

# OAT LIPIDS<sup>1</sup>

V. L. YOUNGS<sup>2</sup>

## ABSTRACT

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Oat groats contain 5–9% free and 1.5–3% bound lipids. The highest lipid concentration is in the oat embryonic axis and scutellum, but most of the total oat lipid is associated with bran and endosperm because of their greater abundance. Several components have been identified and measured, and over 40% of the total crude lipid is triglyceride. Fatty acid composition of oat lipids is primarily palmitic acid (16–22%), oleic acid (28–40%), and linoleic acid (36–46%). Lipid concentration in the

groat is heritable, and preliminary evidence indicates that the fatty acid composition of oat lipids also may be heritable. The main synthesis of oat lipids takes place early in seed formation while the seed still contains more than 50% water. Lipids in oats are quite stable unless the groat is cracked or ground; then the enzyme lipase catalyzes the release of fatty acids. Rancidity will result eventually from degradation of these fatty acids.

Lipids in food represent a concentrated energy source, and oats (*Avena sativa* L.) contain higher levels of lipid than any other cereal grain. In the United States, oats is the third largest cereal crop, but less than 10% of the crop is used directly for human consumption. The remainder is used for animal feed, either as a grain feed or forage.

## LIPID CONCENTRATION IN OAT CULTIVARS

Most publications on oat lipids include data on the lipid levels in several cultivars or selections. In the most comprehensive study, Brown and Craddock (1) reported a 3.1–11.6% range in lipid concentration of oat groats among more than 4,000 entries in the world collection; 90% of the entries ranged from 5% to 9%. Five entries were more than 11% and 25 were less than 4% lipid. These data were from nuclear magnetic resonance (NMR) analysis and are comparable with data from conventional nonpolar organic solvent extraction (2).

When oats or oat groats are further extracted with polar solvents or polar solvent systems, bound lipids are removed; the amounts depend on the solvents used and the cultivar extracted. Bound lipid values of 2.5% (3), 1.5% (4,5), and 1.84–3.28% (6) are reported. Thus, total lipid values (free plus bound) would be higher than the NMR values.

Researchers agree that lipid concentration in oats is highly heritable (7–10). Brown and Aryeetey (11), working with  $F_1$  and  $F_2$  plants, stated that selection for oil content among individual groats on the same plant would probably be

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<sup>2</sup>Research chemist, U.S. Department of Agriculture; and Adjunct professor, Department of Agronomy, University of Wisconsin, Madison.

ineffective because of maternal control of oil content in oats.

Many correlations have been cited between lipid concentration and other quality factors such as protein, groat weight, heading date, plant height, kernel density, percent hull, lodging, yield, and test weight (1,7,10,12,13). Generally, correlations are low, but results vary and in some cases conflict. These differences may be partially explained by the stable lipid concentration in oats and minor role of environmental conditions. The other quality factors are not stable, are altered by environmental conditions, and vary from year to year and from location to location.

#### DISTRIBUTION OF LIPIDS IN THE KERNEL

Lipid concentration in parts of the oat kernel varies among cultivars, but relative distribution is similar. Concentration is lowest in hulls (less than 3% total lipids) and increasingly higher in starchy endosperm (6–8%), the bran (8–11%), embryonic axis (15–16%), and scutellum (23–25%) (5). The embryo (embryonic axis and scutellum) is rich in lipid but comprises only about 3% by weight of the groat. Most of the lipid is in the bran and starchy endosperm.

Only 1.3–1.6% (14) and 1.3% (15) lipids are reported in oat starch. Isolated individually by centrifugation, protein fractions from bran and starchy endosperm contain about 21% and 23% lipid, respectively (14). Rohrllich and Niederauer isolated from oats and other cereals a proteolipid that behaved as a uniform molecule in paper electrophoretic and thin-layer chromatographic patterns (16,17).

#### COMPOSITION OF OAT LIPIDS

Aylward and Showler (18) isolated a glyceride fraction and two phospholipid fractions (phosphatidylcholine and phosphatidylethanolamine) from oat lipids and reported total phospholipids of 10.15%. Acker and Becker (15) found that 51.6% of the lipids in oat starch was lysophosphatidylcholine, 5.1% lysophosphatidylethanolamine, 7.0% lysophosphatidylinositol, and 7.7% free fatty acids. Tevekelev reported that 0.293–0.446% of the dry weight for two oat cultivars was phospholipid and that the percentage of phosphatidylinositol was twice that in other cereals (19). Price and Parsons (20) extracted and separated lipids from chief oats into three classes by column chromatography. Values were neutral lipid, 72.9%; glycolipid, 17.0%; and phospholipid, 10.1% (acetone insoluble fraction). They also used thin-layer chromatography (TLC) to identify but not quantify several specific lipid components. We used TLC to separate and quantify 12 lipid components in groats and groat fractions from two oat cultivars grown during two crop years (5). Average values appear in Table I. The extremely small quantities of sterol esters could not be measured. The triglyceride fraction was most abundant in the groats and all fractions and most concentrated in the embryo. Digalactosyldiglycerides were next in abundance in the groats, bran, and endosperm but could not be measured in the embryo. Most of the other components were present in small amounts.

Oat sterols have received minor attention. Knights (21,22) used gas-liquid chromatography to study the sterol composition of oats and reported values for eight sterols (23). Sitosterol was most abundant (39%), followed by  $\Delta^5$ -

avenasterol and  $\Delta^7$ -avenasterol. We (5) combined thin-layer chromatography and gas-liquid chromatography and analyzed the free sterols in one cultivar. Of the six sterols measured, the three most abundant were sitosterol, 69%; campesterol, 10%; and stigmasterol, 8%.

### FATTY ACIDS

Considerable data have been reported on the fatty acid composition of oat lipids in mature seeds (excluding maturity studies) (3–5,9,13,18,20,24–26). Most authors agree that the concentration of each fatty acid varies among cultivars. Table II shows ranges reported by two authors. In addition to the fatty acids

**TABLE I**  
Distribution of Lipid Components in Oat Groat Fractions<sup>a</sup>  
(% of Total Lipids)

Component	Source				
	Groats	Bran	Endosperm	Scutellum	Embryonic Axis
Triglycerides	41	39	41	50	58
1,3-Diglycerides	2	2	2	1	2
1,2-Diglycerides	1	1	1	2	2
Free fatty acids	5	3	3	2	2
Sterols	1	1	1	1	1
Sterol glucosides	1	1	1	1	1
Monogalactosylmonoglycerides	4	4	5	...	...
Digalactosyldiglycerides	7	9	8	...	...
Phosphatidylethanolamine	2	3	2	1	1
Lysophosphatidylethanolamine	1	2	2	...	...
Phosphatidylcholine	5	4	4	3	3
Lysophosphatidylcholine	2	3	3	...	...
Components not measured (Obtained by difference)	28	28	27	39	30

<sup>a</sup>Data from Youngs and co-workers (5).

**TABLE II**  
Relative Fatty Acid Composition of Oat Strains

Fatty Acid	Groats of 15 Oat Strains <sup>a</sup>		Nine Strains of Oats <sup>b</sup>	
	Range (%)	Mean (%)	Range (mol %)	Mean (mol %)
Myristic	0.4– 0.8	0.6	...	...
Palmitic	16.1–21.8	18.9	17.2–23.6	19.6
Stearic	1.2– 2.0	1.6	0.8– 1.8	1.4
Oleic	28.4–40.3	36.4	26.5–47.5	38.7
Linoleic	36.6–45.8	40.5	33.2–46.2	38.9
Linolenic	1.5– 2.5	1.9	0.9– 2.4	1.5

<sup>a</sup>Data on three replications of each strain, grown at three locations in the United States during two crop years, reported by Youngs and Puskulcu (26).

<sup>b</sup>Calculated from data reported by de la Roche and associates (4) for oats grown in Canada.

listed in Table II, Lindberg and associates (24) reported the presence of C<sub>16:1</sub>, C<sub>17:0</sub>, C<sub>17:1</sub>, C<sub>20:0</sub>, and C<sub>20:1</sub>.

Welch (25) reported greater unsaturation in lipids in winter sown oats than in spring sown oats. In a controlled temperature study, Beringer (27,28) reported greater unsaturation in oats grown at 12°C than in those grown at 28°C. De la Roche and colleagues (4) found no difference in fatty acid composition in an oat selection and a parent grown two years at two locations. We (26) found significant differences in individual fatty acids in 15 cultivars grown at three locations for two years, but the differences between locations and between years were not significant. Broad-sense heritabilities were high for all acids except stearic.

Correlations of individual fatty acids with total lipid content or with total fatty acid content are shown in Table III. With only one exception, authors report highly significant relationships between each of the three major fatty acids (palmitic, oleic, linoleic) and total lipids or total fatty acids. The data suggest certain trends. As lipids are increased genetically in oats, lower concentrations (percent of lipids) of palmitic and linoleic acids and increased concentrations of oleic acid might be expected.

### CHANGES IN LIPIDS

#### Maturity

The main synthesis of oat lipids occurs early in seed formation, probably during the first 15 days after flowering (29,30), or while the seed still has more than 50% water (31). Low temperatures increase lipid concentrations (27,28), and nitrogen fertilization decreases them slightly but not uniformly (30).

Early in lipid development, the percentage of linolenic acid is high, but it decreases and linoleic acid increases as the seed matures (29–31). We investigated changes in 12 lipid components as the seed matured.<sup>3</sup> Triglycerides increase and free fatty acids decrease while kernel moisture is above 50%. These findings agree

<sup>1</sup>Unpublished data.

TABLE III  
Fatty Acid Concentration in Oats

Fatty Acid	Correlation Between % Fatty Acid and			
	Total Lipid <sup>a</sup>	Total Lipid <sup>b</sup>	Total Lipid <sup>c</sup>	Total Fatty Acid <sup>d</sup>
Palmitic	-0.89 (p < 0.01)	-0.76 (p < 0.01)	-0.08	-0.74 (p < 0.001)
Stearic	...	...	0.03	0.33 (p < 0.05)
Oleic	0.98 (p < 0.01)	0.91 (p < 0.01)	0.37 (p < 0.01)	0.76 (p < 0.001)
Linoleic	-0.98 (p < 0.01)	-0.85 (p < 0.01)	-0.38 (p < 0.01)	-0.55 (p < 0.001)
Linolenic	...	...	-0.36 (p < 0.01)	-0.39 (p < 0.01)

<sup>a</sup>Data from de la Roche and associates (4).

<sup>b</sup>Data from Youngs and Puskulcu (26).

<sup>c</sup>Data from Frey and Hammond (9).

<sup>d</sup>Data from Welch (25).

with those of Brown and co-workers (29). Also, levels of free sterols and phosphatidylcholine decrease with maturity, but other lipid components change little.

### Storage

Lipid changes that take place in oats during storage are generally monitored by measuring the increase in free fatty acids. These acids are freed by the action of lipase, primarily on the triglycerides, the major component of oat lipids. Lipase is located on the surface of the caryopsis (32,33). Lipase activity is optimum at 37–38°C and pH 7.4 (33) and is strongly influenced by the amount of water in an oat (flour) dough (9). Frey and Hammond (9) reported a 20-fold variation in lipase among 352 oat collections.

In whole oats or undamaged oat groats stored at normal temperatures and low moisture (less than 10%), lipids show little change. Naked oats (*Avena nuda*) store as well as husked cultivars, unless the kernels are bruised (34). A temperature increase to 30°C does not significantly affect lipids in unground samples (35), but free fatty acids increase at moistures above 10% (9,36). In ground oats, free fatty acids increase rapidly during storage and the increase is enhanced at 30°C (35).

Popov and Cheleev (37) concluded that during storage the degree of saturation also increased in free fatty acids because of enhanced lipoxygenase activity on linoleic acid. That conclusion was based on their finding that lipoxygenase oxidizes hydrolyzed oat oil more extensively than nonhydrolyzed oil. Nechaev and associates confirmed the change in saturation of fatty acids (38,39). The peroxide numbers and oxidation of unsaturated compounds also increase with humidification (36). Popov and Cheleev (37) also found that addition of sodium linoleate to oat oil decreases oxidation, but its addition increases oxidation in maize oil.

Heimann and co-workers (40) incubated oat enzymes and linoleic acid to study the products of linoleic acid oxidation and reported that lipoxygenase catalyzes the formation of 9-hydroperoxyoctadecadienoic acid. Isomerase-controlled enzymatic and nonenzymatic processes and secondary decomposition of the hydroperoxides by lipoperoxides lead to the formation of several hydroxy acids. They reported that lipoxygenase activity is maximum at pH 6.75.

Most of the changes in oat lipids can be controlled by denaturing the lypolytic enzymes, particularly lipase. Industrially, groats are commonly steam-treated before rolling. Several laboratory methods have been suggested, including abrasion (32,33), treatment with 1N acid (32), or with 95% ethanol (9), and boiling or hydrothermal treatment (9,41). Frey and Hammond found boiling most effective but had no success with acid treatment (1N HCl for 30 min) or with abrasion. We successfully denatured lipase by soaking the groats in 1N HCl for only 30 sec but were unsuccessful with abrasion.

Among cereal grains, oats is unique, particularly in protein and lipid concentrations. Currently, U.S. oat breeders are giving much attention to protein but little to lipids. If future demands for food and feed energy increase, oat lipids should be emphasized because they have genetic potential for changes in both the lipid concentration and the degree of fatty acid saturation.

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