Relation of Polar Lipid Content to Mixing Requirement and Loaf Volume Potential of Hard Red Winter Wheat Flour[1]

O. K. CHUNG, Y. POMERANZ, and K. F. FINNEY,[2] U.S. Grain Marketing Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture,[3] Manhattan, Kansas 66502

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ABSTRACT

Lipids were extracted (with petroleum ether) from 21 samples of hard red winter wheats and 23 samples of experimentally milled straight-grade flours that varied in bread-making potential. Wheat protein content varied from 11.5 to 15.7%, flour mixing time from 7/8 to 9 min, and loaf volume (LV) per 100 g of flour from 523 to 1,053 cc. The total lipids from 10 g of flour (db) were fractionated into polar lipids (PL) and nonpolar lipids (NL); total lipids were analyzed colorimetrically for carbohydrates, mainly galactose (GAL). PL content varied from 14.8 to 28.1 mg per 10 g of wheat and from 10.6 to 27.3 mg per 10 g of flour; NL/PL ratios were 6.31–11.32 for wheat and 2.47–6.91 for flour; lipid GAL ranged from 1.61 to 5.49 mg and from 2.64 to 5.61 mg in 10 g of wheat and flour, respectively. Significant linear correlations were found between LV and the following variables: PL content ($r = 0.877$ for wheat and 0.888 for flour), NL/PL ratio ($r = -0.902$ for wheat and -0.907 for flour), and lipid GAL ($r = 0.745$ for wheat and 0.905 for flour). PL, NL/PL ratio, and lipid GAL were curvilinearly related to mixing time requirement. The correlation coefficients of LV with PL, NL/PL ratio, and lipid GAL generally were somewhat improved when LV and lipid contents were corrected to a constant protein basis. The data indicate that the quantity of PL or galactolipids occurring naturally in wheat is related to bread-making (functional) properties and may govern or be closely related to other factors that govern functional properties of good and poor varieties of wheat. The highly significant correlations point to the potential usefulness of PL, NL/PL ratio, and lipid GAL for estimating LV potential of hard red winter wheat flours.

Significant contributions of wheat flour proteins to loaf volume (LV) of breads have been well demonstrated. Two major factors account for variations in LV of wheat varieties. One is protein content (Finney and Barmore 1948, Finney and Fryer 1958), which is influenced mainly by environmental factors; the other is protein quality, which is primarily genetically controlled (Finney and Barmore 1948, Finney and Fryer 1958, Whiteside 1958). Lipids, minor components of wheat flour, function importantly in breadmaking (Chung et al 1978, Daftary et al 1968, Lin et al 1974, MacRitchie 1977, Pomeranz 1973). Shollenberger et al (1949) reported that the petroleum ether-extractable lipids were a varietal characteristic. Many scientists tried to correlate lipid content or composition with genetic differences in bread-making quality of wheats (Fisher et al 1964, 1966; Pomeranz et al 1966a, 1966b), but no significant relationship was established. Fisher et al (1964, 1966), however, demonstrated varietal and environmental effects on the quantity and quality of lipids that could be extracted with water-saturated 1-butanol. Those and other studies implied that sound wheats of the same class and unexposed to extremes in environment might best differentiate wheats according to bread-making quality.

The composition and amounts of lipids that can be extracted from a flour depend on the genetic makeup of the wheat from which the flour was produced, milling yield of the flour, particle size and moisture content of the sample, and conditions of lipid extraction, including time and temperature of extraction, type of extractor, and type of solvent. Solubility parameter values or polarities of extractants can be varied by the use of different solvents alone or in combination with water. A preliminary study (Chung et al 1980) showed the conditions of lipid extraction that will differentiate hard red winter (HRW) wheat flours that vary in bread-making potential. Six solvents (petroleum ether, Skellysolve B, benzene, acetone, 2-propanol, and water-saturated 1-butanol) were compared. The ratio of nonpolar lipids (NL) to polar lipids (PL) extracted with petroleum ether or Skellysolve B best differentiated the five flours according to LV potential.

We have extended that preliminary study to HRW wheats grown in the Great Plains of the United States and to their straight grade flours. We report the relation of the petroleum ether-extractable lipids and their fractions to mixing requirement and LV potential, two of the functional (bread-making) properties that define quality (Finney 1979).

MATERIALS AND METHODS

Materials

Each of the first 10 samples was a variety composite of samples harvested in 1975 at 10 locations in Kansas (Table I). The next 10 samples represented wheats grown at Manhattan, KS, in the designated year, except that the Cch/2* Tmp (KS644) sample was a composite of samples harvested in 1974 and 1976. Each of the last three was a regional baking standard and was a composite grist of many HRW wheat varieties harvested throughout the Great Plains in 1973–1975. Wheat samples had been stored at 4°C until they were ground or milled. Whole wheat samples were ground on a Weber pulverizer to pass a screen with 0.024-in. round openings. The bushel weight of the wheats ranged from 59.7 to 63.9 lb. The wheat ash content ranged from 1.31 to 1.77% and the protein content from 11.5 to 15.7% (14% mb).

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[2]Research chemists.
[3]Reference to a company or product does not imply approval or recommendation of the product by the USDA to the exclusion of others that may be suitable.

After milling on an Allis Chalmers experimental mill, 23 straight grade flours were obtained. The flour yield ranged from 70.6 to 76.8%, and the flours contained 0.33–0.46% ash and 10.2–14.1% protein (14% mb).

Organic solvents were analytical reagent grade, and solutions were prepared from analytical reagent-grade compounds. Analytical-reagent silicic acid (100 mesh) for lipid chromatography was from Mallinckrodt (New York).

Baking Procedure

The optimized procedure described by Finney (1945), Finney and Barmore (1943, 1945a, 1945b), and Finney et al (1976) was used for the baking tests with 100 g (14% mb) of flour. The amount of oxidant was 5 or 10 ppm potassium bromate (5 ppm for flours requiring mixing times longer than 4 min) and 50 ppm ascorbic acid. Bakes were replicated twice.

Extraction and Fractionation of Lipids

Lipids were extracted with petroleum ether from 10 g (db) of wheat or flour sample by Soxhlet for 16 hr at a solvent condensation rate of 4–5 drops per minute. The unfractionated lipids were defined as total lipids (TL). Lipids were fractionated by silicic acid column chromatography into NL (eluted with chloroform) and PL (eluted with methanol). Lipid extractions were replicated four times and fractionations three times. Total average recovery of lipids from silicic acid column fractionation was 98.2% (96.5–99.5%).

Analytical Procedures

Protein (N × 5.7), ash, and moisture contents were determined by AACC methods (1976). Total carbohydrate content of the lipids was determined by the colorimetric (phenolsulfuric acid) method of Dubois et al (1956) with galactose as a standard. The sugar in the cereal glycolipids is mostly galactose (Morrison 1978), and total carbohydrate content was reported as galactose content. The lipids extracted with petroleum ether from a 10-g (db) sample were hydrolyzed by 8 ml of methanolic HCl (Applied Science Lab., Inc., State College, PA) according to Kates (1964). The hydrolysate that partitioned into an aqueous layer was diluted to 50 ml; a 1-ml aliquot was mixed with 1 ml of deionized water, 1 ml of 5% phenol, and 5 ml of H_2SO_4, and the absorbance was read at 490 nm.

Analysis of Data

Analysis of variance and tests for Fisher's least significant difference at $\alpha = 0.05$ were computed according to Fryer (1966). We computed the linear correlation coefficients (r) between LV of bread and amounts of TL, NL, or PL; the ratio of NL to PL; lipid galactose; and protein contents of the wheat and flour samples. To compare bread-making (mixing time and LV) and lipid-content data, both were expressed on the basis of 100 g of flour (14% mb). A least-square regression line, the regression equation, and the standard deviation of a dependent variable in the population about a least-square regression line was estimated according to Fryer (1966). The confidence limits at 90% were plotted above and below the sample regression line; a confidence belt or zone was depicted as dotted lines (Snedecor and Cochran 1976).

RESULTS AND DISCUSSION

Baking Characteristics

Flour protein contents of the 23 flours varied from 10.2 to 14.1%, mixing times from 7/8 to 9 min, and LV from 523 to 1,053 cc (Tables I and II). For a given variety or quality level, LV increases with increasing protein content; thus, LV of the 23 flours was corrected to the average protein content of 12% (Finney 1979). Mixing time, however, decreases with increasing flour protein content up to 12% and then remains constant (Finney 1979). Even after the correction, the ranges of mixing times (7/8–9 min) and LV (493–1,098 cc) were still wide; these enormous differences in corrected mixing times and LV among samples largely represent inherent differences in protein quality.

TABLE I
Milling and Chemical Data for 23 Hard Red Winter Wheats and Flours

		Wheat				Flour	
Sample Designation[a]	Crop Year	Bushel Weight (lb)	Ash[b] (%)	Protein[b] (%)	Flour Yield (%)	Ash[b] (%)	Protein[b] (%)
Parker (C.I. 13285)	1975	62.7	1.61	11.9	74.9	0.37	10.6
Eagle (C.I. 15068)	1975	62.0	1.58	12.1	76.8	0.41	11.1
Osage (C.I. 17292)	1975	61.9	1.56	11.7	75.9	0.43	10.8
Plainsman V	1975	61.8	1.59	14.1	75.6	0.41	13.1
7303	1975	61.5	1.72	13.9	76.4	0.41	13.0
Lancota (C.I. 17389)	1975	61.9	1.59	12.4	75.5	0.37	11.4
CIMMYT/Scout							
KS73159	1975	61.1	1.51	11.9	72.2	0.41	10.5
KS73199	1975	61.5	1.52	11.5	74.0	0.41	10.2
KS73H590	1975	61.5	1.60	11.9	74.8	0.39	10.8
KS73H593	1975	61.8	1.61	12.2	73.6	0.41	11.1
White RCf	1971	63.9	1.55	13.9	73.7	0.36	13.1
Qv/Tm/2/Mql/Oro (C.I. 12995)	1972	62.2	1.32	13.1	72.8	0.35	12.1
Cch/2* Tmp(KS644)	1974 & 1976	62.2	1.56	13.4	72.8	0.33	12.5
Cfk/Tm							
KS501097	1973	61.9	1.44	14.5	73.3	0.46	13.4
KS501099	1972	63.6	1.31	12.8	74.2	0.37	11.7
Ot Sel. (KS619042)	1972	62.1	1.43	13.2	70.6	0.38	11.9
	1973	61.2	1.62	15.7	74.5	0.42	14.1
	1975	61.0	1.77	14.9	74.7	0.41	13.4
Shawnee (C.I. 14157)	1973	61.4	1.41	14.2	75.4	0.40	13.0
	1975	59.7	1.70	13.7	73.8	0.42	12.5
RBS (composite)	1973	60.2	1.60	13.5	72.5	0.41	12.4
	1974	59.7	1.65	13.6	71.3	0.42	12.4
	1975	60.6	1.59	13.4	71.5	0.42	12.4

[a] CIMMYT = International Maize and Wheat Improvement Center, RCf = Red Chief; Qv/Tm/2/Mql/Oro = Quivira/Tenmarq/2/Marquillo/Oro; Cch/2* Tmp = Concho/2* Triumph; Cfk/Tm = Chiefkan/Tenmarq; Ot Sel. = Ottawa selection; RBS = regional baking standard; numbers are C.I. (cereal investigation) or selection numbers.
[b] Expressed on 14% moisture basis.

Wheat vs Flour Lipids

Amounts of TL (Table III) were much higher in wheats (average 191.8 mg/10 g) than in flours (average 94.0 mg/10 g) because aleurone (in bran) and germ are richer in lipids than is the endosperm fraction (Pomeranz and Chung 1965, Sullivan and Near 1928). The high levels of NL in wheat (average 170.1 mg/10 g) were responsible for the large difference in TL of wheat and flour and for the much higher ratios of NL to PL in the wheats (6.31–11.32, average 8.05) than in the flours (2.47–6.91, average 3.60). NL comprised 82–86% of the lipids in germ or aleurone (Hargin and Morrison 1980). The amounts of PL in wheat (average 21.7 mg/10 g) were somewhat higher than those in flour (average 20.4 mg/10 g), a result that is corroborated by the data of Hargin and Morrison (1980) if appropriate calculations are made. Those calculations showed that the sum of PL (excluding starch lipids) in the structural parts of hand-dissected wheat kernels (10 g) was slightly higher than the calculated nonstarch PL in 10 g of endosperm.

The linear correlation of wheat and flour PL was greatly higher than that of wheat and flour NL (Fig. 1). The PL contents of the flours were linearly related to those of the wheats ($r = 0.951$). Thus, the PL content of flour could be estimated from that of the wheat by applying the linear regression equation shown in Fig. 1, bottom. At a given wheat PL content, the estimated flour PL content would be within the confidence zone. Although the linear correlation of NL contents of wheat and flour was statistically significant ($r = 0.480$), estimating the NL content of flour from that of the wheat would be of no practical value because of the high standard deviation (4.45) of the least-square regression line (Fig. 1, top).

The galactose content of wheat TL (average 2.12%) was less than half that of flour TL (average 4.97%, Table IV), because the nonstarch endosperm lipids are richer in glycolipids than are the germ or bran lipids (Hargin and Morrison 1980, Pomeranz and Chung 1965). The average lipid-galactose content (4.07 mg) of 10 g of wheat was somewhat less than that (4.68 mg) of 10 g of flour.

Relationship Between Lipids and Mixing Requirement

Mixing requirements of flours were curvilinearly related to the corresponding lipid-galactose contents (Fig. 2, left). Because mixing times of flours that had protein contents below 12% were corrected, the differences in corrected mixing times were largely inherent (varietal). The mixing requirement increased slowly (about 0.04 min/mg) as lipid-galactose content increased to about 35 mg and then increased rapidly (about 0.6 min/mg) as lipid-galactose content increased above 35 mg. A similar curvilinear relation existed for mixing time and LV when both were corrected to 12% protein (Fig. 2, right). Mixing requirement increased slowly (about 0.003 min/cc) as LV increased to about 900 cc and then very rapidly for further increases in LV to about 1,000 cc. Mixing times greater than about 5.5 min (associated with excessively strong physical dough properties) account for decreasing dough extensibility and for the corresponding small decreases in LV. A similar relation between LV and mixing time of flours from about 300 wheat progenies was reported by Finney and Yamazaki (1967).

Thus, flours containing 38 mg of lipid-galactose per 100 g (14% mb) would have mixing times of about 2¼ min and LV of about 880 cc on a 12% protein basis. Similar curvilinear relations were found for mixing time and wheat lipid-galactose, wheat PL, and flour PL contents (figures not shown). When flours contained about 167 mg and wheat about 179 mg of PL (per 100 g, 14% mb), mixing times (on 12% flour protein basis) were about 2¼ min. Mixing time was also curvilinearly related to the ratio of NL to PL in flours and wheats. It decreased rapidly with increasing ratios up to 3.8 and 7.8, respectively, and slowly up to 5.3 and 11, respectively, and then remained constant (figures not shown). Those flours and wheats that had NL/PL ratios greater than about 4 and 9, respectively, had mixing times less than 2 min. However, linear relationships were established when the log of corrected mixing time was correlated with lipid galactose, PL, and NL/PL ratio of flour and wheat; correlation coefficients (0.728–0.890) were very highly significant ($\alpha = 0.01$).

No significant correlations were found between mixing time and NL of wheat or flour (data not given). Although flour mixing time

TABLE II
Bread-Making Characteristics of Flours[a]

Sample[b]/ Crop Year	Mixing Time		Loaf Volume (100 g of flour)	
	As Received (min)	Corrected[c] (min)	As Received (cc)	Corrected[c] (cc)
Parker/1975	4½	3¾	785	875
Eagle/1975	6¾	6	885	950
Osage/1975	3⅜	2⅞	853	938
Plainsman V/1975	9	9	1,000	924
7303/1975	4¼	4¾	988	919
Lancota/1975	4⅛	3⅞	930	975
KS73159/1975	4⅞	4	965	1,098
KS73199/1975	6⅜	5	922	1,077
KS73H590/1975	2¾	2⅜	815	894
KS73H593/1975	2⅜	2⅛	835	894
White RCf/1971	2⅛	2⅛	898	833
C.I. 12995/1972	7	7	940	933
KS644/1974 & 1976	2⅜	2⅜	923	890
KS501097/1973	⅞	⅞	523	493
KS501099/1972	1⅜	1⅜	827	845
Ot Sel./1972	1⅜	1⅜	688	692
Ot Sel./1973	⅞	⅞	612	553
Ot Sel./1975	1⅜	1⅜	726	669
Shawnee/1973	4⅝	4⅝	1,053	978
Shawnee/1975	5⅝	5⅝	1,021	983
RBS/1973	3¾	3¾	1,003	973
RBS/1974	4¾	4¾	995	965
RBS/1975	4¾	4¾	1,006	976

[a] Averages of two replicates; average standard deviation: 20 cc for loaf volume, less than ⅛ min for mixing time.
[b] Samples are described in Table I.
[c] Corrected to a 12% protein basis.

TABLE III
Petroleum Ether-Extractable Total (TL), Nonpolar (NL), and Polar (PL) Lipids from 10 g (dry basis) of Hard Red Winter Wheats and Flours[a]

Sample[b]/Crop Year	Wheat Lipids (mg)			Flour Lipids (mg)		
	TL	NL	PL	TL	NL	PL
Parker/1975	195.9	177.6	18.3	87.5	70.1	17.4
Eagle/1975	188.5	167.1	21.4	92.5	72.5	20.0
Osage/1975	210.0	187.0	23.0	103.3	83.5	19.8
Plainsman V/1975	188.6	163.6	25.0	99.6	74.8	24.8
7303/1975	194.5	169.9	24.6	108.7	82.6	26.1
Lancota/1975	181.4	158.5	22.9	93.3	69.9	23.4
KS73159/1975	181.8	157.8	24.0	90.0	67.0	23.0
KS73199/1975	195.0	172.3	22.7	101.2	77.8	23.4
KS73H590/1975	185.5	164.6	20.9	92.7	73.7	19.0
KS73H593/1975	190.7	170.3	20.4	91.6	73.6	18.0
White RCf/1971	188.8	170.4	18.4	86.9	69.0	17.9
C.I. 12995/1972	230.3	202.2	28.1	104.5	77.2	27.3
KS644/1974 & 1976	192.2	168.0	24.2	94.9	72.3	22.6
KS501097/1973	182.3	167.5	14.8	83.8	73.2	10.6
KS501099/1972	176.5	158.6	17.9	83.4	67.1	16.3
Ot Sel./1972	184.0	166.0	18.0	92.9	75.8	17.1
Ot Sel./1973	186.7	171.5	15.2	90.6	74.9	15.7
Ot Sel./1975	184.7	164.5	20.2	92.8	72.4	20.4
Shawnee/1973	204.1	178.1	26.0	94.6	67.4	27.2
Shawnee/1975	190.0	164.0	26.0	89.5	63.7	25.8
RBS/1973	...	...	...	91.0	68.9	22.1
RBS/1974	...	...	...	95.8	70.6	25.2
RBS/1975	196.9	173.1	23.8	99.8	74.8	25.0
Average	191.8	170.1	21.7	94.0	72.7	20.4
Average standard deviation	6.0	3.0	1.4	2.1	1.9	1.1
LSD ($\alpha = 0.05$)[c]	11.5	7.0	2.6	3.8	3.4	2.0

[a] Averages of four replicates for TL and of three replicates for NL and PL.
[b] Samples are described in Table I.
[c] LSD = least significant difference.

was linearly and significantly correlated to TL of wheat (r = 0.448) and of flour (r = 0.543), the coefficients indicate that only 20 and 29%, respectively, of the variation in mixing time was accounted for by TL content.

Relationship Between Lipids and Loaf Volume

The correlation coefficients of LV vs the ratio of NL to PL and the amounts of PL and lipid galactose of both wheats and flours were very highly significant (Table V). The significant but impractical (for predicting) correlation coefficients (r = 0.453) of LV and flour TL was attributable to the PL fraction. Loaf volume of bread was not significantly related to the protein contents of the samples (Table V) because of the extremely wide range in protein quality (Table II). Limited but comparable data (not given) indicated that PL and lipid-galactose, but not NL, contents increased with increasing protein content within good-quality samples. Thus, PL and lipid-galactose contents of flours were

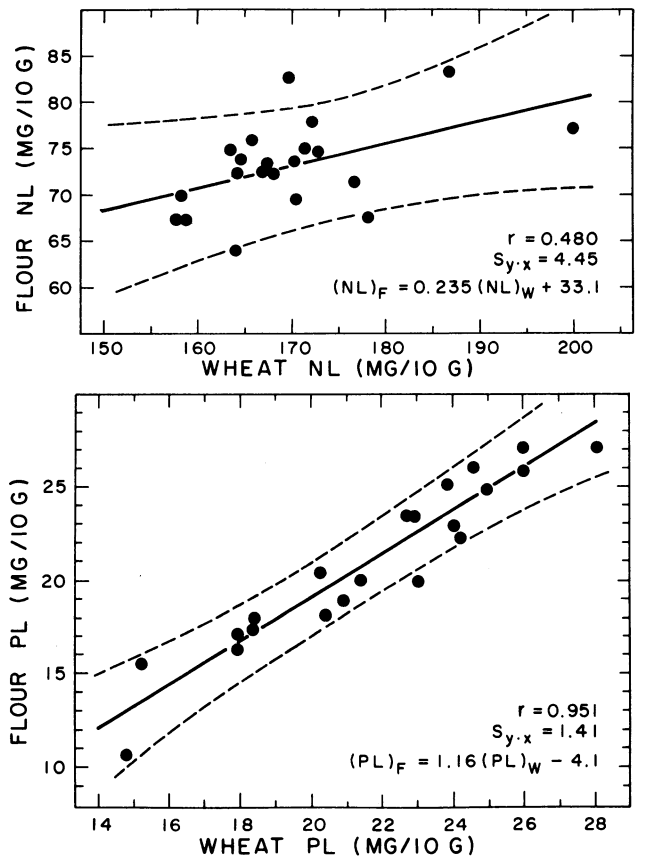

Fig. 1. Relation between wheat **(W)** and flour **(F)** lipids. **Top,** nonpolar lipids **(NL)**; **bottom**, polar lipids **(PL)**; --- = confidence zone; $S_{y \cdot x}$ = standard deviation.

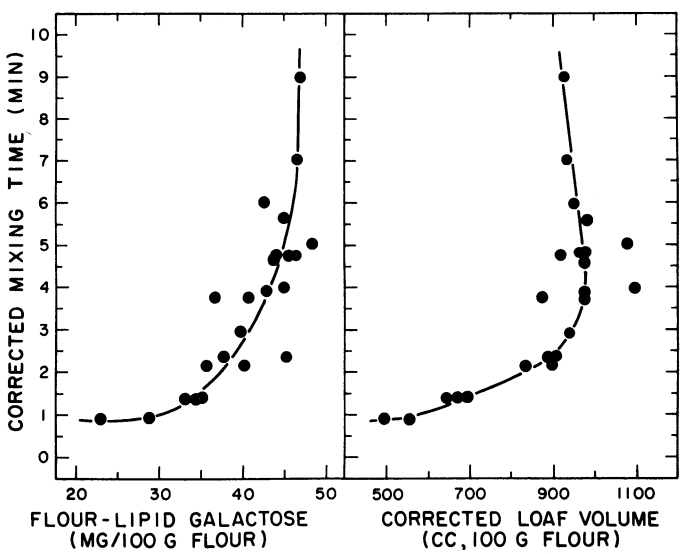

Fig. 2. Relation between mixing time (to the point of minimum mobility) corrected to 12% protein and galactose in petroleum ether-extractable flour lipids **(left)** and loaf volume corrected to 12% protein **(right)**.

TABLE IV
Galactose Content in Lipids Extracted with Petroleum Ether from Hard Red Winter Wheats and Flours[a]

	Galactose (%) in TL[c] of		Lipid Galactose (mg) in 10 g (db) of	
Sample[b]/Crop Year	Wheat	Flour	Wheat	Flour
Parker/1975	1.65	4.89	3.23	4.28
Eagle/1975	2.47	5.34	4.66	4.94
Osage/1975	2.21	4.46	4.64	4.61
Plainsman V/1975	2.79	5.48	5.26	5.46
7303/1975	2.40	4.94	4.67	5.37
Lancota/1975	2.32	5.35	4.21	4.99
KS73159/1975	3.02	5.80	5.49	5.22
KS73199/1975	2.66	5.54	5.18	5.61
KS73H590/1975	2.03	4.72	3.77	4.38
KS73H593/1975	2.48	4.47	4.73	4.09
White RCf/1971	1.85	5.36	3.49	4.66
C.I. 12995/1972	1.95	5.19	4.49	5.42
KS644/1974 & 1976	2.46	5.55	4.73	5.27
KS501097/1973	0.88	3.15	1.61	2.64
KS501099/1972	1.89	4.62	3.34	3.85
Ot Sel./1972	1.99	4.32	3.66	4.01
Ot Sel./1973	1.57	3.70	2.93	3.35
Ot Sel./1975	1.69	4.35	3.12	4.04
Shawnee/1973	1.84	5.36	3.76	5.07
Shawnee/1975	2.07	5.84	3.93	5.23
RBS/1973	...	5.16	...	4.70
RBS/1974	...	5.32	...	5.10
RBS/1975	2.29	5.29	4.51	5.28
Average	2.12	4.97	4.07	4.68
Average standard deviation	0.04	0.09	0.10	0.09
LSD ($\alpha = 0.05$)[d]	0.11	0.23	0.23	0.21

[a] Averages of two replicates (average of four determinations per replicate).
[b] Samples are described in Table I.
[c] TL = unfractionated total lipids extracted by petroleum ether.
[d] LSD = least significant difference.

TABLE V
Linear Correlation Coefficients of Wheat or Flour Components and Loaf Volume

Wheat or Flour Component(s)[a]	Loaf Volume	
	As Received	Corrected[b]
Wheat		
TL	0.343	...
NL	0.089	...
PL	0.877[c]	0.907[c]
Ratio of NL to PL	−0.902[c]	−0.925[c]
Lipid galactose	0.745[c]	0.854[c]
Protein	0.225	...
Flour		
TL	0.453[d]	...
NL	−0.186	...
PL	0.888[c]	0.905[c]
Ratio of NL to PL	−0.907[c]	−0.904[c]
Lipid galactose	0.905[c]	0.928[c]
Protein	−0.157	...

[a] TL = petroleum ether-extractable total lipids, NL = nonpolar lipids, PL = polar lipids.
[b] Loaf volume and flour lipid content were corrected to a 12% and wheat lipid content to a 13% protein basis. Corrected ratio of NL to PL was obtained from NL content (as received) divided by PL content (corrected to a 12% protein for flour or 13% for wheat).
[c] Significant at 0.01 level.
[d] Significant at 0.05 level.

corrected to an average of 12% and those of wheats to an average of 13% protein. For example, PL or lipid-galactose content of a given flour was divided by its protein content and then multiplied by 12. The corrected ratio of NL to PL was obtained from NL contents (as received) divided by PL content (corrected to 12 or 13% protein).

The correlation between LV and NL/PL ratio was very highly significant for both wheat and flour, both on the as-received and the constant protein basis (Fig. 3). The range of NL/PL values was somewhat greater for the wheats than for the flours, especially on a constant protein basis.

The linear correlation coefficients of LV and PL were usually slightly lower than those of LV and NL/PL in both wheat and flour (Table V). The slightly higher correlation coefficients probably would not justify the two assays in the NL/PL determination, compared to only one in the PL determination. If PL content of a wheat or flour is known, LV could be estimated, from the linear equations, within the 90% confidence zones (Figs. 4 and 5, top).

The loaf volumes and PL contents at the tops of Figs. 4 and 5 are functions of both the quality and quantity of proteins. The variation in flour protein content of 10.2–14.1% (Table I) would account for 85–300 cc, depending on protein quality (Finney 1979). However, protein quality (LV corrected to 12% protein, Table II) varied 605 cc from 493 to 1,098 cc, a variation that was about 2–7 times that attributable to protein content. Because quality of protein has 2–7 times as much influence on LV (as received) as does quantity of protein, correlation coefficients of PL contents and LV increased after correcting both for protein content (Table V and Figs. 4 and 5, bottom). The improved correlation coefficients of the corrected values warrant the expression of PL content on a constant protein basis to estimate LV potential of a flour.

About 180 mg of native petroleum ether-extractable PL per 100 g of wheat or flour appears to be required for satisfactory LV of about 875 cc at 12% protein. An increase of 10 mg of PL per 100 g of flour was accompanied by an increase of 35 cc in LV (Fig. 5, bottom). About 500 mg of good quality protein would be required to attain such an increase in LV (Finney 1978). Thus, the very important contribution of PL to LV of wheat flour, revealed under the conditions of our assays, can be attributed, at least in part, to genetic differences.

Polar lipids are a mixture of glycolipids and phospholipids. Consequently, measuring some marker component in either glycolipids or phospholipids should provide an estimate of the PL content. We preferred measuring the galactolipid component, galactose, because glycolipids are more involved in breadmaking than phospholipids are (Daftary et al 1968, Lin et al 1974), petroleum ether-extractable PL are about three times richer in glycolipids than in phospholipids (Chung and Tsen 1975), and the lipid-galactose content is more highly related to mixing time or LV than is lipid-phosphorus content (Chung et al 1980).

Lipid galactose was significantly correlated with LV ($\alpha = 0.01$), and the linear correlations were higher for flour than for wheat (Table V). The linear relationship between LV of bread and flour-lipid galactose was improved somewhat when LV and flour-lipid galactose content (Fig. 6, left) were corrected to 12% protein (Fig. 6, right). At least 40 mg of petroleum ether-extractable lipid galactose per 100 g of flour or 35 mg/100 g of wheat appear to be required for satisfactory LV.

CONCLUSIONS

We have found that several petroleum ether-extractable lipid fractions or their ratios are highly related to genetic differences in mixing requirement and LV potential. The NL/PL ratio and the amount of PL and lipid galactose of either wheat or flour were more highly correlated with LV than with mixing time. Significant correlations of LV and the lipid content, when both were corrected to a constant protein basis, indicated that PL are related largely to protein quality and to a limited extent to protein quantity. The petroleum ether-extractable PL, especially glycolipids, are a

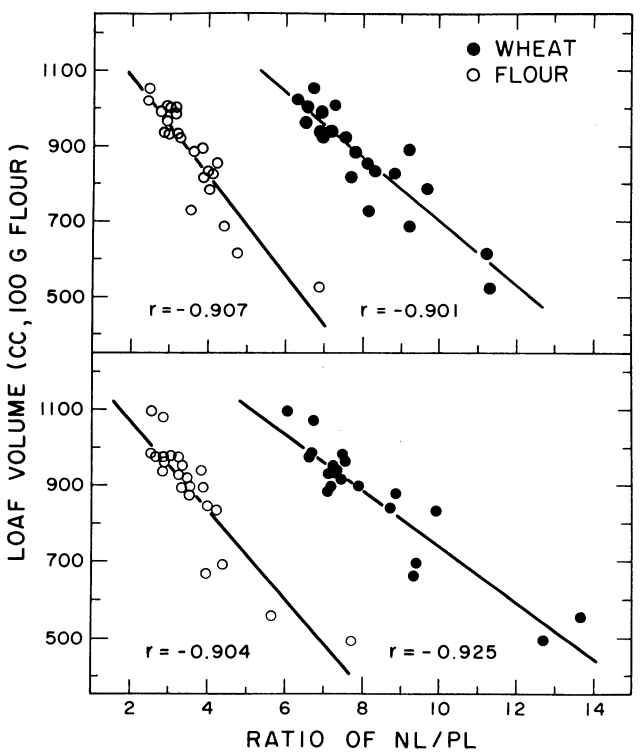

Fig. 3. Relation between loaf volume **(LV)** of bread baked from 100 g of flour and the ratio of nonpolar lipids **(NL)** to polar lipids **(PL)** of wheat or flour. **Top,** LV and NL/PL ratio on the as-received basis of protein content; **bottom,** LV and NL/PL ratio corrected to a constant protein basis. The corrected ratio of NL to PL was obtained from NL content (as received) divided by PL content corrected to 12% protein for flour or 13% for wheat.

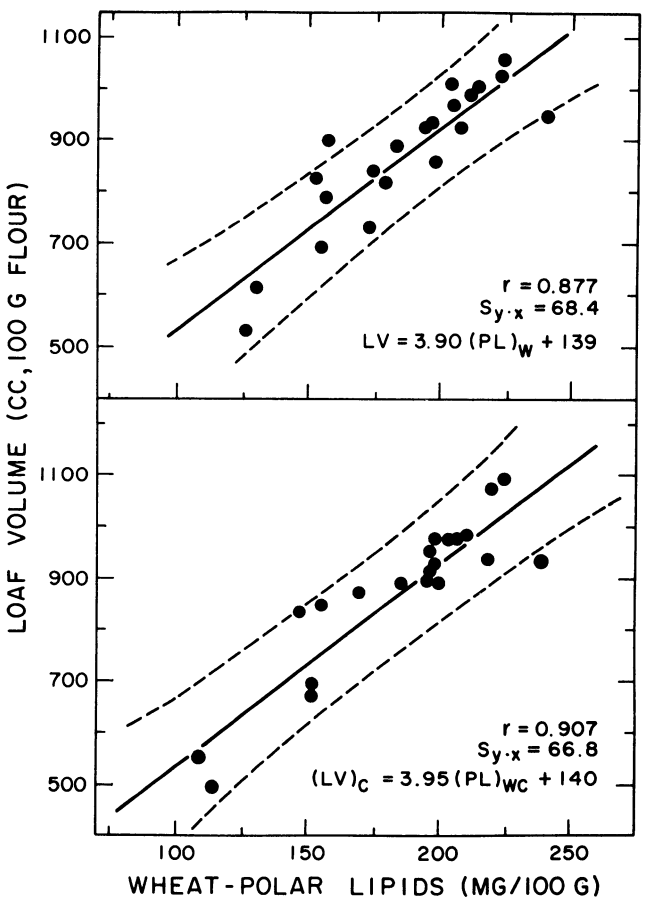

Fig. 4. Relation between loaf volume **(LV)** of bread baked from 100 g of flour and petroleum ether-extractable polar lipids of wheat **$(PL)_w$. Top,** LV and $(PL)_W$ on the as-received protein basis; **bottom,** LV corrected to 12% and $(PL)_W$ to 13% protein content. **C** = corrected, $S_{y \cdot x}$ = standard deviation.

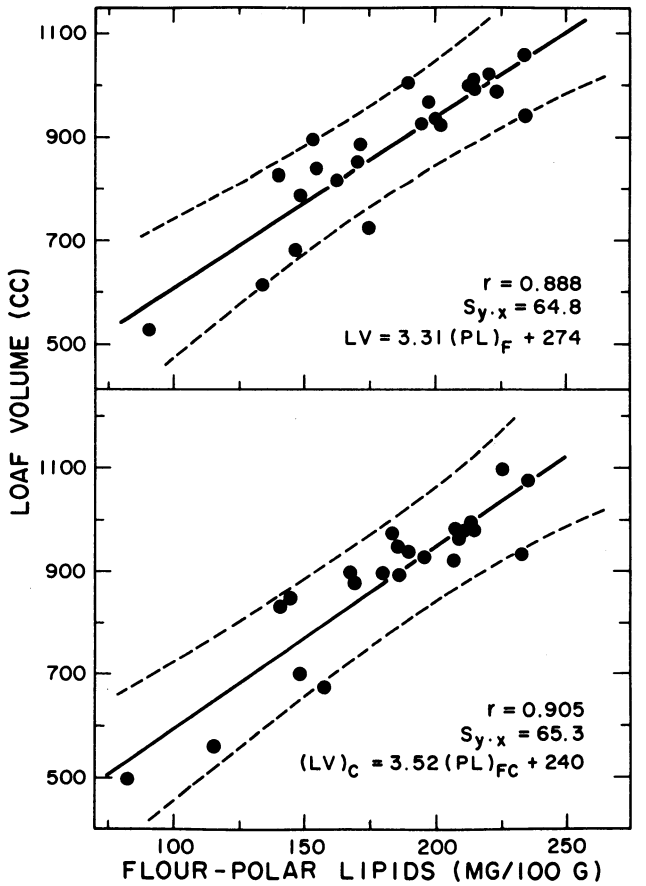

Fig. 5. Relation between loaf volume **(LV)** of bread baked from 100 g of flour and petroleum ether-extractable polar lipids of flour $(PL)_F$. **Top**, LV and $(PL)_F$ on the as-received protein basis; **bottom**, LV and $(PL)_F$ corrected to 12% protein content. **C** = corrected, $S_{y \cdot x}$ = standard deviation.

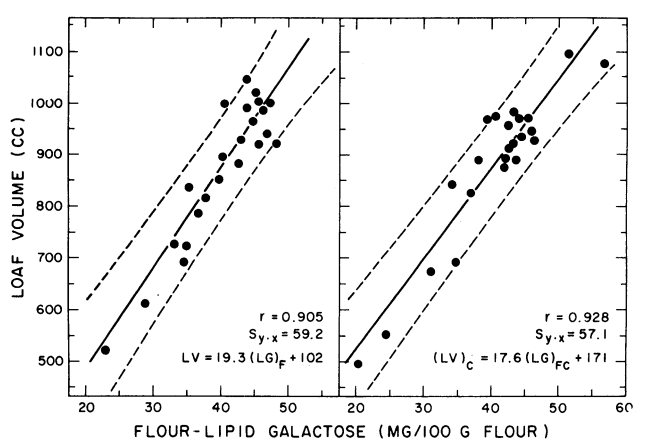

Fig. 6. Relation between loaf volume **(LV)** of bread baked from 100 g of flour and galactose in petroleum ether-extractable lipids of flour $(LG)_F$. **Left**, LV and $(LG)_F$ on the as-received protein basis; **right**, LV and $(LG)_F$ corrected to 12% protein content. **C** = corrected, $S_{y \cdot x}$ = standard deviation.

function of or are somehow involved in governing protein quality. Therefore, the determination of PL or lipid-galactose content in addition to a protein assay could be used to estimate LV and mixing time of sound HRW wheat grown under similar conditions. Conducting a similar study on another group of sound bread-making wheats, ie, hard red spring as well as winter, would be appropriate. The present method is still too complicated and time-consuming for screening samples in plant breeding programs. For screening bread-wheat progenies, development of a rapid and simple method of extracting lipids and a direct measurement (without hydrolysis) of some functional PL component or group in the lipid extracts would be necessary.

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LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 08-11, approved 1961; Method 44-15A, approved April 1967; and Method 46-11, approved April 1961. The Association: St. Paul, MN.

CHUNG, O. K., POMERANZ, Y., and FINNEY, K. F. 1978. Wheat flour lipids in breadmaking. Cereal Chem. 55:598.

CHUNG, O. K., POMERANZ, Y., JACOBS, R. M., and HOWARD, B. G. 1980. Lipid extraction conditions to differentiate among hard red winter wheats that vary in breadmaking. J. Food Sci. 45:1168.

CHUNG, O. K., and TSEN, C. C. 1975. Changes in lipid binding and distribution during dourgh mixing. Cereal Chem. 52:533.

DAFTARY, R. D., POMERANZ, Y., SHOGREN, M. D., and FINNEY, during dough mixing. Cereal Chem. 52:533.K. F. 1968.

Functional breadmaking properties of lipids. II. The role of flour lipid fractions in breadmaking. Food Technol. 22(3):79.

DUBOIS, M., GILLES, K. A., HAMILTON, J. K., REBERS, P. A., and SMITH, F. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

FINNEY, K. F. 1945. Methods of estimating and the effect of variety and protein level on the baking absorption of flour. Cereal Chem. 22:149.

FINNEY, K. F. 1978. Contribution of individual chemical constituents to the functional (breadmaking) properties of wheat. Page 139 in: Pomeranz, Y., ed. Cereals '78: Better Nutrition for the World's Millions. Am. Assoc. Cereal Chem.: St. Paul, MN.

FINNEY, K. F. 1979. Wheat proteins: What they do. Page 50 in: Proceedings, Wheat Protein Conference, Kansas State Univ., Manhattan, October 16–17, 1978. Agricultural Res. Manual ARM-9. U.S. Dept. Agric.: Washington, DC.

FINNEY, K. F., and BARMORE, M. A. 1943. Yeast variability in wheat variety test baking. Cereal Chem. 20:194.

FINNEY, K. F., and BARMORE, M. A. 1945a. Varietal responses to certain baking ingredients essential in evaluating the protein quality of hard red winter wheats. Cereal Chem. 22:225.

FINNEY, K. F., and BARMORE, M. A. 1945b. Optimum vs fixed mixing time at various potassium bromate levels in experimental bread baking. Cereal Chem. 22:244.

FINNEY, K. F., and BARMORE, M. A. 1948. Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25:291.

FINNEY, K. F., and FRYER, H. C. 1958. Effect of loaf volume of high temperatures during the fruiting period of wheat. Agron. J. 50:28.

FINNEY, K. F., and YAMAZAKI, W. T. 1967. Quality of hard, soft, and durum wheats. Page 471 in: K. S. Quisenberry and L. P. Reitz, eds. Wheat and Wheat Improvement. No. 13 in Agronomy Series. Am. Soc. of Agronomy, Inc.: Madison, WI.

FINNEY, P. L., MAGOFFIN, C. D., HOSENEY, R. C., and FINNEY, K. F. 1976. Short-time baking systems. I. Interdependence of yeast concentration, fermentation time, proof time, and oxidation requirement. Cereal Chem. 53:126.

FISHER, N., BELL, B. M., RAWLINGS, C. E. B., and BENNETT, R. 1966. The lipids of wheat. III. Further studies of the lipids of flours from single wheat varieties of widely varying baking quality. J. Sci. Food Agric. 17:370.

FISHER, N., BROUGHTON, M. E., PEEL, D. J., and BENNETT, R. 1964. The lipids of wheat. II. Lipids of flours from single wheat varieties of widely varying baking quality. J. Sci. Food Agric. 15:325.

FRYER, H. C. 1966. Concepts and Methods of Experimental Statistics. Allyn and Bacon, Inc.: Boston, MA.

HARGIN, K. D., and MORRISON, W. R. 1980. The distribution of acyl lipids in the germ, aleurone, starch, and nonstarch endosperm of flour wheat varieties. J. Sci. Food Agric. 31:877.

KATES, M. 1964. Simplified procedure for hydrolysis or methanolysis of lipids. J. Lipid Res. 5:132.

LIN, M. J. Y., D'APPOLONIA, B. L., and YOUNGS, V. L. 1974. Hard red spring and durum wheat polar lipids. II. Effect on quality of bread and pasta products. Cereal Chem. 51:34.

MacRITCHIE, F. 1977. Flour lipids and their effects in baking. J. Sci. Food Agric. 28:53.

MORRISON, W. R. 1978. Cereal lipids. Page 221 in: Pomeranz, Y., ed. Advances in Cereal Science and Technology, Vol. II. Am. Assoc. Cereal Chem.: St. Paul, MN.

POMERANZ, Y. 1973. Interaction between glycolipids and wheat flour

macromolecules in breadmaking. Adv. Food Res. 20:153.
POMERANZ, Y., and CHUNG, O. K. 1965. Lipid composition of a single wheat kernel and its structural parts. J. Chromatogr. 19:540.
POMERANZ, Y., CHUNG, O. K., and ROBINSON, R. J. 1966a. The lipid composition of wheat flours varying widely in breadmaking potentialities. J. Am. Oil Chem. Soc. 43:45.
POMERANZ, Y., CHUNG, O. K., and ROBINSON, R. J. 1966b. Lipids in wheat from various classes and varieties. J. Am. Oil Chem. Soc. 43:511.
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. Tech. Bull. 995. U.S. Dept. Agric.: Washington, DC.
SNEDECOR, G. W., and COCHRAN, W. G. 1976. Statistical Methods, 6th ed. Iowa State Univ. Press: Ames, IA.
SULLIVAN, B., and NEAR, C. 1928. Lipoid phosphorus of wheat and its distribution. Cereal Chem. 5:163.
WHITESIDE, A. G. O. 1958. The plant breeder and wheat quality. Page 25 in: Proc. Symp. Annual Mtg. 1958. Arbeitsgemeinschaft Getreideforsch: Detmold, Germany.

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