Natural Levels of Nutrients in Commercially Milled Wheat Flours. I. Description of Samples and Proximate Analysis[1]

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ABSTRACT

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The overall purpose of this study was to determine the baseline levels and the variations of the nutrients proposed for enrichment of wheat flours in the United States and Canada. This initial paper details the selection, procurement, sampling, and proximate analyses of the 63 flour and parent wheat samples used in this study. The type of wheat and the milling parameters of all samples were documented by the mill. The classes of flour analyzed included bread, family, hearth, cake, and cookie-cracker flours. The samples were procured from mills selected on the basis of geographic location and type of flour produced to permit the assessment of variability of the studied nutrients due to wheat, milling practices, and other regional factors. The collected samples were sent to 13 laboratories for 39 separate assays of each flour and 17 assays of each parent wheat. Analyses reported here include protein, ash, starch damage, and Kent-Jones flour color values.

Conversion of wheat into white flours by milling reduces the level of nutrients from their original level in wheat. Restoration of these factors (thiamin, riboflavin, niacin, and iron) to flour has been a common practice since 1941 (Federal Register 1970b) and 1953 (Anonymous 1952) in the United States and Canada, respectively. A Food and Nutrition Board proposal (NAS/NRC 1974) recommended that wheat flour be fortified with additional nutrients for which evidence shows a potential risk of deficiencies in significant numbers of the population. A similar policy has been adopted in Canada (Anonymous 1975). The types and levels of the nutrients presently used and those proposed for additional enrichment/fortification in both countries are given in Table I.

Full-scale implementation of both proposals requires a study of technological feasibility in order to establish proper addition levels of the nutrients and to determine their stability, design proper methods for their incorporation, and evaluate their effects on flour functionality and on quality of bakery and cereal-based foods. Both proposals suggest that certain nutrients be added to bring the flour to specified levels rather than that certain amounts of each nutrient be incorporated. Consequently, knowledge of natural levels of these factors is essential as a first step in this type of study. Published data on the natural contents of these nutrients in commercially milled wheat flours are considered inadequate for calculating the supplementation requirements due to changing milling practices, differences in assay methods, and insufficient information on the variation in nutrient levels in and among various flour types.

The purpose of this study was to determine natural levels and variations of these nutrients in commercial wheat flour types milled in the United States and Canada to provide a baseline for estimating the present and proposed enrichment requirements.

MATERIALS AND METHODS

Sampling

The sampling objective was to obtain a collection of wheat flours representative of present commercial production. Two criteria were used in the selection of samples: flour type and mill location. All samples were derived from the 1975 crop year. A 10-lb flour sample and a 1-lb parent wheat sample were taken at the site of production.

Flour Type. Flours were divided into five major categories depending on the end-use (Table II). Bread flour designates wholesale flour for production of white pan bread and rolls. Family flour is all-purpose flour sold retail. Hearth flour is intended for use in French and Italian breads and generally has a higher protein and ash content than does bread flour. Of the soft wheat flours, cake flour is low in ash and protein, and cookie-cracker flour is generally higher in ash and protein. The latter is also used in a variety of chemically leavened bakery foods.

The number of U.S. samples of each flour type chosen was based on the production data shown in Table II, with some adjustments. Additional cake flours were taken to achieve a statistically more adequate sample size. Also, the number of family flours was increased because we felt that more variation may exist in this group. Both groups were increased at the expense of bread flour samples, which were expected to show least variation. The distribution of samples in this collection (Table II) is similar to the typical production distribution, however. The Canadian samples were selected on the basis of the geographic distribution of mills.

Mill Location. The second criterion on which the sample distribution was based, the mill location, is given in Table III. Different mill locations provided flours produced from wheats

TABLE I
Current and Proposed Enrichment/Fortification Levels of Flour for the United States and Canada

Nutrient	United States Current[a] (mg/lb)	United States NAS Proposed[b] (mg/lb)	Canada Current[c] (mg/100 g)
Thiamin	2.9	2.9	0.44–0.55
Riboflavin	1.8	1.8	0.27–0.33
Niacin	24	24	3.5–4.4
Folic acid	···	0.3	0.040–0.050
Vitamin B_6	···	2.0	0.25–0.31
Vitamin A	···	4,333 IU/lb[d]	···
Pantothenic acid	···	···	1.0–1.3
Iron	13–16.5[e]	13–16.5[e]	2.9–3.6
Zinc	···	10	···
Calcium	960[f]	900	110–140
Magnesium	···	200	150–190

[a] U.S. Code of Federal Regulations 1977.

[b] NAS/NRC 1974.

[c] Canada, Department of National Health and Welfare 1977.

[d] Originally proposed as 2.2 retinol equivalents, later corrected to 1.3 retinol units (NAS/NRC 1974). Because 10,000 IU of vitamin A = 3 retinol units, 4,333 IU = 1.3 retinol units.

[e] Original proposal (Federal Register 1970) specifying an iron standard of 40 mg/lb was ruled against in favor of the original standard shown (Federal Register 1979).

[f] Optional according to the U.S. Code of Federal Regulations, 1977.

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grown in different geographical areas and milled by different milling practices, reflecting regional variations, if any. The distribution of samples for this purpose was allocated according to the 1972 figures (Anonymous 1975) for active milling capacity in each of the geographic regions shown.

Sample Documentation. Each mill was asked to fill out a documentation form after collecting the sample, to help identify it by type and origin of wheat, milling extraction rate and method of calculation, patent percentage, type of flour, intended end-use, treatments applied to flour, and other details relating to the history of the sample. Mill analyses of wheat (protein, moisture) and of flour (protein, moisture, ash) were also requested and were supplied when available.

Flour Treatment. At the mill the samples received treatments that may or may not affect the levels of certain vitamins. This information received from the mills is given in Table IV.

Sample Handling. Samples received from the mills were kept in frozen storage (−20° F). Each flour sample was given a code number, blended in a Hobart mixer for 10 min, distributed into 8-oz plastic containers, and shipped to the 13 participating laboratories for assays.

The laboratories were coded A through M. Of these, laboratories A, B, and C performed proximate analysis; laboratories D, G–J, and M reported mineral analyses; and laboratories C–F, H, and K–M contributed the vitamin data.

Analytical Methods

Proximate analyses of wheat and flour samples were performed at the USDA Soft Wheat Quality Laboratory, Wooster, OH, and at the Canadian Grain Commission Laboratory, Winnipeg, Manitoba. Both laboratories determined protein by the standard Kjeldahl procedure (AACC 1961). In addition, the Winnipeg Laboratory measured protein content of the flour samples by the scanning infrared method (Williams 1975). Moisture and ash contents were estimated by conventional methods (AACC 1975, 1961). Farrand damaged starch values (Farrand 1964) and Kent-Jones flour color (Kent-Jones et al 1956) were also determined on the flour samples in the Winnipeg Laboratory. Statistical evaluation was conducted according to methods described by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Protein

Wheat and flour protein levels are shown in Table V.

Hard Red Wheats and Flours. The protein content of hard red spring wheats (HRS) was higher than that of hard red winter (HRW) wheats, with comparable differences in the resulting flours. The protein content of the wheat blends was, as expected from the relative proportions of the blends (72% HRW, 28% HRS), intermediate between those of the HRS and HRW wheats.

The flours varied somewhat in protein depending on the type. Hearth flours were milled exclusively from HRS wheats, and their protein content was higher than that of other flour types. The bread flours were slightly higher than the family flours regardless of the class of wheat from which they were milled. Protein levels of flours derived from spring-winter wheat blends were predictably intermediate between those from HRS and HRW wheats. In general, the conversion of wheat to flour resulted in a reduction of the original protein content by 1.0–1.3%, except in spring bread and hearth flours, where protein reductions were lower (0.7 and 0.5%, respectively). The protein reduction in milling of blends was intermediate (1.0%).

Soft Wheat Flours. Protein contents of different soft wheats were very similar, and the corresponding flour protein levels varied within a narrow range. Thus, some differences in flour protein levels can be attributed to milling procedures as well as to differences in parent wheats. This conclusion is supported by the corresponding ash values. Of all the flour types, the family (all-purpose) flours showed the greatest variation in protein content, both in the wheats and the flours. This is because family flour can be made from any class of wheat whereas the other products are restricted in their feedstocks.

Validity of Protein Assays. The two collaborating laboratories showed excellent agreement in the Kjeldahl protein values (Table VI) ($r = 0.993$ for wheat and 0.999 for flour). The mills and the laboratories reported fairly good agreement between the protein values ($r = 0.965$ for wheat and 0.988 for flour).

Variability of Protein. With the Kjeldahl method, protein content of flour and wheat can be estimated with a precision of 0.15–0.18% (Williams 1975). The standard deviations of the various wheat and flour classes generally exceeded this analytical precision, reflecting the variability attributable to nonuniformity in parent wheats and in blending procedures used by the mills. The highest variability was among family flours, followed in decreasing order by bread and hearth flours. The variability of cake and cookie-cracker flours was substantially below that of the other flour groups. Variability of this type is typical for many features of wheat and flour. The economics of the industry place significant restraints on the degree

TABLE II
Sample Distribution by Flour Type

Flour Type	Sample Number U.S.	Sample Number All	Sample Percent U.S	Sample Percent All	% U.S. Production
Bread	18	23	39	37	53
Family (all-purpose)	10	14	22	22	12
Hearth	5	7	11	11	10
Cake	6	8	13	13	5
Cookie-cracker	7	11	15	17	20
Total	46	63	100	100	100

TABLE III
Sample Distribution by Mill Location

Regional Area	Sample Number	Sample %	% of Active Milling Capacity
United States			
Northwest	4	9	6
Southwest	4	9	7
Northcentral	5	11	11
Central	11	24	32
Midwest	9	19	18
Southeast	7	15	13
Northeast	6	13	13
Total	46	100	100
Canada			
Eastern	12	71	...
Western	5	29	...
Total	17	100	...

TABLE IV
Number of Flours Receiving Specified Treatments

Treatment	All Flours (63)[a]	Wheat Type Hard (43)	Wheat Type Soft (20)	Flour End Use Hearth (7)	Flour End Use Bread (23)	Flour End Use Cookie (11)	Flour End Use Family (14)	Flour End Use Cake (8)
Untreated	27	14	13	3	3	8	9	4
Azodicarbonamide	21	21	0	2	15	0	4	0
Potassium bromate	12	12	0	4	7	0	1	0
Ascorbic acid	1	1	0	0	1	0	0	0
Chlorine dioxide	2	2	0	0	2	0	0	0
Benzoyl peroxide	27	22	5	2	15	2	5	3
Chlorine	8	3	5	0	1	1	2	4
Barley malt	14	14	0	3	11	0	0	0
Fungal amylase	2	2	0	0	0	0	2	0
Enrichment	5	4	1	0	4	1	0	0

[a] Numbers in parentheses = number of flours.

to which the miller can select and import wheats, and in many cases, the mill is disposed to use the wheat that is closest and most readily at hand.

Flour Ash

The distribution of protein and some other nutrients (eg, thiamin, riboflavin, and niacin) within the wheat kernel is known to be positively correlated with its mineral content, as indicated by the ash values. The level of inorganic components decreases with the distance toward the center of the kernel. Consequently, the ash of flour is a commonly used index of milling and flour quality, reflecting the amount of endosperm in a flour. The correlation of ash and protein values was r = 0.696.

The flour ash values obtained by the two laboratories agreed quite well (r = 0.982), and the ash data reported by the mills were

TABLE V
Wheat and Flour Protein Levels[a]

Wheat Class	Flour Type	Number of Samples	Wheat Protein, % Mean	Wheat Protein, % SD	Flour Protein, % Mean	Flour Protein, % SD
Hard						
Red Spring	Bread	9	13.3	0.3	12.6	0.4
	Family	5	13.2	0.4	11.9	0.1
	Hearth	6	14.3	0.6	13.8	0.5
	All	20	13.6	0.6	12.8	0.4
Red Winter	Bread	6	12.3	0.4	11.1	0.6
	Family	6	11.2	0.3	10.0	0.4
	All	12	11.8	0.7	10.6	0.6
Blends	All	9	12.6	0.5	11.6	0.4
Total	All	41	12.8	1.0	···	···
Soft	Family	2	10.6	0.3	8.4	0.7
	Cake	7	10.1	0.4	8.0	0.2
	Cookie-cracker	9	10.1	0.3	8.9	0.4
	All	18	10.2	0.4	8.5	0.6
Hard-Soft Blends	All	4	10.6	0.5	9.3	0.7
All	Bread	23	12.8	0.6	11.9	0.8
	Family	14	11.8	1.1	10.5	1.3
	Hearth	7	14.1	0.7	13.5	0.8
	Cake	8	10.2	0.4	8.0	0.3
	Cookie-cracker	11	10.1	0.3	8.9	0.4

[a] % Protein values (Kjeldahl procedure) on 14% moisture basis, average of two laboratories.

TABLE VI
Comparison of Protein Values from Different Laboratories

Source of Analysis	Method	Mean Protein Values[a] Wheat	Mean Protein Values[a] Flour
Mill	Unknown	11.95	10.74
Lab. A	Kjeldahl	12.03	10.82
Lab. B	Kjeldahl	11.93	10.71
Lab. B	Infrared	···	10.42

	Correlations Between Labs r	n	r	n
Lab. A Kjeldahl vs Lab. B Kjeldahl	0.993	61	0.999	63
Mill vs Lab. B Kjeldahl	0.965	58	0.988	57
Lab. A Kjeldahl vs Lab. B Infrared	···	···	0.989	63
Lab. B Kjeldahl vs Lab. B Infrared	···	···	0.991	65

[a] All results given on 14% moisture basis.

TABLE VII
Extraction Rate, Patent Percentage, and Ash Contents

Wheat Class	Flour Type	Number of Samples	Extraction Rate, % (E) Mean	Extraction Rate, % (E) SD	Patent Percentage, %(P) Mean	Patent Percentage, %(P) SD	Percent of Wheat in Flour (E × P)	Ash, %[a] Mean	Ash, %[a] SD
Hard									
Spring	Bread	9	73.9	1.3	88	15	65	0.488	0.030
	Family	5	73.3	0.7	57	21	42	0.428	0.051
	Hearth	6	74.6	1.3	95	12	71	0.535	0.050
	All	20	74.0	1.2	···	···	···	···	···
Winter	Bread	6	73.9	1.0	95	1	70	0.454	0.020
	Family	6	73.9	2.5	93	7	67	0.425	0.043
	All	12	73.9	1.8	94	4	70	···	···
Blends	All	9	74.1	1.2	90	8	67	0.457	0.032
Total	All	41	74.0	1.4	···	···	···	···	···
Soft	Family	2	72.5	3.5	66	22	48	0.379	···
	Cake	7	73.8	2.5	41	20	30	0.353	···
	Cookie-cracker	9	72.9	2.3	87	23	63	0.453	···
	All	18	73.2	2.4	···	···	···	···	···
Hard-Soft Blends	All	4	74.4	2.3	···	···	···	···	···
All	Bread	23	74.1	1.1	91	11	67	0.450	0.093
	Family	14	73.6	2.0	77	23	57	0.408	0.050
	Hearth	7	74.2	1.5	92	12	68	0.523	0.056
	Cake	8	73.5	2.5	39	20	29	0.361	0.030
	Cookie-cracker	11	73.4	2.4	85	23	62	0.444	0.041
Total		63	73.8	1.8	···	···	···	···	···

[a] Data given on 14% moisture basis.

also in good agreement with the laboratory assays. In 60% of the cases, the values were within the ±0.01 range, and more than 90% of the reported results were within the ± 0.03 range.

Mean ash values of flour types (Table VII) showed the expected trend: hearth flour values were highest, followed by bread and cookie-cracker (with equal values), family, and cake flours in decreasing order. In the wheat classes, the ash content of the bread flour was higher for HRS than for HRW flours, although the ash contents of these two types of wheat were similar.

Extraction Rates

Flour Yields. The relationship between extraction rate and nutrient content is well established. The greater the extraction rate in the milling of flour, the higher the percentage of the original nutrient content that is retained by the flour. In view of this relationship, the National Academy of Sciences, in addition to proposing expanded fortification, urged wheat processors to "refine flours no more than is actually required for consumer acceptance in the interest of retaining the maximum amount of all nutrients indigenous to wheat" (NAS/NRC 1974). Variations in extraction rates may have a direct bearing on the variation of nutrients in flours. Consequently, the mills were asked to provide information on extraction rates and patent percentages in order to determine the effect of these factors on the nutrient composition. Unfortunately, the mills reported the yields on nonuniform bases without giving sufficient information to permit conversion to comparable yield values.

Most mills calculated the extraction rates on one of two bases, by the dry and dirty method, that is, as the wheat came out of the boxcar before cleaning, or by the clean and tempered method, that is, after cleaning and conditioning or just before entering the first break. No attempt was made to equate the yields by the two methods because of the lack of uniformity in the reports.

U.S. Flours. The 21 mills reporting on the dry and dirty basis averaged 74.34% yield, and the 38 mills using the clean and tempered method averaged 73.23% (Table VIII). The slightly higher yield measured by the dry and dirty method is presumably due to the presence of dockage, the exact amount of which is unknown. A certain wheat and flour moisture relationship also affected the computations. The remaining mills either indicated that the extraction rate was calculated on the clean and dry basis or failed to show the method of calculation. The overall average U.S. extraction rate from this survey was 73.5 ± 1.6%. This is slightly lower than the average extraction rate of 74.2% given to the Department of Commerce by the U.S. mills in 1976 (Anonymous 1976) without specifying the basis of computation.

Canadian Flours. The extraction rates were essentially similar for the U.S. and Canadian mills. Slightly lower values for the U.S. than for the Canadian flours given by the mills using the clean and tempered method can be attributed to a greater number of soft wheat flour samples from the United States than from Canada.

Patent Percentage in Flours. Although the extraction rate is the percentage of wheat milled into flour, not all of this flour becomes part of the final product. The portion of flour used is called the "patent percentage." The product of the extraction rate and the patent percentage (E × P) indicates the portion of wheat in the flour (Table VII). This figure does not fully define the flour because the patent may consist of different selected streams blended to attain a flour of desired characteristics. The omitted flour streams may not always be those that are high in nutrients (protein, vitamins, mineral components). Thus, this value may be misleading in estimating the nutrient profile of flours.

Patent Level in Flour Classes. Bread, hearth, and cookie-cracker flours are generally long patents. The patent percentage of bread flours milled from HRW wheats was within a narrow range, around 95%; that of bread flours derived from HRS wheats and spring-winter wheat blends was slightly lower in patent (88 and 90%, respectively), presumably to help mellow the inherently strong spring wheat. Hearth flour, generally derived from HRS has a longer patent than is apparent from the mean value of all hearth flours (92%). Four of six mills reported 100% patent percentage for hearth flour and the remaining two indicated 80% patent and 20% clear.

The patents in family flours differ greatly depending on whether they were milled from HRS (57 ± 7% patent) wheats or HRW (93 ± 7% patent) wheats. Four of six of the HRS flours were from Canadian mills, which have little access to HRW wheats and have to reduce the patent level in order to obtain all-purpose flours from HRS wheats. Patents of 50 and 82% were reported for the two family flours made from soft wheats. Both of these flours were from the southeastern United States, where a weaker family flour for use in chemically leavened bakery foods is more common than in other parts of the country.

There is little difference in the types of wheat and extraction rates of cake and cookie-cracker flours. However, cake flours are short patents and the cracker-cookie flours long patents with 39 ± 20% and 85 ± 23% patent percentages, respectively.

Correlation of Extraction Rates with Flour Indices. Extraction rates reported by the mills are in a very narrow range and indicate little about the flour products. They show very low correlations with flour protein (r = 0.269) and flour ash (r = 0.155).

Higher correlations can be achieved with the E × P values, but their meaning is doubtful in view of the uncertainties in estimating the extraction rates and the types of mill streams included in the patent. The relation between E × P values and flour ash are higher for HRS wheats (r = 0.74) and soft wheats (r = 0.72) than for HRW wheats (r = 0.31), which stay within a very narrow E × P range. A somewhat better correlation exists between E × P and the change in protein from wheat to flour (r = 0.83 for HRS, −0.61 for HRW, and −0.68 for soft wheats).

Other Flour Indices

Flour Color. The Kent-Jones color score is used in England and Canada instead of flour ash as an index of extraction rate. Because bleaching affects the results of this extraction rate test, only the samples untreated with benzoyl peroxide, chlorine, or chlorine dioxide are considered in Table IX. The flour color scores correlate

TABLE VIII
Flour Extraction as Reported by the Mills

	Number of Mills	Mean Extraction Rate	Range of Extraction Rate
U.S. mills			
Dry-dirty	17	74.3 ± 1.2	70–75.5
Clean-tempered	24	73.0 ± 1.7	70–76
Combined	41	73.5 ± 1.6	70–76
Canadian mills			
Dry-dirty	4	74.4 ± 1.0	73–75.5
Clean-tempered	14	73.7 ± 2.2	70–77.2
Combined	18	73.9 ± 2.0	70–77.2
All mills			
Dry-dirty	21	74.3 ± 1.2	70–75.5
Clean-tempered	38	73.2 ± 1.9	70–77.2
Combined	59	73.6 ± 1.7	70–77.2

TABLE IX
Kent-Jones Flour Color and Flour Ash in Unbleached Samples

		Unbleached Flour				
		Number of	Flour Color		% Ash	
Wheat Class	Flour Type	Samples	Mean	SD	Mean	SD
HRS	All	10	1.3	1.8	0.48	0.08
HRW	All	8	0.3	0.7	0.44	0.04
Hard blends	All	8	0.8	0.9	0.45	0.03
Soft	All	14	0.5	1.1	0.40	0.06
All	Bread	12	0.7	0.7	0.45	0.02
	Family	10	0	0.9	0.41	0.05
	Hearth	5	2.6	1.5	0.53	0.06
	Cake	4	−0.5	1.0	0.35	0.04
	Cookie-cracker	9	1.3	0.7	0.44	0.04

TABLE X
Starch Damage[a]

Wheat Class	Flour Type	Number of Samples	Farrand Starch Damage	
			Mean	SD
HRS	Bread	9	28.1	4.4
	Family	5	29.9	3.1
	Hearth	6	26.3	3.0
	All	20	28.0	3.8
HRW	Bread	6	22.3	2.2
	Family	6	27.9	4.6
	All	12	25.1	4.5
HRS-HRW Blends	All	9	21.7	3.4
Soft	Family	2	1.2	0.9
	Cake	7	3.4	5.2
	Cookie-Cracker	9	7.0	8.4
	All	18	5.0	6.9
Hard-Soft Blends	All	4	16.0	2.7
All	Bread	23	24.2	4.7
	Family	14	24.1	10.6
	Hearth	7	26.1	2.7
	Cake	8	4.6	6.2
	Cookie-Cracker	11	8.5	8.3

[a] In Farrand units.

quite well with flour ash, as expected (r = 0.86 for all unbleached samples, 0.95 for hard wheats, and 0.76 for soft wheats).

The mean color and flour ash scores followed the same trend for each flour type except for cookie-cracker, which had a color score higher than expected from the ash values. The correlation between color score and flour ash in cookie-cracker flour (r = 0.24) was low. On the other hand, all other types showed high correlations (r = 0.75 for bread, r = 0.84 for family, r = 0.98 for hearth, and r = 0.81 for cake flours).

No better relationship was found between color scores and E × P values (r = 0.60) than with the ash values (r = 0.66).

Starch Damage. This parameter reflects the wheat kernel hardness and severity of milling due to mechanical damage (Table X). The mean values for the wheat classes followed a sequence of decreasing starch damage: HRS > HRW > total hard = hard-soft blends > soft wheat. The difference between hard and soft wheat flour in the degree of starch damage is so large that, except for a single sample of a cookie-cracker flour, no overlapping occurred. Starch damage values of bread, family, and hearth flour were similar. Although cake and cookie-cracker flours showed a very low damage in comparison to the hard wheat products, the cake flours were below those of cookie-cracker flours.

Statistical correlations were found between starch damage, wheat protein (r = 0.72), and flour protein (r = 0.73) that simply reflected the difference in protein contents of soft and hard wheats. No similar relationship was detected for the hard (r = 0.18) and soft (r = 0.01) wheat groups.

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