Enrichment and Fortification of Cereals and Cereal Products with Vitamins and Minerals

Clinton L. Brooke

Enrichment of cereal products with B vitamins and minerals became feasible in the late 1930's, as the vitamins became commercially available and prices declined. The bread and flour enrichment program, inaugurated in the United States in 1941, was followed by programs to enrich corn meals and grits, rice, and other products. White flour and corn meals are enriched at the mill by metering a mixture of vitamins and iron into the flour stream. Enriched bread may be made with flour enriched at the mill, or the enriching ingredients may be added at the bakery in powdered or tablet form. Corn grits and farina are enriched through admixture of vitamin-containing, rinse-resistant particles or a powdered vitamin-iron mixture. Rice is enriched with premix kernels of rice which have been coated or impregnated with vitamins and iron and made resistant to washing losses, or with a powder which adheres to the rice, but is not resistant to washing. Flour enriched at the mill is preferred for macaroni and noodle products made by continuous processes. Breakfast cereals are usually enriched at several stages of processing, by separating enrichment ingredients and adding the heat-labile thiamine to the toasted product by spray application. The development of dry forms of vitamin A has expanded the scope of cereal enrichment. A flour enrichment program recently instituted in the Near East includes vitamin A in powdered form, as well as thiamine, riboflavin, niacin, and iron.

The purpose of this paper is to tell how cereal products are enriched and fortified—to explain how the vitamins and minerals are combined and incorporated in wheat flour and bread, corn meals and grits, durum flour for macaroni products, rice, and breakfast cereals.

The history of cereal enrichment and fortification—the story of the steps that have been taken to correct nutritional deficiencies through the supplementation of basic foods with vitamins and minerals—has been well covered in a number of publications.

Harris (1959) has published a comprehensive survey of food supplementation with vitamins. In a series of publications, the Committee on Cereals, Food and Nutrition Board (1944a, 1944b, 1946, 1947, 1948, 1950, 1958) kept pace with developments in the cereal enrichment program from its inception in 1941 until 1958.

The early history of enrichment and recent developments in relation to the world food situation were reviewed in several papers included in the symposium on enrichment presented by the American Association of Cereal Chemists (1966).

ENRICHMENT OPERATIONS IN THE FLOUR MILL

Flour is enriched at the mill by metering a vitamin-mineral mixture into the stream of flour flowing to the packing bins or by incorporating a weighed quantity of the enrichment mixture into flour in a batch mixing operation. The rate of addition in large mills is usually 1 ounce of mixture per 100 pounds of flour. Small mills prefer to add a less concentrated mixture at the rate of $^1/_2$ ounce per 100 pounds of flour.

National Center for Chronic Disease Control, U. S. Public Health Service, Bethesda, Md. 20014

When enrichment of flour at the mill began in mid-1941, each miller had to make his own enrichment mixture by adding carefully weighed quantities of thiamine, niacin, and iron to a given quantity of flour and mixing thoroughly to produce a more or less uniform premix. By mid-1942, the miller was relieved of the troublesome task of making premixes through the introduction, by several manufacturers, of accurately compounded, finely milled enrichment mixtures, with wheat or corn starch as the carrier for the thiamine, niacin, and iron.

Definitive formulas for flour enrichment mixtures were recommended to the milling industry and its suppliers by the Millers National Federation (1944). Riboflavin had been included in the enrichment formula late in 1943 when an adequate supply became available. These formulas include a safety factor of 10%, intended to cover fluctuations in the rate of flow of the flour stream, and to ensure that the enriched flour conforms to the Standard of Identity for Enriched Flour (1955).

The feeders used to dispense the enrichment mixtures are dry chemical feeders, often referred to as powder feeders. Because the feeder is a volumetric and not a gravimetric device, and because the bulk density of the enrichment mixture will vary, the rate of feed must be monitored frequently by intercepting and weighing the quantity of enrichment mixture delivered in a period of several minutes. The output of the feeder is either dropped into the flour conveyor by gravity or picked up in an air stream and blown into the flour moving along in the conveyor.

If as little as $^1/_4$ ounce of enrichment mixture is to be uniformly distributed throughout 100 pounds of flour, a ratio of 1 in 6400, the blending operation between the point of addition and the storage bin is of vital importance. Whether the flour is conveyed by mechanical means or by air, the conveyor must be long enough and must be constructed so as to ensure uniform distribution of the enrichment ingredients in the finished product. Screw conveyors for blending usually are equipped with cut flights to facilitate distribution.

Since the levels of the three B vitamins and iron are carefully controlled by the manufacturer of the enrichment mixture, a check of the enriched flour for a single ingredient gives reasonable evidence that the other three are present in the correct amounts. Many mills make use of a quick, roughly quantitative test for riboflavin. A flattened, wetted wedge of enriched flour on a glass or metal strip is examined in the dark under ultraviolet light. The intensity of fluorescence exhibited by the wetted particles of riboflavin provides an approximation of the level of enrichment. Where quantitative analyses are made, thiamine is most often checked as the index ingredient.

In the United States, little interest has been shown in adding the optional ingredients, calcium and vitamin D, to flour at the mill.

ENRICHMENT OF BREAD

Several years prior to the introduction of enriched flour, a few large bakeries experimented with nutritional supplementation of bread through the use of high-B_1 yeast, synthetic thiamine, and high-vitamin fractions of wheat. By the time the mills began to enrich flour in mid-1941, the baker had at his disposal other methods of incorporating the B vitamins and iron in his bread, mainly the use of enriched yeast. This was a compressed baker's yeast, containing thiamine, niacin, and iron in such quantities that when the yeast was used at the customary level, the resulting bread would contain the amounts of enrichment ingredients required by the Standard of Identity for Enriched Bread (1955). The thiamine in enriched yeast was somewhat lower in cost than synthetic thiamine, since the final step of synthesis was completed in vivo in the yeast from synthetic intermediates added to the fermenter. For the next two years, enrichment of bread was accomplished chiefly through the use of this type of yeast, not only because it was cheaper to enrich by this method, but also because it eliminated the necessity of purchasing a special flour for the production of enriched bread.

A third method of enriching bread at the bakery level, also introduced in 1941, was the enrichment tablet or wafer. Like the enrichment mixture used in the mill and the enriched yeast used in the bakery, the tablet supplied only thiamine, niacin, and iron because riboflavin was not yet available in sufficient quantity. During the next two years, the use of tablets found increasing favor with bakers as a simple, accurate, and selective method of enriching only the flour that was being made into dough for enriched bread. The tablets, consisting of the amounts of enrichment ingredients required for units of 50 or 100 pounds of flour with a rapid-swelling starch as the carrier, were allowed to disintegrate in a portion of the water used to make the dough, and the resulting suspension was added during the mixing of the dough.

The inclusion of riboflavin in the enrichment formula, beginning October 1, 1943, brought about rapid changes in methods of enriching bread. During the first two years of enrichment, 1941 and 1942, approximately 80% of the bread being enriched utilized yeast as the source of the vitamins and iron. The remaining 20% was enriched by means of vitamin mixtures, mostly in the form of tablets. Only a negligible proportion of the bread was made from flour enriched at the mill. During this time, however, practically all flour used in home baking was being enriched at the mill.

With the introduction of riboflavin, the yeast manufacturers found it impractical and uneconomical to add this vitamin to their product. Not only did it impart a highly undesirable orange-yellow color to their creamy-white product, it also was not well assimilated by the yeast cells, and an excessive amount was lost in the waste liquor.

The cost of enrichment had been declining steadily as vitamin manufacturers expanded their production. The addition of riboflavin halted the decline, but only briefly. Bakers use milk in their breads, usually in the form of nonfat milk solids, and milk is a good source of riboflavin. If the baker used enriched flour and also used nonfat milk solids in his dough, the resulting bread contained more riboflavin than required by the Standard of Identity for Enriched Bread. Accordingly, the manufacturers of enrichment tablets made it possible for the baker to take credit for the riboflavin in his milk powder by offering two types of tablets, one for bread made with less than 3% and the other for bread with more than 3% milk powder. This adjustment to the baker's requirements and the resulting saving, plus the fact that the use of the tablet eliminates the need to purchase a special flour for enriched bread, have made the enrichment tablet the preferred medium for enrichment throughout the baking industry. Flour enriched at the mill finds little application in commercial baking operations.

Instead of enrichment tablets, some bakers are finding it convenient to use enriched salt, in which the enrichment ingredients are combined with salt in such proportions that the amount of salt commonly used in bread dough will carry with it the amounts of vitamins and iron needed for bread meeting the requirements of the Standard of Identity for Enriched Bread. Enrichment mixtures are also combined with other ingredients which are added to the dough in small but fairly constant amounts. Such combinations may be packaged in water-soluble edible film and the packet allowed to disintegrate in the dough water.

Although calcium and vitamin D were included as optional ingredients in the Standards of Identity for Enriched Flour and Enriched Bread, little interest was shown in these as enrichment ingredients until 1953, when one large bakery chain began adding calcium and soon thereafter included vitamin D. Other bakers followed suit, and for several years a large share of the enriched bread produced in this country included the optional ingredients. From a promotional point of view, the bakers found little value in these new supplements, and one by one the bakers discontinued their use.

The feasibility of including three other nutrients in the enrichment program has been discussed by Rubin (1966) who points out the probable need for supplementation of the American diet with vitamin E, vitamin B_6, and lysine, which could be added to flour either at the mill or at the bakery. Rubin also mentions the development of stabilized beadlets of vitamin A in a form suitable for flour enrichment.

Trials of vitamin A beadlets as an ingredient of a flour enrichment mixture including B vitamins and iron were made in December 1966 in a pilot installation in a flour mill in Amman, Jordan, as the first step in a nationwide fortification program. Brooke (1968) has reported that after the feasibility of adding vitamin A to the national diet through the medium of wheat flour had been demonstrated, the Technical Executive Committee recommended to the government's Higher Nutrition Council that the 10 or 12 large mills producing about 80% of Jordan's wheat flour be required to purchase and install enrichment feeders. It was further recommended that the government of Jordan purchase and distribute to the mills, as needed, the quantities of vitamin-mineral mixture required for fortification of all of their white flour. This recommendation was made not only for public health reasons, but also for reasons of economy, to prevent unjustified increase in the prices of flour and bread. So far as is known, this was the first time vitamin A in dry form had been added to flour in a commercial milling operation. Unfortunately, the program was interrupted by the war in the Middle East.

ENRICHMENT OF CORN MEALS AND GRITS

Experience gained in the enrichment of wheat flour at the mill through the addition of vitamins and iron made it apparent that corn meals could be enriched in the same manner. In the southeastern states, where high consumption of corn meals and grits was paralleled by a high incidence of pellagra, methods were developed for the enrichment of locally ground corn products as well as those shipped in from other sections of the United States.

Mandatory enrichment of degerminated corn meal, a finely ground meal from which most of the bran and germ have been removed, began in South Carolina in 1943, two years after the inception of the wheat flour enrichment program. Within the next few years, North Carolina, Georgia, Alabama, and Mississippi also adopted legislation requiring that corn meals and grits be enriched to the same levels as white flour. Legislation in these five southeastern states was followed by the promulgation of Standard of Identity for Enriched Corn Meals and Grits (1955) covering products moving in interstate commerce.

Mixtures for the enrichment of corn meals differ slightly in formulation from those used for enriching wheat flour. They are added to the corn meal on stream, using the same types of powder feeders and mixing conveyors as for wheat flour.

The enrichment of corn grits, which are made by coarse grinding of the endosperm of the corn kernel, presented several problems. Grits were usually sold in bulk, and most housewives in the southern states washed the grits before cooking, discarding the wash water. Consequently, the finely powdered vitamins and iron had to be added in such a form that they would not separate from the granular grits in the dry state or be lost when the grits were rinsed before cooking. The problem was solved by the development of rinse-resistant premixes, consisting either of grits granules coated with enrichment ingredients and protected with an insoluble coating, or of simulated grits granules made from a corn meal dough in which the vitamins and iron had been incorporated. The cost of these premixes, which were added to the grits at the rate of 2 ounces per 100 pounds, was much higher than that of a powdered enrichment mixture. In recent years, however, grits have been marketed mostly in printed paper bags and cartons instead of unprinted cotton sacks. This has made it possible to print a statement on the container, warning the housewife not to wash, as washing removes valuable ingredients. With the washing requirement removed, the costly rinse-resistant type of premix is no longer needed, and grits can be enriched with a specially formulated powdered mixture which adheres to the granules and does not settle out in the package.

ENRICHMENT OF MACARONI PRODUCTS

Macaroni, spaghetti, vermicelli, noodles, and many other alimentary pastes are commonly classed together as macaroni products. These products are made from flours and semolinas milled from durum wheat. In the early years of enrichment, when the B vitamins were high priced and in short supply, it was felt that it would be wasteful to enrich macaroni products, because as much as 50% of the added thiamine, 40% of the niacin, and 30% of the riboflavin might be lost in cooking and draining.

By 1946, five years after the beginning of flour and bread enrichment, the cost of vitamins had dropped to a level low enough to permit establishment of a Standard of Identity for Enriched Macaroni Products (1955) which took into account the losses to be expected in cooking and draining and prescribed levels of thiamine, riboflavin, niacin, and iron in the uncooked product, anticipating that the cooked product would contain the same levels per pound as enriched flour.

Formulas were written for an enrichment mixture to be added on stream at the mill and for an enrichment wafer to be added, in suspension, during mixing of the dough. Most macaroni plants have continuous mixers and presses, so the only possible way to make enriched macaroni is to use flour enriched on stream at the mill. An enrichment tablet was made available for the small plants operating on the batch basis, but was discontinued within a few years.

ENRICHMENT OF RICE

Rice millers began experiments with the application of vitamins to rice in the early years of the enrichment program, and vitamin-fortified rice was on the U. S. market several years before the Standard of Identity for Enriched Rice was established (1958).

The first process for making a premix for the enrichment of rice was developed in Manila by an American company. This process consisted of impregnating rice kernels with thiamine, niacin, and iron, then covering the impregnated kernels with a rinse-resistant coating. The premix kernels were blended at local rice mills with ordinary white rice in the ratio of 1 to 200, to produce enriched rice providing the same levels of vitamins and iron as enriched flour. Rice enriched with premix kernels was used in the Bataan experiment in the Philippines during 1948–50, which gave dramatic proof of the importance of enrichment.

A second process for making rice premix by coating rice kernels with vitamins and iron and protecting the added nutrients with a rinse-resistant coating was developed several years later and placed in production in two plants on Formosa in 1958 to provide premix for the rice consumed by the Chinese Nationalist Army as well as for civilians. This second process for making premix kernels differed from the first by including riboflavin. Consequently, the vitamin-covered kernels were distinctly yellow in color, and when rice carrying one pound of these yellow kernels in each 200 pounds was cooked, yellow splotches appeared in the cooking pot. This presented no problem in the Army mess kitchens where the cooked rice was invariably stirred thoroughly before serving, but the native housewife was at first so suspicious of the yellow spots that she dug them out with the tip of a spoon and discarded them. Some years later, Chen and Tung (1955) reported that not only had the consumer's suspicion of the yellow spots been removed, but that some said the yellow color gave a sense of security.

Enrichment of rice by admixture of rinse-resistant premix kernels is an effective and practical method for those parts of the world where rice, the most important food, is often contaminated in transit and in storage and is invariably washed before cooking. The premix kernel method seals the enrichment ingredients on the rice kernels in such a way that the vitamins and iron are not released and dispersed until the rice is cooked.

Some success has been achieved with a premix consisting of simulated rice kernels, made by extruding a dough consisting of enrichment ingredients and a suitable binder through a short-goods die in a macaroni press.

For white rice marketed in printed cartons or bags, enrichment with a finely powdered vitamin and iron mixture, so formulated that it will adhere to the surfaces of the kernels and will not sift out, has proved very satisfactory, but the ease with which such a mixture can be washed off the rice poses a problem.

The Standard of Identity for Enriched Rice (1958) stipulates, in effect, that powder-enriched rice packed in consumer packages must bear the statement "To retain vitamins do not rinse before or drain after cooking." However, this statement is not required for precooked rice packed in consumer packages labeled with directions which, if followed, will avoid washing away or draining off enriching ingredients.

When the Standard of Identity for Enriched Rice was published, it required the same levels of thiamine, riboflavin, niacin, and iron as for enriched flour, corn meals and grits, and macaroni products after cooking. However, the requirement for riboflavin was stayed "until final action should be taken disposing of the objections after public hearing thereon." This exception was made because several of the large rice millers objected to the slight yellowish tint that the riboflavin imparted to their polished white rice. More than nine years have passed, and no hearing has been held. With one or two notable exceptions, rice millers in the United States do not include riboflavin in their enrichment mixtures.

Whereas in the premix kernel method of enrichment, the vitamins and iron are applied to only 0.5% of the total weight of the rice, in the powder method, a mixture of vitamins and iron with a suitable carrier is applied on stream to the entire body of rice. But this is not simply a matter of blending one powdered substance with another; it is necessary literally to rub the vitamins and iron into the surfaces of the kernels by passing the stream of rice through a slowly rotating baffled cylinder (trumbol) or a sequence of cylinders where the attrition of kernel on kernel serves to work the enrichment ingredients into the surfaces of the kernels. This treatment eliminates segregation in the bag or package.

ENRICHMENT AND FORTIFICATION OF BREAKFAST CEREALS

The bewildering array of breakfast cereals now on the grocery shelves and the variety and range of their label claims make it difficult to generalize about the fortification of these products. The only breakfast cereal that can be labeled "Enriched" is farina which is a hot cereal—i.e., one that requires cooking. A Standard of Identity for Enriched Farina (1955) requires the same enrichment levels for enriched farina as for the other enriched products mentioned in the foregoing. Farina may be enriched with a premix made in the same way as corn grits premix, or a powder may be used, as with corn meals.

The numerous ready-to-eat or cold cereals are usually fortified at least to whole-grain levels in respect to thiamine, niacin, and iron, but an increasing number are boosting both the levels and the number of vitamins and minerals added during processing. Dietary labeling claims for fortified cereals are expressed both in milligrams and in percentages of minimum daily requirements supplied by a 1-ounce serving.

Some of these products supply, in a 1-ounce serving, one third of the minimum daily requirements of a half-dozen vitamins and one or more minerals; others supply one half; and several supply a full 100%, including in the list vitamin B_6 and vitamin B_{12}. The vitamins are added at different stages of processing, depending on the physical and chemical characteristics of the substance. Heat-stable vitamins and the minerals may be added to the mixture of raw cereal, flavoring, and other supplements before cooking. The heat-labile vitamins, such as thiamine, are usually sprayed on the toasted product as it emerges from the oven.

COST OF ENRICHMENT

In 1956, the year that marked not only the fifteenth anniversary of enrichment but also the twentieth anniversary of the synthesis of thiamine, the American Institute of Baking (1956) published a booklet of letters from eminent scientists, testifying to the genius of R. R. Williams, the man who took the great stride toward making enrichment possible. The following is taken from the tribute paid to Williams and to the flour and bread enrichment program, in the letter from the dean of American cereal chemists, C. H. Bailey.

"It is one thing to discover scientific truths through research; it is another thing to translate them into services to the human population, and particularly without disturbing normal routines or adding to the cost of living. Yet that dual function was discharged in the instance of the flour and bread enrichment program. It not only involved making essential nutrients available in adequate quantities, but did so without altering the delectable qualities of the foods involved, and with a minimum of inconvenience to the processor, and of cost to the consumer."

It is instructive and heartening to the chemist, nutritionist, and food technologist to compare enrichment costs in 1941 and 1967.

In 1941, the cost of enriching 100 pounds of flour at the mill was 17 cents; in 1967, it is two cents. In 1941, the baker could enrich 10 pounds of bread for 1 cent; in 1967, he can enrich 57 pounds of bread for 1 cent.

With these figures before us, and knowing as we do that enrichment of cereal products can be accomplished with a minimum of inconvenience, we can agree heartily with Bailey's statement.

LITERATURE CITED

American Association of Cereal Chemists, "Enrichment, The Quiet Miracle," *Cereal Sci. Today* **11,** No. 6 (1966).

American Institute of Baking, *Institute News* **13,** No. 2, Chicago, Ill., March–April 1956.

Brooke, C. L., "Fortification of Wheat Flour in Jordan with Vitamin A, Thiamine, Riboflavin, Niacin and Iron," Centennial Proc., University of Beirut, in press, 1968.

Chen, K.-P., Tung, T.-C., *J. Formosan Med. Assoc.*, **54,** No. 3, 113–121 (1955).

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "Enrichment of Flour and Bread," *Bull.* **110,** 1944a.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "The Facts about Enrichment of Flour and Bread," 1944b.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D.C., "Supplement to the Facts about Enrichment of Flour and Bread," 1946.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "Bread and Flour Enrichment, 1946–47," 1947.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "Outlook for Bread and Flour Enrichment, Review of Events During 1947–48," 1948.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "Flour and Bread Enrichment, 1949–50," 1950.

Committee on Cereals, Food and Nutrition Board, National Research Council, National Academy of Sciences, Washington, D. C., "Cereal Enrichment in Perspective," 1958.

Harris, R. S., J. Agr. Food Chem. **7,** 88–102 (1959).

Millers National Federation, Chicago, Ill., Recommended Specifications for Enrichment Premixes, news release, Oct. 2, 1944.

Rubin, S. H., *Cereal Sci. Today* **11,** 234–9, 280 (1966).

Standard of Identity for Enriched Bread, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 17, Sec. 17.2, 1955.

Standard of Identity for Enriched Corn Meals and Grits, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 15, Subpart B, Sec. 15.513, 15.514, 1955.

Standard of Identity for Enriched Flour, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 15, Subpart A, Sec. 15.10, 1955.

Standard of Identity for Enriched Farina, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 15, Subpart A, Sec. 15.140, 1955.

Standard of Identity for Enriched Macaroni Products, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 16, Sec. 16.9, 16.10, 16.11, 16.12, 1955.

Standard of Identity for Enriched Rice, Code of Federal Regulations, Title 21, Food and Drug Admin., Part 15, Subpart E, Sec. 15.525, 1958.

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