Note on Levels of Nutrients to Add Under Expanded Wheat Flour Fortification/Enrichment Programs

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One incentive for studying the natural levels of vitamins and minerals in commercially milled wheat flour reported by Kulp et al (1980), Keagy et al (1980), and Lorenz et al (1980) was the need for determining the nutrient addition rates required under the expanded fortification policy proposed for the United States by the Food Nutrition Board of the National Research Council (1974) and under the (1978) expanded Canadian optional enrichment program. Suitable levels of nutrients and nutrient sources to add to flour and bread need to be established in order to better evaluate the feasibility of these proposals.

RESULTS AND DISCUSSION

Nutrient Addition Rates for Wheat Flour

The proposed U.S. fortification standards, mean natural levels ± one standard deviation, and the suggested levels of nutrients to add for meeting the U.S. standards are given in Table I. Table II provides the same type of information for the expanded Canadian enrichment program. The natural levels of vitamins and minerals were derived from previous reports (Keagy et al 1980, Lorenz et al 1980). Values are on an "as is" moisture basis given in the same units in which the standard is stated (milligrams per pound for the United States and milligrams per 100 g for Canada).

A number of factors need to be considered in determining nutrient addition rates. The fortification or enrichment standards set the primary goal of total nutrient content in the final product. The U.S. standards are expressed in terms of a single minimum level (except for iron), with reasonable overages allowed within the limits of good manufacturing practices (U.S. Code of Federal Regulations 1978). The Canadian standards (1978) specify an allowable range, which was enlarged (Canada Gazette 1978) for easier compliance.

A second consideration is the natural content of the nutrient in the flour to be fortified. The amount of nutrients to be added must at least make up for the difference between the minimum fortification or enrichment standard and the mean natural content. Some additional amount needs to be added, however, to allow for variation in the natural content and to provide a safety factor to insure that the minimum requirement will be achieved. A 10% mean overage, which includes both of these factors, is normally considered to be an adequate and proper safety margin. A final consideration is the desirability of obtaining a common addition rate for as wide a variety of flour types as possible. This would allow the use of a standard nutrient premix formulation, which greatly simplifies the enrichment process performed at the mill or the bakery.

The suggested nutrient addition rates given in Table I and II were derived by the following formula, which takes all of these considerations into account:

$$A = 1.06\,(R - \overline{X} + S)$$

where A = level of the nutrient to add, R = level of the nutrient required in the final product according to the standard, $\overline{X}$ = mean natural level of the nutrient in the product, and S = standard deviation of $\overline{X}$. For example, the level of niacin to add (based on the values provided in Table I) becomes: 1.06 (24 − 5.4 + 1.4) = 21 mg/lb.

This formula makes the level to add equal to the difference between the fortification goal and an estimate of a low naturally occurring level (the mean level reduced by one standard deviation) plus a 6% safety factor.

A 6% safety factor was used because, combined with the allowance for variation in natural levels, it provides the desired mean overage of about 10% for most nutrients. In the example, the mean final niacin content in enriched flour is $A + \overline{X} = 21 + 5.4 = 26.4$ mg/lb. This is 2.4 mg/lb above the niacin standard of 24 mg/lb or a 10% mean overage.

There are a few exceptions in the use of this formula. The level of viamin A is entirely dictated by its fortification standard because wheat flour does not naturally contain this vitamin. The addition rate shown (5,000 IU/lb) provides a 15% overage, which is in line with the anticipated stability and processing losses associated with this vitamin in flour, as found by Anderson and Pfeifer (1970) and Borenstein (1969).

The U.S. iron addition rate involves some special problems. The proposed NAS/NRC fortification policy stated that iron was to be in fortified flour at a level of 40 mg/lb. This was in accordance with the enrichment standards proposed for flour at the time (Federal Register 1973). The increased iron proposal was later rescinded (Federal Register 1978), causing the iron standard to remain at its original level of 13–16.5 mg/lb. Further complications are the nutrition labeling regulations (U. S. Code of Federal Regulations 1978) that require at least 14.4 mg/lb of iron in enriched flour. The

TABLE I
Suggested Levels of Nutrient Addition to Wheat Flour for Meeting Proposed U.S. Fortification Standards

Nutrient	Fortification Standard (mg/lb)	Natural[a] Level (mg/lb)	Addition Level (mg/lb)
Thiamin	2.9[b]	0.6 ± 0.2	2.65
Riboflavin	1.8[b]	0.2 ± 0.1	1.8
Niacin	24.0[b]	5.4 ± 1.4	21.0
Folacin	0.3	0.075 ± 0.020	0.26
Pyridoxine	2.0	0.18 ± 0.07	2.0
Vitamin A	4,333 IU/lb[c]	0	5,000 IU/lb
Iron	13–16.5[b]	5.1 ± 1.7	11
Calcium	900[d]	62 ± 11	880
Zinc	10		
In Flour Type			
Bread		3.5 ± 0.5	7.5
Family		2.9 ± 0.6	8
Hearth		4.5 ± 1.0	7
Cake		2.1 ± 0.5	9
Cookie-cracker		3.4 ± 0.9	8
All		3.3 ± 0.9	8
Magnesium	200		
In Flour Type			
Bread		116 ± 23	110
Family		92 ± 29	130
Hearth		140 ± 23	80
Cake		61 ± 18	160
Cookie-cracker		91 ± 18	130
All		102 ± 32	110

[a] Mean natural level ± one standard deviation on an "as is" moisture basis, taken from studies by Keagy et al (1980) and Lorenz et al (1980).
[b] Current U.S. enrichment standards.
[c] Originally proposed as 2.2 retinol equivalents and then revised to 1.3 retinol equivalents = 4,333 IU.
[d] Currently the optional U.S. enrichment standard is 960 mg/lb in flour.

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effective iron standard, then, is 14.4–16.5 mg/lb. The suggested iron addition rate of 11 mg/lb is simply the difference between the 14.4 mg/lb minimum and the mean natural level reduced by one standard deviation (5.4 − 1.7 = 3.4 mg/lb). No additional amount is provided as an overage because the mean enrichment level (11 + 5.4 = 16.4 mg/lb) is already on the top end of the allowable range. There is no practical way to consistently stay within such a narrow range, because of the large variation in natural levels and the high assay error associated with this nutrient.

A reduced safety margin of 4% was used in calculating the U.S. addition rate for calcium. This was done because the high bulk requirements of calcium make its addition easier to control and because additional levels of this nutrient are probable from other flour additives, such as maturing and oxidizing agents, which normally contain some calcium salts as fillers or free-flowing agents. Products, such as self-rising flour, that have significant levels of calcium added for non-nutritional reasons would require reduced addition rates. These would have to be determined on an individual basis.

The natural levels of zinc and magnesium show enough variation to alter the addition rates needed in the United States. Table I provides zinc and magnesium addition rates for different types of flours. The addition rate needed for these two minerals might also be based on a flour's ash content because ash was highly correlated with natural zinc (r = 0.79) and magnesium (r = 0.77) levels in flour (Lorenz et al 1980).

The linear regression lines between milligrams per pound of zinc (Z) and magnesium (M) and the percent flour ash content (A) in that study were: Z = 14.2A − 2.9 and M = 480A − 106. By substituting these into the formula used to calculate addition rates we get:

Z (mg/lb) to add = 14.4 − 15.1 (%A)
M (mg/lb) to add = 350 − 510 (%A)

As an example of the use of these formulas, the zinc content of a 0.48% ash bread flour is estimated to be 14.2 (0.48) − 2.9 = 3.9 mg/lb, and the amount of zinc to add to this flour is 14.4 − 15.1 (0.48) = 7.2 mg/lb.

Use of these formulas on the individual base-line study flour samples gave mean overages of 11.0 ± 0.4% for zinc and 10.5 ± 10.2% for magnesium. This means that the formula for magnesium is not as good an estimator for levels to add as is the formula for zinc. The reason is that the natural content accounts for a higher proportion of the magnesium standard (51 ± 16%) than of the zinc standard (33 ± 9%).

The natural magnesium level in flour accounts for only 15 ± 5% of the Canadian magnesium enrichment standard, which allows a single addition rate to be used for most flours. The Canadian enrichment standard for magnesium is more than three times that of the U.S. standard. If this causes functional and organoleptic problems, which appears likely, the standard may have to be reduced to a level that warrants an adjustment in addition rate based on flour ash content.

Addition Rates of Nutrient Sources to Flour

The addition rates of actual nutrient sources that might be used under the proposed U.S. fortification program (grams per hundredweight) and in the expanded Canadian enrichment program (grams per 40 kg) are given in Table III. Vitamin sources need a molecular weight adjustment when the form of the vitamin used is different from the specified vitamin reference form (U.S. Code of Federal Regulations 1978). This is the case for thiamin (the reference standard of which is thiamin chloride hydrochloride), pyridoxine, and pantothenic acid. Mineral sources need to be adjusted on the basis of mineral content.

In practice, all of the vitamins and the iron and zinc would be added through a single premix. Calcium and magnesium would in many cases be added separately because of their higher bulk requirements. A standard fortification premix designed to add the level of nutrients shown in Tables I and II could still be used for flours with natural nutrient contents slightly lower than average (such as a low-ash cake flour) or higher than average (such as a high-ash hearth bread flour) by adjusting the addition rate of the premix accordingly. This procedure has limits, however. A different premix formulation would be highly desirable for any flour with an ash content greater than 0.8%.

Addition Rates to Bread and Bakery Flour

The nutrient addition levels suggested here for the proposed U.S. fortification program would apply to any flour used in making nonstandardized bakery products. Whether they apply to bread flour or to fortification at the bakery is open to question because no one has yet determined whether the addition levels of nutrients such as zinc, calcium, magnesium, and folacin should be further adjusted to take into account the significant but variable

TABLE II
Suggested Levels of Nutrient Addition to Wheat Flour for Meeting Canadian Expanded Enrichment Standards

Nutrient	Enrichment Standard (mg/100 g)	Natural[a] Level (mg/100 g)	Addition Level (mg/100 g)
Thiamin	0.44–0.77[b]	0.13 ± .05	0.38
Riboflavin	0.27–0.48[b]	0.044 ± .021	0.26
Niacin	3.5–6.4[b]	1.2 ± .3	2.8
Folacin	0.04–0.05[c]	0.017 ± .004	0.029
Pyridoxine	0.25–0.31[c]	0.040 ± .015	0.24
Pantothenic Acid	1.0–1.3[c]	0.32 ± .09	0.82
Iron	2.9–4.3[b]	1.1 ± .4	2.4
Calcium	110–140[d]	14 ± 2	105
Magnesium	150–190[c]	22 ± 7	140

[a] Mean natural level ± one standard deviation on an "as is" moisture basis, taken from studies by Keagy et al (1980) and Lorenz et al (1980).
[b] Currently required.
[c] Currently optional.
[d] Required in Newfoundland but optional elsewhere.

TABLE III
Suggested Rates of Nutrient Sources to Add to Wheat Flour for Meeting Proposed U.S. Fortification Standards and Canadian Expanded Enrichment Standards

Nutrient	Source	Nutrient[a] Activity (%)	Addition Rate: United States (g/100 lb)	Addition Rate: Canada (g/40 kg)
Thiamin	Mononitrate	103	0.257	0.148
Riboflavin	Hydrochloride	100	0.180	0.104
Niacin	Niacin (nicotinic acid)	100	2.10	1.12
Folacin	Folic acid	100	0.026	0.0116
Pyridoxine	Hydrochloride	82.5[b]	0.242	0.096
Pantothenic acid	Calcium pantothenate	92	···	0.357
Vitamin A	Palmitate	250,000 IU/g	2.00	···
Iron	Reduced	98	1.12	0.98
	Ferrous Sulfate	32	3.44	···
Calcium	Sulfate (anhy.)	29	303	···[c]
	Carbonate	40	220	105
Zinc	Oxide	80	1.0[d]	···
	Sulfate	36	2.2	···
Magnesium	Oxide	60	18.3[d]	93
	Carbonate	25	44	224
	Sulfate (dried)	14	79	400

[a] For vitamins, the percent nutrient activity = 100 (molecular weight of the vitamin reference standard/molecular weight of the vitamin source). For minerals, it equals the percent concentration of the element in the source.
[b] The U.S. vitamin reference standard for pyridoxine is pyridoxine with a molecular weight of 169.18. The addition rate for Canada is based on pyridoxine HCl as the standard.
[c] Canadian flour enrichment regulations (1978) allow only calcium carbonate, chalk B.P., or edible bone meal, as the source of calcium. There is no provision for the use of calcium sulfate.
[d] Based on the average addition rate for all flours (8 mg/lb for Zn and 110 mg/lb for Mg).

contribution of these nutrients from other bakery ingredients.

A number of bread ingredients add calcium, including calcium propionate, milk solids, yeast food, yeast, calcium stearoyl-2-lactylate, and unsoftened water. Depending on the baking formulation, 10–75% of the U.S. calcium standard could already be present in bread. A typical white pan bread would require the addition of less than 400 mg/lb of calcium in order to achieve the fortification standard.

Baking ingredients other than flour can also contribute significant amounts of zinc and magnesium. Zook et al (1970) reported mineral levels in flour and bread of 10–20% of the NAS/NRC standard for zinc and 25–30% of that for magnesium. Tabekhia et al (1978) found that baking ingredients other than flour contributed less than 5% of the zinc standard and less than 25% of the magnesium standard. When these contributions are added to those naturally present in flour, the totals are 30–60% of the zinc standard and 70–100% of the magnesium standard. Emodi and Scialpi (1978) assayed commercially made white pan breads and found them to contain 70, 80, and 75% of the proposed standards for calcium, zinc, and magnesium, respectively.

The level of folacin that would need to be added to bread could be reduced by roughly half that given in Table I if the contribution of this vitamin from yeast, which contains significant amounts of folic acid (Calhoun et al 1958), is taken into consideration.

Under the current enrichment programs, nutrient contributions from bakery ingredients other than flour are not large enough to cause similar problems. The United States has maintained separate enrichment standards for flour and bread (the latter standard being simply 63% of the former) and allows bread enrichment to be accomplished either through the use of enriched bakery flour or by enrichment at the bakery. This would no longer be possible if the significant, but often variable, contributions of the minerals and folacin from baking ingredients other than flour were to be considered as contributing toward the proposed standards. Under such an interpretation, the cost of fortification would be dramatically reduced (because fewer nutrients would have to be added), functional problems would be less likely, and fortification would best be performed at the bakery. On the other hand, this interpretation somewhat dilutes the intent of the original proposal, which is to increase the intake of nutrients deficient in U.S. diets. The extent of that increase would be determined solely by the amounts of nutrients added. This issue needs to be resolved if the proposed U.S. fortification standards are to be put into effect.

In contrast to the United States, Canada allows only flour to be enriched; no provision is made for adding nutrients at the bakery. Nutrient contributions from bread ingredients other than flour will not lower the nutrient rates suggested here for meeting the expanded Canadian enrichment standards.

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