Enrichment of Sugar and Sugar Products

Juan M. Navia

An important function of vitamins and minerals is to assist in the metabolism of carbohydrates, proteins, and fats. The principal vitamins required for the metabolism of starches and sugars are thiamine and niacin. Calorie-rich processed foods are often deficient in vitamins and minerals, and depend upon the so-called "protective foods" to make up for their nutrient deficits. It is now economically feasible and scientifically sound to supplement food products with nutrients to make them metabolically self-sufficient. Consideration should be given to the feasibility of enriching sugar-rich food products with vitamins and minerals, and especially thiamine and niacin. Because sugar products may promote dental caries, thought should be given, also, to the supplementation of sugar products with cariostatic-phosphates.

During the past 60 years, there has been a continual increase in the per capita consumption of sugar and sugar products in the world (Table I). The per capita intake in 1967 was approximately $2^1/_2$ times that in 1909. In certain countries, such as in the U.S.A., the per capita consumption of sugar is twice the world average.

Sugar is an excellent and palatable source of carbohydrate calories. The sugar generally eaten by mankind is so highly refined that it contains nothing but calories. When sugar is eaten, therefore, it must force out of the diet other foods which contain proteins, minerals, and vitamins if an increase in calorie intake is to be avoided. In other words, an increase in sugar consumption can cause a decrease in the nutritional quality of man's diet.

The problem created by increased consumption of refined sugar by mankind may be solved by one of three approaches: remove the refined sugars from the diet (and possibly use of synthetic sweeteners); increase the use of very nutritious natural foods from plant and animal sources; and enrich sugar and sugar products with vitamin and mineral supplements. The food habits of mankind are too stubborn and motivations are too weak to permit the first or the second approach to succeed. Factors involved in the last approach are now evaluated.

The ability of a diet to meet the nutritional requirements of an individual is determined by many factors, including his nutrient requirements and the kinds and amounts and availabilities of the nutrients eaten day by day. Man's choice of foods is restricted by the geographical area where he lives, the cultural and religious groups with whom he is identified, and his economic status (Harris, 1962).

Though the majority of people can select their diet from several hundred varieties of foods, most limit their diet to several dozen. They select the foods they like from among those foods they can pay for, and have neither the ability nor the motivation to choose a well balanced diet. This may explain why teenagers, and many who are their elders, often select bizarre or monotonous diets which seldom supply their nutritional needs (Hampton *et al.*, 1967). The major foods of mankind are cereals—e.g., wheat, rice, corn, etc.—tubers and roots—e.g., potatoes, sweet potatoes, cassava—legumes—e.g., beans, peas, soybeans—fruits, and refined cane and beet sugar. In many regions, such combinations of cereals and legumes such as rice-soybeans, corn-beans, manioca-beans provide over 80% of the calorie requirements. These staple foods provide at least a minimum level of subsistence for people in most areas of the world.

Table I. World Sugar Consumption

Year	Pounds per Capita	Increase %[a]
1909	16.5	100
1929	27.3	165
1949	26.0	157
1951	28.4	172
1959	36.0	218
1966	38.9	236
1967 (est.)	42.6	258

References: F. Whitlok Dixon Rept., August 1967; Viton and Pignalosa, 1961; U.N. Demographic Yearbook, 1959.

[a] Increase relative to the 1909 consumption.

Cultural and technological considerations have led to the refinement of cereals. Those foods which man eats in considerable quantity day after day are mild flavored. Refinement of foods can also be justified on the ground that it improves the storage life, and removes parts which are indigestible or mildly toxic. Food refinement and processing may also remove or destroy significant amounts of nutrients (Harris and von Loesecke, 1960). In fact, the Food and Nutrition Board of the National Research Council considered the effects of milling of cereals to be so serious that it recommended the enrichment of refined cereals (wheat, rice, corn) with selected minerals and vitamins. It is now generally agreed that the enrichment of cereals in the United States according to standards promulgated by the U.S. Food and Drug Administration has improved the nutritional status of the people. Enrichment of foods should not be indiscriminate; it should be based upon scientific principles and designed to accomplish valid objectives.

Harris (1968) has outlined the six philosophies which influence most food enrichment programs. The philosophy of "fortification to make a food or food product metabolically self-sufficient" is the one which should guide discussions concerned with the advisability and feasibility of the enrichment of sugar and sugar-rich food products with vitamins and minerals.

Department of Nutrition and Food Science, Massachusetts Institute of Technology, Cambridge, Mass. 02139

PATTERNS OF CONSUMPTION OF SUGAR AND SUGAR PRODUCTS

Most of the world's sugar is obtained from sugar cane (60%) and sugar beet (30%). Sugar cane is a perennial tropical grass and is the world's most productive plant in terms of calories per acre (Hockett, 1950, 1955). Sugar beet is a biennial plant grown on huge plantations in temperate climates.

Yudkin (1964, 1967) has commented that the world consumption of sugar has increased more rapidly than any other food commodity and more rapidly than human populations, especially in technically underdeveloped areas (Tables I and II). The per capita consumption of sugar in the United States has stabilized in recent years at a level of approximately 97 pounds per capita per year (Table III), which is twice the world average of about 43 pounds per capita per year (U.S. Food Consumption Suppl., 1965; Leverton, 1963; Antar *et al.*, 1964). Similar trends in carbohydrate consumption have been noted in the United Kingdom (Greaves and Hollingsworth, 1964, 1966; Hollingsworth and Greaves, 1967), with a decreased consumption of starch compensated by an increased intake of sugar. After studying the sugar consumption pattern of the world, Yudkin (1964) concluded that: increased national incomes are associated with increased sugar-to-total carbohydrate ratios; increased economic prosperity leads to relatively more sugar being bought as manufactured foods than as household sugar; and increased consumption of sugar-containing foods reduces the consumption of nutritionally superior foods, such as fruit and meat.

Table II. Regional Increase in Yearly Sugar Consumption, Kg./Head

Region	Consumption Prewar	1957	Increase, %
Far East (excluding China)	4.7	6.6	40
Near East	4.9	12.4	145
Africa	5.0	10.0	100
Eastern Europe and U.S.S.R.	12.9	25.8	100
Central America	16.6	28.3	70
South America	16.8	29.1	73
Western Europe	25.2	32.4	27
Oceania	43.3	45.4	5
North America	46.5	46.1	−1

Reference: Viton and Pignalosa, 1961.

Table III. Sugars and Sweeteners, per Capita Consumption in the U.S.A.

	1963	1964	1965
Cane and beet sugar, 1 lb.	96.6	96.5	96.5
Corn sugar	4.5	4.4	4.5
Syrups			
Cane	0.2	0.2	0.2
Corn	12.3	13.6	13.6
Maple	0.2	0.2	0.2
Refiners	0.2	0.2	0.2
Edible cane molasses	0.3	0.3	0.4
Honey	1.5	1.4	1.5
All sugars and sweeteners	115.8	116.8	117.1

Reference: *U. S. Dept. Agr. Statist. Bull.* No. **364** (1965).

Yudkin pointed out that there is a reasonable association between high intake of sugar and the etiology of atherosclerosis and, to a lesser extent, diabetes. Antar *et al.* (1964) evaluated the changes in the American diet over the past 70 years, and suggested that the increase in the consumption of simple sugars, especially in the first part of the century, may have been a factor in the rise of coronary heart disease. Ošancovà (1967) analyzed the trends of carbohydrate and sugar consumption during post-war years in Czechoslovakia, and found evidence of a statistically significant relationship between regional differences in sugar consumption and the ratio of complex-to-simple carbohydrates on one hand, and morbidity and mortality from cardiovascular disease and possibly obesity on the other.

Dental caries has been influenced by the intake of sugar and particularly sucrose. Although there are some indications that carbohydrate consumption has a systemic influence on the composition of teeth and saliva in experimental animals (Speirs, 1964), there is still not sufficient evidence to accept it as a mechanism of action. Rather, most investigators—e.g., Hartles, 1967—hold the view that sugars provide a substrate to bacterial plaque on the tooth surface which in turn stimulates the decalcification of the enamel surface, or enter in the synthesis of bacterial polysaccharides (Gibbons and Socransky, 1962). These polysaccharides can be formed from sucrose and may be utilized either as energy reserve or as a way to facilitate implantation and fixation of the organism on the tooth surface.

The Vipeholm study is the classic illustration of the influence of the type and frequency of ingestion of dietary carbohydrates on dental caries development (Gustafson *et al.*, 1954). This was a 5-year study of 436 mental patients with a mean age of 32 years in an institution in Vipeholm, Sweden. The first year was used to establish a base line caries index. During the next 4 years, 10 groups were fed the same basal diet, with or without several types of sugar fed at mealtime or between meals.

The data from this study indicated that sugar stimulated caries activity by local action in the mouth, sugar was more effective than bread carbohydrate, the time retention and the form of the sugar in a sugar-containing food was of critical importance, and the caries activity of a sugar-containing food increased with frequency of eating.

This last point is probably the most important, since the increase in caries activity was greatest when sugar in the form of sticky toffees or caramels was eaten frequently between meals. The caries activity was but slightly increased when sugar was consumed in solution and at meals in amounts even twice the Swedish average consumption.

Even though some of these relationships between sugar consumption patterns and disease are not fully understood, the problem evidently deserves further study. If a direct cause and effect relationship can be demonstrated, then it still must be determined whether it is due to sugar per se, or to deficiencies in nutrients in sugar-rich diets, or both.

NUTRITIONAL BIOCHEMISTRY OF SUGAR ENRICHMENT

Foods compete for space in the stomachs of mankind. Every time a person selects a sugar-rich food, he does it at the expense of other foods, and these other foods are always better as a source of vitamins and minerals than the sugar which replaces them. It is now economically and practically feasible to enrich sugar-containing foods with at least those vitamins and minerals which are required to metabolize it. Vitamin enrichment with thiamine and niacin is especially advisable. Thiamine is involved in the oxidation of α-keto acids and is a key vitamin in the metabolism of carbohydrates and proteins. It is an essential component of the cocarboxylases which participate in all oxidative decarboxylations which lead to the formation of carbon dioxide. Pyruvic acid is the end product in the anaerobic breakdown of carbohydrates in animals. Carboxylases are required for the next step in the metabolic process in which pyruvic acid enters the cycle in which decarboxylation and oxidation reactions take place. Thiamine deficiency interferes with pyruvic acid degradation, and there is an accumulation of pyruvic and lactic acids in the blood, and a series of deficiency symptoms and signs develop. Thus, thiamine is required for the metabolism of sucrose; since sucrose is devoid of thiamine, it must depend upon other foods in the diet to supply the thiamine needed for its metabolism.

Thiamine requirement of human beings is influenced by carbohydrate rather than by fat. Stirn *et al.* (1939) reported that when the carbohydrate fraction of a thiamine-free diet was isocalorically replaced by fats, this diet relieved the polyneuritic symptoms in thiamine-deficient rats. Reinhold *et al.* (1944) working with women and Holt and Snyderman (1955) using infants found that the replacement of dietary fat calories by carbohydrate calories caused a decrease in urinary thiamine excretion.

Human subjects were fed diets which were restricted in thiamine content, and the thiamine excreted in the urine was measured. By this procedure, Keys *et al.* (1943), Najjar and Holt (1943), and Horwitt (1948) determined that the minimum requirement of thiamine is approximately 0.20 mg. per 1000 calories consumed.

Niacin is a major component of the coenzymes which control glycolysis and tissue respiration. These coenzymes serve as hydrogen acceptors from metabolites activated by certain anaerobic dehydrogenases, passing H to the flavoproteins. Horwitt *et al.* (1956) determined that human subjects subsisting on diets providing more than 4.4 niacin-equivalents per 1000 calories did not develop pellagra, while those on diets with lower niacin-calorie ratios developed the deficiency syndrome. He related the niacin value of foods and the niacin requirements to the calorie content of foods. Goldsmith *et al.* (1952, 1956) also demonstrated that the niacin requirement is dependent upon the calorie intake.

Based on these studies, the Food and Nutrition Board of the National Research Council (1964) established a recommended allowance of 6.6 mg. of niacin-equivalent per 1000 calories and 0.4 mg. of thiamine per 1000 calories, for a daily diet which contains less than 3000 calories; this allowance was to be increased by 0.2 mg. of thiamine for each additional thousand calories consumed.

The fortification of sugar products with other vitamins such as riboflavin, pyridoxine, pantothenic acid, or biotin does not seem necessary since these vitamins are involved more with protein and fat metabolism than with carbohydrate metabolism. Similarly, the fat-soluble vitamins A, D, E, and K should not be considered for sugar enrichment since they do not contribute directly to the metabolism of carbohydrate. Thus, only thiamine and niacin are directly involved in the metabolism of sucrose, and only these should be considered as necessary to make sugar self-sufficient metabolically.

The percentages of total nutrients contributed by major food groups in the U.S.A. are shown in Table IV. While sugars contribute 35.6% of the total carbohydrate and 16.3% of the total food energy, they provide less than 0.05% of the thiamine and 0.1% of niacin. Sugar-rich foods cannot always depend upon other foods in the diet to supply the vitamins and minerals in which they are deficient.

Therefore, consideration should be given to the enrichment of sugar-rich foods at levels of 0.2 mg. of thiamine and 3.6 mg. of niacin per 100 grams of sucrose to make these foods metabolically self-sufficient. These suggested levels are based on approximately twice the minimum requirement of these vitamins per 1000 calories discussed previously.

Table V shows the calculated thiamine and niacin value of several types of confectionery products before and after enrichment with thiamine and niacin at these levels. In contrast to their high energy content, these products at present contain few vitamins. Only when other components are added to sugar, as in nut and peanut bars,

Table IV. Percentage of Total Nutrients Contributed by Major Food Groups, 1965[a] Consumed in the U.S.A.

Food Group	Food Energy	Protein	CHO	Ca	P	B_1	Niacin
Meat, poultry, fish, including fat pork cuts	19.0	38.5	0.1	3.2	23.8	27.3	44.6
Eggs	2.2	5.8	0.1	2.4	5.9	2.5	0.1
Dairy products, excluding butter	12.5	23.8	7.5	76.9	38.4	10.5	1.9
Fruits, total	3.1	1.0	6.6	2.0	1.7	4.0	2.6
Vegetables, total	2.7	3.7	4.9	6.1	5.4	8.1	6.9
Potatoes	2.4	2.2	4.6	0.7	3.5	5.9	6.8
Sweet potatoes	0.3	0.1	0.5	0.2	0.2	0.4	0.2
Dry beans, peas, nuts, soya products	3.0	5.1	2.2	2.5	5.7	5.9	6.7
Flour and cereal products	21.1	19.3	37.3	3.4	13.0	35.4	24.3
Sugars and other sweeteners	16.3	[b]	35.6	1.0	0.2	[b]	0.1

[a] Reference: *U.S. Dept. Agr. Statist. Bull.* No. **364** (1965). [b] Less than 0.05%.

Table V. Comparison of Thiamine and Niacin Values Reported in the Literature for Some Confectionery Products and Calculated Values for the Fortified Product, Mg./100 Grams

	Thiamine		Niacin	
	Normal[a]	Fortified[b]	Normal	Fortified
Butterscotch	0	0.14	Trace	2.52
Caramels, plain	0.03	0.13	0.2	2.00
Chocolate with nuts	0.11	0.21	0.2	2.00
Chocolate flavor rolls	0.02	0.12	0.1	1.90
Chocolate, sweet	0.02	0.10	0.3	1.74
Fondant	Trace	0.18	Trace	3.24
Fudge, vanilla	0.02	0.12	0.1	1.90
Vanilla with nuts	0.05	0.15	0.1	1.90
Jelly beans	0	0.10	Trace	1.80
Marshmallows	0	0.12	Trace	2.16
Peanut bars	0.43	0.49	9.4	10.48
Sugars, brown	0.01	0.20	0.2	3.60
Granular	0	0.20	0	3.60

[a] Watt and Merrill, 1963.
[b] Calculated values based on supplementation of 100 grams of sucrose with 0.2 mg. of thiamine and 3.6 mg. of niacin.

do the mineral and vitamin values of sugar-rich products increase.

ENRICHMENT OF SUGAR PRODUCTS AND CARIES-REDUCING AGENTS

The scientific evidence indicates that the additions of sucrose to the diets of experimental animals and human beings will accelerate the development of dental decay (Newbrun, 1967). Apparently, the addition of fluorides to the water supply and the addition of phosphates to foods are the two best nutritional methods for combating this disease, and the simultaneous use of phosphates and fluorides is highly effective.

Some years ago, it was demonstrated that the development of dental decay in rats was accelerated when their diet was deficient in phosphorus (Wynn *et al.*, 1956), calcium (Wynn *et al.*, 1959), or both calcium and phosphorus. Caries was significantly reduced when the diet was made adequate in these elements. Harris *et al.* (1957) have demonstrated that phosphate above the level required for adequate nutrition is even more effective in the control of caries in rodents. When sufficient amounts of phosphate were added, caries was prevented. The results of more than 150 animal experiments indicate that inorganic and organic phosphates are effective in the control of dental decay (Nizel and Harris, 1964). Ship and Mickelsen (1964) and Averill and Bibby (1964) reported inconclusive results when dicalcium phosphate was fed in the school lunches of children. On the other hand, Stralfors (1964) has reported significant reductions in the development of caries when this dicalcium phosphate dihydrate was fed in the school lunches of children. Stookey *et al.* (1967) have reported significant reductions when sodium orthophosphate was incorporated into the daily dry cereal of children, and Finn and Jamison (1967) have reported significant reductions when children chewed daily a gum which was fortified with dicalcium phosphate dihydrate. In Australia, Harris *et al.* (1967) recently reported the results of a study in which sucrose phosphates were added to carbohydrate foods in the diets of children. They found a significant reduction in dental caries of children 5 to 12 years of age. Animal research in in the author's laboratories has demonstrated that sodium trimetaphosphate at a level of 0.5% reduced caries significantly and is therefore the most effective of the 30 or more phosphates that have been tested (Navia *et al.*, 1967). Phytate, the major form of phosphorus in cereal seeds and in many edible plants, and a major form of phosphorus in crude sugar juice, has been proved to be as effective as orthophosphate in the control of caries in experimental animals.

The author suggests the addition of phosphate to sugar and sugar products at approximately the 1.0% level. This amount of phosphate could significantly reduce caries development, especially when added to the types of sucrose-rich foods which are retained in the mouth.

TECHNOLOGICAL ASPECTS OF SUGAR ENRICHMENT

Sugar is involved in the manufacture of a large number of food products. These include cured meats (Kraybill, 1955), baked products (Eisenberg, 1955), canned fruits (Alston, 1955), frozen fruits (Talburt, 1955), jellies (Joseph, 1955), carbonated beverages (Gortatowsky, 1955), and confectionery products (Alikonis, 1955; Martin, 1955). Sugars are used in these diverse food products because of their organoleptic, physical, chemical, and nutritional properties which they impart (Table VI).

The treatment which sugar receives during processing may destroy significant amounts of the food nutrients and the nutrients which may be added to sugar-containing foods as part of an enrichment program. Thiamine is rather unstable to heat especially under alkaline conditions and in the presence of oxidizing agents. Niacin is somewhat more stable and phosphates are fairly stable. None of these three nutrients should affect the palatability of food products. Each food product will require special

Table VI. Properties of Sugars Which Determine Their Use in Food Manufacturing Processes

Property	Effect	Food Product
Organoleptic	Increase sweeteners Enhance flavor and color Body or texture	Canned and frozen fruits; confectionery products; meat products; chewing gum
Physical	Solubility	Carbonated beverages
	Density; viscosity	Sirups; liquid sugar
	Osmotic pressure; penetration into tissues	Fruit products
	Crystallization; grain or texture	"Fondant," hard candy
	Freezing point depression	Ice cream, sherbet
	Hygroscopicity; moisture control	Creams, icings
Chemical	Caramelization	Breadcrust, caramels
	Antioxidant	Fruit products
Microbiological	Fermentation	Leavened goods
	Preservation	Fruit sirups and preserves
Nutritional	Calorie source	Sugar and sugar-containing foods

study to develop the best procedure for its enrichment, and enrichment of certain types of sugar-rich products may not be feasible.

CONCLUSION

Although the consumption of sugar in the United States has not increased in the past 20 years, the per capita consumption is twice the world average. Adolescents and young adults consume large quantities of carbohydrates, especially sucrose.

In response to cultural and technological demands, sugar is now so purified that many sugar-rich foods are nearly devoid of minerals and vitamins, and contribute nothing but calories to the diet. The public expects the food industries to provide food products which are palatable, safe, inexpensive, and nutritious.

Food products may now be enriched and fortified with vitamins, minerals, and amino acids at very low cost. The additions may be made to improve nutritional values and to control the development of dental decay.

Consideration should be given to the enrichment of sugar and sugar-rich food products with thiamine and niacin to make sugar metabolically independent.

Consideration should be given, also, to the supplementation of sugar and sugar-rich food products with phosphates to thus combat the development of dental decay which pure sugar promotes.

The enrichment of sugar-containing foods with nutrients, and the supplementation of sugar with phosphate may create problems in food technology which should not be difficult to solve. Enrichment of certain sugar-rich food products may be undesirable because processing procedures are severe.

Raising the nutritional quality of these products through supplementation should not stimulate an increased consumption of sugar but rather prevent nutritional problems brought about by the extensive use of sugar in manufactured products.

If enrichment of sugar-containing foods is advisable for the U.S. and the western hemisphere, it is certainly even more important in the less technically developed countries of the world where the consumption of sugar-containing foods is increasing.

The fortification of sugar-containing products to make them nutritionally self-sufficient is advisable, although the author fully recognizes that there are complex legal, administrative, and technological difficulties which must be solved before this program can be fully implemented.

LITERATURE CITED

Alikonis, J. J., *Advan. Chem. Ser.* No. **12,** 57 (1955).
Alston, P. W., *Advan. Chem. Ser.* No. **12,** 75 (1955).
Antar, M. A., Ohlson, M. A., Hodges, R. E., *Am. J. Clin. Nutr.* **14,** 169 (1964).
Averill, H. M., Bibby, B. G., *J. Dental Res.* **43,** 1150 (1964).
Eisenberg, S., *Advan. Chem. Ser.* No. **12,** 78 (1955).
Finn, S. B., Jamison, H. C., *J. Am. Dental Assoc.* **74,** 987 (1967).
F. Whitlok Dixon Rept., August 1967.
Gibbons, R. J., Socransky, S. S., *Arch. Oral Biol.* **7,** 73 (1962).
Goldsmith, G. A., Gibbens, J., Unglanb, W. G., Miller, O. N., *Am. J. Clin. Nutr.* **4,** 151 (1956).
Goldsmith, G. A., Sarett, H. P., Register, U. D., Gibbens, J., *J. Clin. Invest.* **31,** 533 (1952).
Gortatowsky, C., *Advan. Chem. Ser.* No. **12,** 70 (1955).
Greaves, J. P., Hollingsworth, D. F., *Proc. Nutr. Soc. Engl. Scot.* **23,** 136 (1964).
Greaves, J. P., Hollingsworth, D. F., *World Rev. Nutr. Dietet.* **6,** 34 (1966).
Gustafson, B. E., Quensel, C. E., Lanke, L., Lundqvist, C., Grahmen, H., Borrow, B. E., Krasse, B., *Acta Odont. Scand.* **11,** 232 (1954).
Hampton, M. C., Huenemann, R. L., Shapiro, L. R., Mitchell, B. W., *J. Am. Dietet. Assoc.* **50** (5), 385 (1967).
Harris, R. S., J. Agr. Food Chem. **16,** 149 (1968).
Harris, R. S., *Arch. Environ. Health* **5,** 144 (1962).
Harris, R. S., Loesecke, H. von, "Nutritional Evaluation of Food Processing," Wiley, New York, 1960.
Harris, R. S., Nizel, A. E., Gardner, D. S., *Intern. Congr. Nutr.* **4th,** 195 (1957).
Harris, R., Schamschula, R. G., Gregory, G., Roots, M., Beveridge, J., *Australian Dent. J.* **12,** 105 (1967).
Hartles, R. L., *Am. J. Clin. Nutr.* **20,** 152 (1967).
Hockett, R. C., *Advan. Chem. Ser.* No. **12,** 114 (1955).
Hockett, R. C., *J. Calif. State Dental Assoc.* **26,** 71 (1950).
Hollingsworth, D. F., Greaves, J. P., *Am. J. Clin. Nutr.* **20,** 65 (1967).
Holt, L. E., Jr., Snyderman, S. E., *J. Nutr.* **56,** 495 (1955).
Horwitt, M. K., *Natl. Res. Council Bull.* No. **116** (1948).
Horwitt, M. K., Harvey, C. C., Rothwell, W. S., Cutler, J. L., Haffron, D., *J. Nutr.* **60,** Suppl. 1, 43 (1956).
Joseph, G. H., *Advan. Chem. Ser.* No. **12,** 49 (1955).
Keys, A., Henschel, A. F., Mickelsen, O., Brozek, J. M., *J. Nutr.* **26,** 399 (1943).
Kraybill, H. R., *Advan. Chem. Ser.* No. **12,** 83 (1955).
Leverton, R. M., *U.S. Dept. Agr. ARS,* 41st Annual Agr. Outlook Conf., Washington, D.C., 1963.
Martin, L. F., *Advan. Chem. Ser.* No. **12,** 64 (1955).
Najjar, V. A., Holt, L. E., Jr., *J. Am. Med. Assoc.* **123,** 683 (1943).
Natl. Acad. Sci.–Natl. Res. Council, Publ. No. **1146** (1964).
Navia, J. M., Lopez, H., Harris, R. S., *Intern. Assoc. Dental Res.,* 45th Meeting, Washington, D.C., 1967.
Newbrun, E., *Odont. Rev.* **18,** 373 (1967).
Nizel, A. E., Harris, R. S., *J. Dental Res.* **43,** 1123 (1964).
Ošancovà, K., *Am. J. Clin. Nutr.* **20,** 73 (1967).
Reinhold, J. G., Nicholson, J. T. L., Elsom, K. O., *J. Nutr.* **28,** 51 (1944).
Ship, L. L., Mickelsen, O., *J. Dental Res.* **43,** 1144 (1964).
Speirs, R. L., *Proc. Nutr. Soc. Engl. Scot.* **23,** 129 (1964).
Stirn, F. E., Arnold, A., Elvehjem, C. A., *J. Nutr.* **17,** 485 (1939).
Stookey, G. K., Carroll, R. A., Muhler, J. C., *J. Am. Dental Assoc.* **74,** 752 (1967).
Stralfors, A., *J. Dental Res.* **43,** 1137 (1964).
Talburt, W. F., *Advan. Chem. Ser.* No. **12,** 89 (1955).
U.N. Demographic Yearbook, 1959.
U.S. Dept. Agr. Statist. Bull. No. **364** (1965).
Viton, A., Pignalosa, F., *Food Agr. Organ. U.N. Commod. Bull. Ser.* No. **31** (1961).
Watt, B. K., Merrill, A., *Agr. Handbook* No. **8** (1963).
Wynn, W., Haldi, J., Bentley, K. D., Law, M. L., *J. Nutr.* **58,** 325 (1956).
Wynn, W., Haldi, J., Bentley, K. D., Law, M. L., *J. Nutr.* **67,** 645 (1959).
Yudkin, J., *Proc. Nutr. Soc. Engl. Scot.* **23,** 149 (1964).
Yudkin, J., *Am. J. Clin. Nutr.* **20,** 108 (1967).

Received for review October 20, 1967. Accepted February 5, 1968. Presented before the Division of Agricultural and Food Chemistry, Symposium on Enrichment and Fortification of Foods with Nutrients, 154th Meeting, ACS, Chicago, Ill., September 1967. Contribution No. 1137, Department of Nutrition and Food Science, Massachusetts Institute of Technology, Cambridge, Mass.