kentucky University as an assistant to the Director of the University Farms the fall semester of 1997; attended Oklahoma State University, on a graduate research and teaching assistantship, Oklahoma State University, Department of Plant and Soil Sciences, 1997 to 2003. Worked as an Assistant Plant Breeder/ Team Leader II for Garst Seed Company at the Marshall Research Station from April 2003 to June 2005

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: OIL AND FATTY ACID PROFILE OF SOYBEAN (MATURITY GROUPS IV, V,AND VI)

Pages in Study: 62 Candidate for the Degree of Doctor of Philosophy

Major Field: Crop Science

Scope and Method of Study: The objective of this research was to evaluate the relationship between grain yield, oil content, and fatty acids composition in soybean cultivars and experimental lines in maturity groups IV, V, and VI. Data were collected at three locations: the Vegetable Research Station at Bixby, OK, the Eastern Research Station at Haskell, OK, and the South Central Research Station at Chickasha, OK. The oil content was determined by using the Soxtec extraction system. Profiles on the percentage of the fatty acids were made by using the AOCS Official Method (Ce2-66) for sampling and analysis of commercial fats and oils. Significant genotype effects and variances were determined by using the PROC MIXED procedure and correlations were determined by using the PROC CORR procedure.

Findings and Conclusions: In 2000, when temperatures were above what was considered optimal for seed development the soybeans had high C18:1 content and low C18:2 and C18:3 contents. Oil percentages should have been higher, but it was found that the soybeans grown at the three locations during 2000 had low oil content when compared to the 18% standard. This was the case for all genotypes that were evaluated. The main cause of this was the heat and/or drought stress that occurred during seed development. In 2001, temperatures were still above optimum, but there was no drought stress during seed development; this led to the fatty acid composition being normal, but oil percentages were still low. Genotypes were identified that had improved fatty acid composition in both years for two or more fatty acids. These may be useful to soybean breeding projects. In both years the oil content of all soybean lines was much lower than the normal 18%. Further studies are needed to determine the cause of this. As has been reported by other, negative correlations were found between C18:2/C18:0, C18:2/C18:1, and C18:3/C18:1.

ADVISER'S APPROVAL: Dr. Arthur Klatt