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Genetics, Characteristics, and Utilization of Oil in Caryopses of Oat Species
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ABSTRACT
For oats to be an economically feasible oilseed crop in Iowa, the oil percentage would have to be increased to ca. 16%. A survey of the oil percentage in 445 oat cultivars and collections gave a range of 2.0-11.0%. The oil percentage was only slightly affected by growing oats in 5 different locations in Iowa. Inheritance studies indicated that oil percentage was inherited polygenically, and there was a tendency for high oil percentage to be partially dominant. Analysis of 64 cultivars and collections showed a wide variation of fatty acid composition: palmitic, 14-23%; stearic, < 1-4%; oleic, 29-53%; linoleic, 24-48%; linolenic, < 1-5%. The oil percentage was positively correlated with oleic acid and negatively correlated with linoleic and linolenic acids. Oats contained a lipase that made extraction of oil with low acid values difficult. The lipase was strongly affected by moisture and was most active in oat doughs containing 25-50% moisture. There was at least a 20-fold variation in lipase activity in oat cultivars and collections. Whole oats may be kept in dry storage for several years without significant lipolysis, but in broken or crushed caryopses, lipolysis occurs even at low moisture levels. The lipase may be inactivated by heat or 95% ethanol treatments.

INDEX
358-362 GENETICS, CHARACTERISTICS, AND UTILIZATION OF OIL IN CARYOPSES OF OAT SPECIES, by K.J. Frey and E.G. Hammond
363-365 DEVELOPMENT OF A LOW GLUCOSINOLATE, HIGH ERUCIC ACID RAPESEED BREEDING PROGRAM, by W. Calhoun, J.M. Crane, and D.L. Stamp
366-369 CARBON-13 NUCLEAR MAGNETIC RESONANCE ANALYSIS OF INTACT OILSEEDS, by J. Schaefer and E.O. Stejskal
370-373 BREEDING FOR LIPID COMPOSITION IN CORN, by E.J. Weber and D.E. Alexander
374-376 RECENT RESEARCH ON SAFFLOWER, SUNFLOWER, AND COTTON, by P.F. Knowles
377-385 GENETIC STUDIES OF PEANUT PROTEINS AND OILS, by Y.P. Tai and C.T. Young
386-389 VARIATION IN CRAMBE, CRAMBE ABYSSINICA HOCHST, by K.J. Lessman

INTRODUCTION
A high proportion of the arable land in midwestern United States is devoted to the cultivation of corn and soybeans. This lack of crop diversity makes midwestern agriculture especially vulnerable to epidemics of insects and diseases, but it persists because no other crop adapted to the midwestern USA is as profitable as corn and soybeans. During the first half of the twentieth century, oats were a major crop in Iowa, but recently, they have proved less profitable than corn and soybeans. Currently, oats are grown with poor field husbandry on land that is too steep to be sown in corn or soybeans. If oats could be made more profitable, their acreage would be expanded, and Iowa agriculture would enjoy greater diversity. One way to make oats more profitable might be to grow them as an oilseed crop.

Traditionally, oats have not been used as a source of edible oil because: a) the amount of oil in the caryopses of commercial oat cultivars is quite low, generally ranging from 3.9-8.5%, according to Brown, et al., (1); and b) a potent lipase enzyme is extracted with the oat oil which causes rapid hydrolysis and deterioration of the oil quality, according to Hutchinson and Martin (2). However, Brown and Craddock (3) have analyzed lines from the World Oat Collection and found 25 lines with < 4.0% oil, 63 lines with > 10.0% oil, and 5 with > 11.0% oil. These results suggest that there is considerable genetic variation for this trait among cultivated oat lines. Baker and McKenzie (1), using crosses between low, medium, and high oil varieties, found that the heritability of oil percentage in oat caryopses varied from 68-93% except in 1 cross. These values predict that selection for oil percentage in oats would be accomplished with ease.
We undertook this study to obtain information about oat oil and its biology for use in deciding whether it would be possible to breed oats with sufficiently high oil content to make extraction profitable, and to study some problems associated with extracting the oil.

**MATERIALS AND METHODS**

**Oat Materials**

The materials used for our studies were carpoyses samples from oat genotypes representing several oat species (*Avena* spp.). For the survey of oil percentages, we used samples from 5 diploid species, *A. breviss*, *A. ludoviciana*, *A. pilosa*, *A. strigosus*, and *A. wiestei*, 1 tetraploid species, *A. barbata*, and 3 hexaploid species, *A. fatica*, *A. sativa*, and *A. sterilis*. These 445 collections and cultivars were grown in unreplicated hill plots spaced 75 cm apart in perpendicular directions with 80 plots per row. Three check cultivars of *A. sativa* were sown systematically at 20-plot intervals. Each plot was harvested and threshed when mature. From each plot, we dehulled 20 seeds, and this sample of carpoyses was used to determine the oil content via the nuclear magnetic resonance (NMR) method of Conway and Earle (5).

To determine the stability of oat genotypes in oil percentage, we used 6 cultivars, 'Multiline E73,' 'Grundy,' 'Clintford,' 'Otee,' 'O'Brien,' and 'Dal,' each grown at 6 locations in Iowa. Samples (5 g) of dehulled seeds of these cultivars were assayed for oil on a replicate basis. Five experiments had 3 replicates, and the other had only 2. A pooled analysis of variance was conducted on the data collected in this experiment.

For the inheritance study on oil percentage, we used 60-80 F₂ derived lines from each of 3 interspecific oat crosses and 10-20 lines from each parent. The crosses used were 'CI 8044' x 'B 439,' (Iowa accession numbers), 'Clintford' x 'B 449,' and 'Clintford' x 'B 440.' 'CI 8044' and 'Clintford' are *A. sativa* cultivars, and 'B 439' and 'B 440' are *A. sterilis* accessions. The F₂ derived lines were in F₂ when analyzed, and the intracultivar lines were derived as single plant progenies. F₂ derived and parental lines were in hill plots spaced 30 cm apart in perpendicular directions in a randomized design with 1 replicate. The block of plots was surrounded by 2 rows of hills to provide competition for all test plots. Twenty carpoysis samples of these lines were used for oil determinations.

The oat plants used in all of these studies were grown on highly fertile soil, and they were sprayed at weekly intervals from anthesis to maturity with a fungicide to control foliar diseases.

**Laboratory Methods**

The fatty acid composition of oats cultivars and collections was determined on 10 carpoyses of a cultivar after they were dried in a vacuum oven at 105 °C and crushed. The crushed carpoyses were extracted with 1 ml hexane, and an aliquot of the hexane solution was treated with 1 N sodium methoxide solution in methanol to convert the oil to methyl esters. The methyl esters were analyzed by gas chromatography on a 2 m EGSX column at 180 °C.

To screen oat cultivars and collections for lipase activity, 3 carpoyses from each type were pressed into tributyrin agar prepared according to Ellinghausen and Sandvik (6). After 24 hr at room temperature (ca. 25 °C), the size of the clear zones around the carpoyses was judged visually on a scale from 0-4. Zero represented no visible clear zone, and 4 represented a clear zone ca. 2 mm wide.

For a more exact determination of the lipase activity of oats, 5 carpoyses were weighed and crushed with a glass rod. Enough water was added to give 30% by wt of the carpoyses, and 50 μl of a 10% solution of soybean oil in heptane was added. After mixing thoroughly, the oat paste was left at 37 °C for 1 hr; then 10 ml chloroform:methanol (2:1, v:v) was added and mixed thoroughly to stop the reaction and extract the lipid. The chloroform:methanol extract was centrifuged, and the supernatant was collected, treated with 2.0 ml water, cooled in ice water, and centrifuged again. An aliquot of the chloroform layer was made to 4 ml with chloroform and heptane so that the ratio of heptane to chloroform in the final mixture was 1:1 (v:v). The free fatty acid content in the mixture was determined by the cobalt soap method of Novak (7).

In one study, we tested the relationship of grain moisture content and lipase activity. To obtain several grain moisture levels for storage, carpoyses were placed in desiccators containing anhydrous CaSO₄ and saturated solutions of NaNO₃, CaCl₂, and MgCl₂. The moisture level obtained after 4 months was determined by drying a sample at 110 °C overnight in a vacuum oven.

To test the effect of lipase inactivation procedures on the development of free fatty acids during fat extraction, 50 g of carpoyses were ground in a Wiley mill and extracted immediately in a Soxhlet apparatus with heptane. The solvent was evaporated, and the acid value of the residue was determined by AOCS method Cd 3a-63 (8).

**RESULTS AND DISCUSSION**

**The Economics of Producing Oat Oil**

The exact percentage of oil required to make oats profitable as an oilseed crop is an elusive figure, because the costs of production vary. Table 1 shows the return per acre for Iowa farmers growing oats, corn, and soybeans under typical conditions and assuming the only income was from selling grain at standard market prices (R.N. Wisner, personal communication, 1974). Of course, corn and soybeans are preferred because they produce more net income per acre than do oats. One way to make oat grain command a higher price would be to increase the oil and protein content of the seed without corresponding increases in production costs or loss in grain yield. The protein content of oats has increased from a typical value of 17% to 21% in some new cultivars, without a sacrifice in grain yield. Oat protein has the best biological value of the cereal proteins (9), but it is not as good as soy protein. On the other hand, oat protein does not have the toxic factors that soy protein has. The composition of oat oil suggests that it should be more stable than soybean oil. If one assumes that oat protein is worth about as much as soy protein, and that oat oil is worth as much as corn oil, the value of an oat cultivar with 21% protein and 17% oil would make oats as profitable as soybeans under typical conditions in Iowa. Most commercial varieties of oats now contain about 4-6% oil.

**Survey of Oil Content of Oat Species**

The results of our survey of oil percentages in oat cultivars and collections are shown in Table 2. Among the diploid species, the range of oil percentages was 3.5-9.0%, among tetraploid species, it was 5.5-8.0%, and among hexaploid species, it was 2.0-11.0%. The major portion of the hexaploid samples belonged to the species *A. sterilis*, a weedy species of oat that grows in the waste areas sur-