LIPID CONTENT OF SELECTED CEREAL GRAINS AND THEIR MILLED AND BAKED PRODUCTS[1]

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ABSTRACT

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A review of the literature and of unpublished information on the total lipid content and fatty acid composition of selected cereal grains and related products was made to determine the problems in evaluating and compiling data and the factors affecting fatty acid composition. Although lipid components represent a small amount of the nutrients in the cereal grains, they have both nutritional and functional significance.

A comprehensive review of the world literature and of unpublished sources on the total lipid and fatty acid content of cereal grains and related products was made. Information from this review is needed to evaluate the nutritional significance of lipids in cereal grain products such as polyunsaturated/saturated (P/S) fatty acid ratios, and to help explain differences in functional properties of grains and quality factors of processed foods. Data from this research are being included in the computerized Nutrient Data Bank (NDB) now being developed by the Agricultural Research Service, in the revision of Agriculture Handbook 8, "Composition of Foods—Raw, Processed, Prepared," which is underway, and in other tables of food composition.

The lipid components of cereal grains represent a small constituent compared with carbohydrate and protein components. This fact is probably the primary reason why research scientists in nutrition have paid little attention to this subject in the past. In recent years, however, a number of studies have been made on the amounts of fatty acids in cereals and their commonly used processed and baked products. Cereal chemists have known for some time that cereal grain lipids have important effects on functional and storage properties of grain products used in baking. Discussed here are corn, rice, rye, and wheat, and the factors affecting their composition.

PROBLEMS IN EVALUATING AND COMPILING DATA

In assembling data and in developing tables of fatty acids in foods, problems have been encountered concerning description of samples, lack of uniform terminology, methods of analysis used, and reporting of results.

Description of Samples

Fatty acid data for foods are often reported for samples that are inadequately described. Details of treatment, production, processing, cooking methods, physical state, portion form in which data are reported (*i.e.*, dry basis, fresh basis), and other factors influencing fatty acid composition may be lacking in these descriptions. Adequate sample descriptions are essential for proper evaluation of the data.

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Terminology

In the cereal milling and processing industries, the terminology used to describe the products should be specific for each particular product. In corn dry milling, for example, qualifying or further descriptive phrases may be used to describe the terms corn meal, corn grits, corn flour, etc., and they should be specific for a particular product within the industry. When uniform or standard terminology is used, data on nutrient analysis can be coded and recorded accurately for the NDB, and can be properly grouped for summarizing. Close cooperation with and among the members of the American Association of Cereal Chemists is needed to avoid errors in product classification and to update the code. The assistance of groups such as corn dry millers, corn refiners, rice millers, rye millers, wheat millers, and members of the baking industry is needed.

Methodology

Extraction and determination of cereal lipids present problems because of the tendency of polar lipids to bind to protein and carbohydrate. MacMurray and Morrison (1) isolated, identified, and quantified 23 lipid classes from wheat flour which they grouped into major categories as follows: nonpolar lipids, 50.9% (including 20.8% triglycerides); glycolipids, 26.4%; and phospholipids, 22.7%. The lipid components of corn, brown rice, and rye have been investigated and found to be equally complex (2–4). Relative amounts of polar and nonpolar lipids in corn, rice, rye, and wheat are given in Table I. A serious problem in evaluating data is determining whether accurate methods for analysis have been used so that representative values for fatty acids and total lipids can be determined. The most reliable data are derived from multiple solvent systems for the extraction of total lipid (5–7). Results from only those determinations using adequate extraction techniques were considered in developing values for the NDB, Handbook 8, and tables of fatty acids in foods.

Polar solvent systems are required to more completely extract the bound lipids (5,6,8). Water-saturated 1-butanol yields the best recoveries of total lipid from wheat and its milled fractions. However, nonlipid materials extracted by this solvent necessitate a subsequent solvent wash of the extract leading to small unavoidable lipid losses.

Nonpolar solvents such as hexane and petroleum ether extract only the free

TABLE I
Composition of Lipids in Selected Grains

Fraction	Corn[a] %	Brown Rice[b] %	Rye[c] %	Wheat Flour[d] %
Nonpolar lipids	91.9	86.7	92.7	50.9
Polar lipids (total)	8.1	13.3	7.3	49.1
Glycolipids		(9.2)	(0.4)	(26.4)
Phospholipids		(4.1)	(6.9)	(22.7)

[a]Weber (3).
[b]Hirayama and Matsuda (2).
[c]Chung and Tsen (4).
[d]MacMurray and Morrison (1).

lipids whose fatty acid distribution is not representative of that of the total lipids. It has been observed that more polar solvents cause an appreciable relative increase of linoleic acid and a relative decrease of oleic acid (9–11).

Acid hydrolysis methods are unsuitable for investigation of lipid classes (12) because they cause degradation of the lipid components as they occur naturally in cereal grains. If the conditions of hydrolysis are severe, only the fatty acids will be subsequently extracted, and a low lipid value will result. The nonfatty acid portions of the lipid consisting of glycerol, phosphate, organic bases, and/or carbohydrate are lost. For example, fat by hydrolysis represents only 72% of the total lipids in wheat grain.

Reporting of Results

For use in food composition tables, over 90% of the data on cereal products require conversion from percentage composition of fatty acid methyl esters to absolute units (13). For the conversion, three items of information are needed: 1) the amount of each fatty acid in terms of weight percentage of its methyl ester; 2) the total lipid content; and 3) the amount of total fatty acids in the lipid. Procedures for calculating fatty acids have been described in previous publications (14–16).

FACTORS AFFECTING FATTY ACID COMPOSITION

Common and experimental cultivars of corn vary between 1 and 18% total lipids. The value of 4.1% lipid content in corn grain represents an average of many commercial samples (Table II). It does not reflect the influence of unusual or experimental cultivars. The values presented in the tables are not necessarily arithmetic averages. They may be weighed averages that were arrived at by considering such pertinent factors as cultivar, geographical differences, and production. As expected, the extraction rate of dry milled corn products influences lipid values, as shown by the descending values of 3.9, 3.4, 2.6, and 1.2% lipid for the whole ground corn meal, bolted corn meal, corn flour, and degermed corn meal, respectively. The influence of higher lipid content on decreasing the storage quality of these products is well known in the corn dry-milling industry.

The mean lipid value of 2.3% for brown rice is in contrast to a value of 0.8% for

TABLE II
Total Lipids in Corn, Rice, and Rye[a]

Grain	Lipid %	Milled Product	Lipid %
Corn	4.1	Whole ground corn meal	3.9
		Bolted corn meal	3.4
		Flour	2.6
		Degermed corn meal	1.2
Rice, brown	2.3	Milled rice	0.8
Rye	2.2	Medium flour	1.4

[a]Moisture basis (13).

regular milled rice. Lipids are lost to the germ and bran. Solvent extractive milling (trademarked X-M) carried out under a blanket of solvent produces a rice containing half of the lipid content of regular milled rice (17). Rye grain containing 2.2% lipid was reduced to 1.4% lipid for medium rye flour (4).

Durum wheats and semolina were higher in lipid content than were the respective soft or hard wheats and their milled flours, and in all instances the processed product contained less lipid than the whole grain (Table III).

The fatty acid composition of corn, rice, and rye varies somewhat as shown in Table IV. Content of palmitic acid in the lipid of rice is more than double that of corn and considerably higher than that of the lipid of rye. The wide range in values for palmitic, stearic, oleic, and linoleic acids in corn reflects the influence of cultivar. The fatty acids of lipid in rye show that oleic acid is lower and linolenic acid higher than in the other two grains. Rice lipid contains approximately 65% as much linoleic acid as is present in the lipid of the other two grains.

TABLE III
Total Lipids in Wheats[a]

Whole Grain	Lipid %	Milled product	Lipid %
Hard spring	2.7	Flour	1.5
Hard winter	2.5	Flour	1.4
Soft	2.4	Flour	1.4
Durum	3.3	Semolina	1.8

[a]Moisture basis (13).

TABLE IV
Fatty Acids in Corn, Rice, and Rye Grains

	wt % Methyl Esters		
Fatty Acid[a]	Corn	Rice	Rye
16:0 Mean	11	26	16
Range	(6–22)	(21–31)	(12–19)
18:0 Mean	2	2	1
Range	(1–15)	(2–3)	(<1–2)
18:1 Mean	25	28	14
Range	(14–64)	(21–38)	(12–16)
18:2 Mean	61	40	59
Range	(19–71)	(36–42)	(57–65)
18:3 Mean	1	1	9
Range	...	(1–2)	(3–12)

[a]16:0, Palmitic; 18:0, stearic; 18:1, oleic; 18:2, linoleic; and 18:3, linolenic.

Values for the fatty acid content of the lipids of three types of wheat are given in Table V. Although, as stated previously, durum wheats are generally higher than soft or hard wheats in total lipids, fatty acid patterns of the three are quite similar. All three types of wheat were low in stearic acid as were corn, rice, and rye. The wheats contained about the same percentages of palmitic, oleic, and linoleic acids as did rye. Linolenic acid, lowest in corn and rice and highest in rye lipid, was intermediate in the three wheats, which had essentially identical values.

TABLE V
Fatty Acids in Different Types of Wheat Grain

Fatty Acid[a]	wt % Methyl Esters		
	Hard	Soft	Durum
16:0 Mean	18	19	21
Range	(16–25)	(18–20)	(18–24)
18:0 Mean	1	1	1
Range	(<1–1)	(<1–1)	(<1–1)
18:1 Mean	15	14	17
Range	(10–19)	(12–16)	(14–21)
18:2 Mean	60	62	57
Range	(54–68)	(61–63)	(55–67)
18:3 Mean	5	5	5
Range	(4–8)	(4–5)	(4–6)

[a]16:0, Palmitic; 18:0, stearic; 18:1, oleic; 18:2, linoleic; and 18:3, linolenic.

TABLE VI
Fatty Acids in Pastry Made with Different Fats

Fatty Acid	wt % Methyl Esters		
	Corn oil[a]	Hydrogenated vegetable shortening[b]	Margarine[c]
16:0	4.6	5.4	4.8
18:0	0.7	3.8	2.3
16:1	0.1	0.1	0.1
18:1	8.4	13.3	13.8
18:2	17.2	8.2	9.6
18:3	0.3	0.6	...

[a]32.8% Lipid.
[b]33.0% Lipid.
[c]32.1% Lipid. Phillips and Vail (18).

The fatty acid content of baked products is markedly influenced by the total lipid content and the proportion of fat-containing ingredients. The effects of the use of corn oil, hydrogenated vegetable fat, and margarine on the fatty acid composition of pastry (18) are shown in Table VI. In the product, the flour and added fat are the only sources of fatty acids. Pastry made with hydrogenated fat was highest of the three in stearic acid (18:0) and, along with pastry made with margarine, was considerably higher in 18:1 than was pastry made with corn oil. Fatty acid (18:2) in corn oil pastry was about twice that in pastry made with either of the other two fats. Linolenic acid content of pastry made with margarine was too small to be measured by the method used, and linolenic acid in pastry made with hydrogenated vegetable fat was double that of pastry made with corn oil. Overall total saturated fatty acids of pastry made with corn oil were lower, and one unsaturated fatty acid was higher (18:2), than were comparable fatty acids in pastries made with the other two fats.

The influence of the same three fats on the fatty acid patterns of plain cake is

TABLE VII
Fatty Acids in Plain Cake Made with Different Fats

Fatty Acid	wt % Methyl Esters		
	Corn oil[a]	Hydrogenated vegetable shortening[b]	Margarine[c]
16:0	1.8	1.9	2.0
18:0	0.3	1.3	1.0
16:1	0.1	0.1	0.1
18:1	3.4	4.8	5.4
18:2	5.8	2.6	3.3
18:3	0.1	0.2	<0.1

[a]12.0% Lipid.
[b]12.4% Lipid.
[c]12.4% Lipid. Phillips and Vail (18).

TABLE VIII
Fatty Acids in Cookies Made with Different Fats

Fatty Acid	wt % Methyl Esters		
	Corn oil[a]	Hydrogenated vegetable shortening[b]	Margarine[c]
16:0	2.7	3.3	3.0
18:0	0.5	2.4	1.3
16:1	0.1	0.1	0.1
18:1	5.1	8.2	8.3
18:2	9.1	5.0	5.8
18:3	0.1	0.4	...

[a]17.5% Lipid.
[b]19.3% Lipid.
[c]18.5% Lipid. Phillips and Vail (18).

shown in Table VII (18). This product contained egg yolks as an additional source of fatty acids. The lower lipid content of plain cake compared with pastry probably accounts for the less marked differences among the fatty acids in cake made with these fats. Contents of 18:1 and 18:2 fatty acids in cakes were in the same relation to each other as they were in pastry.

The fatty acid pattern of cookies made with the same fats as described for pastry and plain cake is given in Table VIII. Egg was also a source of fat in the cookie formulation. The content of 18:1 and 18:2 fatty acids in cookies made with hydrogenated vegetable shortening and with margarine was about the same; on the other hand, values for these two fatty acids for cookies made with corn oil were inversely related to those for samples made with the other two fats. These examples of fatty acid content of baked products demonstrate the importance of a complete sample description of baked products. Of special help in assessing fatty acid composition is information on the amount, processing methods, and type of fat-containing ingredients. Ideally, the type and brand of fat should be reported.

The fatty acid contents of two pasta products, macaroni and egg noodles, are given in Table IX. The presence of egg solids in noodles gave the product a somewhat different fatty acid content, with four times as much palmitic acid and twice as much stearic acid in egg noodles as in macaroni, which contains no egg. Higher values for unsaturated fatty acids in egg noodles than in macaroni reflect the added fat used in egg noodles in contrast to no added fat in macaroni.

Fleischman *et al.* (19), in a survey of total lipids and fatty acids in 26 commercial breads, reported large variations in total lipids and P/S ratios. They noted differences among white breads, rye breads, and so-called dietetic breads, and among different types of bread produced in one bakery. For calculating fatty acid content of diets, he recommended computing a diet by using a knowledge of the type and brand of bread. Variations in total lipids and fatty acid content can be attributed to the kind and amount of fat used in the bread formulation.

The NDB contains data on the fatty acid distribution in oils and shortenings used commercially for baking. This kind of information may be used to calculate the fatty acid content of baked goods from recipes. The linking of a particular baked product with an appropriate shortening should become easier when a regulation by the Food and Drug Administration for labeling shortenings by type and ingredient oils, *e.g.*, vegetable oil shortening (soybean and cottonseed oil), goes into effect in January 1978 (20).

TABLE IX
Fatty Acids in Macaroni and Noodles

	wt % Methyl Esters	
Fatty Acid	**Macaroni**[a]	**Egg noodles**[b]
16:0	0.2	0.8
18:0	0.1	0.2
18:1	0.2	1.1
18:2	0.6	1.0
18:3	<0.1	0.1

[a]1.5% Lipid.
[b]4.6% Lipid.

FUNCTIONAL PROPERTIES OF LIPIDS IN CEREAL PRODUCTS

Corn lipids play a vital part in the storage quality of dry milled products. Whole ground and bolted corn meals can be stored only a short while before they become rancid. Degermed corn meal which contains approximately 1% lipid can be stored for much longer periods. Wyss (21) reported that different types and qualities of corn will produce grits and flour with widely differing fat contents, even though the corn is milled under identical conditions. He also stated that age of the corn is important because fat migrates from the germ into the endosperm during storage. The migration is more pronounced during unfavorable storage conditions such as when corn is exposed to direct sunlight or when corn lies close to the walls of metal storage bins exposed to the summer sun. Storage up to 6 months causes little fat migration, but after 18 months the endosperm may contain up to three or four times as much fat as it did initially. These variations in storage treatment of corn, therefore, are directly related to the quality of dry milled corn products.

Fujino and Sukata (22) have identified six glycolipids in rice grain. Some complex with glucose and mannose, some with glucose alone, and others with galactose and glucose. They did not relate glycolipids to functional and physical properties of the rice grain, although the starch components amylose and amylopectin are directly related to cohesiveness and other properties of the cooked rice. According to Houston (17), lipids are a problem in relation to the storage quality of milled rice. Deterioration of lipids causes development of off-flavors and off-odors, increased acidity, and other changes affecting eating-quality characteristics of rice.

Very little information has been published on lipids and their functional qualities in rye. Our ongoing review showed that total lipid of rye grain was just slightly lower than that of wheat; fat content of medium rye flour was the same as, or slightly lower than, that of whole wheat flours (4). However, Pomeranz (23) reported that concentration of galactolipids in total lipids is lower in rye than in wheat. These facts, along with differences in gluten properties, may have some relation to baking quality of rye flour.

Mecham (5), in the AACC monograph on wheat chemistry and technology, extensively reviewed the functions of lipids in breadmaking. Pomeranz *et al.* (24) have published a number of papers on the subject. They demonstrated the importance of polar and nonpolar wheat-flour lipids in breadmaking. Adding 3 g of vegetable fat/100 g of flour improved crumb grain and loaf volume. The presence of 0.5 g of nonpolar, polar, and unfractionated lipids, in addition to the 3 g of vegetable fat in the bread dough, had no significant effect on crumb grain or loaf volume of bread. However, adding 0.5 g of polar flour lipid and no vegetable fat in the formulation increased loaf volume significantly. On the other hand, adding 0.5 g of nonpolar lipids had no effect on bread quality, and adding 0.5 g unfractionated flour lipids of a 1:1 ratio of polar to nonpolar lipids gave an intermediate loaf volume. Fractions rich in galactosylglycerides increased loaf volume of bread baked from defatted flours substantially more than did those rich in phospholipids.

Increasing length of dough-mixing was found to increase binding of free flour lipids (25). Binding decreased slightly with overmixing. The presence of nonpolar lipids reduced binding of polar lipids. By adding high levels of protein supplements plus glycolipids, it is possible to maintain consumer acceptance of bread fortified with products such as soy flour, cottonseed flour, peanut flour, fish protein concentrate, and edible yeast.

Little attention has been given to modification of lipids during processing of products other than bread. Fabriani *et al.* (26) indicated that during mixing, extrusion, and drying of pastas, changes occur in triglycerides, phospholipids, and fatty acids which result in a smaller percentage of extracted fats. Infrared absorption analyses and gas chromatography were used to confirm these results.

CONCLUSIONS

Lipid components of cereal grains such as corn, rice, rye, and wheat (durum, hard, and soft) are nutritionally significant because of their high P/S ratios. The lipid components are functionally important in imparting desirable characteristics to baked products, but they can cause storage problems because of their relatively high content of polyunsaturated fatty acids. Polar flour lipids such as glycolipids improve loaf volume of breads with and without fortification of the doughs with products such as soy flour, cottonseed flour, peanut flour, fish protein concentrate, and yeast.

Mixing of bread doughs and mixing, extrusion, and drying of pastas cause binding of lipids.

The type and amount of added fat ingredient and other ingredients containing fat used in dough and batter formulations of breads, cakes, cookies, and pastry cause a marked difference in the polyunsaturated/saturated fatty acid patterns of the respective finished baked products.

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