# Evaluation of the Nutrient Composition of Wheat. I. Lipid Constituents[1,2]

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ABSTRACT

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Nutrient composition was evaluated in wheats from five market classes: hard red winter (HRW), soft red winter (SRW), hard red spring (HRS), durum, and white in subclasses hard white winter (HWW), soft white winter (SWW), hard white spring (HWS), and soft white spring (SWS). Wheats comprised 290 samples, 124 varieties, three crop years, and 40 growing locations. This article presents a summary of the analyses for total fat, tocopherols, and fatty acid profiles. Total fat varied significantly by class and by crop year; some data indicated that they also varied by growing location. The range of total fat was from 0.88% for Wanser (HRW/Pendleton, OR/1973) to 3.33% for 6922A1-160 (SRW/Lafayette, IN/1975) with an overall mean of 2.34 ± 0.02% (all on a dry weight basis). α-Tocopherol content, in contrast, showed only small but significant differences by growing year. Total (α + β + γ + δ)-tocopherol content ranged from lows of 0.49 mg/100g for Avon (SWW/Ithaca, NY/1975) to 4.01 mg/100g for Coulee (HWW/Walla Walla, WA/1974). (β + γ)-Tocopherol content varied significantly by growing year and by class or subclass. γ-Tocopherol content varied significantly by crop year and class or subclass, and some data indicated that it also varied by growing locations. Fatty acid methyl esters (FAME) were analyzed by gas liquid chromatography and the results were expressed as the percent of the total FAME represented by each. Of the fatty acids evaluated, only oleate varied significantly by market class, and only oleate did not vary significantly by crop year. Linoleate, palmitate, and oleate comprised approximately 96% of the fatty acids. Palmitate comprised 11% of the fatty acids for Centurk (HRW/Altus, OK/1974) and ranged to 32% for Luke (SWW/Walla Walla, WA/1974) and Hyslop (SWW/Pendleton, OR/1974). Stearate ranged from none for many wheats to 4.6% of total FAME for Brookings (HRS/Brookings, SD/1975). Oleate ranged from 11% for Nugaines (SWW/Walla Walla, WA/1974) to 29% for Botno (durum/Brookings, SD/1975). Linolenate ranged from 0.71% for Winalta (HRW/Pondera, MT/1974) to 4.84% for Coulee (HWW/Pendleton, OR/1973). The most striking variability was in linoleate, which had a range from 45% for Botno (durum/Brookings, SD/1975) to 74% for Scout-66 (HRW/Altus, OK/1974). Data from Centurk grown in 11 locations demonstrated the problems in establishing standards to enforce Title 21 of the Code of Federal Regulations 121.3, which prohibits "Generally Recognized as Safe" status for new varieties that do not provide 80% or more of any nutrient for which that plant is considered to be a significant source.

Because wheat is a crop of great nutritional and economic importance, a baseline of information on the composition of a wide range of varieties in the common market classes of wheat is needed. Such information would be used to guide breeders and agronomists in developing varieties that are nutritious and meeting food labeling and Food and Drug Administration regulations.

The latter regulations are especially important because Title 21 of the Code of Federal Regulations 121.3 does not permit a new variety to be classed as Generally Recognized as Safe (GRAS) if "significant alteration of composition by breeding or selection" has occurred and if "the change may reasonably be expected to alter to a significant degree the nutritive value or the concentration of toxic constituents therein." A significant change was defined by the FDA as a decrease of 20% or more in any nutrient for which the plant is considered a significant source or an increase of 10% or more in a natural toxicant, when compared to the commercial variety or varieties that the new one is intended to replace (Crosby 1975). Wheat is a significant source of protein, thiamine, niacin, vitamin $B_6$, and magnesium.

As a result of this need for information, a cooperative project involving the University of Idaho (UI), Oregon State University (OSU), and Washington State University (WSU) was funded by the National Wheat Institute. The varieties and classes of wheat were selected from existing commercial varieties and from new genetic material. The samples of wheat were analyzed for proximate composition (OSU); 17 amino acids (OSU); vitamins—niacin (OSU), thiamine (OSU), riboflavin (OSU), $B_6$ (OSU), and tocopherols (UI); 12 minerals (OSU); amylase inhibitor (UI); fatty acid profiles (UI); and protein efficiency ratio by chick bioassay (WSU).

This report summarizes the information on the lipid constituents (crude fat, tocopherols, and fatty acid profiles) of wheats. Although the lipid fraction of wheat is relatively minor, tocopherols (vitamin E) and polyunsaturated fatty acids, especially linolenic and linoleic acids, are of interest nutritionally, functionally, and for their effect on storage stability.

## MATERIALS AND METHODS

Samples of wheat were obtained from wheat breeders across the United States. A sample consisted of one variety from one growing location for one crop year. During the three-year span of the project, the procedures for obtaining samples resulted in a large number of varieties (124) and locations (40), but only a few varieties were replicated in numerous locations for more than one crop year. Because of this sampling problem, the statistical analyses for variety or location effects can be considered only as indicators of trends. Variety effects are not discussed, and location effects are given only for general information.

The 124 varieties of wheat represented five market classes: hard red winter (HRW), hard red spring (HRS), soft red winter (SRW), durum, and white, the last in four subclasses—soft white winter (SWW), soft white spring (SWS), hard white winter (HWW), and hard white spring (HWS). The growing locations are summarized in Table I.[6] Following each year's harvest, samples of wheat were shipped to the three universities. At the University of Idaho, where lipid analyses were done, the samples were placed in moisture-proof bags and stored at −10° C until they were ground for analysis. The samples were analyzed as rapidly as possible in order to minimize changes during storage. All lipid assays were done in triplicate.

Fifty-gram samples of wheat were ground for 2 min in a CRC water-cooled micromill. "Total fat" as reported here was determined by overnight Soxhlet extraction of 10-g portions of wheat with 50 ml of hot ethanol. Following extraction, the ethanol was removed, using a rotary film evaporator. The hexane-soluble material was quantitatively filtered into a tared flask with 5 × 10-ml portions of hexane. The hexane was removed and the weight of the "total fat residue" determined. Ten milliliters of absolute ethanol, 10 ml of concentrated potassium hydroxide (160 g in 100 ml of distilled water), 5 g of ascorbic acid, and 2 g of propyl gallate were

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[6]Names of and analytical values for individual varieties are available from the authors.

added to the "total fat residue." The mixture was saponified under condensers for 15 min. The saponification mixture was transferred to a separatory funnel, and the flask was rinsed five times with distilled water and five times with absolute ethanol alcohol (5-ml portions). The unsaponifiable materials were extracted by adding 75 ml of hexane and gently swirling the mixture. After the phases separated, the lower aqueous phase was drawn off and put into a second separatory funnel. The hexane extraction was repeated and the portions combined and washed with a few milliliters of water. The unsaponifiable portion was used for tocopherol assay and the saponified portion for fatty acid profile determinations. All operations were done under subdued light to protect the tocopherols.

The unsaponifiable portion was chromatographed on a column of Florisil according to the method of Dicks-Bushnell and Davis (1967) and Davis (1973). The eluate containing the tocopherols was

**TABLE I**
**Wheat Classes and Growing Locations for the 1973, 1974, and 1975 Crop Years**

| Class or Subclass[a] | 1973 Locations | Number of Varieties[b] | 1974 Locations | Number of Varieties[b] | 1975 Locations | Number of Varieties[b] |
|---|---|---|---|---|---|---|
| SWW | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA | 9 | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA<br>Pullman, WA<br>Madras, OR<br>Ithaca, NY | 34 | Pendleton, OR<br>Corvallis, OR<br>Pullman, WA<br>Aberdeen, ID<br>Logan, UT<br>Ithaca, NY | 24 |
| SWS | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA | 3 | Aberdeen, ID<br>St. Anthony, ID<br>Sandpoint, ID<br>Pendleton, OR | 3 | Aberdeen, ID | 1 |
| HWW | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA | 1 | Pendleton, OR<br>Pomeroy, WA<br>Walla Walla, WA | 1 | | |
| HRW | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA | 4 | Pendleton, OR<br>Sherman Co., OR<br>Pomeroy, WA<br>Pullman, WA<br>Logan, UT<br>Ft. Collins, CO<br>Bozeman, MT<br>Glasgow, MT<br>Pondera, MT<br>Clay Center, NE<br>Meade, NE<br>Grant, NE<br>McCook, NE<br>North Platte, NE<br>Wauneta, NE<br>Altus, OK<br>Goodwell, OK<br>Lahoma, OK<br>Woodward, KS<br>Manhattan, KS<br>Bushland, TX | 8 | Pullman, WA<br>Aberdeen, ID<br>Ft. Collins, CO<br>Burlington, CO<br>Alliance, NE<br>Manhattan, KS<br>Bozeman, MT<br>Conrad, MT<br>St. Paul, MN<br>Lahoma, OK<br>Stillwater, OK<br>Perkins, OK<br>Bushland, TX<br>Brookings, SD | 29 |
| HRS | Pendleton, OR<br>Corvallis, OR<br>Walla Walla, WA | 3 | Pendleton, OR<br>Aberdeen, ID<br>Sandpoint, ID<br>St. Anthony, ID<br>Davis, CA<br>Bozeman, MT<br>Glasgow, MT<br>Pondera, MT<br>Langdon, ND<br>Brookings, SD<br>St. Paul, MN | 7 | Davis, CA<br>Aberdeen, ID<br>Brookings, SD<br>St. Paul, MN<br>Fargo, ND<br>Bozeman, MT<br>Conrad, MT<br>Bridger, MT<br>Malta, MT | 17 |
| SRW | | | Lafayette, IN<br>Raleigh, NC<br>Blacksburg, VA | 3 | Pullman, WA<br>Lafayette, IN | 8 |
| HWS | | | Pendleton, OR<br>Sherman County, OR | 2 | | |
| Durum | | | Langdon, ND<br>Minot, ND<br>Ellensburg, WA | 4 | Brookings, SD<br>Fargo, ND<br>St. Paul, MN<br>Conrad, MT | 6 |

[a] HRW = hard red winter, HRS = hard red spring, SRW = soft red winter. Subclasses of white: SWW = soft white winter, SWS = soft white spring, HWW = hard white winter, HWS = hard white spring.
[b] Number of varieties evaluated in each class or subclass this crop year.

reduced to dryness, dissolved in isooctane or hexane containing *n*-octacosane as an internal standard, and then subjected to gas liquid chromatography (GLC). The analysis of α-tocopherols, β + γ-tocopherols, and δ-tocopherols was done on a Packard 7400 Series gas chromatograph equipped with a dual flame ionization detector and a 6 ft × 4-mm pyrex column filled with 5% SE-30 silicone gum rubber phase on 100–200 mesh Gas Chrom Q[7]. β-Tocopherols and γ-tocopherols eluted from the column as one peak and are reported together (Slover et al 1967, 1969).

The saponified portion of the lipid extract was acidified with 20–30 ml of 4*N* HCl. The liberated fatty acids were extracted with 75 ml of hexane, either by 20 min of agitation on a shaker or by standing overnight. The mixture was transferred to a separatory funnel, and quantitative transfer was accomplished by rinsing the container with three 5-ml portions of hexane. Emulsion formation was a problem, but the addition of a few milliliters of absolute ethanol was effective in breaking an emulsion. The aqueous phase was discarded, and the hexane phase was quantitatively transferred to a round-bottomed flask and evaporated to dryness with a rotary film evaporator. The fatty acids were quantitatively transferred with hexane to 6-ml or 10-ml hypovials.

As an internal standard, 0.5 ml of heptadecanioc acid methyl ester (0.5% in isooctane) was added to the vial. The contents were evaporated to dryness in a block heater under a stream of nitrogen. Methylation was done with 4.5 ml of $BF_3$-methanol (14%) for 2 min according to Metcalf et al (1963). The fatty acid methyl esters (FAME) were identified and quantified by using a Barber-Coleman Series 5000 model gas chromatograph equipped with a flame ionization detector and a temperature programmer. The samples were injected onto a 6-ft × 4-mm pyrex column filled with 15% Hi-Eff 1 BP[7] polyester diethylene glycol succinate liquid phase on 100–200 mesh Gas Chrom Q.[7] The temperature was programmed to rise from 150 to 200° C at 4° per min. Methyl-heptadecanoate was used as an internal standard. A FAME standard [7] containing both saturated and unsaturated fatty acids was used to aid in the identification of the fatty acids.

Analysis of variance (ANOVA) was done by computer using the Harvey Procedure of the Statistical Analysis System (Harvey 1977). The least significant differences (LSD) were calculated according to Steel and Torrie (1960) only when significant F values were found with ANOVA.

## RESULTS AND DISCUSSION

### Total Fat

The total fat content of the ground whole wheat ranged from 0.88% for Wanser (HRW/Pendleton, OR/1973) to 3.33% on a moisture free basis for 6922A1-160 (SRW/Lafayette, IN/1975). Information in the parentheses gives class or subclass, growing location, and crop year. The class mean values are presented in Table II. The class mean for all years, annual mean for all classes, and the overall mean are summarized in Table III. ANOVA gave statistically significant differences in total fat content by class, by year, and by location. The LSD by years showed that, overall, the 1975 crop year wheats had significantly greater fat content (2.46%) than did wheats from the 1973 crop (2.29%) and the 1974 crop

[7]Available from Applied Science Laboratories, State College, PA.

**TABLE II**
**Fat and Tocopherol Contents of Wheat by Class and Year[a,b]**

| Class or Subclass[c] | Year | Number of Samples | Fat (%) | Tocopherols, mg/100g | | |
|---|---|---|---|---|---|---|
| | | | | α | β + γ | δ |
| SWW | 1973 | 22 | 2.27 ± 0.05a | 1.64 ± 0.15a | 0.51 ± 0.04b | 0.53 ± 0.03b |
| | 1974 | 35 | 2.15 ± 0.02b | 1.88 ± 0.13a | 1.44 ± 0.05a | 2.22 ± 0.09a |
| | 1975 | 31 | 2.26 ± 0.04a | 0.79 ± 0.07b | 0.27 ± 0.02c | 0.28 ± 0.02c |
| | Mean ± 20% | | 1.78–2.66 | 1.14–1.72 | 0.63–0.95 | 0.89–1.33 |
| SWS | 1973 | 7 | 2.26 ± 0.09 | 1.41 ± 0.26a | 0.58 ± 0.06b | 0.56 ± 0.07 |
| | 1974 | 6 | 2.08 ± 0.17 | 1.84 ± 0.23a | 1.75 ± 0.31a | 2.90 ± 0.80 |
| | 1975[d] | 1 | 2.30 ± 0.00 | 0.47 ± 0.00b | 0.19 ± 0.00b | 0.20 ± 0.00 |
| | Mean ± 20% | | 1.75–2.63 | 1.22–1.84 | 0.85–1.27 | 1.23–1.85 |
| HWW | 1973 | 3 | 2.12 ± 0.17a | 1.78 ± 0.55 | 0.57 ± 0.12a | 0.46 ± 0.01a |
| | 1974 | 3 | 1.66 ± 0.17b | 1.60 ± 0.41 | 1.83 ± 0.59b | 4.07 ± 1.44b |
| | Mean ± 20% | | 1.51–2.27 | 1.35–2.03 | 0.96–1.44 | 1.80–2.72 |
| HRW | 1973 | 7 | 2.17 ± 0.26a | 1.72 ± 0.20a | 0.55 ± 0.04b | 0.65 ± 0.03b |
| | 1974 | 57 | 2.27 ± 0.03ac | 2.17 ± 0.15a | 0.90 ± 0.08a | 1.24 ± 0.12a |
| | 1975 | 39 | 2.39 ± 0.05ab | 0.73 ± 0.06b | 0.29 ± 0.03c | 0.32 ± 0.02c |
| | Mean ± 20% | | 1.85–2.77 | 1.28–1.92 | 0.51–0.77 | 0.68–1.02 |
| HRS | 1973 | 7 | 2.57 ± 0.09a | 1.64 ± 0.26b | 0.50 ± 0.05b | 0.53 ± 0.04b |
| | 1974 | 18 | 2.42 ± 0.06ab | 2.46 ± 0.25a | 1.53 ± 0.18a | 1.81 ± 1.25a |
| | 1975 | 21 | 2.59 ± 0.05ac | 0.63 ± 0.07c | 0.20 ± 0.01c | 0.21 ± 0.01c |
| | Mean ± 20% | | 2.02–3.02 | 0.80–1.20 | 0.62–0.92 | 0.70–1.06 |
| SRW | 1974 | 6 | 2.45 ± 0.12 | 2.25 ± 0.42a | 1.23 ± 0.29a | 2.21 ± 0.75a |
| | 1975 | 8 | 2.66 ± 0.16 | 0.98 ± 0.11b | 0.22 ± 0.03b | 0.25 ± 0.01b |
| | Mean ± 20% | | 2.06–3.08 | 1.22–1.82 | 0.52–0.78 | 0.87–1.31 |
| HWS | 1974 | 2 | 1.90 ± 0.44 | 2.60 ± 0.56 | 2.38 ± 0.12 | 4.88 ± 0.86 |
| | Mean ± 20% | | 1.52–2.28 | 2.09–3.03 | 1.90–3.76 | 3.90–5.86 |
| Durum | 1974 | 7 | 2.69 ± 0.07 | 2.78 ± 0.31a | 1.25 ± 0.06a | 1.57 ± 0.08a |
| | 1975 | 10 | 2.89 ± 0.10 | 0.52 ± 0.09b | 0.24 ± 0.03b | 0.19 ± 0.01b |
| | Mean ± 20% | | 2.25–3.37 | 1.21–1.81 | 0.52–0.78 | 0.60–0.90 |

[a]All values are mean ± standard error of the mean on a moisture free basis.
[b]Within each class in a column, values followed by different letters are different from each other at the 0.05 level of significance using the LSD test (Steele and Torrie 1960).
[c]HRW = hard red winter, HRS = hard red spring, SRW = soft red winter. Subclasses of white: SWW = soft white winter, SWS = soft white spring, HWW = hard white winter, HWS = hard white spring.
[d]No LSD calculated because of few observations and only one year represented.

(2.26%). This trend was apparent, if not significant, for all classes represented in the 1975 crop year. Of the classes, durum wheats had the highest fat content (2.81%) and HWW had the lowest (1.89%). This trend was apparent in any crop year where either class was represented.

This range of fat values compares favorably with values reported by others: 2.52–3.3% (Pomeranz et al 1966), 1.4–2.6% (Shollenberger et al 1949), and an overall range of 0.91–3.8%, as summarized by Mecham (1971). The values obtained by Pomeranz et al (1966) were obtained using water-saturated butanol (WSB) as an extractant, whereas Shollenberger et al (1949) used petroleum ether (PE) and this study used ethanol. Graveland (1968) reported, "The amount of lipid extracted from flour is enhanced by increasing polarity of the solvent. If a solvent contains ethanol or methanol, its effectiveness is greatly enhanced, especially for polar lipids. The presence of water slightly increases extractability." Ethanol is intermediate in polarity between PE and WSB, and therefore our results are intermediate between those of Shollenbergber et al (1949) and Pomeranz et al (1966).

**Tocopherols**

When pure tocopherols were subjected to the entire range of analytical procedures through chromatography on Florisil, recoveries for $\alpha$-tocopherols, $\beta$-tocopherols, and $\delta$-tocopherols were 101, 87, and 99%, respectively. The mean values on a moisture free basis for the individual tocopherols are summarized in Tables II and III. Total ($\alpha + \beta + \gamma + \delta$)-tocopherol content ranged from lows of 0.49 mg/100 g for Avon (SWW/Ithaca, NY/1975), 0.59 mg/100 g for Hyslop (SWW/Pendleton, OR/1975), and 0.60 mg/100 g for Scout (HRW/Manhattan, KS/1975) to a high of 4.01 mg/100 g for Coulee (HWW/Walla Walla, WA/1974). This range was greater than the range of 4.3–5.8 mg/100 g previously reported (Green 1958; Hall and Laidman 1968; Slover 1971; Slover et al, 1967, 1969). SWS in 1975 with 0.86 mg of total tocopherols per 100 g was the lowest for any class in any year and represented only one sample. HWS in 1974 with 9.86 mg/100 g had the highest amount for any class in any year but represented only two samples. Generally, samples from the 1974 wheat crop contained greater amounts of total tocopherols; in the cases of HWS (1974) with 9.86 mg/100 g and HWW (1974) with 7.50 mg/100 g, the increased levels were due primarily to a very high content of $\delta$-tocopherol (Table II).

Since $\alpha$-tocopherol is considered to be the most biologically active form of vitamin E, the relatively narrow range of the $\alpha$-tocopherol content of all wheats is interesting. $\alpha$-Tocopherol content varied significantly only by growing year and was significantly less in 1975 than in earlier years. When the differences in tocopherol contents were considered by year, wheat grown in 1974 had significantly greater tocopherol content (2.15 mg/100 g) than did wheat grown in 1973 (1.63 mg/100 g), and 1973 wheat samples had significantly more tocopherol than did 1975 (0.73 mg/100 g) wheat samples. These differences by year were much larger than the differences by class, suggesting that growing conditions can markedly affect the tocopherol content of the wheat. Much of the wheat in 1974 was harvested during a rainy season. High amylase values[8] in some of the samples indicated that the wheat had begun to germinate. Germination may be one major cause of the differences related to the year of harvest. Fordham et al (1975) observed that, on a wet weight basis, pea and bean sprouts 4–6 days old contained considerably less lipid and tocopherol than did the seeds, but if their values were converted to a dry weight basis, the lipid and tocopherol content increased at least twice.

($\beta + \gamma$)-Tocopherols had significant differences by both year and class (Table III). Wheats grown in 1974 (1.24 mg/100 g) had significantly more ($\beta + \gamma$)-tocopherols than did those grown in 1973 (0.5 mg/100 g), and those in 1973 had significantly more than those grown in 1975 (0.25 mg/100 g). HWS had significantly more ($\beta + \gamma$)-tocopherols (1.24 mg/100 g) and $\delta$-tocopherols (4.88 mg/100 g) than did the other classes or subclasses; however this represented only two samples and might not be truly representative of the class. Durum wheats (0.66 mg/100 g) contained significantly less $\delta$-tocopherols than did the other classes. Overall, no other significant class effects in the tocopherol content of wheat were found.

**Fatty Acid Profiles**

Data on the major fatty acids in wheat are summarized in Tables IV and V. Recovery experiments were not run and results are therefore expressed in relative amounts, the percent of total fatty acids represented by each fatty acid. The standard FAME mixtures contained methyl esters of the saturated fatty acids 8 (capyrlate), 10 (caprate), 12 (laurate), 14 (myristate), 16 (palmitate), 18 (stearate), 20 (arachidate), and 22 (behenate) and of the unsaturated fatty acids 14:1 (myristoleate), 16:1 (palmitoleate), 18:1 (oleate), 18:2 (linoleate), 18:3 (linolenate), 20:1 (eicosenoate), and 22:1 (erucate).

In some wheat samples (notably in the 1973 crop), peaks representing less than 1% of the total fatty acids were found for caprate, laurate, myristate, and other unidentified peaks. Stearate and linolenate were usually present in the range of 1–3% each. Linoleate, palmitate, and oleate were the three major fatty acids

[8]Unpublished data.

**TABLE III**
**Fat and Tocopherol Contents of Wheat by Classes (Three Years Combined) and by Year (All Classes Combined)[a,b]**

| Class or Subclass[c] | Year | Number of Samples | Fat (%) | Tocopherols, mg/100 g | | |
|---|---|---|---|---|---|---|
| | | | | $\alpha$ | $\beta + \gamma$ | $\delta$ |
| SWW | All | 88 | 2.22 ± 0.02cde | 1.43 ± 0.08b | 0.79 ± 0.06b | 1.11 ± 0.10b |
| SWS | All | 14 | 2.19 ± 0.08df | 1.53 ± 0.19b | 1.06 ± 0.21b | 1.54 ± 0.46b |
| HWW | All | 6 | 1.89 ± 0.15f | 1.69 ± 0.31b | 1.20 ± 0.39b | 2.26 ± 1.02b |
| HRW | All | 103 | 2.31 ± 0.03bcd | 1.60 ± 0.11b | 0.64 ± 0.05b | 0.84 ± 0.08b |
| HRS | All | 46 | 2.52 ± 0.04abc | 1.50 ± 0.16b | 0.77 ± 0.12b | 0.88 ± 0.15b |
| SRW | All | 14 | 2.57 ± 0.10ab | 1.52 ± 0.25b | 0.65 ± 0.18b | 1.09 ± 0.41b |
| HWS | All | 2 | 1.90 ± 0.44f | 2.60 ± 0.56a | 2.38 ± 0.12a | 4.88 ± 0.86a |
| Durum | All | 17 | 2.81 ± 0.07a | 1.58 ± 0.27 | 0.60 ± 1.11b | 0.66 ± 0.16c |
| All | 1973 | 46 | 2.29 ± 0.05a | 1.63 ± 0.10a | 0.53 ± 0.02b | 0.55 ± 0.02b |
| All | 1974 | 134 | 2.26 ± 0.02a | 2.15 ± 0.09b | 1.24 ± 0.05a | 1.82 ± 0.10a |
| All | 1975 | 110 | 2.46 ± 0.03b | 0.73 ± 0.08c | 0.25 ± 0.01c | 0.27 ± 0.01c |
| Overall | | 290 | 2.34 ± 0.02 | 1.53 ± 0.06 | 0.74 ± 0.04 | 1.01 ± 0.06 |
| Mean ± 20% | | ... | 1.87–2.81 | 1.22–1.84 | 0.61–0.91 | 0.82–1.22 |

[a]All values are mean ± standard error of the mean on a moisture free basis.
[b]Within a column, values followed by different letters are different from each other at the 0.05 level of significance using the LSD test (Steele and Torrie 1960).
[c]HRW = hard red winter, HRS = hard red spring, SRW = soft red winter. Subclasses of white: SWW = soft white winter, SWS = soft white spring, HWW = hard white winter, HWS = hard white spring.

observed, and together they constituted, on the average, over 96% of the fatty acids of the ethanol-hexane extract of whole ground wheat.

Palmitate's lows were 11% of total FAME for Centurk (HRW/Altus, OK/1974) and 12% for Moro (SWW/Corvallis, OR/1973) and Yamhill (SWW/Corvallis, OR/1973). Its highs were 31% for Ward (durum/Langdon, ND/1974), Beca (HRW/Ft. Collins, CO/1975), Borah (HRS/Aberdeen, ID/1975), and Luke (SWW/Pullman, WA and Pendleton, OR/1974) and 32% for Luke (SWW/Walla Walla, WA/1974) and Hyslop (SWW/Pendleton, OR/1974). ANOVA gave significant differences in palmitate for growing location and year. However, a significant interaction was demonstrated by the fact that in 1974 Corvallis produced SWW wheats containing the lowest palmitate content (Moro and Yamhill with 12%) as well as with quite high content (Luke with 32%). Class mean values ranged from 21% for SWS and HWW to 26% for durum wheats. The significant differences by LSD are shown in Table V. Differences in growing year were quite marked, 16% for 1973 and 25% for 1974 and 1975. The lower value in 1973 for palmitate was accompanied by the appearance of numerous other smaller peaks. Garton et al (1963) and Mihailovic et al (1963) reported the presence of C13 and C17 fatty acids in Italian and Yugoslav wheats.

The stearate low was none in many varieties, including the following from the 1974 crop, each from several locations: Waldron (HRS), Anza (HRS), Fortuna (HRS), Borah (HRS), Arthur (SRW), and Coulee (HWW). Highs were 4.64% for Brookings (HRS/Brookings, SD/1975), 3–4% for Scout (HRW/Ft. Collins, CO/1975), Hyslop (SWW/Pendleton, OR/1975), K-126-1-2 (SWW/Pendleton, OR/1975), and OR7147 (SWW/Pendleton, OR/1975). Class means ranged from 0.65% for HWW to 1.35% for SWW. The significant differences as shown by the LSD are presented in Table V. Significant differences were found by year, with 1975 (1.80%) greater than the other two years.

Oleate ranged from lows of 11% for Nugaines (SWW/Walla Walla, WA/1973), Scout 66 (HRW/Meade, NE/1974), and Nugaines (SWW/Pullman, WA/1974) to a high of 29% for Botno (durum/Brookings, SD/1975). Class means ranged from 15% for SWW to 21% for durum. The significant differences determined by the LSD are shown in Table V. Significant differences were found by year; 1973 wheats had a lower content of oleate (15%) than did 1974 and 1975.

Linoleate was by far the major fatty acid, with mean class values of 50% (durum) to 59% (SWS and HWW). Linoleate content in individual varieties ranged from lows of 44% for Botno (durum/Brookings, SD/1975) and 45% for Era (HRS/Brookings, SD/1975) to highs of 73% for Centurk (HRW/Altus, OK/1974) and Scout 66 (HRW/Meade, NE/1974) and of 74% for Scout 66 (HRW/Bushland, TX/1974). Significant differences between classes and between years were shown by the LSD, with the difference in years being most apparent (Tables IV and V). The linoleate content of 1973 wheats (61%) was much higher than that of the other two years. According to Morrison (1975), the lipolysis that occurs during storage at ambient temperatures may alter gluten and dough-forming properties. However, Garton et al (1963) found that phospholipids can have a transient form of linoleic acid that

**TABLE IV**
**Fatty Acid Profiles of Wheat by Class and Year[a,b]**

| Class or Subclass[c] | Year | Number of Samples | Percent of Fatty Acids Represented by | | | | |
|---|---|---|---|---|---|---|---|
| | | | Palmitic 16 | Stearic 18 | Oleic 18:1 | Linoleic 18:2 | Linolenic 18:3 |
| SWW | 1973 | 22 | 17 ± 1.07b | 1.00 ± 0.09b | 14 ± 0.61a | 61 ± 2.24a | 2.99 ± 0.31 |
| | 1974 | 35 | 28 ± 0.37a | 1.05 ± 0.12b | 16 ± 0.36b | 53 ± 0.54b | 2.51 ± 0.07 |
| | 1975 | 31 | 27 ± 0.31a | 1.94 ± 0.10a | 15 ± 0.43a | 54 ± 0.54b | 2.07 ± 0.06 |
| | Mean ± 20% | | 20–30 | 1.08–1.62 | 12–18 | 44–66 | 1.98–2.98 |
| SWS | 1973 | 7 | 15 ± 0.97b | 0.81 ± 0.09b | 14 ± 0.41c | 66 ± 1.24a | 3.22 ± 0.21a |
| | 1974 | 6 | 27 ± 0.50a | 0.22 ± 0.22c | 18 ± 0.65a | 53 ± 0.34b | 2.36 ± 0.11b |
| | 1975[d] | 1 | 27 ± 0.00a | 2.16 ± 0.00a | 16 ± 0.00b | 53 ± 0.00b | 2.14 ± 0.00b |
| | Mean ± 20% | | 16.8–25.2 | 0.43–0.78 | 12.8–19.2 | 47.2–70.8 | 2.22–3.32 |
| HWW | 1973 | 3 | 14 ± 0.45b | 1.3 ± 0.16a | 13 ± 0.84b | 66 ± 0.49a | 3.65 ± 0.60a |
| | 1974 | 3 | 27 ± 0.02a | 0.0 ± 0.00b | 18 ± 1.60a | 53 ± 0.72b | 2.39 ± 0.06b |
| | Mean ± 20% | | 16.8–25.2 | 0.42–0.78 | 12.8–19.2 | 47.2–70.8 | 2.42–3.62 |
| HRW | 1973 | 7 | 18 ± 0.61c | 1.02 ± 0.11b | 18 ± 1.31 | 58 ± 4.09a | 3.21 ± 0.21a |
| | 1974 | 57 | 22 ± 0.65b | 1.10 ± 0.07b | 19 ± 0.44 | 56 ± 1.00a | 2.22 ± 0.08b |
| | 1975 | 39 | 25 ± 0.37a | 1.61 ± 0.08a | 19 ± 0.44 | 53 ± 0.40ab | 1.99 ± 0.09b |
| | Mean ± 20% | | 17.6–26.4 | 1.02–1.54 | 15.2–22.8 | 44–66 | 1.81–2.71 |
| HRS | 1973 | 7 | 16 ± 1.68b | 1.00 ± 0.14b | 19 ± 1.15 | 59 ± 3.48 | 2.59 ± 0.08a |
| | 1974 | 18 | 25 ± 0.67a | 0.66 ± 0.20b | 20 ± 0.54 | 53 ± 0.44 | 2.06 ± 0.11b |
| | 1975 | 21 | 25 ± 0.52a | 1.88 ± 0.16a | 19 ± 0.58 | 53 ± 0.60 | 1.53 ± 0.06c |
| | Mean ± 20% | | 19.2–28.8 | 1.03–1.52 | 15.2–22.8 | 43.2–54.8 | 1.52–2.28 |
| SRW | 1974 | 6 | 24 ± 0.66a | 0.64 ± 0.30b | 20 ± 1.46 | 54 ± 0.75 | 2.52 ± 0.19 |
| | 1975 | 8 | 21 ± 0.61b | 1.54 ± 0.09a | 21 ± 0.67 | 55 ± 0.88 | 2.43 ± 0.13 |
| | Mean ± 20% | | 17.2–26.4 | 0.92–1.38 | 16–24 | 43.2–54.8 | 1.98–2.96 |
| HWS[d] | 1974 | 2 | 24 ± 0.48 | 0.00 ± 0.00 | 20 ± 0.32 | 54 ± 0.12 | 2.23 ± 0.04 |
| | Mean ± 20% | | 19.2–28.8 | ··· | 16–24 | 43.2–54.8 | 1.78–2.65 |
| Durum | 1974 | 7 | 27 ± 0.79a | 0.32 ± 0.22b | 20 ± 1.04 | 50 ± 0.64 | 2.02 ± 0.10a |
| | 1975 | 10 | 25 ± 0.65b | 2.12 ± 0.08a | 22 ± 1.05 | 50 ± 0.96 | 1.60 ± 0.11b |
| | Mean ± 20% | | 20.8–31.2 | 1.10–1.66 | 16.8–25.2 | 50–60 | 1.42–2.11 |

[a] Values are the mean ± standard error of the mean on a moisture free basis.
[b] Within each column and class, values followed by different letters are different from each other at the 0.05 level of significance using the LSD test (Steele and Torrie 1960).
[c] HRW = hard red winter, HRS = hard red spring, SRW = soft red winter. Subclasses of white: SWW = soft white winter, SWS = soft white spring, HWW = hard white winter, HWS = hard white spring.
[d] No LSD calculated because of few samples and only one year of observation.

appears as a doublet peak. They reported that the transient form acts as an oxygen transfer agent in the oxidation of sulfur bonds during baking. The doublet, formed in the presence of oxidizing agents or following storage of ground samples, disappears after baking. The transient form was found to be polymerized linoleic acid. Furthermore, increased linoleic acid content and the ability to form the polymers is directly correlated with baking quality. According to Morrison (1975), however, starch lipids contain 82–86% of the flour phospholipids. Although data on phospholipids and baking quality are not available for the wheats in this study, marked differences in baking quality would presumably be found between wheats with 44% of the FAME as linoleate and wheats with 74% as linoleate.

Linolenate was a minor constituent but has nutritional importance and important effects on keeping quality in milled products and on baking quality (Pratt 1971). In individual varieties, linolenate ranged from lows of 0.71% for Winalta (HRW/Pondera, MT/1974) and 0.8% for Itana (HRW/Aberdeen, ID/1975) to highs of 4.02% for Franklin (HWW/Pendleton, OR/1973), 4.43% for Twin (SWS/Pendleton, OR/1973), and 4.84% for Coulee (HWW/Pendleton, OR/1973). No significant differences between classes were found by LSD, but the years were significantly different, with 1975 (3.00%) greater than 1974 (2.29%) and 1974 greater than 1973 (1.93%) as shown in Table V.

The results were not unlike those of Morrison et al (1975) and Welch (1975). Wheat flour lipids (WSB extract) contained 15% palmitate, 1.13% stearate, 14% oleate, 66% linoleate, and 5.13% linolenate (Morrison et al 1975, calculated to percent basis). Whole grain lipids (acidified methanol extract) contained 15.4–23.9% palmitate, 0.92–2.45% stearate, 18.8–35% oleate, 43.5–53.0% linoleate, and 1.76–3.59% linolenate (Welch 1975). The overall mean FAME distribution in the wheats in this study were 23.50% palmitate, 1.27% stearate, 17.7% oleate, 54.7% linoleate, and 2.27% linolenate.

Factors that have been associated with alterations of fatty acid composition in wheat include growing temperature, crop year, growing location, and fertilizer (Welch 1975). Welch reported that colder growing temperature can result in increased lipid content and an increased amount of unsaturation. Germination can probably also alter the fatty acid pattern.

Location effects have been alluded to in various sections of this article. Due to the sampling problems, location effects must be viewed with caution. As an indicator, however, comparison of the $\alpha$-tocopherol content of Centurk (HRW/1974) grown in 11 locations (Table VI) is interesting. The values ranged from 0.45 mg/100 g (Clay Center, NE) to 4.09 mg/100 g (Ft. Collins, CO),

**TABLE V**
**Fatty Acid Profiles by Class (Three Years Combined) and by Year (All Classes Combined)[a,b]**

| Class or Subclass[c] | Year | Number of Samples | Percent of Fatty Acids Represented by | | | | |
|---|---|---|---|---|---|---|---|
| | | | Palmitic 16 | Stearic 18 | Oleic 18:1 | Linoleic 18:2 | Linolenic 18:3 |
| SWW | All | 88 | 25 ± 0.5a | 1.35 ± 0.08a | 15 ± 0.26a | 55 ± 0.73ab | 2.48 ± 0.06 |
| SWS | All | 14 | 21 ± 1.76b | 0.66 ± 0.17b | 16 ± 0.63a | 59 ± 2.00a | 2.77 ± 0.17 |
| HWW | All | 6 | 21 ± 2.95b | 0.65 ± 0.30b | 16 ± 1.37a | 59 ± 2.86a | 3.02 ± 0.39 |
| HRW | All | 103 | 22 ± 0.44b | 1.28 ± 0.06a | 19 ± 0.31b | 55 ± 0.64ab | 2.26 ± 0.06 |
| HRS | All | 46 | 24 ± 0.63a | 1.27 ± 0.14a | 19 ± 0.38b | 54 ± 0.67ab | 1.90 ± 0.08 |
| SRW | All | 14 | 22 ± 0.60b | 1.15 ± 0.72a | 20 ± 0.72b | 54 ± 0.59ab | 2.47 ± 0.11 |
| HWS | All | 2 | 24 ± 0.48a | ··· c | 20 ± 0.32b | 54 ± 0.12ab | 2.23 ± 0.04 |
| Durum | All | 17 | 26 ± 0.07a | 1.38 ± 0.24a | 21 ± 0.76bc | 50 ± 0.61bc | 1.77 ± 0.09 |
| All | 1973 | 46 | 16 ± 0.64a | 0.99 ± 0.05a | 15 ± 0.50b | 61 ± 1.38a | 3.00 ± 0.09a |
| All | 1974 | 134 | 25 ± 0.38b | 0.88 ± 0.06a | 18 ± 0.27a | 54 ± 0.47b | 2.29 ± 0.05b |
| All | 1975 | 110 | 25 ± 0.25b | 1.80 ± 0.05b | 18 ± 0.20a | 53 ± 0.27b | 1.93 ± 0.05c |
| Overall | | 290 | 23.50 ± 0.28 | 1.27 ± 0.04 | 17.67 ± 0.20 | 54.83 ± 0.36 | 2.27 ± 0.04 |
| Mean ± 20% | | ··· | 18.86–28.28 | 1.00–1.50 | 13.90–20.84 | 43.78–65.68 | 1.82–2.72 |

[a] All values are mean ± standard error of the mean on a moisture free basis.
[b] Within a column, values followed by different letters are different from each other at the 0.05 level of significance using the LSD test (Steele and Torrie 1960).
[c] HRW = hard red winter, HRS = hard red spring, SRW = soft red winter. Subclasses of white: SWW = soft white winter, SWS = soft white spring, HWW = hard white winter, HWS = hard white spring.

**TABLE VI**
**Composition of Centurk[a] from the 1974 Crop Grown in 11 Locations**

| Growing Location | Fat[b] (%) | Tocopherols[b], mg/100 g | | | Percent of Fatty Acids Represented by | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\alpha$ | $\beta + \gamma$ | $\delta$ | Palmitic 16 | Stearic 18 | Oleic 18:1 | Linoleic 18:2 | Linolenic 18:3 |
| Ft. Collins, CO | 2.48 | 4.09 | 1.70 | 1.53 | 21 | 0.72 | 22 | 52 | 2.97 |
| Manhattan, KS | 2.58 | 2.88 | 1.13 | 0.91 | 21 | 0.40 | 22 | 53 | 2.20 |
| Bozeman, MT | 2.14 | 3.33 | 1.57 | 1.46 | 21 | 0.45 | 22 | 53 | 2.62 |
| N. Platte, NE | 2.44 | 1.33 | 0.77 | 0.74 | 17 | 0.56 | 21 | 58 | 3.45 |
| Clay Center, NE | 2.54 | 0.45 | 0.19 | 0.29 | 13 | 0.54 | 17 | 65 | 3.26 |
| Meade, NE | 3.04 | 0.95 | 0.35 | 0.35 | 11 | 0.66 | 13 | 71 | 2.63 |
| Goodwell, OK | 2.60 | 1.31 | 0.63 | 0.46 | 11 | 0.76 | 13 | 71 | 2.60 |
| Altus, OK | 2.93 | 0.98 | 0.36 | 0.35 | 11 | 0.27 | 13 | 73 | 2.44 |
| Wauneta, NE | 2.25 | 2.13 | 1.35 | 3.61 | 26 | 0.58 | 18 | 52 | 2.56 |
| McCook, NE | 2.27 | 3.24 | 2.12 | 4.00 | 26 | 0.40 | 17 | 55 | 2.02 |
| Grant, NE | 2.30 | 0.73 | 0.30 | 0.38 | 25 | 0.95 | 19 | 53 | 2.66 |
| Mean ± SE[c] | 2.50 ± 0.28 | 1.96 ± 1.24 | 0.95 ± 0.66 | 1.28 ± 1.33 | 18 ± 6.01 | 0.57 ± 0.19 | 18 ± 3.62 | 60 ± 8.53 | 2.67 ± 0.42 |

[a] Hard red winter wheat.
[b] Moisture free basis.
[c] Standard error of the mean.

almost a 10-fold difference. In the samples, palmitate had a range from 11% (Altus, OK) to 26% (Wauneta, NE), stearate from 0.27% (Altus, OK) to 0.95% (Grant, NE), oleate from 13% (Altus, OK) to 22% (Bozeman, MT), linoleate from 52% (Ft. Collins, CO and Wauneta, NE) to 73% (Altus, OK). Unfortunately, these samples were not repeated in the same locations for a second year.

This Centurk data would have important ramifications if the GRAS regulations were applied to some of the lipid components of wheat. The mean-minus-20% value of $\alpha$-tocopherol for HRS (Table II) is 1.20 mg/100 g. Using the class mean as the criterion, if Centurk from Clay Center ($\alpha$-tocopherol, 0.45 mg/100 g) were to be introduced as a new variety, it would not be accepted under the regulation. The palmitate mean-minus-20% value for HRS (Table IV) is 19.2%. Centurk from Altus, OK, (11%) contains less than 19.2%. If the GRAS regulations are to be applied to wheat, the implications hinted at here must be extensively evaluated. The chemical composition of wheat differs markedly between varieties, between classes, and between locations. The establishment of a suitable standard or set of standards is an enormous task.

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## LITERATURE CITED

CROSBY, E. A. 1975. GRAS regulations: concerns of the food processing industry. HortScience 10:8.

DAVIS, K. C. 1973. Vitamin E content of selected baby foods. J. Food Sci. 38:442.

DICKS-BUSHNELL, M. W., and DAVIS, K. C. 1967. Vitamin E content of infant formulas and cereals. Am. J. Clin. Nutr. 20:262.

FORDHAM, J. R., WELLS, C. E., and CHEN, L. H. 1975. Sprouting of seeds and nutrient composition of seeds and sprouts. J. Food Sci. 40:552.

GARTON, G. A., MIHAILOVIC, M. L., ANTIC, M., and HADZIJEV, D. 1963. Chemical investigation of wheat. VI. Grain lipids of some high yielding wheat varieties. Bull. Soc. Chim. Beograd 28:555.

GRAVELAND, A. 1968. Combination of thin layer chromatography and gas chromatography in the analysis on a microgram scale of lipids from wheat flour and wheat flour doughs. J. Am. Oil Chem. Soc. 45:834.

GREEN, J. 1958. The distribution of tocopherols during the life-cycle of some plants. J. Sci. Food Agric. 9:801.

HALL, G. S., and LAIDMAN, D. L. 1968. The determination of tocopherols and isoprenoid quinones in the grain and seedlings of wheat (Triticum vulgare). Biochem. J. 108:465.

HARVEY, W. R. 1977. Least squares and maximum likelihood general program for fixed models, revised. Statistical Analysis System, Dairy Science Department. Ohio State University: Columbus, OH.

MECHAM, D. K. 1971. Lipids. Page 393 in: Pomeranz, Y. (ed). Wheat: Chemistry and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.

METCALF, L. D., SCHMITZ, A. A., and PELKA, J. R. 1963. Rapid preparation of fatty acid esters from lipids for gas chromatographic analysis. J. Anal. Chem. 38:514.

MIHAILOVIC, M. L., GARTON, G. A., ANTIC, M., and HADZIJEV, D. 1963. Chemical investigation of wheat. V. Some chromatographic investigations of wheat lipids. Bull. Soc. Chim. Beograd 28:179.

MORRISON, W. R., MANN, D. L., SOON, W., and COVENTRY, A. M. 1975. Selective extraction and quantitative analysis of non-starch and starch lipids from wheat flour. J. Sci. Food Agric. 26:507.

POMERANZ, Y., CHUNG, O. K., and ROBINSON, R. J. 1966. Lipids in wheat from various classes and varieties. J. Am. Oil Chem. Soc. 43:511.

PRATT, D. B., Jr. 1971. Criteria of flour quality. Page 201 in: Pomeranz, Y. (ed.). Wheat: Chemistry and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.

SHOLLENBERGER, J. H., CURTIS, J. J., JAEGER, C. M., EARLE, F. R., and BAYLES, B. B. 1949. The chemical composition of various wheats and factors influencing their composition. U. S. Dept. Agric. Tech. Bull. 995. Cited in: MECHAM (1971).

SLOVER, H. T. 1971. Tocopherols in foods and fats. Lipids 6:291.

SLOVER, H. T., LEHMANN, J., and VALIS, R. J. 1969. Vitamin E in foods: Determination of tocols and tocotrienols. J. Am. Oil Chem. Soc. 46:417.

SLOVER, H. T., SHELLEY, L. M., and BURKS, T. L. 1967. Identification and estimation of tocopherols by gas-liquid chromatography. J. Am. Oil Chem. Soc. 44:161.

STEELE, R. G. D., and TORRIE, J. H. 1960. Principles and Procedures of Statistics. McGraw-Hill: New York.

WELCH, R. W. 1975. Fatty acid composition of grain from winter and spring sown oats, barley and wheat. J. Sci. Food Agric. 26:429.

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