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Technology of FORTIFICATION OF FOODS

PROCEEDINGS OF A WORKSHOP

Subcommittee on Food Technology
COMMITTEE ON FOOD PROTECTION
Food and Nutrition Board
Division of Biological Sciences
Assembly of Life Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1975

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Preface

Many of the recent trends and practices in fortification of a variety of foodstuffs, although fully evaluated as to nutritional efficacy and safety, do not take adequately into consideration the purely technological difficulties encountered in carrying out the decisions reached.

It therefore seemed appropriate that a workshop of specialists who are actively engaged in the technological fortification of foodstuffs be convened to explore technological problems involved in fortification of foods.

The workshop was designed to consider general problems associated with a variety of product categories. Each presenter was asked to consider, in addition to the technological difficulties involved in fortification, the following points as they apply to an assigned food category:

- Differences in process and storage losses (particularly for vitamins) in foods that are (a) frozen, (b) refrigerated, (c) dried (hot air vs. freeze-dried), (d) canned (still retort, continuous retort, aseptic).
- Where nutrients are degraded, present what is known concerning breakdown products.
- The effect of the fortifying nutrient on the product itself and in some cases on foods prepared from the product fortified. For example, iron fortification often causes protein instability, not only in the original carrier product but also in food preparation when dishes are prepared

from iron-fortified materials; organoleptic changes may be caused, particularly by added minerals.

Time was provided for discussion of each presentation and for a summary to point out areas requiring further research and the need for early solutions to the problems highlighted.

B. BORENSTEIN

Vitamin Fortification Technology

The technology of fortification with vitamins for most food products is simpler than the establishment of agreement on the specific nutrients and levels to be added. Nevertheless, fortification projects can be frustrating for the following reasons:

1. Sparsity of stability data that can be extrapolated to the project under consideration. Kinetics data are rarely available. Specifics on blanching, F values in retorting, and pH of food are rarely given in the literature. Frequently, the description of the market forms of vitamins used are not given. Consideration of water activity as a highly significant variable in food stability studies is only a few years old.
2. Industry secrecy about processing specifics. Success is frequently due to engineering skills in designing process and safeguards, for example, spraying breakfast cereals with vitamins. In such cases, details are not available.
3. Lack of experience in fortification may cause excessive development costs due to lack of knowledge about the availability of advisory services, inaccuracy of analytical methodology, and inexperience with vitamin chemistry.

ADDITION OF VITAMINS

In some food processes, vitamins can be added at several stages. Whenever possible, it is desirable to make additions *after* operations involving heat, aeration, and washing. The mode of addition and the appropriate market forms of the vitamins must also be decided upon prior to actual development work. The differences between specific vitamins in stability and the commercial availability of coated vitamins designed for specific processes makes it imperative to evaluate the variables to the extent possible before laboratory fortification work is initiated. Vitamin stability and organoleptic changes as affected by processing and storage of foods are always product, as well as process specific, but guidelines that can minimize product development costs are available.

For example, fortification of bread with most nutrients is not technologically complex. The addition of the four presently allowed nutrients by means of a dry premix metered continuously into the flour, or by a tablet or preweighed packet added to the dough water, is routine. Riboflavin dissolves slowly and if not completely dissolved and dispersed can leave yellow specks in the bread. This can be avoided by the use of fine-particle-size riboflavin and adequate design and mixing of premixes. Thiamin is available both as the hydrochloride and the mononitrate. The mononitrate is preferred for dry mixes, because it is less hygroscopic.

Fortification of potato chips provides an interesting recent example of how decisions about where in the process to add vitamins are made. The unit operations are peeling, slicing, washing, frying, salting, and packaging. The addition of fat- and water-soluble vitamins to the frying oil would, at best, be extremely inefficient. Our approach was to select appropriate market forms of the vitamins for premixing with the salt to be applied in the salting step. This has worked quite successfully. Another new product development is the fortification of textured vegetable protein with vitamins B_1 (thiamin), B_2 (riboflavin), B_6, B_{12} (folic acid), niacin, and calcium pantothenate (plus iron and magnesium). In this case, processors have been able to follow their own preferences in mode of addition, and micronutrient premixes are being added at every process point, e.g., to the soy flour prior to granulation or to the finished product by means of a spray of the micronutrient premix suspended in vegetable oil. In the latter approach, the only problem has been rapid erosion of pumps due to abrasiveness of the ferrous sulfate used as the source of iron in the nutrient premix.

Technologically, we have relatively little experience in fortification of many foods, e.g., pretzels, canned vegetables, pizza, french fries. Thiamin and riboflavin can generally be expected to have adequate stability in baked goods with the exception of high pH chocolate cakes. Feliciotti and Esselen (1957) showed an increase in destruction rate of thiamin in model systems as the pH was raised from 4.5 to 6.0 and then a sharper increase from pH 6.0 to 7.0 over a wide temperature range.

At 228°F the half-life of thiamin was 286 min, 124 min, and 15 min, respectively at pH 4.5, 6.0, and 7.0. In unpublished work, we have found $\geq$90-percent destruction of added thiamin caused by baking chocolate cakes, pH 8.0–9.0, at 365–450°F for 20–25 minutes. We have not learned how to overcome this problem.

In one series of unpublished experiments, the destruction in preparing doughnuts from a doughnut mix was 35 percent for thiamin and 18–27 percent for riboflavin. The vitamins in this case were premixed with other dry ingredients in the flour-base mix.

Thiamin and riboflavin are stable in enriched white bread when exposed to light, although light rapidly destroys riboflavin in beverages packaged in clear glass containers.

It should be noted that chemical stability of a specific vitamin, e.g., niacin, does not ensure retention in a process in which leaching can occur, e.g., home cooking of pasta products, blanching, and brine-grading vegetables. This is extremely important, since processing steps such as brine grading can cause large extraction losses of most naturally occurring vitamins.

In recent experiments, we found the following losses in cooking macaroni: thiamin, 33–43 percent, riboflavin, 12–27 percent. The difference between retention of the vitamins in cooked macaroni is probably due to the poor water solubility of riboflavin and the greater leaching of thiamin into the cooking water.

Suitable market forms of vitamin A palmitate are available for a wide range of applications. These include oil in water emulsions, polysorbate-based solutions, preisomerized vitamin A palmitate oil and dry, water-dispersible, beadlets and powders. These products should be carefully identified in product-development projects, because stability data cannot be extrapolated from one product to another. A dry, fine-particle-size, stabilized form of vitamin A palmitate can be added to conventional flour premixes containing thiamin, riboflavin, niacin, and iron and metered continuously into flour streams in the usual way.

Niacin and niacinamide have essentially the same molecular weight and biopotency, and both can be used in almost all food applications. Both are stable in baking and in other stress processes. Niacinamide has better solubility in water but lumps readily in handling and storage at ambient relative humidities. The vasodilator effect of niacin does not occur at food-use levels, but can affect workers handling the material.

In the early development of WSB (wheat–soy blend) and CSM (corn–soy–milk blend), vitamin C was not incorporated in these products despite its nutritional desirability because of the assumption that it would not be stable during storage of these relatively high moisture dry mixes. Data were then obtained by Vojnovich and Pfeifer (1970) indicating only a 5 percent loss of ascorbic acid from wheat flour, moisture content 12.6–14.6 percent, stored at room temperature for 6 months. At higher temperatures, the destruction rate of vitamin C in wheat flour is significantly dependent on moisture content, as shown in Figure 1. Vitamin C was less stable in CSM, moisture 8.0–11.8 percent, than in wheat flour, moisture 12.9–14.6 percent, indicating that such variables as equilibrium relative humidity of the product and iron and copper content are as important as moisture *per se* with respect to vitamin C stability. The USDA maximum moisture specification of 10.0 percent for CSM and 11.5 percent for WSB assures adequate vitamin C stability in these products. Both ascorbic acid and sodium ascorbate are stable when added to a commercial instant farina, retention ≥90 percent after storage for 12 months at room temperature. Degradation

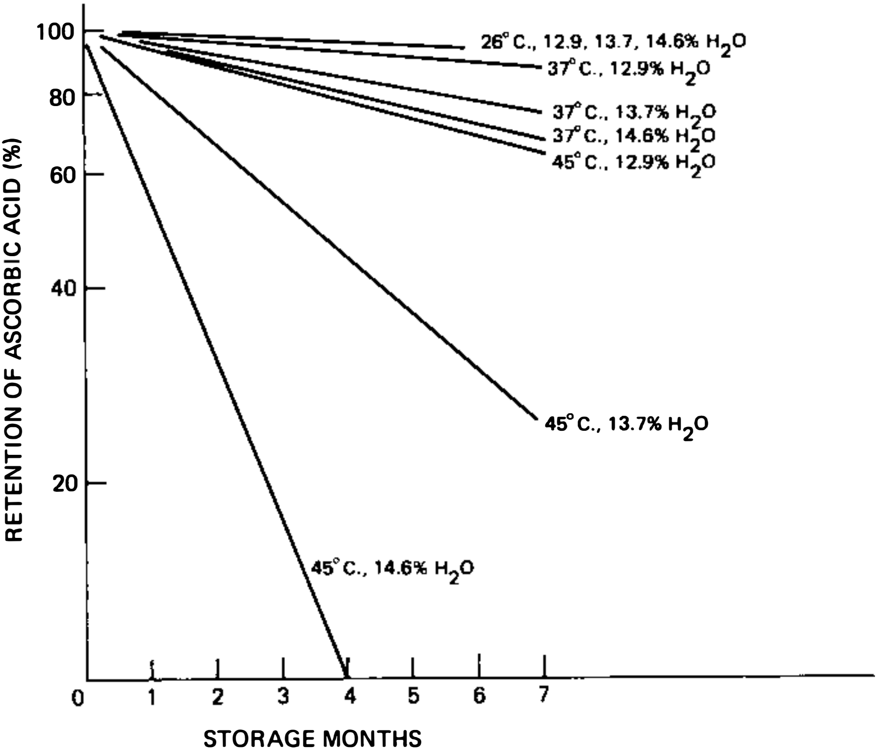

FIGURE 1 Effect of moisture content and temperature on retention of ascorbic acid in wheat flour (Vojnovich and Pfeifer, 1970).

of vitamin C can produce pink or tan off-colors. In most products, this is not a problem. Vitamin C is unstable at baking temperatures and oxidizes readily at high pH. Technology for fortification of bread and cake with vitamin C does not exist at this time. Bread could be fortified by spraying with a solution of vitamin C, which also can be successfully added to cake fillings, as in the USDA specification FNS Notice 180, "Fortified Baked Product with Creamed Filling." In this specification, the only permitted iron source is ferrous sulfate. Since soluble iron salts catalyze ascorbic acid oxidation, it is desirable in this type of application to add the iron to the baked component and the vitamin C to the filling. This product is designed as a breakfast food for the school lunch program.

Few data are available on the stability of vitamin B_{12} (cyanocobalamin), pantothenic acid, and folic acid in food processing. The optimum pH for solutions of B_{12} is 4.5–5.0, and retorting at pH 7.0–7.5 causes severe losses. We would, therefore, assume that baking at pH 6.5 or above would be destructive of B_{12}. Since ferrous salts cause rapid destruction of vitamin B_{12}, simultaneous fortification of a food with B_{12} and high levels of ferrous iron would merit special attention.

BREAKFAST CEREALS

The technology for addition of vitamins to breakfast cereals is based partly on the specific process and product involved and partly on the preferences of the processor. Much of the information in this field is proprietary. Heat-stable vitamins can be added prior to cooking of the mash or in the dough phase of those products that are so processed. Puffed and flaked whole cereals must be fortified at a later stage by a spray, dust, or infusion process. Heat-labile vitamins, such as thiamin, are usually sprayed onto toasted cereals as they leave the oven. Emulsions (or water dispersible solutions) of vitamin A can be sprayed onto breakfast cereals after toasting, but stability is greatly dependent on the composition of the spray solution. In general, stability of vitamin A is excellent in presweetened cereals. The added sugars apparently coat the vitamin A and act as an oxygen barrier. Losses in process and during cereal storage cannot be generalized because of the large number of vitamin A market forms available and cereal process variables.

It is best to add vitamin D at the same stage as vitamin A. The vitamin D market form should be similar in composition and stability to the vitamin A market form so that the vitamin A stability profile can be used to monitor vitamin D. This is desirable because the extremely poor accuracy of vitamin D assays at food fortification levels makes it almost impossible to study vitamin D stability in foods. Because ascorbic acid is so readily oxidized, it is similarly desirable to add it to breakfast cereals as late in the process as possible. Stability of ascorbic acid during cereal storage is dependent on many variables discussed previously.

Vitamin E, in the form of *d,l* or *d* α-tocopheryl acetate, is quite stable in food processing and can be added to cereals in the same system as vitamin A or via an oil solution or a dry powder. α-Tocopherol is available commercially, but generally should be used as an antioxidant rather than for nutrient fortification.

Thiamin may be lost during storage of breakfast cereals and the degraded thiamin may cause off-odors in some products. The odor is caused by even minimal thiamin degradation. It is objectionable in some products, e.g., orange drinks, particularly at high-fortification levels, but is desirable in bread and meat products.

SUMMARY

The technology of fortification requires judicious choice of the best in-process point for additions and selection of the proper market forms of the additives.

Niacin is stable in almost every type of food-processing operation. Vitamin C is sensitive to oxygen, iron, copper, and anthocyanin pigments. Fortification with vitamin C requires substantial overages above the label claim in almost all applications to insure label claim for the intended shelf life of the product. Riboflavin has good stability in most applications but is extremely light-sensitive. Thiamin has two potential problems, heat lability and odor. Its heat stability is pH-dependent.

In most products, the bulk of stability data should be obtained on vitamins A, B_1, and C. Fortification with all vitamins requires overages to insure compliance with label claims, because of variability in distribution and analytical variation. It is usually not difficult to establish a logical overage for each vitamin in each application.

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GRANT H. HARTMAN, JR.

Technological Problems in Fortification with Minerals

INTRODUCTION

In an effort to improve the nutritional quality of the diets of human beings, the food industry has turned in recent years to the fortification of individual foods and food products. Many technological problems occur when foods are fortified with vitamins and minerals. Most of these are not discussed in the literature, because industry has had to solve them during the development of various fortified food products. The problems of color, flavor, physical body and texture, cost, and control created by the fortification of foods with various mineral salts have been largely left for each manufacturer to solve.

The biological value or availability of the added mineral in the food product must also be considered when fortifying foods with minerals. It makes little sense to fortify a food if the consumer cannot benefit from the resulting fortification, yet breads, cereals, and flours have been fortified with iron for more than 30 years; and large segments of our population still suffer from iron deficiency anemia. The biological value of minerals in processed foods is a problem that few manufacturers have the capability to resolve.

This chapter will primarily deal with the problems one would encounter in mineral fortification of foods for special dietary use. The biological value of various iron sources will also be discussed in some detail.

MINERALS USED TO FORTIFY FOODS

Recently revised nutritional labeling regulations have been issued by the Food and Drug Administration. The nutrients and levels were derived from the Recommended Dietary Allowances (RDA), prepared by the Food and Nutrition Board, National Academy of Sciences–National Research Council. Table 1 shows the levels for adults and children 4 or more years of age, which represents the adult USRDA (U.S. Recommended Daily Allowances) used in nutritional labeling. In addition to the minerals listed in Table 1, chlorine, potassium, sodium, sulfur, fluorine, and manganese are recognized as essential in human nutrition, but no USRDA have been established for them. However, label claims for many of these minerals are made for foods intended for special dietary uses.

Table 2, prepared by Sarett (1973) for the Codex Alimentarius Committee on Foods for Special Dietary Uses, shows the mineral salts suitable for addition to infant foods. Since there are many suitable salts of most minerals, this list is not complete; but it represents minerals commonly used for the fortification of foods. Minerals should not be prohibited from use unless good scientific evidence indicates that the mineral is not available from the salt, or that the anion or cation is not desirable in the diet.

TECHNOLOGICAL ASPECTS

Most of the comments here regarding technological problems result from experience obtained fortifying meal replacement products, special dietary

TABLE 1 U.S. Recommended Daily Allowances for Minerals in Foods for Special Dietary Uses

	Infants	Children <4 yr	Adults[a] >4 yr	Women—Pregnant Lactating
Calcium (g)	0.6	0.8	1.0	1.3
Phosphorus (g)	0.5	0.8	1.0	1.3
Iodine (μg)	45	70	150	150
Iron (mg)	15	10	18	18
Magnesium (mg)	70	200	400	450
Copper (mg)	0.6	1.0	2.0	2.0
Zinc (mg)	5	8.0	15	15

[a] RDA used for nutrition labeling of usual consumer foods.

TABLE 2 Mineral Salts Suitable for the Fortification of Foods

- Calcium
  - Calcium carbonate
  - Calcium chloride
  - Calcium citrate
  - Calcium gluconate
  - Calcium glucuronate
  - Calcium glycerophosphate
  - Calcium hydroxide
  - Calcium lactate
  - Calcium malate
  - Calcium phosphate, monobasic
  - Calcium phosphate, dibasic
  - Calcium phosphate, tribasic
  - Calcium tartrate
  - Edible bone phosphate (bone meal)
- Phosphorus
  - Calcium phosphate, monobasic
  - Calcium phosphate, dibasic
  - Calcium phosphate, tribasic
  - Magnesium phosphate, dibasic
  - Magnesium phosphate, tribasic
  - Potassium phosphate, monobasic
  - Potassium phosphate, dibasic
  - Sodium phosphate, dibasic
  - Sodium ferric pyrophosphate
- Copper
  - Cupric acetate
  - Cupric citrate
  - Cupric gluconate
  - Cupric sulfate
- Iodine
  - Calcium iodostearate
  - Potassium iodide
  - Sodium iodide
  - Sodium chloride, iodized
- Magnesium
  - Magnesium acetate
  - Magnesium carbonate
  - Magnesium chloride
  - Magnesium oxide
  - Magnesium phosphate, dibasic
  - Magnesium phosphate, tribasic
  - Magnesium sulfate
  - Magnesium trisilicate
- Iron
  - Ferrous carbonate, stabilized
  - Ferrous citrate
  - Ferrous fumarate
  - Ferrous gluconate
  - Ferrous glucuronate
  - Ferrous glycerophosphate
  - Ferrous lactate
  - Ferrous succinate
  - Ferrous sulfate
  - Reduced iron (Ferrum reductum)
  - Ferric ammonium citrate
  - Ferric oxide saccharated
  - Ferric phosphate
  - Ferric pyrophosphate
  - Ferric tartrate
  - Sodium ferric pyrophosphate
- Zinc
  - Zinc acetate
  - Zinc chloride
  - Zinc lactate
  - Zinc sulfate

products, or infant formula products. In general the trace minerals, with the exception of iron, have not produced serious problems in these products.

COLOR

As one might expect, many color problems occur due to the addition of mineral salts to foods for special dietary uses. When sterile liquid dietary products, such as chocolate- or strawberry-flavored ones, are fortified with insoluble calcium or magnesium salts, a lighter color than would otherwise result is produced in the product, which could lessen its appeal to the consumer. However, if soluble salts are used at the high levels found in special dietary products, a darker color than normal will persist in the chocolate products, which may also detract from the quality.

The level of mineral fortification is very important. In general, the seriousness of problems increases with increasing level and reactivity of the mineral salt added. In liquid, sterilized, formula products fortified with iron at levels of 15 mg/qt, the finished products are darker than those formulated with lower levels of iron. Fortification of sterilized soy products with ferrous sulfate produced a liquid product with a dark color. This was improved by the substitution of sodium iron pyrophosphate, a difficult salt to hold in suspension. The solubility and chemical reactivity of the salt in the food system is very important in mineral fortification. In fact, we have a product to which iron could not be added in any form without producing an objectionable dark color.

Hodson (1970) reported that iron added to canned liquid weight-control meals as ferric orthophosphate was largely dissolved and reduced to the ferrous state during 2–5-month storage. Since this much time often elapses between processing and consumption, it seems that all of the flavor and appearance benefits resulting from the fortification with ferric orthophosphate may be enjoyed without sacrificing the nutritional benefits that are attributed to ferrous iron.

Bookwalter (1973) prepared stable syrup blends with iron levels of 0.015 percent (100 mg/pint) using ferric ammonium citrate, ferric choline citrate, ferrous gluconate, or ferrous sulfate. However, color and flavor problems were encountered during storage with various combinations of syrup and iron salts. For example, regular conversion corn syrup combined with 0.015-percent iron added as ferrous gluconate or ferrous sulfate produced a black precipitate during storage at 77°F for 6 months.

Many unexpected interactions, such as color problems, can occur with the ingredients in powdered products. This has occurred with a vanilla-flavored product fortified with ferrous citrate. In the powdered form this product had a normal white appearance; but when this powder was added to milk, the resulting mixture was a dark gray. It was found that the vanilla flavor interacted with the iron and sodium ascorbate in the product and contributed to the dark color.

Sometimes minerals can be added at various stages in the process to eliminate potential color problems. If iron is dry-blended into the finished powdered product, the color of the reconstituted product is better than if the iron is added in the liquid stage of processing. Dry-blending eliminates the chemical reactions with the other ingredients that can take place during liquid processing steps in the manufacture of the powdered product.

FLAVOR

Flavor problems can result from the fortification of products with minerals, especially when significant proportions of the RDA are added to small serving sizes. It is difficult to fortify frozen dessert products with more than 10 percent of the iron RDA in a 3 oz serving size, because the soluble iron salts produce an astringent aftertaste. High levels of magnesium and calcium salts produce astringency or chalkiness in the finished product, while potassium and chloride cause bitterness. In some cases, chalkiness can be reduced by adding the salt early in the process, particularly prior to homogenization. It is more difficult to fortify nondairy nutritional products low in indigenous minerals because of the flavor problems encountered by the necessary addition of high levels of mineral salts.

PHYSICAL

Many physical problems are encountered in the fortification of foods with minerals. High levels of soluble magnesium salts may promote gelation of sterilized liquid dietary products, whereas the insoluble salts settle out during processing and storage. Physical stability problems are often encountered in sterile liquid products with high levels of protein. Calcium and magnesium will interact with the protein and cause sedimentation or gelation of the product during storage. If the food system is not buffered or is sensitive to slight pH changes, the addition of slightly soluble basic or acidic salts will cause problems in sterilization. For example, if MgO is added to a liquid product and the pH is adjusted before sterilization, the pH will change as the magnesium goes into solution. The resulting product will gain or increase in viscosity in the sterilizer. Selection of the salt that fits the product is an important consideration when fortifying foods with minerals. In very sensitive products, the desired level of fortification may not be feasible.

In processing sterile liquid products, care must be taken during the addition of the minerals. If the minerals are added too quickly or in a concentrated form, localized protein precipitation may occur and cause a grainy or settling defect in the finished product. This problem may not occur during the laboratory or pilot plant development of the product but may take place under conditions of commercial production.

In the case of magnesium fortification at the RDA level, a relatively large amount of salt must be added because of the low concentration of magnesium in the salts of choice. It may be necessary to combine magnesium sources to achieve a balance of the anions. A balance between the soluble and insoluble magnesium salts is also desirable for physical stability of sterile liquid products. In the case of calcium and phosphorus, it is very important nutritionally that a Ca/P ratio equal to or greater than one be maintained, especially if the food constitutes a major portion of the diet.

COST

Cost is another factor in the fortification of foods with minerals. In foods for special dietary use, magnesium is the single, most costly mineral nutrient added to meet the RDA levels. If dibasic magnesium phosphate is used to provide one-third of the adult RDA, 0.95 g of this salt must be added per serving. This will increase the raw material cost of the product by 0.2 cent per serving. For products with raw materials low in the mineral constituents, fortification will make a significant contribution to the raw material costs. This is especially true with major minerals like calcium and magnesium that have high RDA requirements. The control costs of mineral fortification are often as great as or greater than the cost of the added minerals.

CONTROL

The control of mineral-fortified foods is another technological problem that must be faced by the manufacturer. The consumer has a right to expect the product to contain the amount of nutrients claimed by the label. Yet, when all or part of the mineral is provided by the raw materials, natural variation occurs, which makes the formulator's task difficult. FDA's Compliance Procedures for Nutrition Labeling Regulations (*Federal Register,* 1973) provide that naturally occurring nutrients in composite values will be no more than 20 percent below the label value. However, variation in the mineral content of raw materials used by food manufacturers may be greater than the allowable 20 percent, dictating a conservative approach in establishing label claims.

The analytical capability needed to measure minerals in fortified foods depends on the mineral and its level in the food product. If measured in parts per hundred, accuracy of ±2 percent is considered adequate (Horwitz, 1972). In most fortified foods calcium, phosphorus, and magnesium will be in this range if these salts are well distributed in the product.

Measurements of iron or zinc in raw or processed materials may have an accuracy of ±10 percent. Analytical techniques used to measure trace minerals in parts per billion may be accurate to ±32 percent (Horwitz, 1972). The control of iodine is difficult because of analytical problems and raw material variations.

A sound sampling program is required in order to control accurately the fortification of the mineral constituents. Settling problems in liquid products, poor distribution in dry blended products, and raw material variability are among the control problems that can be encountered. Analytical methods developed for one food system may not be best for another. Analytical testing procedures are sophisticated and costly to set up and perform at low volumes. However, in-house analytical testing capability is important for those manufacturers producing products fortified with minerals.

In order to improve added mineral uniformity and reduce control costs, vitamin–mineral premixes are used. The minerals used must not be hydroscopic because of caking problems during storage. The trace minerals should not be mixed or stored with the vitamins because of vitamin-stability problems. Thus physical and chemical stability of the premixes must first be established in careful storage and use studies.

AVAILABILITY CONSIDERATIONS

It is important to overcome the technological problems that may occur when fortifying foods with mineral constituents. Equally as important is the biological value of the added mineral constituent to the consumer. Perhaps too much importance is given to the label claim and the chemical measurement of the mineral instead of the relative nutritive value of the fortified mineral. Even though the USRDA levels have taken into account the average availability for each of the minerals in foods, certain added minerals may be unavailable biologically.

The recommended dietary intake of iron is predicted on the basis of 10-percent absorption of food iron. Fritz (1970) reported that the biological value of iron from various dietary sources varied from 0 to 133 percent, compared to ferrous sulfate as the reference standard. These results are summarized in Table 3. Ferrous chloride and ferrous sulfate were somewhat better utilized by both rats and chicks than comparable ferric salts. Among the food sources of iron, there is no clear distinction in availability between animal and vegetable foods. This

TABLE 3 Relative Biological Value of Iron from Various Dietary Sources

Iron Source	No. Samples	Relative Biological Value	
		Average	Range
Iron compounds			
EDTA, dihydrogen ferrous salt	1	99	97–100
Ferric ammonium citrate	1	107	98–115
Ferric choline citrate	1	102	—
Ferric chloride	1	44	26–67
Ferric citrate	1	73	70–76
Ferric glycerophosphate	1	93	86–100
Ferric pyrophosphate	1	45	38–52
Ferric orthophosphate	4	14	7–32
Ferric oxide	1	4	0–6
Ferric sulfate	1	83	65–100
Ferrous ammonium sulfate	1	99	99–100
Ferrous carbonate	5	2	0–6
Ferrous chloride	1	98	—
Ferrous fumarate	1	95	71–133
Ferrous gluconate	1	97	—
Ferrous sulfate ($FeSO_4{\cdot}7H_2O$)	1	100	—
Ferrous sulfate, anhydrous	1	100	—
Ferrous sulfate, feed grade	1	100	—
Ferrous tartrate	1	77	70–83
Reduced iron	6	37	8–66
Sodium iron pyrophosphate	3	14	2–23
Food and feed ingredients			
Biscuits with ferrous sulfate	1	89	77–100
Blood meal	1	35	—
Corn meal enrichment mix	1	46	—
Corn germ	1	40	—
Egg yolk	1	33	—
Fish protein concentrate	2	28	8–53
Enriched breakfast cereal	1	43	—
Enriched flour	1	32	—
Oat flour	1	21	—
Smectite–vermiculite	1	11	3–17
Soybean protein (isolated)	2	97	70–125
Trace mineral mix (commercial)	2	12	0–21
Wheat germ	1	53	—

SOURCE: Fritz *et al.*, 1970.

differs from views expressed by Layrisse *et al.* (1968), who considered foods of animal origin to have higher iron availability.

The relative availability of the iron in various iron salts when added to foods has been controversial. Steinkamp *et al.* (1955) reported that the absorption of iron from bread mixed with radioactive ferrous sulfate, reduced iron, ferric orthophosphate, or sodium iron pyrophosphate was similar, regardless of the form of iron added. Street (1943), on the other hand, indicated that the iron of sodium iron pyrophosphate was less than 50 percent as available as the iron of ferrous sulfate or ferric sulfate, whether the iron was given as such or baked into bread.

Theuer *et al.* (1971) reported an increase in the relative availability of the iron of ferric pyrophosphate from 39 to 93, expressed as a percentage of ferrous sulfate, and an increase in availability of sodium iron pyrophosphate from 15 to 66 by processing a fortified soy-based formula. Processing had little effect on the availability of ferrous sulfate in this system. Theuer *et al.* (1973) also reported that sterilization of milk-based formulas increased the relative iron availability of ferric pyrophosphate from 75 to 125, and of sodium iron pyrophosphate from 40 to 60. Milk-based formulas containing ferrous sulfate had relative iron availabilities of 114 to 129. The results on the availability of iron in milk-based formulas are summarized in Table 4.

TABLE 4 Availability of Iron in Milk-Based Infant Formula Products Made with Various Iron Salts

	Processed	Relative Availability[a] (%)
Ferrous sulfate	no	126
	no	114
	yes	129
Ferric pyrophosphate	no	78
	no	71
	yes	125
Sodium iron pyrophosphate	no	42
	no	39
	yes	60
Ferrous citrate	yes	148
Ferric citrate	yes	122
Ferric gluconate	yes	139
Ferrous lactate	yes	118
Ferric glycerol phosphate	yes	135

SOURCE: Theuer *et al.*, 1973.

[a] Based on hematopoietic response in rats relative to ferrous sulfate added to basal diet.

These results demonstrated that the availability of iron added to foods should be determined after processing. The salts of ferrous citrate, ferric citrate, ferric gluconate, ferrous lactate, and ferric glycerol phosphate can be added to sterilized soy or milk-based products to provide available iron comparable to that provided by ferrous sulfate.

It was observed by Fritz (1970) that iron sources with at least some minimal availability can be used for food fortification provided enough of the source is used to furnish the needed quantity of available iron. In some applications, technological problems (rancidity, discoloration) may make it impractical to use iron compounds that have maximum availability, and the less-available source thus provides an alternative for food fortification.

Forbes (1971) categorized the chemical iron sources for food additives according to their relative biological values. Of the four most commonly used forms of iron for enrichment purposes, ferrous sulfate was a good source; reduced iron was a moderately available source; and ferric orthophosphate and sodium iron pyrophosphate were relatively poor sources. However, because of the improved biological value produced by processing sodium iron pyrophosphate reported by Theuer (1971), detailed studies of various types of processed foods enriched with this source of iron are needed.

Relatively little information is available on the comparative biological availability of magnesium from various sources. Cook (1973) found that magnesium carbonate was the most available form based on absorption, retention, and femur concentration. The magnesium salts of carbonate, chloride, oxide, phosphate, sulfate, and silicate ranged in absorption from 65 to 54 percent when rats were fed the above salts blended into a purified diet.

The availability of minerals in foods is further complicated by the chelation of the various mineral constituents by such natural food components as phytic acid. Likuski (1965) reported that dietary phytic acid lowered magnesium absorption and, in some instances, decreased the absorption of zinc. There are also reports in the literature that sodium phytate greatly reduces the absorption of iron. Thus the presence of chelates in the food product may influence the availability of the fortified minerals in that food product.

Our experience has led us to the following conclusions:

1. Problems of color, flavor, physical body and texture, cost, and control are created by the mineral fortification of foods.
2. Technological problems increase as a higher proportion of the RDA is included per serving of product.

3. In foods for special dietary use, the addition of calcium, magnesium, and iron are the most difficult.

4. The biological value of minerals must be determined in the food product as consumed.

ACKNOWLEDGMENTS

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JOHN J. BIRDSALL

Stability and Availability of Nutrients

The topics *stability* and *availability* involve many interrelated variables. So many, in fact, that space does not allow the most comprehensive review possible. This chapter will, however, describe the general state of the art as it exists today and provide a base for discussion of problems involved. First, some general facts regarding stability will be reviewed. Then, those nutrients for which USRDA have been established will be treated individually.

Four basic factors influence stability of added nutrients: (a) the composition of the food, (b) the manner of addition, (c) processing procedures, and (d) storage and other conditions prior to consumption.

COMPOSITION OF THE FOOD

Components of foods that have the most profound effect on stability of added nutrients are fats, moisture, minerals, carbohydrates, proteins, and antioxidants, whether naturally occurring or added. Fat has a tendency to protect fat-soluble vitamins from oxidative deterioration, yet peroxides formed during fat breakdown can be quite destructive to other vitamins, particularly ascorbic acid. Lower levels of moisture in foods can result in decreased susceptibility of vitamins to heat and/or light. On the other hand, soluble reactants can concentrate in the water phase of low- and intermediate-moisture products to a point where reactions are triggered. Iron and copper catalyze many oxidative reactions and must be taken into consideration. Antioxidants such as ascorbic acid and α-tocopherol can be beneficial in some products, not only to provide nutritional value but also to prevent oxidation of fats and other vitamins. Other components of food that affect stability are buffers, chelating agents, antivitamin or antimineral factors, entrapped air, and preservatives. Some of these will be discussed in conjunction with individual vitamins and minerals.

MANNER OF ADDITION

In an article in *Food Engineering,* Bauernfeind and Brooke (1973) presented an excellent guideline for "nutrifying" foods. They described four basic methods of addition: pure compound; direct addition tablets, wafers, or cubes; solutions, emulsions, or dispersions; and dry premixes. Each method has advantages and disadvantages for different types of foods.

The manner of addition should "provide uniformity of distribution and maximum stability in the product." Choice should include consideration of factors such as chemical and physical properties of the nutrients and the food and how the food is to be treated following addition. Time of addition is also critical, since it is best to subject some nutrients to the least amount of heat or the least exposure to air.

The actual chemical form of the nutrient is of some importance. Certain salts or esters are more stable than others. It may be necessary, in some food systems, to add the nutrient in a protective carrier or coating in order to prevent destruction or substantial losses during processing or storage. Of course, such protective mechanisms must not interfere with the availability of the nutrient upon ingestion.

PROCESSING

At the Institute of Food Technologists meeting in Minneapolis in May 1972, a symposium was held on the effects of processing storage and handling on nutrient retention in foods. The authors presented review papers with more than 150 references. How can all this information be concisely summarized?

Thermal Processing

Thermal processing has to be optimized in order to obtain its desirable values yet minimize nutrient losses by leaching or destructive reactions. Some of the most significant losses of vitamins and minerals occur during washing and blanching of fruits and vegetables. Water soluble vitamins and certain trace minerals are the most affected. Obviously, any additions of fortifying nutrients would be made after these steps.

More difficult to deal with are the destructive effects of retort sterilization. Thiamin, pantothenic acid, and several other vitamins are quite heat labile (Table 1). Substantial overages have conventionally been utilized to compensate for these losses. If reducing sugars are present or if they are formed during processing, proteins may be degraded by the Maillard or other reactions. If added, lysine, threonine, and the

TABLE 1 Stability of Nutrients [a]

Nutrient	pH 7	Acid	Alkaline	Air	Light	Heat	Cooking Losses (% Range)
Vitamins							
Vitamin A	S	U	S	U	U	U	0–40
Ascorbic acid (C)	U	S	U	U	U	U	0–100
Carotenes (pro-A)	S	U	S	U	U	U	0–30
Cobalamin (B_{12})	S	S	S	U	U	S	0–10
Vitamin D	S	S	U	U	U	U	0–40
Niacin	S	S	S	S	S	S	0–75
Vitamin B_6	S	S	S	S	U	U	0–40
Riboflavin (B_2)	S	S	U	S	U	U	0–75
Thiamin (B_1)	U	S	U	U	S	U	0–80
Tocopherols (E)	S	S	S	U	U	U	0–55
Essential amino acids							
Isoleucine	S	S	S	S	S	S	0–10
Leucine	S	S	S	S	S	S	0–10
Lysine	S	S	S	S	S	U	0–40
Methionine	S	S	S	S	S	S	0–10
Phenylalanine	S	S	S	S	S	S	0–5
Threonine	S	U	U	S	S	U	0–20
Tryptophan	S	U	S	S	U	S	0–15
Valine	S	S	S	S	S	S	0–10
Essential Fatty Acids	S	S	U	U	U	S	0–10
Mineral Salts	S	S	S	S	S	S	0–3

SOURCE: R. E. Hein and I. J. Hutchings, "Influence of Processing on Vitamin and Mineral Content and Biological Availability in Processed Foods," a paper presented at the Symposium on Vitamins and Minerals in Processed Foods, American Medical Association, Chicago, March 1971.

[a] S=Stable.
U=Unstable.

sulfur amino acids are particularly reactive to heat as are proteins containing these amino acids.

Dehydration and Baking

Many of the above reactions also occur during drying of foods and, in some cases, at a more rapid rate. Careful control of drying conditions, use of additives such as sulfites, and encapsulation methods of addition can be helpful; but, if possible, any additions of heat-labile nutrients should be made after drying has been accomplished. An example is the addition of nutrients to frostings on baked items.

Even freeze-drying has been shown to cause some vitamin losses but is certainly far superior to other dehydration processes.

Freezing

The least destructive of all processing methods, freezing offers the most potential for satisfactory fortification of foods. Losses of nutrients can occur during any blanching steps required, but minimal reactions occur during subsequent freezing and packaging.

Storage, Shipping, Retail Sale, and Cooking

Losses of nutrients can occur during storage, shipping, and sale, but generally these losses are minimal and can be avoided. Particular attention must be focused on time–temperature relationships and protection from light and oxygen. Proper packaging and inventory controls are effective means of avoiding problems.

Final preparation for consumption, however, can result in similar reactions and losses as those caused by thermal processing and dehydration. Foods that require minimal or no heat treatment prior to consumption would be the most ideal candidates for fortification.

With this rather general overview in mind, we will now consider the stability and availability characteristics of some specific nutrients.

PROTEINS AND AMINO ACIDS

Millions of words have been written about protein and amino acid stability and availability. The most obvious fact is that the two characteristics are interwoven to an extent that they can't be discussed separately.

The primary factor governing protein availability or utilizability is the amino acid composition. Degradation of one or more of the essential amino acids will result in an imbalance and subsequent loss in quality, as measured by many chemical, animal, and human study techniques. The value of high-quality proteins, such as egg or milk proteins, can be damaged by a number of factors, each affecting amino acids. Foremost, perhaps, is the Maillard reaction, whereby amino acids react with reducing sugars to produce pigments that are similar to caramel color. The amino acids, particularly lysine and threonine, are thus made unavailable and protein quality suffers. This reaction can be avoided or impeded by low-temperature storage, avoidance of appreciable amounts of reducing sugars in formulated foods, and by reducing water activity. It certainly has to be considered highly significant relative to lysine fortification.

Other factors affecting protein availability are substances such as trypsin inhibitor in soybeans and similar inhibitors found in cereal grains, which fortunately can be destroyed by relatively mild heat treatment. The existence of other, yet unknown, inhibitors, in other foods at low levels is a distinct possibility and could be responsible for some unpredictable results obtained occasionally in animal studies.

Lipid oxidation can produce levels of peroxides and aldehydes that also may react with certain amino acids and destroy their activity. The exact nature of such reactions is not yet fully understood, but fat degradation should be avoided in protein or amino acid fortified foods.

Amino acids, especially free sulfur-containing amino acids, can also be destroyed directly by heat; therefore, processes must be developed and monitored carefully.

CARBOHYDRATES

Little need be said about carbohydrates except that their stability and availability as energy sources are favorable. One exception is the reducing-sugar reactions cited previously. Another is the problem of lactose intolerance in certain segments of the population.

Fats

Deterioration of fats can be quite readily controlled through judicious use of antioxidants, proper fat selection for formulated foods, and proper packaging and storage conditions. Especially important, of course, is the inclusion and preservation of linoleic acid in a wide variety of products.

VITAMINS

Because they have been discussed in detail in previous chapters, vitamins and minerals will be treated here briefly.

Vitamin C

Undoubtedly, this vitamin has received more attention than any other, because of its important role in nutrition, its susceptibility to destruction, and its antioxidant properties. Its major instability is due to the presence of oxygen and metal ions (copper being much more reactive than iron). If oxygen is absent, there is evidence that light has no effect on ascorbic acid and that in acid products ferrous iron may even be added with no effect. This could be extremely important in future product development and fortification, since there is evidence to indicate that the availability of iron is enhanced when ingested with ascorbic acid.

New evidence also exists that ascorbic acid losses in heat processed products can be greatly reduced by careful, rapid handling of the incoming fruit or vegetable. If these improvements can be implemented, levels of fortification could be reduced.

Thiamin

This vitamin, as well as ascorbic acid, is often utilized as a monitor of product stability. Whereas ascorbic acid is sensitive to oxygen, light, and certain metals, thiamin is unstable to heat, sulfite, and high pH. Thus, its addition to products that require heat treatment is in amounts often double that desired in order to compensate for processing losses. It is also affected by thiaminase, an enzyme found in some fish. The enzyme is easily destroyed by heat. Higher levels of fat plus lower levels of carbohydrate seem to increase availability.

Riboflavin

Riboflavin is light-sensitive, especially under alkaline conditions. In most products, it is relatively stable, decreasing in amount only after rather long storage periods. As long as it is present, there is little question about its availability.

Vitamin A and β-Carotene

Vitamin A and its precursor (β-carotene) are quite unstable. Fortunately, stabilized synthetic forms have been developed. Precautions should still be maintained, however, against the effects of heat, light, air, and acidity.

While fats tend to protect vitamin A and β-carotene by preferential oxidation, an antagonism exists between unsaturated fatty acids and low levels of β-carotene. If carotene levels are elevated, the antagonism is overcome. Other antagonists are lipoxidase, thyroxine, and citral.

Vitamin A can be toxic if high levels of intake occur (i.e., 22,000 IU per day for infants and 25,000–50,000 IU per day for older children). For this reason, the Food and Drug Administration has ordered that oral preparations that provide in excess of 10,000 IU per recommended daily intake be classified as drugs and as such be restricted to prescription sale. The implications to food fortification are obvious.

Niacin

Nicotinic acid is one of the most stable vitamins and poses few problems in food fortification.

Vitamin D

This vitamin is relatively unstable, being susceptible to destruction by heat, light, and oxygen under alkaline conditions. Vitamin D is stable to pasteurization, evaporation, and sterilization of milk (pH 6.6–6.8). Antagonists to vitamin D are generally materials that affect the availability of calcium and/or phosphorus. These include oxalates and phytates.

Like vitamin A, vitamin D has been subject to a recent order by the FDA in which oral preparations containing in excess of 400 IU per dosage unit or recommended daily intake are drugs. This could pose some very significant problems relative to fortification and monitoring of D content of milk and other foods. More sensitive methods, accurate at low levels, may certainly be needed.

Vitamin E

The tocopherols, principally α-tocopherol, act as antioxidants and are important factors in fat stability. They are sensitive to oxygen, heat, and light. While fat facilitates absorption and availability of vitamin E, it is also antagonistic. Vitamin E is used up in protecting unsaturated fatty acids from oxidation. Linoleic acid is particularly antagonistic. Other antagonists have been described, and metals such as copper and iron catalyze the destructive reactions.

Since vitamin E and linoleic acid are so closely related, special attention should be placed on the comparative levels of these nutrients in fortified foods.

Vitamin B_6

The stability of this vitamin is influenced by oxygen, heat, pH, and light. Of the three forms, pyridoxine hydrochloride is the most stable. Pyridoxamine and pyridoxal at low concentrations in high-moisture foods are readily destroyed by oxygen, light, and heat. Moisture content, water activity, and storage temperature affect stability of B_6 in dehydrated foods, particularly if browning reactions are occurring during storage. Few known antagonists exist; and, if the vitamin does not degrade, it is readily available.

Vitamin B_{12}

Cyanocobalamin is relatively stable but is sensitive to oxygen and light and can be destroyed with heat and dilute alkali under certain conditions. There appear to be few fortification problems in products where the pH range is 4.0–6.5.

Naturally occurring B_{12} is in bound form in some foods, and some of these forms are less available than others. High-protein diets and amino acid imbalances affect the amounts of B_{12} required but do not necessarily affect availability.

Folic Acid

Folacin is quite unstable, being readily destroyed by heat under acid conditions and subject to storage losses. It is antagonized by high levels of nicotinamide.

A recent order has established that no more than 0.4 mg may be added to that amount of food that comprises a maximum daily intake. Permissible levels are lower for infants and higher for pregnant or lactating women.

Biotin

Biotin is quite stable. It requires rather strong oxidizing agents to cause inactivation. Avidin, present in raw egg white, combines with biotin to produce a stable complex that renders the biotin unavailable. Heating breaks down the complex. This has been a recent practical problem with the new low-cholesterol egg substitutes.

Pantothenic Acid

This vitamin is most stable at neutrality. It is quite unstable at the low pH conditions most favorable for many other vitamins. Thus, with present technology, considerable overages are necessary in systems favorable to the other vitamins.

Its availability is dependent upon the concurrent availability of folic acid and biotin.

MINERALS

The minerals are all quite stable. Their availability, however, is extremely complex and has been the subject of many studies. The roles of each element are in many cases interrelated with those of other elements, and the availability of one affects that of another.

Calcium availability is favored by vitamin C, vitamin D, lactose, and small amounts of fats. Reductions in availability may be caused by excess fat, phosphates, oxalates, and phytates.

Phosphorus availability is tied closely to that of calcium. An abnormal Ca/P ratio interferes with availability of both, as does an excess of fiber. Excesses of iron, aluminum, and magnesium can cause formation of unavailable phosphates. Availability of phosphorus is favored by an acid state in the intestine, a proper Ca/P ratio, and low fiber.

Iron availability has been the subject of much recent controversy, principally over which forms of iron are best suited for fortification. The work of Pla and Fritz (1970) with rats shows marked differences in the relative biological value of a number of sources of iron, although it can be argued that their values should not be uncritically accepted until comparative studies can be run with other species, including man. Until more work is completed, it appears judicious to utilize those forms of iron that have a high degree of availability to the rat and adjust levels of other forms to compensate for lesser availability.

IODINE

Potassium iodide is the only form of iodine presently permitted to be added to foods. The iodine is relatively available. A recent order permits potassium iodide to be used "provided the maximum intake of the food as may be consumed during a period of one day . . ." will not result in an intake in excess of 225 μg. Levels are 45 μg for infants, 105 for children under 4, and 300 for pregnant or lactating women.

Of interest regarding iodine is the growing increase of the element in milk due to feeding practices and residues of sanitation chemicals. We know little about the availability of this iodine.

BIOLOGICAL ASSAY METHODS

Useful information on biological assay methods used in determining levels of vitamins and minerals in laboratory animals may be found in the following publications.

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Toxicants Occurring Naturally in Foods. 1966. NAS–NRC Publ. 1354, Washington, D.C.

"Vitamins in Milk and Milk Products," American Dairy Science Assoc. (October, 1965).

DISCUSSION

Dr. Graham asked if one needs to be concerned about the interaction of nutrients in a premix.

DR. BORENSTEIN: Very much so; in a concentrated system such as a vitamin–mineral premix one has to worry about interactions. A moderately soluble iron salt cannot be used with sodium ascorbate. The rate of discoloration is accelerated by the iron. The concern here is not with vitamin C loss and meeting labeling claims, but with the aesthetic imperfection that can occur in a matter of weeks. Switching from sodium ascorbate to ascorbic acid in such a premix remedies the situation. It is also very important to control the moisture content and the type of carrier that is used in premixes. At the food level, the concern about interaction is minimal because of the low level of reactants, e.g., approximately one microgram of B_{12} and a few milligrams of vitamin C per ounce of liquid food react very slowly.

DR. GRAHAM: Are there any incompatibilities in a multivitamin mixture in a premix?

DR. BORENSTEIN: Not if the moisture is low and proper market forms of the vitamins are chosen.

DR. BAUMAN: What kind of instructions are given to the user of a premix stored in large drums?

DR. BORENSTEIN: All directions are the same, except for different shelf lives, that is, to store in a cool, dry place in a sealed container. When speaking about preparations one must know the form, e.g., there are a number of vitamin A market forms available. When one discusses stability the market form of the ingredient used is important since the data are not extrapolable from one system to another.

In response to a question, Dr. Borenstein said that in most products vitamins A, B, and C are the ones that should be assayed after extended storage. It depends, of course, on the experience of the processors or formulators. He noted that the approaches available for fortification in old established systems, such as baking bread, are infinite as compared to fortifying a new product with very little or no previous experience.

There followed a discussion of the availability of a metal that is chelated to a protein. Is the metal available after the protein is digested?

A further problem in measuring the bioavailability is the degree of nutritional depletion of the subject as concerns that metal; this is particularly true of iron. Also one must take into consideration the foods being eaten when measuring availability. Much work needs to be done in this area, taking into account all the variables. For example, we know that the availability of iron in fortified bread is diminished when eggs are eaten with the bread. There is a selective uptake mechanism in operation in the human body that must be carefully considered.

Dr. Chichester noted that we need to examine the fortificants to make sure they are not producing deleterious degradation products. An example given was vitamin A or β-carotene, where very small amounts of in-chain epoxides are formed in the carotene. Reports from Romania show these to be carcinogenic in laboratory animals.

DR. BIRDSALL: A further breakdown product to be considered is the oxalates from plant foods. Also, the breakdown products of tocopherol are quinones that are or have been shown to be toxic. However, one should not be concerned with the breakdown products if they occur at very low levels, and the composition of the product is not amenable to their formation.

DR. GRAHAM: A number of products that for years past have contained BHA and BHT are now advertised as not containing any antioxidants and/or preservatives. Does this mean that in the total dietary system there is less antioxidant than there was previously, and is this important? Dr. Bauman stated that there has been no decrease in the use of antioxidants, but the BHA and BHT have given way to natural antioxidants such as oat flour or even vitamin E itself.

DR. GRAHAM: What are the possibilities for interaction between the various redox systems such as iron and riboflavin that occur in foods? Are there further examples of oxidizable vitamins or sulfhydryl groups?

DR. BAUMAN: Yes. Thiamin.

DR. BIRDSALL: The literature is full of examples that take place both in model systems or in actual foodstuffs, and one must be alert to the possibility of these reactions when fortifying foods. In addition, many of the vitamins are measured microbiologically and this gives one a certain degree of confidence regarding bioavailability since at least they are available to a living system. This degree of confidence is not available with chemical analyses. This is a risk that is involved with the reversion to an all-chemical methodology. We need a program to increase our capability to measure microbiologically many materials simultaneously.

Dr. Schweigert noted that Dr. Birdsall's presentation indicated some concern with lactose-intolerant individuals using protein supplements from dairy-product sources. This should be clarified, since the amounts that would be contributed by any supplement used in fortification would be insignificant and not in any way a nutritional or public health hazard.

Dr. Birdsall asked if there are any metabolic or toxicologic data on the vitamin breakdown products. Dr. Borenstein replied that there are few data available or necessary. Some work has been done by CIBA in the meat field for degradation of ascorbic acid in meat curing. Oxalic acid was found as a degradation product. Toxicologic studies on β-ionone are very limited. Much work is going on with B_1. The University of Nebraska is very active in this field and has found at least 30 degradation products of little importance.

Dr. Hartman, in response to a question, pointed out that the presence of naturally occurring ingredients decreases the availability of minerals in general.

Dr. Hartman noted that it is essential, when considering the availability of reduced iron, to define the particle size.

RAY C. FRODEY

Technological Problems Encountered in Fortifying Infant Foods

This chapter is concerned with nutrients that have been used to fortify infant foods. Generally, the fortification of infant foods has been limited to the use of vitamin C in fruits and fruit juices, the use of the B vitamins and minerals in cereal products, and the general fortification (including, also, the fat-soluble vitamins, amino acids, and trace minerals) of formula products designed as the sole source of nutrients in the infant diet. The reason that other foods have not been supplemented is that, with the supplementation currently used, the U.S. infant will obtain adequate nutrition by consuming any reasonably balanced diet.

VITAMIN C

In the case of fruit juices, the goal in fortification with vitamin C is to bring them up to the same level as can be expected in orange juice. In the case of the fruits, the aiming point is generally 50 percent of the daily requirement in each jar that is considered a serving. Because of standards of identity, however, this has been varied in the case of one product.

The sensitivity of vitamin C to oxidation and to heat is quite well known. Most processors have studied the losses of vitamin C in their product and add a sufficient excess to compensate for the expected loss during the normal shelf life of the product, assuming it is kept under normal storage conditions.

Our experience with fruits and juices is that the losses of vitamin C are somewhat variable, depending on the particular product being fortified. We are not able to predict this and thus depend on individual storage studies for each product that we fortify or plan to fortify. Generally speaking, the citrus juices tend to retain vitamin C better than most fruit juices. We have considered pH as being one variable; however, this does not correlate in a significant manner to our experience, although it certainly is one of the variables involved. Storage temperature and dissolved oxygen are also important factors. Optimal vitamin C retention usually correlates with maintenance of flavor and color. In a product with xanthocyanin pigments, however, vitamin C may degrade the color.

We also know that the level of vitamin C retention is best in a plain tin container. The tin has sufficient reducing action to keep the vitamin C in a reduced form as contrasted to enameled cans or, particularly, to glass or aluminum containers.

It also is generally known that certain types of metal contamination, particularly copper, can cause very rapid loss of vitamin C. Vitamin C may often be used for its antioxidant characteristics; but in infant foods, usage has been primarily for nutritional reasons.

VITAMIN B_1—THIAMIN

This vitamin presents numerous problems because of its heat sensitivity, poor stability at high pH, and its sensitivity to sulfite and oxidizing agents. Thiamin mononitrate is preferred to the hydrochloride for use in dry products and its greater stability in such products.

Where extensive application of heat is used, fortification with thiamin has often been accomplished by adding the vitamin through a surface application after the heat process is completed. This has been done, for example, in the case of cookies and certain toasted cereals.

RIBOFLAVIN—VITAMIN B_2

This vitamin is generally fairly easy to handle except for its sensitivity to light. Losses are minimized by the use of packaging that protects the product from light. The color of riboflavin can be an advantage or disadvantage, depending on the use, and this must be considered.

NIACIN

This is the most stable of the B vitamins and generally presents few problems. There is, however, often confusion as a result of the utilization or lack of utilization in labeling of niacin equivalents based on tryptophan content.

VITAMIN B_6

This vitamin is very unstable, being sensitive to heat, light, and pH. This is especially true of the pyridoxal form. Pyridoxal is the normal form present in milk and in association with other animal products. This form is not used in fortification. These problems of instability are generally handled by the use of the methods noted for the other unstable vitamins, including the addition of large overages to assure levels that meet label declaration in the product as used.

FOLIC ACID—VITAMIN B_{12}

Both of these are very heat sensitive, and substantial overages must be added to assure adequate quantities in the finished product.

VITAMIN MIXES

Generally, there are advantages to the use of vitamin mixes when fortifying industrial products. These are primarily from the standpoint of convenience to the manufacturer and better control under most conditions.

There are certain disadvantages, including the fact that one mix often does not fit all products; and thus a number of mixes must be kept in inventory. It also presents the disadvantage that analysis of a vitamin mix is difficult. Therefore, most processors rely on certification by the supplier, followed by subsequent checks of the vitamin level in the finished product.

IRON

As all of you know, the question of fortification with iron is controversial because of the conflicting results that have been obtained with the various forms of iron. The question, of course, is the availability of the iron and its utilization by man. I won't attempt to review the recent work and the controversy. I believe most of you are familiar with them and I am sure there is considerable difference of opinion even within this group. One thing I believe we will get general agreement on is that the nutritional availability of iron is a very complex subject and there are a number of variables concerned with this that are not fully understood at this time. We know that there are variations by and within species and individuals, depending on age, state of nutrition, foods consumed, and other factors.

To the food processor, fortification with iron generally presents potential problems. One of these is discoloration of the product as a result of the iron added. Another is the development of off-flavors, including rancidity of fat. There are other minor problems that arise under certain conditions, e.g., sedimentation of the iron compound when insoluble forms are used.

For a number of years, the baby food industry used sodium iron pyrophosphate as the source of iron in dry products. This was based on some clinical studies done a number of years ago that indicated that this was an effective form of iron fortification. However, based on more recent work, the industry is generally switching to electrolytically reduced iron of very small particle size for fortification of dry products. Reduced iron, on the other hand, is not suitable for some products, including most "wet canned" products. For these products, ferrous sulfate or other soluble iron salts are often used, when they do not cause undesirable side effects in man. Also being considered for use in certain types of products is iron that is encapsulated in a digestible material. Again, this presents obvious limitations but in certain types of products can be very effective, especially with production procedures where heat treatment after addition of the iron is not involved.

At any rate, this problem is still with us, and considerable additional work is being done and will be done in regard to overcoming the technological problems that occur with the use of iron fortification.

VITAMINS A, D, AND E

These vitamins are used in baby foods only for the formula products that are designed to be the sole source of nutrients.

Because of the toxicity of vitamins A and D at high levels, the control of the addition of these vitamins must be precise. Fortunately, these vitamins are also more stable in most processed foods than are B vitamins. Thus, the overages necessary are less. Vitamin E can be an effective antioxidant in food under certain conditions and, from this standpoint, offers some functional advantages in addition to its function as a vitamin.

VITAMIN K

Vitamin K is currently used only in a few formula products, because K deficiency has been demonstrated only under abnormal circumstances, such as diarrhea, where intestinal synthesis is retarded.

Control of vitamin K in products is extremely difficult because of the very poor and slow chick assay technique that must be used. This also makes process losses almost impossible to estimate accurately. Obviously, what is needed here is an analytical technique that is sufficiently rapid and accurate.

IODINE

Iodine is now used in some baby foods in the form of iodized salt. With the reductions in the level of salt in infant food, however, its significance is open to some question. There are certain technological problems in connection with the use of iodine in food products. One of these is preferential solubility when used in certain types of brinemakers. This, of course, does not show up when it is added to food in the dry form. There also have been reports of adverse effects on the organoleptic characteristics of products under certain conditions. In baby food products, these have been shown to be insignificant at the levels of iodine used. There is also a question of the possibility of excessive iodine intake as a result of fortification of salt plus variable and sometimes high levels present in milk.

OTHER MINERALS

Calcium salts are used in some infant products. The primary technological problems are due to the insolubility of these salts and their effect on pH when added to acid products. The calcium phosphate salts are the most satisfactory forms from most aspects, but this then presents problems in maintaining the optimal Ca/P ratio.

A few other minerals are used as supplements in products designed as the sole source of nutrients. The question of the effect of natural sequestrants has come up most recently in regard to the phytate–zinc relationship. Oxalates also can function as sequestrants for zinc and, under some conditions, also for calcium and iron.

AMINO ACIDS

Apparently, the only current use of amino acids in infant foods is the use of methionine in certain soy formulas. Amino acids have, however, been considered for use in other infant food products. One problem that occurs with the use of amino acid fortification is that the individual amino acid, particularly lysine, is more reactive than the whole protein, due to the availability of the amino groups. This is particularly true in the presence of reducing sugars.

For this reason, mixtures of protein sources are often a better way to obtain the desired amino acid balance than fortification with amino acids. This is particularly true where application of heat is substantial. Sometimes this can be bypassed by applying the amino acid desired, in some manner, after the application of heat. The possibility of the growth of organisms on media that have been supplemented with amino acids has been considered as a method of increasing the amino acid content of some single-cell proteins. This is only in preliminary stages, and its feasibility has not been conclusively demonstrated.

SUMMARY

In summary, there are technological problems in fortifying infant foods, and additional work is needed in some areas to resolve them. The industry itself is working on them, but some are broad and basic in nature and require more adequate resources than are now available in the infant food industry. Most of the problems also apply to fortification of adult foods. We hope that this workshop will point out these problems and create interest in research to help answer the questions posed.

HOWARD E. BAUMAN

Cereal Products

Historically, wheat flour, bread, and rolls have shared the spotlight with salt and milk as food carriers of nutrients that have largely eradicated specific deficiency diseases in the United States. The contributions of B vitamins in enriched cereal products to the eradication of beri beri, pellagra, and ariboflavinosis; of iodized salt to goiter; and of vitamin D-fortified milk to rickets are strong testimony to the importance of enriching and fortifying foods.

Current and developing factors, however, are making it difficult to extend, or even maintain, successful enrichment and fortification programs. For one thing, most remaining nutrition problems are less well defined than vitamin or mineral deficiencies; and, therefore, desirable food characteristics are less-easily determined, and the effects of dietary intervention are measured with limited confidence. A second factor relates to the increasing diversity and the rapidly changing patterns of dietary habits. The third factor is the increasingly complex variety of food products and eating environments available to the consumer.

These conditions will intensify old questions about the philosophy of nutrient addition to foods: i.e., should nutrient addition be based on restoring nutrients to "normal" levels for individual foods (whether natural or analog) or exclusively on health needs with no undue consideration to composition of the original product? Criteria for nutrient additions to date, based on the joint policy statement of the American Medical Association's Committee on Food and Nutrition (AMA–CFN) and the National Academy of Sciences' Food and Nutrition Board

(NAS–FNB), agree more closely with the former view by limiting nutrient additions (1) to nutrients diminished during processing, (2) to products widely and regularly consumed, and (3) to "normal" levels unless a specific need is documented and the effectiveness of the particular food as a vehicle substantiated.

The most recent policy statement from the AMA–CFN approaches the more broad-scale diet intervention, however, by giving guidelines for fortification of snacks in relation to caloric content.

A unified approach to food fortification necessitates resolution of the philosophical question, but the prerequisites for resolution—maturity of nutritional sciences and a national nutrition policy—do not appear to be immediately attainable.

Whether or not all food fortification is guided by consistent, perhaps mandatory, policy, responsible fortification of any individual food must be influenced by considerations that have been or will be covered in detail by other speakers. These include (1) the stability of the added nutrient to processing, storage, distribution, and preparation steps; (2) cost to the manufacturer and consumer, relative to benefits; (3) ability to measure, detect, or predict the benefits and the negative effects or lack of results; (4) bioavailability at the time of consumption; and (5) knowledge of the importance of limiting or controlling nutrients and ingredients that cause allergic reactions or that may be in danger of excessive consumption, as might be phosphorus.

Responsible dietary intervention also requires simultaneous attention to areas other than food technology. At least three such areas can be enumerated. The first is education: Food habits or dietary patterns are too variable and volatile to permit rigid control of the population's diet exclusively by intervention. The consumer is sophisticated enough to increase personal responsibility for dietary management, and nutrition labeling provides the necessary tool. Proper education will put the consumer back in the game and thereby help regulatory agencies relinquish the role of policeman and assume the more proper role of referee for consumer/manufacturer interaction.

The second area is that of agricultural (genetics) research, which involves the development and selection of commodities based on nutrient levels and characteristics—like high-lysine corn and wheat—in addition to maximum yields, economics, and the like.

The third area is that of nutrition research, and it relates to the need for a new generation of coordinated, highly sophisticated methods of human research that rely on measurement of variable interaction rather than factor control and sequential change of variables.

In determining which foods to fortify and with what, we have a new ball game that requires serious study and consideration. For instance, the per capita consumption of flour has changed over the years. Further, more of the cereal-based products that are eaten are now available as convenience foods, resulting in less flour being used in the home. This means that cereal-based products in finished form should be enriched, since otherwise a decrease in intake of the nutrients provided in enriched flour would ensue. The argument has been advanced that any one product may be eaten only once a week and therefore why enrich? However, we must keep in mind that there may be 15 or 20 or more of a variety of cereal-based products eaten per week, and together they may represent a substantial intake of the enrichment added to flour. In effect, much of the cereal flour eaten today is hidden—as piecrusts, corn muffins, rice cereals, etc.

An additional factor to consider when determining what should be added must take into account whether other foods that have been sources of nutrients are now not eaten in any quantities—at least by some segments of the population. One example is the ghetto area of Chicago, where the consumption of flour is high but very little milk is used. Should flour for this reason contain at least calcium, which it appears may be low in some ghetto diets? We must remember that as eating habits change, for whatever reason, we should have a dynamic fortification policy that will allow for needed changes.

Like the nutrition considerations discussed above, the following general technology considerations should also apply to fortification of all the specific cereal-based products to be discussed:

1. The means of nutrient addition, including availability of reliable equipment, must be carefully considered and selected.
2. Uniformity of nutrient addition and distribution is extremely important, and the means of addition must assure proper distribution.
3. Quality-assurance procedures—on the supplement premix or additive mixture, and on the final product—must be precise and accurate. Rapid and reliable methods for indicator or trace nutrients for production quality-assurance should also be available.
4. Process effects on added nutrient levels must be defined and understood—from destruction (vitamins) by heat or aeration to removal (reduced iron) by metal-detecting magnets.
5. General limitations to the addition of nutrients to specific products must likewise be understood—e.g., effect of riboflavin on color of rice and catalytic effect of metal ions on flavor or physical stability.

The remainder of the chapter will deal with specific cereal products and product categories, delineating important considerations in the fortification of each.

The form of the nutrients, the point of addition, and the mechanism of adding them to various products must be treated on an individual product basis, since many factors can be involved that may affect the nutrient levels of the final product.

The fortification mixture for cereal products is generally used in the following forms, depending on the product and the process constraints:

- dry powders—added by vibrating feeders to a stream of flour or meal;
- tablets or wafers—generally added at the dough-mixing stage;
- sprays—usually on particulate products that have a heat treatment in the process and thus would sustain losses of some nutrients if they were added earlier;
- packets with the product—such as packaged rice; and
- liquid mixtures—whereby some of the product is impregnated with the enrichment, dried, and then blended back to the bulk of the product.

The following cereal-based products are examples, with suggested mechanisms of addition of the enrichment mixture.

Corn meal and wheat flour enrichment is added by vibrating volumetric feeders during the milling process.

Enriched flour may be used in baking mixes, bread, rolls, etc. The more common practice, especially in bakeries, is to add enrichment tablets and wafers, or bags of mixture, to a known amount of product in the mixer. This also has an added advantage of permitting the use of ferrous sulfate rather than reduced iron or iron phosphate, which would generally be supplied by the enriched flour, because ferrous sulfate catalyzes changes in flour on storage and cannot be used in the mill as an iron enrichment. Work is being done on a stabilized ferrous sulfate that might solve this problem.

If a nutrient such as lysine is to be added to flour, great care must be used, since density can vary greatly.

Pasta products usually have the enrichment added in the mixer.

Toasted breakfast cereals have the enrichment sprayed on—after toasting—because of losses during the heating process. It is important to get an adequate uniform blending of these products after addition, as the spray is not totally uniform on all products.

Rice presents unique problems in that the riboflavin tends to color the rice and in many instances is left out of the enrichment mix unless required by state law. Some manufacturers have included a packet of enrichment mixture in the package, to be added during cooking. A newer approach is to make synthetic rice pellets containing the nutrients to be added and include these in the rice at about 1 pellet per 200 rice grains. One must be careful not to have the pellet noticeable; otherwise people may throw it out or avoid it.

A technique of liquid addition of lysine and other nutrients to *bulgur and whole wheat* has been developed that is very interesting. This is done by impregnating or coating a kernel and using one or two of these per 100–200 kernels of grain.

Cereal beverages usually have the materials added to the liquid prior to homogenization; however, subsequent drying or oxidation could cause losses.

In some products, such as *corn grits,* the enrichment mixture is added after milling, by blending.

Problems to watch out for in cereal fortification are:

- segregation of the nutrients from the product,
- trace metals present that may affect ascorbic acid,
- pH effects in a liquid or dough process,
- heat effects during the process,
- exposure to oxygen over time,
- exposure to light,
- moisture level over time, and
- uniformity of the blend.

Once these factors are recognized and taken care of, it is important that a suitable quality-assurance system be employed to monitor continuously the fortification to ensure that the specifications are being met. Usually, following one specific nutrient is sufficient (generally one that is easy to determine), provided the basic enrichment mixture is uniform.

A major problem is equating or determining the loss of nutrient availability over time, since the values declared must be present at the end of shelf life. From this type of data, the overages necessary in initial production can be calculated; and if losses are too high, some form of stabilization may be necessary. Analysis for nutrients is not a simple process and requires considerable equipment and skills to accomplish. Thus, in most instances it more than pays to purchase premade blends of nutrients from a basic supplier, on a guaranteed minimum-analysis basis. Additionally, the basic supplier can furnish a great deal of help, based on his knowledge in difficult areas.

In summary, the fortification of cereal-based products is a good means of getting needed nutrients to the consumer. There are, and will continue to be, problems in the addition of specific nutrients to these products, primarily based on stability within a given system. However, techniques of stabilizing through coating, encapsulation, or other means are available and can be applied with probably a minimum of research and development time. The biggest problem in the future will be developing adequate data on population needs and eating patterns to determine what vehicles should be used for fortification and which nutrients should be added.

D. F. OWEN *and* J. M. MCINTIRE

Technologies of the Fortification of Milk Products

Milk, as a food, sustains us during the first few months of life until we are able to vary the diet with other sources of nutrients. We are never entirely free of milk and its by-products during the course of our lives. As a single item of the variety of foods available to the average U.S. citizen, milk probably ranks among the top three contributors of our daily nutrient intake (Hansen, 1956; Hartman, 1965; Nutting, 1970).

G. C. Nutting (1970) quotes some interesting statistics when he states, "In 1966 dairy products, excluding butter, supplied as percentages of total food nutrients contributed to the U.S. diet: protein 23.6%; fat 14.5%; carbohydrate 7.4%; calcium 76.7%; phosphorus 38.1%; riboflavin 44.5%; and food energy 12.5%." This is an impressive contribution for any product.

Of the 119 billion pounds of milk produced in 1967, slightly more than 50 percent went to produce the three major products—market milk and products, evaporated milks, and nonfat dry milks—as well as the two minor proprietary products to be evaluated in this discussion (Nutting, 1970).

Inasmuch as the market milks and fresh products do comprise approximately 50 percent of the total, this chapter will begin with three of the more common fresh milk products and follow with a consideration of evaporated milk, instantized nonfat dry milk, and two commercially marketed dietary dairy products.

Two of the aims of this presentation are to point up the facts that (1) fortification is generally possible, although often difficult and expensive, and (2) that the variations in milks due to season, breed of cow, and geographic origin, as well as an analytical variance, make any one set of figures representing the whole highly suspect as to absolute finality. This notation will become apparent with the presentation of each class of dairy products.

FRESH MILK PRODUCTS

Pasteurized 3.5 percent milk, or whole milk, is the fat and solids nonfat standardized product of the market or home delivery truck. In California, by law, this product must contain 3.5 percent fat and 8.15 percent solids nonfat, minimum. Other states have their codes for fresh whole milk ranging from 3 to 3.8 percent fat and from 8 to 9 percent solids nonfat. Additionally, some states regulate total solids minimum. To describe fresh milk, even though "standardized," with one set of figures is thus misleading, as was emphasized in the introduction. Table 1 must be qualified then as a general set of values in that assay data have been pulled in from many geographically different sources. The ranges as shown reflect not only location differences but also breed, time of year, and feeding practices (Archibald, 1958; Armstrong, 1959; Graham, 1973; Gregory, 1962; Hansen and Carlson, 1956; Hartman and Dryden, 1965; McGillivray, 1958; Nickerson, 1960, 1961).

Total losses in nutrient levels of fresh milks are generally minimal due to the mild heat conditions applied during pasteurization and a short refrigerated shelf life. Little or no losses are ascribed to processing fresh milk according to McGillivray's (1958) report on the works of Natvig, DeGroot, and Mancini. Oxygen (Scanlan and Shipe, 1962), mineral content (Archibald, 1958; Murthy *et al.,* 1972), and exposure to sunlight (Gregory, 1962; Hartman and Dryden, 1965) appear to be the major items to avoid during handling in order that original levels of labile vitamins may be maintained. Riboflavin degradation by sunlight is the classic example (Funai, 1967) as is oxidation of ascorbic acid in the presence of copper or iron (Hansen and Carlson, 1956; Scanlan and Shipe, 1962). Deaerators, glass and stainless steel equipment, and opaque packaging have reduced processing losses to insignificance in fresh milks.

Storage loss over the relatively short, refrigerated shelf life is shown in Table 2 for three fresh milk products. As one would expect, and as stated by Hartman (1965), the ascorbic acid content drops off rather substantially. It is probably safe to assume that vitamin C loss in whole milk is on the exaggerated side, although not completely unreasonable. According to literature sources, the balance of vitamins come through

TABLE 1 3.5 Percent Whole Milk Values—Literature and Assay

Property or Nutrient	Selected Literature Values (100 g Basis)	Range of Literature Values (100 g Basis)
Total solids (%)	12.6 [c]	11.25–12.0 [h]
Protein (%)	3.5 [c]	—
Fat (%)	3.5 [c]	3.0–3.8 [h]
Ash (%)	0.7 [c]	—
Vitamin A, IU	143 [b]	119–176 [f]
Vitamin D, IU	Fortified	Fortified
Vitamin E	0.098 [f]	0.020–0.184 [f]
Ascorbic acid (mg)	0.820 [b]	1.65–2.75 [f]
Thiamin (mg)	0.028 [b]	0.020–0.080 [f]
Riboflavin (mg)	0.168 [b]	0.081–0.258 [f]
Pyridoxine (mg)	0.040 [a]	0.022–0.190 [f]
Niacin (mg)	0.080 [b]	0.030–0.200 [f]
Pantothenic acid (mg)	0.340 [a]	0.260–0.490 [f]
Vitamin B_{12} (μg)	0.400 [a]	0.240–0.740 [f]
Folic acid (μg)	0.600 [e]	0.040–0.620 [f]
Calcium (mg)	118 [b]	100–140 [g]
Phosphorus (mg)	93 [c]	75–110 [g]
Potassium	144 [c]	135–155 [g]
Magnesium (mg)	13 [d]	10–15 [g]
Iodine (μg)	8.2 [d]	—
Zinc (mg)	0.40 [d]	—
Iron (mg)	0.04 [b]	—
Copper (mg)	0.04 [d]	—

[a] USDA Home Economics Res. Rep. no. 36.
[b] USDA Home and Garden Bull. no. 72.
[c] USDA Handbook no. 8.
[d] *The Composition of Milks*, NRC Bull. 119.
[e] *Folic Acid Content of Foods*, USDA Handbook no. 29.
[f] *Fundamentals of Dairy Chemistry*, Webb and Johnson, 1965.
[g] *Principles of Dairy Chemistry*, Jenness and Patton, 1959.
[h] Minimum Values Regulated by State Statutes.

the pasteurization and homogenization processes with little loss. Gregory (1962) reports that Wodsak (1960) and Pol and DeGroot (1960) confirm the stability of niacin and riboflavin, as well as pantothenic acid to heat treatment. Sokolov reports a slight vitamin A loss on pasteurization according to McGillivray (1962). This view is not shared by most workers as reported by Hartman and Dryden (1965). Losses of thiamin during pasteurization are shown to range from 5.5 to 25 percent, depend-

TABLE 2 Nutrient Changes During the Normal Shelf-Life of Refrigerated Dairy Products—10 Day Storage at 38°F

Product Nutrient	3.5% Milk		2% Fortified Milk[a]		Cottage Cheese	
	Initial	Final	Initial	Final	Initial	Final
Vitamin A (IU/100 g)	46	51	217	238	175	115
Thiamin (mg/100 g)	0.033	0.035	0.108	0.113	0.014	0.012
Riboflavin (mg/100 g)	0.129	0.135	0.141	0.156	0.089	0.075
Ascorbic acid (mg/100 g)	2.05	0.36	10.93	6.93	0.42	0.33
Nonprotein nitrogen (%)	0.033	0.033	0.038	0.036	0.022	0.030
Percent loss of nutrients:	Ascorbic acid, 82		Ascorbic acid, 36		Ascorbic acid, 21	

[a] Fortified to provide a minimum of 10% solids not fat, 2,000 IU A/qt, 1 mg B_1/qt, 75 mg C/qt, 400 IU D/qt, and 10 mg niacin/qt.

ing on the method of processing (Hartman and Dryden, 1965). Pyridoxine seems quite controversial in that widely ranging values have been reported. Generally, however, it is assumed that varying degrees of damage to B_6 are heat induced (Hartman and Dryden, 1965).

Fortified, 2 percent milk, as defined in the footnote of Table 2, is a reduced fat, increased solids milk fortified with selected vitamins. Quite simply, this is done to satisfy a demand by a segment of the nutrition-conscious public. This type of product should be of interest to this session in that substantial fortification of an only slightly altered fresh milk product for direct consumption is shown to be feasible.

Cottage cheese was included in this study as a milk product bearing a 10-day pull date (yoghurt, for example, carries a 45-day pull date). Again, vitamin C appears to be the most labile vitamin in the three products tested.

Fortification of fresh milk is not new either in theory or trial application (Tepley *et al.,* 1956). The one whole milk addition allowed to date, vitamin D, is acknowledged to have virtually eliminated rickets in milk-drinking children. The United Nations interest in vitamin A fortification of dried milk no doubt hastened our domestic addition. Investigators in recent years have turned their efforts to minerals and vitamins either normally low in milk or lost in processing or to those that contribute to stability of food value or flavor retention. These investigators include: Bell (1948) of the USDA and Weinstein *et al.* (1949–50) of Oklahoma with their work on the control of oxidized flavor through the use of

TABLE 3 Proximate, Vitamin and Mineral Values for Evaporated Milk (100 g Basis)

Nutrient	Handbook 8 Values—Liquid 3.5% Milk × 2.1	Handbook 8 Evaporated Milk	Ave. Literature Values—Evap. Milk	Range of Lit. Values	Percent Loss Process	Percent Loss 1 Yr Shelf
Total solids (g)	26.46	26.2	26.1 [f]	25.09–27.30	—	—
Protein (N × 6.38) (g)	7.35	7.0	6.7 [f]	6.54–7.35	—	—
Fat (g)	7.35	7.9	7.9 [f]	7.14–8.24	—	—
Carbohydrate (g)	10.29	9.7	10.1 [f]	—	—	—
Calories (Kcal)	136.5	137	138	—	—	—
Vitamin A (activity) (IU)	294 [a]	320	369	342–464	0	0
Vitamin D (IU)	Trace	—	79 (fort. level)	—	0	0
Vitamin E (mg)	0.015–0.367 [a]	0.22 [d]	0.26	0.22–0.30	0	0
Ascorbic acid (mg)	2.1	1.0	1.1	0.4–1.8	50–90	5
Thiamin (mg)	0.063	0.04	0.056	0.04–0.08	20–60	15–50
Riboflavin (mg)	0.357	0.34	0.38	0.28–0.48	0	28
Pyridoxine (mg)	0.098 [a]	0.05 [c]	0.07	0.055–0.137	36–49	0(?)
Vitamin B_{12} (μg)	1.023 [a]	0.16 [c]	0.14	0.10–0.19	90	0(?)
Folicin (μg)	0.468 [a]	0.70 (L. casei) [b]	1.40	-	0	0
Niacin (mg)	0.210	0.20	0.20	0.18–0.23	0	0
Pantothenic acid (mg)	0.714 [a]	0.64 [c]	0.70	0.58–0.80	0	0
Calcium (mg)	247.8	252	258 [e]	—	—	—
Phosphorus (mg)	195.3	205	199 [e]	—	—	—
Iron (mg)	Trace	0.1	0.09 [e]	0.08–1.90	—	—
Copper (mg)	—	—	0.03 [e]	0.009–0.150	—	—

[a] *Newer Knowledge of Milk,* 3rd ed., National Dairy Council, Chicago, Ill., 1973.
[b] *Folic Acid Content of Foods,* Agric. Handbook 29, USDA, 1951.
[c] *Pantothenic Acid, Vit. B_6 and Vit. B_{12} in Foods,* Home Economics Res. Rep. no. 36, USDA, 1969.
[d] *Vitamin E Content of Foods and Feeds,* Bull. 435, Wyoming Agric. Exp. Stn., 1965.
[e] *Fundamentals of Dairy Chemistry,* Webb and Johnson, AVI, 1965.
[f] *By Products from Milk,* Webb and Whittier, AVI, 1970.

ascorbic acid; King (1968) of Maryland in the use of *d*-α-tocopherol in controlling oxidation due to copper addition; the effects of iron fortification on flavor by Scanlan (Scanlan and Shipe, 1962) of Cornell and Demott (1971) of Tennessee. While specific problem-oriented, all of these workers are showing the possibilities open to, as well as the problems associated with, the fortification of fresh milks.

EVAPORATED MILK

According to § 18.520(2) of the Code of Federal Regulations (CFR), evaporated milk is defined as "the liquid food made by evaporating sweet milk to such point that it contains not less than 7.9 percent milk fat and not less than 25.9 percent total milk solids. It may contain one or more of the following optional ingredients:

- Disodium phosphate or sodium citrate or both, or calcium chloride, . . . not more than 0.1 percent by weight of . . . milk.
- Carrageenan or salts of carrageenan . . . in a quantity not exceeding 0.015 percent by weight of . . . milk.
- When an optional ingredient . . . is used, dioctyl sodium sulfosuccinate . . . may be used . . . not in excess of 0.5 percent by weight of . . . ingredient.
- Vitamin D in such quantity as to increase the total Vitamin D content to not less than 25 U.S.P. units per fluid ounce of the finished evaporated milk. . . .

The rest of the section qualifies methodology of assay, labeling, and adjustment of product in standardization.

It is this standardization of evaporated milk to a specific solids and fat level that invariably causes most people to look on this product as one that is uniform in all aspects. When one considers the effects of processing and storage (shelf time), as well as the variations of the vitamin and mineral content in solids and fat due to herd feeding practices (Henry *et al.*, 1942; McGillivray, 1957; Rogers, 1935; Thompson, 1968), the breeds of cows contributing (Erb and Ashworth, 1963; Ford *et al.*, 1956, 1957; Rogers, 1935; Thompson, 1968), and raw milk handling procedures (Ashton, 1972; Ford *et al.*, 1959; Henry *et al.*, 1942; Hodson, 1952), it becomes apparent that this impression is somewhat erroneous. The magnitude of this variation may be seen in the ranges of values found in the review of Hartman and Dryden, "Vitamins in Milk and Milk Products" (1965) and as shown in Table 3.

Fortunately, even minimally retained levels of milk nutrients appear to support growth sufficiently well to preclude nutritional deficiency from any but the most mistreated of evaporated milks. The degree of loss of nutrients may be due either to type of processing or storage conditions or both as shown in Table 3. Vitamins C (Bullock *et al.,* 1968; Conochie, 1959; Davidov *et al.,* 1962, 1963; DeGroot and Engel, 1956; Henry *et al.,* 1942; Kisza *et al.,* 1966; Pelletier and Morrison, 1965; Wodsak, 1961), B_1 (Burton *et al.,* 1967; Chapman *et al.,* 1957, 1958; Davidov *et al.,* 1962, 1963; DeGroot and Engel, 1956; Ford *et al.,* 1959; Henry *et al.,* 1942; Hodson, 1952), B_2 (Adams *et al.,* 1965; Causeret, 1959; Davidov *et al.,* 1962, 1963; Henry *et al.,* 1942; Hodson, 1952), B_6 Burton *et al.,* 1967; Gregory, 1959; Gregory and Burton, 1965; Hassinen *et al.,* 1954; Wodsak, 1961), and B_{12} (Adams *et al.,* 1965; Burton *et al.,* 1967; Chapman *et al.,* 1957, 1958; Ford, 1957; Gregory and Burton, 1965) appear to be the most susceptible, and varying losses of each have been reported by investigators from many countries. Chemical assays at our laboratories show storage and processing losses to fall within acceptable ranges. Our biological evaluations, feed efficiency ratios (e.r.) and protein efficiencies ratios (PER) have verified the loss areas in that the e.r.'s (unsupplemented evaporated milk is the sole item of diet) will be slightly reduced when the animals are fed product that has been held for a year (Table 4). This product, however, will still support a good growth response in the test rat. This is not the case in the PER test where the ration is supplemented with vitamins and minerals and the test material is used only as a protein source. In this evaluation, no change in PER from the initial product, following one year in storage at room temperature, was detectable, thus indicating satisfactory protein stability. Hodson (1952) and Cook (1951) had previously obtained similar results in studies of overall growth response and protein value of stored and heat processed milks.

TABLE 4 Biological Evaluation of Nutrient Loss in Evaporated Milk upon Storage (Room Temp. Storage)

Type Trial	Initial	6 Months	12 Months
Cook, *et al.* (1951)			
PER	2.63	2.16	2.70
Hodson (1952)			
Prot. repletion	64.9±2.20 (g gain)	—	58.7±2.12 (16 mo)
Carnation			(Diff. not significant)
PER	2.42	2.87	2.44
Efficiency ratio	0.380	0.398	0.355

Adams *et al.* (1965) in a 4-year, 32°F storage study also report no loss in protein values for evaporated milk. These results, in light of the purpose of this chapter, pose several problems. Do we fortify to cover processing and shelf life losses of vitamins? Do we fortify to correct certain normal-product nutrient deficiencies, such as iron and copper? If the answers are yes for either, then, as with other products, what particular problems are we facing with evaporated milk? (See Table 5.)

What appears to be a relatively simple procedure of addition immedi-

TABLE 5 Composition of One Company's Evaporated Milk with a Literature Value Comparison (100 g Basis)

Nutrient	Ave. Literature Values	Carnation Values	Percent Loss	
			Processing	Shelf (1 yr)
Total solids (g)	26.1[b]	26.3		
Protein (N × 6.38) (g)	6.7[b]	6.9		
Fat (g)	7.9[b]	7.9		
Carbohydrate (g)	10.1[b]	9.8		
Calories (Kcal)	138	137		
Vitamin A (IU)	369		0–L[c]	0–L, 0–C[d]
Vitamin D (IU)	—		0–L	0–L, 0–C
Vitamin E (mg)	0.26		0–L	0–L
Ascorbic acid (mg)	1.1	1.4	50–90–L	5–L
Thiamin (mg)	0.056	0.045±0.004	20–60–L	15–50–L, 38–C
Riboflavin (mg)	0.38	0.35±0.08	0–L	28–L
Pyridoxine (mg)	0.07	0.06±0.01	36–49–L	(?)-L, 40–C
Vitamin B_{12} (μg)	0.14	0.18±0.02	90–L	(?)-L, 46–C
Folicin (μg)	1.40	—	0–L	0–L
Niacin (mg)	0.20	0.18±0.03	0–L	0–L
Pantothenic acid (mg)	0.70	0.75±0.04	0–L	0–L
Calcium (mg)	258[a]	241.9		
Phosphorus (mg)	199[a]	227.0		
Iron (mg)	0.09[a]	0.11		
Copper (mg)	0.03[a]	—		
e.r. (RAT)				6–C
PER				0–L, 0–C

[a] *Fundamentals of Dairy Chemistry*, Webb and Johnson, AVI, 1965.
[b] *By Products from Milk*, Webb and Whittier, AVI, 1970.
[c] Literature = L.
[d] Carnation = C.

ately becomes a complex one in that several of the nutrients under consideration are, by their nature, antagonistic to the chemical and physical properties of milk. This becomes especially pertinent when the milk solids are approximately doubled as well as undergoing a strenuous heat treatment in proximity with the additive. As an example, let us examine an actual situation where the potential addition of iron to evaporated milk was recently examined.

Initially, our choices of iron forms were made on the following bases: solubility, biological availability, color, reactivity, flavor, and cost. Qualifying to some degree for each of these categories were eleven iron compounds: ferrous fumarate, ferrous gluconate, ammonium ferrous sulfate, ferrous lactate, ferric carbonate, ferric pyrophosphate, ferric ammonium citrate, ferric sodium pyrophosphate, ferric citrate, ferric phosphate, and ferric orthophosphate. All were incorporated into product under plant conditions, and each run at three levels—11, 22, and 42 ppm of iron. Some of these compounds failed due to imparting a gray color to the evaporated milk (ammonium ferrous sulfate, ferric carbonate, ferric ammonium citrate, and ferric citrate), while others were too insoluble (ferrous fumarate) or required excessive levels of stabilizer to process. Ferric sodium pyrophosphate, ferric pyrophosphate, and ferric orthophosphate were not detrimental to heat stability or color. Two of these were chosen for further study—ferric pyrophosphate and ferric orthophosphate. A second screening study indicated a possibility for ferrous sulfate usage as well. Of the original twelve sources, only ferrous sulfate and ferric orthophosphate were considered satisfactory. In a final evaluation, ferrous sulfate was found to have a processing requirement for a high level of stabilizing salts—a color problem in straight evaporated milk at higher iron levels (42 ppm) with an undesirable color as well when the product was used in recipes for puddings, white sauces, and whipped topping to name a few of those tried. A poor texture also was noted in white sauce at the 42 ppm level. On these bases, ferrous sulfate failed (see Table 6). Ferric orthophosphate, while difficult to handle (poor solubility) during processing, was found to be satisfactory on storage—no change in protein complexing, a slightly lower recovery but satisfactory, and, as postulated by the conversion to the ferrous form following processing, good biological availability. No problems occurred when evaporated milk fortified with ferric orthophosphate at the level of 11 ppm iron was used for cooking.

This is a general picture of the type of testing involved with an addition of iron to evaporated milk. Obviously each nutrient addition would have its individual problems depending on the type of product involved.

TABLE 6 Recipe Evaluation of Two Levels of Evaporated Milk Fortification with Ferric Orthophosphate or Ferrous Sulfate

	Ferric Orthophosphate		Ferrous Sulfate	
Recipe or Use	**11 ppm**	**42 ppm**	**11 ppm**	**42 ppm**
Vanilla pudding				
Color	+	—	—	—
Texture	+	—	—	—
Taste	+	—	—	±
White sauce				
Color	+	—	+	—
Texture	+	—	+	—
Taste	±	+	+	+
Meat loaf				
Color	+	+	+	+
Texture	+	+	+	+
Taste	+	+	+	+
Cocoa				
Color	+	—	+	—
Texture	NA	NA	NA	NA
Taste	+	±	+	±
Coffee				
Color	+	—	+	—
Texture	+	+	+	+
Taste	+	—	+	±

+ = Good.
— = Poor.
NA = Not applicable.

INSTANTIZED NONFAT DRY MILK

Spray dried nonfat dry milk, moistened and dried under the proper conditions, forms an agglomerated product that wets easily for improved dispersibility and reconstitution. This product is termed Instantized Nonfat Dry Milk. Both the spray dried and instantized dry milks are defined in the Code of Federal Regulations (CFR) under § 18.540 and Subpart U—§ 58.2750, respectively. Nonfat dry milk is further described under Subpart L—§ 58.2562. This relatively recent addition to the U.S. diet (1954) has become a staple item to a nutrition- and diet-conscious public. The addition of vitamins A and D at the defined levels of 500 and 100 USP units per 8-ounce glass (reconstituted), respectively, was permitted by FDA following a recommendation arising from the White House Conference on Nutrition in 1969.

This "addition" of vitamins A and D, along with mineral level, calcium/phosphorus balance, and good retention of the water soluble B-complex vitamins, make dry nonfat milk an important source of total daily nutrient intake. (Bauernfeind and Allen, 1963; Henry, 1957; Hodson, 1957). See Table 7.

In light of the limitation of additions to vitamins A and D, much of our work and that of other investigators has been aimed at providing vitamin A and D mixtures of (1) maximum stability and (2) the best possible organoleptic qualities (Thomas *et al.,* 1965). Cooperating with

TABLE 7 Composition and Loss Data for Instant Nonfat Dry Milk (100 g Basis)

Nutrient	Handbook 8 Values	Carnation Values	Range of Literature Values	Literature Percent Loss: Processing	Literature Percent Loss: Storage
Moisture (g)	4.0	3.6±0.40	—	—	—
Protein (g)	35.8	35.4	—	—	—
Fat (g)	0.7	0.9	—	—	—
Carbohydrate (g)	51.6	51.5	—	—	—
Ash (g)	7.9	8.3	—	—	—
Calories (Kcal)	359	356	—	—	—
Vitamin A (IU)	36[a]	2773±668[b]	40–250[c]	6	65 (2 yr)
Vitamin D (IU)	—	493±41[b]	—	—	—
Vitamin E (mg)	—	—	.05–0.91[c]	9	24 (2 yr)
Ascorbic acid (mg)	7.0	9.99±2.44	5.3–17.0[c]	28–41	10 (2 yr)
Thiamin (mg)	0.35	0.27±0.11	.22–0.46[c]	<10–26	10 (2 yr)
Riboflavin (mg)	1.78	1.47±0.15	1.3–2.54[c]	0–7	—
Pyridoxine (mg)	0.44[a]	0.55±0.04	.28–0.68[c]	0	—
Vitamin B_{12} (μg)	3.2[a]	4.82±0.35	2.2–4.5[c]	20–40	—
Folicin (μg)	3.1[a]	3.83	2.9–5.9[c]	—	—
Niacin (mg)	0.90	—	.82–1.83[c]	0	—
Pantothenic acid (mg)	0.33[a]	—	2.29–7.70[c]	0	—
Calcium (g)	1.293	1.202±0.048	—	—	—
Phosphorus (g)	1.005	1.287±0.232	—	—	—
Iron (mg)	0.6	0.44±0.276	0.129–0.185	—	—
Copper (mg)	—	0.64±0.18	0.064–0.084	—	—
Potassium (g)	1.725	1.50	1.56–1.98	—	—
Magnesium (mg)	—	147±63	—	—	—

[a] Values according to ADMI.

[b] A&D Fortified to yield a min. level of 2,000 IU and 400 IU of A&D/reconst. quart.

[c] *Fundamentals of Dairy Chemistry,* Webb and Johnson, 1965.

us in our studies and paralleling our work were two major suppliers and the Wisconsin Alumni Research Foundation (WARF). Some of these studies covered an interrupted period of almost 14 years. Specific areas covered were: type of vitamin A used—palmitate dispersed in coconut oil with subsequent homogenization prior to drying or the water-dispersible beadlets blended with the dry milk solids; the form of vitamin D—D_2 or D_3; the relative stabilities of both at room temperature for periods up to 24 months; packaging efficiency at 90 percent relative humidity (Chandet, 1966); and the influence of level of vitamin added on percent loss.

Results of these studies may be summarized as follows:

1. No difference in flavor could be found between samples containing vitamin D_2 or D_3, or when stored at room temperature for 12 months.
2. No loss of vitamin D potency was found on storage through 12 months.
3. Vitamin A levels did not affect flavor although flavor degradation with time was noted.
4. The higher the fortification level for vitamin A, the greater the percentage of loss with time (room temperature).
5. One supplier's product was found to give consistently higher flavor scores than the other two throughout the storage period.
6. The preceding observations are made on the basis that moisture does not exceed 5 percent in the sample.
7. Loss values for vitamin A ranged from 10 percent [low A level (actual use level)—2,800 IU/100 g] to 14 percent [high A level (experimental only)—5,800 IU/100 g] after 6 months at 37°C, to 20 percent for the low A level and 47 percent for the high A level after 15 months at room temperature. Vitamin A is accordingly overfortified in our product by 20 percent to insure the correct potency for at least 1 year.

Our values fall well within the 65 percent storage loss expressed by Davidov *et al.* (1943, 1964).

Perhaps more important than the vitamin and mineral contribution of nonfat dry milk is that of protein of excellent biological value. Further, this protein has been shown by Hodson (1957) and noted by Henry (1957) and our own laboratories to retain its value through the drying and instantizing processes as shown in Table 8. Storage, under conditions of low moisture (<5 percent), likewise appears to have little or no (Hodson, 1957) effect on protein quality as measured by PER (protein efficiency ratio).

Table 8 is an expression of our attempt to show the influence of the

TABLE 8 Influence of Processing on the Biological Value of the Protein of Instantized Nonfat Dry Milk

Rat Group		Ave. Weekly Gain, Grams	Ave. Weekly Protein Cons., Grams	PER[a]
I	Original pilot plant liquid skim	17.1	7.21	2.4
II	Pilot plant spray	17.1	6.91	2.5
III	Pilot plant instant	17.6	6.92	2.5
IV	Plant A spray	17.0	6.81	2.5
V	Plant A instant	16.5	6.93	2.4
VI	Plant B spray	16.2	6.70	2.4
VII	Plant B instant	16.1	7.25	2.2 (I-VII) (0.02–0.05)[b]

[a] Casein control, 2.5.
[b] Significance of difference by rank method.

instantizing process on protein value. Spray-dried samples were compared to instantized product prepared from the same spray-dried material in two of our plants. In addition, we carried out the complete process in our pilot plant (which incidentally uses production size equipment) with gratifying, and literature verifying, results (Chandet, 1966; Fragner *et al.,* 1956; Henry, 1957; Hodson, 1956, 1957). One feature of this study is interesting: No significance is found in the difference of PER's for the spray-dried plant samples. However, when the fresh milk or spray-dried products from the pilot plant or plant A are compared to plant B instantized, a real difference exists. Quite possibly this may be related to location or cow differences in the other two areas. Clearly, however, defined processing losses are nonexistent or negligible.

In a prior study, assays of products on test showed no loss of B_6 and 10 percent loss of B_{12} due to spray-drying. Our study just presented agrees with the results of Chapman *et al.* (1957), who showed little or no loss of B_1, B_2, B_6, niacin, or pantothenic acid during the drying operation. This negligible loss appears to be verified by Fragner *et al.* (1956) as well. It is concluded that nonfat dry milk, spray-dried or instantized, retains a high level of original water-soluble vitamin content as shown in Table 7.

One possible future area of fortification that we have looked at is that of iron. Recently, the practicality of iron fortification of instantized nonfat dry milk stored at room temperature for a year was examined.

Only taste panel results are available. Ferrous sulfate was the iron form tested in quantity to supply 10 milligrams of iron per quart of reconstituted product. Flavor evaluations were held initially; at 3 months for product held at 100°F and at 12 months for product stored at room temperature. Packaging was a commercial pouch holding 3.2 ounces of instantized milk. Flavor scores indicated no significant differences between the original and either treatment or between treatments. Unfortunately, no vitamin assays were carried out. These results agree with those of Kurtz *et al.* (1940), who used an addition to the concentrated milk prior to drying for their product as compared to our dry blending. At a higher level (20 mg/liter of raw skim milk) they did experience a color problem when the fortified, reconstituted milk was used in coffee. It was concluded that iron fortification of nonfat dry milk appears feasible from a flavor standpoint in that the instantized milk used carried a full complement of vitamin A and D fortification to stress the flavor deterioration factor (see Table 9).

DEHYDRATED INSTANT BREAKFAST

Dehydrated instant breakfast (DIB) may be considered a representative of dry blended dairy-based products carrying fairly extensive fortification of vitamins and minerals. Based on the marketing concept, that it be used as a meal replacer, DIB carries a minimum of 25 percent of the FDA's Minimum Daily Requirements (MDR) (when combined with milk) as demonstrated in Table 10. Ascorbic acid is the major exception and is decidedly higher (193 percent) in order that the amount of vitamin C in a glass of orange juice may be attained. Other nutrients

TABLE 9 Vitamin A[a] Loss in Instant Nonfat Milk During Room Temperature Storage (IU/100 g Center)

	Control 0 Add'n.	% Loss	Source A	% Loss	Source B	% Loss
Initial	0.42		28.5		28.0	
3 Months	0.00		30.9		26.0	
6 Months	0.30		28.1		22.3	
9 Months	0.20		27.5		25.5	
12 Months	0.60	0	26.4	7.3	19.6	30.0
18 Months	0.20		29.7		20.1	
24 Months	0.40	0	20.0	29.8	17.2	38.5

[a] Vitamin A palmitate—beadlet form 250.

TABLE 10 Instant Breakfast Panel for Nutritional Information

	One Envelope		8 Fl Oz Milk		One Envelope + 8 Oz. Milk	
Nutrient	Amount	% MDR	Amount [a]	Percent MDR	Amount	Percent MDR
Vitamin A (IU)	1,040.0	26	360.0	9	1,400.0	35
Vitamin D (IU)	0.0	0	100.0	25	100.0	25
Vitamin E (IU)	2.5	—[b]	0.1	—[b]	2.6	—[b]
Niacin (mg)	2.5	25	0.2	2	2.7	27
Vitamin B_1 (mg)	0.2	20	0.1	10	0.3	30
Vitamin B_2 (mg)	0.132	11	0.448	37	0.58	48
Vitamin B_6 (mg)	0.39	—[b]	0.11	—[b]	0.5	—[b]
Vitamin B_{12} (μg)	0.17	—[b]	1.33	—[b]	1.5	—[b]
Vitamin C (mg)	57.9	193	2.1	7	60.0	200
Calcium pantothenate (mg)	1.7	—[b]	0.8	—[b]	2.5	—[b]
Folic acid (μg)	7.0	—[b]	18.0	—[b]	25.0	—[b]

[a] Values from Bowes and Church, *Food Values of Portions Commonly Used*, 11th ed., 1970, J. B. Lippincott Co., Philadelphia.
[b] No MDR established.

that exceed the 25 percent MDR level to a lesser degree are those also found in quantity in the "typical" breakfast of bacon, egg, toast, and orange juice.

Since this product undergoes no processing other than a dry ingredient blending and subsequent instantizing operation, only storage stability is considered for loss coverage. The results of several of these studies are shown in Table 11. Storage studies of record are made under approximate shelf conditions of room temperature and humidity. Accelerated studies (not shown) are much more severe and used only as indicators for projected shelf life values. We examine certain vitamins only, based on experience as to their sensitivity in a specific product type. Admittedly, the ideal trial would include an evaluation of each nutrient. We do, however, spot check others periodically to determine the validity of these empirical choices.

As may be noted in Table 11, losses are shown for vitamins A, C, B_1, and B_2. Of these four, B_2 loss was quite unexpected; it apparently suffered considerable loss over 18 months and, barring inadvertent exposure to light or interaction with particulate matter of high pH, was unusual. Although these riboflavin data were collected from three individual trials, they are still suspect and further studies are under way. Quite possibly, we are seeing the effects of an interaction due to the

TABLE 11 Vitamin Loss in Instant Breakfast When Stored at Room Temperature

Vitamin	No. Observa- tions	Average Loss (%)	Ranges of Loss (%)
A (1 year)	5	15	4–22
(18 months)	2	22	15–28
Ascorbic acid (1 year)	4	25	11–46
(18 months)	3	56	48–63
Thiamin (1 year)	3	29	20–35
Riboflavin (18 months)	3	35	25–49

NOTE: All storage samples contained iron at 80 μ/g product level.
All storage samples contained copper at 6 μ/g product level.

copper/iron/ascorbic fortification. Overall, however, we feel the loss level to be reasonable in light of the heavy mineral fortification. Each pouch contains at least 96 mg of magnesium (hydroxide), 4.9 mg of iron (ferric orthophosphate), and 0.44 mg of copper (basic copper carbonate). It is obvious that the potential for oxidation and pH influence is great. The low product moisture no doubt holds activity to a minimum.

TABLE 12 Nutrient Loss During One-Year Storage Studies on a Canned Liquid Diet Food (Expressed as an Average Percent Loss for 23 Observations)

Nutrient	Percent Loss	Range	
		Min.	Max.
Vitamin A	16	+2	−31
Thiamin	24	+3	−34
Riboflavin	2	+2	−13
Pyridoxine	4	+4	−6
Vitamin B_{12}	58	−15	−89
Ascorbic acid	17	+1	−19
Vitamin D	0	+11	−2
Vitamin E	8	+2	−17
Calcium pantothenate	0	+25	−9
Niacin	8	+17	−11

TABLE 13 Comparison of Four Analytical Laboratories—B_{12} Assay Results for Five Samples (μg/100 g)

Laboratory Sample No.	S	W	R/H	P
G 1062 P	0.58	0.168	0.15	0.17
G 1101 B	0.94	0.408	0.43	—
G 1081 D	0.64	0.111	0.52	—
G 1071 N	0.48	0.071	0.28	Trace
G 1011 K	0.47	0.068	0.18	—

LIQUID DIET FOOD

This sterile, liquid product is designed to be used as the sole item of diet in a 3-week weight reduction program. It is a dairy product in that nonfat milk solids are used as the protein and partial carbohydrate source with fat being supplied by corn oil. Vitamin and mineral fortifications are carried out to the extent that one may satisfy FDA MDR's with four 10-ounce cans of product per day.

As shown in Table 12, our overall major loss areas are roughly those of evaporated milk: specifically, ascorbic acid, thiamin, and B_{12}. (See Table 13.) Riboflavin loss is not apparent in these samplings nor does pyridoxine show the substantial loss noted in evaporated milk. Vitamin A loss during storage is of some concern when compared to that which occurs in evaporated milk; however, overall losses are surprisingly light if the level of mineral fortification is considered. We add, per 10 fl oz can, a minimum of 5 mg of iron (ferric orthophosphate), 0.5 mg manganese (sulfate), 0.5 mg of copper (sulfate) and 0.04 mg of iodine (potassium iodide). The copper content is four times that of whole milk, while iron is boosted to 125-times the usual level found in whole milk. No particular flavor problems have been encountered in this diet other than those normally associated with a canned, sterile milk product. Flavor retention, coupled with a minimal vitamin loss, shows that apparently difficult supplementation can be worked out.

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Technological Problems Involved in Fortification of Meat and Meat Products

A number of innovations in the development of meat processing entailing the use of additives have proved highly effective. The use of these substances has not been intended as nutrient fortification. A listing of the categories of these substances and their functions might be helpful in understanding their use.

- Anticoagulants: Citric acid and sodium citrate to prevent clotting of fresh beef blood.
- Antioxidants to retard rancidity.
- Binders to extend and stabilize product.
- Bleaching agents to remove color.
- Catalysts to accelerate chemical reactions, e.g., nickel in hydrogenation of fats.
- Agents, both natural and artificial, to color casings or rendered fats for sausage casings, oleomargarine, shortening, and marking and branding ink.
- Curing adjuncts: Ascorbic acid, erythorbic acid, their sodium salts, and glucono delta lactone for color acceleration and stability during storage.
- Curing agents: Sodium or potassium nitrate as a source of nitrite in meat curing; sodium or potassium nitrite for development of meat color; sodium chloride for flavor and preservation.
- Denuding agents: Calcium oxide, sodium hydroxide, etc., for denuding mucous membrane.

- Emulsifying agents: Acetylated monoglyceride, esters of mono- and diglycerides, and lecithin to emulsify products and shortenings.
- Flavoring agents: Artificial smoke flavoring, autolyzed yeast extract, harmless bacterial starters, benzoic acid, sodium benzoate, citric acid (protect flavor), corn syrup solids, corn syrup, glucose syrup, dextrose, diacetyl, disodium guanylate, disodium inosinate, hydrolyzed plant protein, isopropyl citrate (protect flavor), malt syrup, milk protein hydrolysate, monosodium glutamate, sodium sulfoacetate derivative of mono- and diglycerides, sodium tripolyphosphate (protect flavor), mixtures of sodium tri-, poly-, and hexametaphosphates (protect flavor), sugars (sucrose and dextrose).
- Miscellaneous: Mold retarders, flavor protectors, neutralizers, shrink preventors or yield agents, tenderizers, refining agents, rendering agents, sweeteners, and synergists.

This list is by no means complete, because in each or several of the categories listed there may be a number of compounds approved for a particular use. Of special importance in this list is the purpose for which a compound is used. Not one compound is used to fortify the nutrient content of the product. A complete list of all of these substances is available from the Animal and Plant Inspection Service of the U.S. Department of Agriculture.

COOKING

Many studies on the differences in nutrient content of raw and cooked meat have been conducted. An important source of information on this subject is "A Summary of the Nutrient Content of Meat," available from the American Meat Institute Foundation (Kiernat *et al.,* 1964). This bulletin contains sections on the proximate energy, mineral, vitamin, amino acid, and lipid content and composition of raw and cooked retail cuts, variety meats, and processed meats. Because of interest in level of dietary fat, the tables on fresh meat include three degrees of trimming retail cuts: entire retail cut, separable lean tissue, and extremely lean portion of retail cuts. Sources of data are provided, and a complete bibliography is given at the end of the bulletin.

Generally, when standard cooking procedures are used, retention figures are: biotin, 80 percent; B_6, 20–25 percent; pantothenic acid, 100 percent; folic acid, 10–50 percent; thiamin, 50–80 percent; niacin, 90–95 percent; and riboflavin, practically 100 percent.

DEHYDRATION

Air drying of meat was practiced by primitive societies. When the meat was dried over a fire, smoked meat was produced, which kept for long periods of time. However, these primitive methods produce a product that is not considered palatable by present day standards. Today, dry and semidry sausage products, as well as dried beef, are considered delicacies by many people. Dry sausages are fermented as part of the production cycle; this decreases the pH, increases storage life, and gives the products their unique taste. The drying cycle is done in rooms of controlled humidity, air circulation, and temperature.

HEAT DEHYDRATION

The hot air drying of meat has not become an extensive commercial practice. In one experiment (Ballantyne *et al.*, 1958a), meat was hot-air dried to a moisture content of 5.6 percent (fat content of 24.5 percent). Freeze-dried meat of similar fat content had only 1.0 percent moisture. After 12 months of storage, the hot-air dried meat contained 5 percent moisture and developed signs of deterioration whereas the freeze-dried meat remained acceptable.

Data are limited on the nutrient value of heat dehydrated meat. Rice and Robinson (1944) reported that dehydrated beef (on the original raw meat basis) retained: 76 percent of the thiamin; 105 percent of the riboflavin; 92 percent of the niacin; and 68 percent of the

TABLE 1 Effect of Storage on Biotin and Folic Acid Content of Dehydrated Pork[a]

Source	Original	Stored at 0° F for 20 weeks	Stored at 120° F for 20 weeks
Biotin			
A	13.6	13.7	13.0
B	13.2	14.2	12.5
C	13.2	11.8	12.1
Folic Acid			
A	2.2	2.2	1.9
B	2.6	2.1	2.0
C	3.0	3.1	3.6

[a] All values micrograms per 100 g.

pantothenic acid. Dehydrated pork retains 63 percent of the thiamin, 105 percent of the riboflavin, 92 percent of the niacin, and 73 percent of the pantothenic acid. Later work by Whitemore *et al.* (1946) confirmed these results and in addition showed that biotin and folic acid stability was virtually unaffected by dehydration (Table 1).

The loss of thiamin is somewhat more extensive in heat dehydration than in curing or freezing and approximately the same as in canning.

Hoaglund and Snider (1946) studied the nutritive value of protein in heat dehydrated pork, mutton, and beef. They found considerable variation among the various sample lots in biological value of the pork and beef proteins due to method and extent of heat treatment employed. Digestibility of the beef protein was variable by lots, while that of pork was relatively constant in all cases. These results indicated that heat dehydration of meats gives variable results in nutritive value of protein because of processing method.

CURING

The method of curing has apparently resulted in differences in nutrient losses. Hoaglund *et al.* (1947) observed that thiamin losses for artery-pumped-cured, dry-cured, and brine-cured hams were 15 percent, 14 percent, and 26 percent, respectively. Protein losses leached out through the pickle were very small, ranging from 0.35 percent to 1.2 percent of the total protein. No differences in biological value or digestibility of protein were observed between cured and fresh hams.

In a similar study by Dunker *et al.* (1953), the vitamin content of hams was related to type of cure (Table 2).

Jackson *et al.* (1945) studied the retention of thiamin, riboflavin, and niacin in smoked bacon cured by wet or dry methods. The wet-

TABLE 2 Vitamin Content of Hams Cured by Different Methods

Type of cure	Thiamin [a]	Riboflavin [a]	Niacin [a]
Sweet pickle, quick cured, tendered	30.5	7.7	182
Sweet pickle, quick cured, ready-to-eat	29.5	8.3	168
Sweet pickle, long cure	29.7	8.6	173
Dry cured, Smithfield	26.2	10.4	248

[a] Expressed in μg/g of protein (N × 6.25).

cured bacons averaged 75 percent thiamin retention, compared to 84 percent for the dry-cured bacon. Riboflavin and niacin retention values were 89 percent and 81 percent for the wet-cured versus 57 percent and 96 percent for the dry-cured, respectively.

REFRIGERATION

Studies on nutrient losses occurring during refrigerated storage are limited. Low-temperature storage is required to develop and retain the eating quality of meat, as well as to prevent bacterial spoilage; at the same time, the retention of the nutritive quality of fresh meat is important. Nutritive losses during refrigerated storage and distribution are minimal. Factors more important at retail include the retention of color and flavor. The emphasis at this stage of meat distribution is to protect against changes that affect eating quality. Conditions of refrigeration can affect tenderness of the meat. Time, temperature, and humidity conditions during the aging of beef do affect tenderness.

Vitamins are stable in pork during storage. Rice *et al.* (1945b) reported no significant changes in the content of any of the vitamins examined (thiamin, riboflavin, niacin, and pantothenic acid) in fresh pork stored at 4 °C for 2 weeks.

Nutrient losses can occur during storage at retail or in supermarket meat cases. Table 3 illustrates the effects of type of tray and time in display of beef round on riboflavin losses under supermarket conditions.

These data indicate that riboflavin losses in meat can be considerable upon exposure to light. The type of packaging material and location in the stack are important.

TABLE 3 Riboflavin Losses in Cuts of Beef Round Packaged under Supermarket Conditions and Displayed under Light

	Hours in case [a]				
Type of Tray	0	4–8	24	48	72
Pulp A (top)[b]	0.18	0.15	0.06	0.05	0.04
Pulp B (middle)	0.18	0.18	0.18	0.18	0.18
Pulp C (bottom)	0.18	0.18	0.18	0.18	0.18
Plastic A (top)	0.18	0.15	0.06	0.05	0.04
Plastic B (middle)	0.18	0.18	0.18	0.18	0.18
Plastic C (bottom)	0.18	0.15	0.06	0.06	0.05

[a] Values in mg/100 g meat.

[b] Trays stacked three or more high in case.

CANNING

The commercial canning of meats is a relatively recent development compared with the age-old practice of curing. Two types of heat processes are usually used to produce "commercially sterile" and "pasteurized" products. The pasteurized products are perishable and should be refrigerated during storage before consumption; commercially sterile products need not be held in refrigerated storage as long as the container is not opened.

Studies on nutritive losses in canned meats are numerous. Thiamin losses have ranged between 20 and 70 percent. These are proportional to the time and temperature beyond a critical temperature. Mayfield and Hedrick (1949) examined canned meat after it had been browned in the oven for 30 minutes and processed in jars for 85 minutes at 121°C. The biological value was 74. When the meat was corned, i.e., cured for 60 days in a curing solution, the biological value was still 76. Bender (1962) found a fall of 30 percent in the biological value of beef on corning and canning but no further loss after 9 years in storage. Dvorak and Vognarova (1965) found that 3 hours heating at 70°C caused a 10 percent loss of available lysine; at 121°C the loss was 20 percent; at 140°C, 40 percent; and at 160°C, 50 percent.

In rat-feeding studies with heated protein foods, Wheeler and Morgan (1958) found a decrease in PER from 2.1 to 1.7 for autoclaved pork heated at 120°C for 2 hours. The authors concluded that this decrease in nutritive value was partly due to slower liberation of amino acids, so all were not simultaneously available for protein synthesis.

Greenwood *et al.* (1944) reported the thermal destruction of thiamin in pork luncheon meat heated at 210°F to 250°F as being a first-order reaction. Rice and Beuk (1945), in studies on pork heated in the range 120–250°F, reported that above 170.6°F, the loss of thiamin proceeded at a constant rate throughout the entire heating interval. Below 170.6°F the rate of loss decreased during the first 16 to 24 hours, after which it remained constant.

FREEZING

The differences in nutrient losses from processing and storage of meat and meat products that are frozen, refrigerated, dried, and canned are variable.

Some data are available concerning losses of protein and vitamins from freezing and then thawing fresh meat prior to use or cooking. Early work (Cook, 1926) with drip losses showed that the fluid from frozen meat upon thawing contained approximately 9 percent protein and that the percent of protein in the drip was about the same for pork, lamb, beef, or veal. Drip losses are reduced by rapid freezing compared to losses occurring during slow freezing and are increased with prolonged freezer-storage time (Ramsbottom and Koonz, 1939; Hiner *et al.,* 1945). In another study (Pearson and Miller, 1950), beef was aged 6 days prior to freezing. Upon thawing the losses in the drip fluid were 12.23 percent of the thiamin, 10.31 percent of the riboflavin, 14.51 percent of the niacin, 9.41 percent of the pyridoxine, 33.26 percent of the pantothenic acid, and 8.07 percent of the folic acid. Unless drippings upon thawing are collected and utilized, nutrient losses can be considerable.

Pearson *et al.* (1959) collected drip from thawed pork and analyzed it for B vitamins and amino acids. The losses in B vitamins ranged from 4.1 percent for riboflavin to 10.69 percent for niacin. Amino acid losses in the drip ranged from 7.1 percent for tryptophan to 11.08 percent for isoleucine. Losses for amino acids were less variable than were losses for the B-complex vitamins. The extent of the losses was not related to the solubility in water of the individual amino acids or B vitamins. This indicates that the losses in drip are partly due to the leaching of more complex substances.

A question of considerable interest that may be of economic importance is to what extent the physiological state of the tissues prior to freezing affects losses. Although considerable research has been done on pale, soft, exudative pork, information is limited on the differences in nutrient content of drip losses from normal versus pale, soft, watery pork. Likewise, nutrient losses in drip from frozen normal beef versus frozen soft watery beef has not been investigated.

FREEZE DRIED

If meat is frozen and dried in a vacuum chamber, a better product results than can be obtained by heat dehydration. In the conventional freeze-dry operation, the meat remains frozen throughout the drying cycle, and the moisture content is reduced to less than 2 percent. There is no appreciable change in volume or shape of the product. In the process, heat must be supplied to the frozen product for sublimation of ice to water vapor without raising the temperature of the product to produce thawing.

The major effects of freeze-drying on muscle tissues are dependent on the rate of freezing prior to lyophilization. From a nutritional standpoint, the biological value of the protein is not significantly affected by freeze-drying.

Brockman (1966) pointed out the various manifestations of nonenzymatic browning in stored freeze-dried meat. In the early stages a reddish-brown discoloration develops along with a roasted flavor that progresses to bitter-burnt unacceptable flavor. Simultaneous changes occur in muscle fibers with lower reabsorption of water and water retention, giving a drier and tougher product when rehydrated. Freeze-dried foods are also subject to several types of oxidative changes, loss of color, development of off-flavors, and loss of vitamin activity. Data regarding nutrient changes due to freeze-drying are limited.

FORTIFICATION OF MEAT

The fortification of meat with nutrients deserves attention because of current interest in nutrition and in the development of new products. Generally, meat is cured with the addition of sodium ascorbate or its isomer for purposes of accelerating cure–color development. The possibility exists that the level of these reducing agents permitted in cured meat, particularly bacon, will be increased.

Meat readily lends itself to fortification in the various processes such as in curing, sausagemaking, and preparation of ground raw meat and various other comminuted meat products. According to the proposed regulations for nutrient labeling, meat ground and mixed with extenders such as soy protein concentrates would be considered fortified.

Kies and Fox (1971) compared the protein nutritional value of TVP (texturized vegetable protein), methionine-enriched TVP, and beef at two levels of intake with human adults. Their results indicated that TVP, methionine-fortified TVP, and beef all meet the protein requirements of adult men when fed at the 8-g nitrogen intake level. At the 4-g nitrogen intake level, beef was found superior to the TVP. With 1 percent fortification of TVP with DL-methionine, the superiority of beef was partially overcome.

In the mechanical boning of some meat products, a certain amount of minute bone particles become a part of the mixture. The amount of calcium (or bone) in the product is variable, depending on how much meat is left on the bone prior to mechanical boning. In view of the low level of calcium in meat, this process offers a method of bolstering the calcium content of a formulation.

SUMMARY

Although a number of substances are used in meat processing, no substances or nutrients are added to fortify fresh or processed meat products. However, in view of the tremendous current interest in nutrition and the nutrient content of foods, the possibility of fortification of meat and meat products offers a challenge to meat processors.

Researchers have long been interested in the effect of processing upon the subsequent nutrient content of various meat products. Results of these studies can be summarized as follows:

- Cooking generally results in losses of a number of vitamins, especially B_6, folic acid, and thiamin. Time and temperature influence the magnitude of losses. Losses in the canning of meat appear to be similar to cooking, the loss being determined by thermal process used.
- Heat processes more severe than used in "pasteurized" or "commercially sterilized" meat can be expected to result in greater losses of vitamins and a decrease in protein quality as measured by available lysine, biological value, or protein efficiency ratio.
- Heat dehydration of meat has resulted in losses of thiamin, niacin, and pantothenic acid; losses of biotin and folic acid have been almost nil. These losses appear to be similar to those observed in canning.
- Differences in the losses of vitamins have been reported for several methods of curing meat. Curing results in vitamin and small protein losses. The digestibility and biological value of meat protein has not been decreased by curing.
- Losses of some vitamins can occur in meat during retail display, for example, riboflavin, which is light-sensitive. However, nutrient losses would be expected to be minimal during refrigerated storage prior to display.
- The freezing of meat presents an opportunity for nutrient losses because of thaw drip. Significant losses of vitamins and protein have been reported during thawing. Proper freezing, freezer storage, and thawing procedures are essential to minimize losses.
- The fortification of meat or meat-containing products is at the embryonic stage of development. Fortification, whether with protein, vitamins, or minerals, provides a unique opportunity for the nutritionist and food industry in bringing new and more nutritious foods to many whose dietary intake of vital nutrients may be suboptimal.

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R. F. CAIN

Factors Influencing the Nutritional Quality and Fortification of Fruits and Vegetables

With the advent of increased emphasis on nutrition and in particular on nutritional labeling, some insight as to the effects of the various unit operations on nutritional qualities becomes useful. Data on this subject have not been compiled since Harris and Von Loesecke's (1960) *Nutritional Evaluation of Food Processing*. Data that are available represent those of only isolated or "incidental" analyses of certain nutritional components. This chapter will present a thumbnail sketch of the subject as it relates to processed fruits and vegetables and the fortification or nutrification thereof. It should provide a working knowledge of the subject and summarize the "state of the art" as it relates to the retention of the nutritional qualities of fruits and vegetables as they are prepared for today's market.

One of the principal responsibilities of the food scientist and food technologist is to preserve the natural level of food nutrients through all phases of food acquisition, processing, storage, and preparation. The overall adequacy of this total process is no better than its weakest link. The key is in the specific sensitivities of the various nutrients, the principles of which are illustrated in Table 1. This table shows the stability of vitamins and minerals to acid, air, light, and heat and gives an indication of the possible cooking losses. For example, vitamins C and D are highly sensitive to alkalinity, air, light, and heat; thiamin, to alkalinity, air, and heat. Because of these sensitivities, cooking losses of some essential nutrients may be in excess of 75 percent.

In normal food processing operations, nutrient losses are generally

TABLE 1 Stability of Certain Vitamins and Minerals

Nutrient	Neutral (pH 7)	Acid (<pH 7)	Alkaline (>pH 7)	Air or Oxygen	Light	Heat	Cooking Losses, Range (%)
Vitamins							
Vitamin A	S	U	S	U	U	U	0–40
Vitamin C	U	S	U	U	U	U	0–100
Carotenes	S	U	S	U	U	U	0–30
Niacin	S	S	S	S	S	S	0–75
Riboflavin	S	S	U	S	U	U	0–75
Thiamin	U	S	U	U	S	U	0–80
Vitamin D	S		U	U	U	U	0–40
Mineral salts	S	S	S	S	S	S	0–3

SOURCE: From Harris and Von Loesecke, 1960.
S = stable (no important destruction); U = unstable (significant destruction).

much less than this. However, in cases where nutrient losses are excessive or in special dietary foods the law permits fortification or enrichment by the replacement of vital nutrients. The proposed FDA special dietary regulations prescribe that if 50 percent or more of the USRDA of vitamins or minerals are added to a single serving of the food it is deemed to be a dietary food and therefore must be labeled and marketed under specific regulations.

Nutritive value begins with plant genetics. Environmental factors such as amount and intensity of light, temperature, season, location, soil fertility, and maturity affect tissue composition of plants and animals consuming these plants. Harvesting practices, transportation, and storage conditions before processing affect content of vitamins and other nutrients. Washing, trimming, heat treatments, and other preliminary processing techniques influence the nutrient content. Canning, evaporating, drying, and freezing alter nutritional values, and the choice of times and temperatures in these operations frequently must be balanced between bacterial destruction and minimum nutrient destruction.

Trimming. Changes in composition that accompany trimming and peeling or other mechanical separation of the component parts of a fruit or vegetable result from unequal distribution of nutrients in the foodstuff (Holman, 1956). For example, the content of ascorbic acid is 3 to 10 times higher in the peel than in the cortex of the apple. This is true for most fruits, including tomatoes. Pineapple, an exception, contains more ascorbic acid in the core than in the flesh next to the shell.

Carotene is confined to the pigmented portions of vegetables. The inner light-colored leaves of cabbage, celery, lettuce, and similar vegetables are practically devoid of carotene. The concentration of ascorbic acid and carotene is higher in the leafy parts than the stalk or rib portions of spinach, chard, and similar vegetables (Holman, 1956). Carrots and potatoes contain higher levels of riboflavin and niacin in the peel than the portion remaining after mechanical peeling. Thiamin is also higher in the peel of potatoes, while ascorbic acid content is similar in the inner and outer tissues according to Holman (1956).

Washing. The specific effect of washing fruits and vegetables on composition has been discussed to a very limited extent in the literature. The studies that have been conducted have involved such topics as cooling vegetables in cold water after blanching (Paul *et al.,* 1952; Hard and Ross, 1956), which does not permit evaluation of the specific influence of washing. These studies suggest that washing or contact with water after blanching may result in considerable loss of water-soluble nutrients such as ascorbic acid from leguminous vegetables. Fog-cooling is an approach to this and also aids waste disposal problems. Harris and Von Loesecke (1960) state that the change in moisture content of both leafy vegetables and foods having a relatively large mass-to-surface-area ratio is probably the most significant change in composition after cold water washing.

Blanching. Most vegetables are blanched in hot water or live steam before canning for several reasons. The procedure and equipment will vary with the vegetable. For example, spinach is blanched by the Thomas process, which involves passing the product by conveyor through a long, covered metal tank containing water held at about 170°F. Peas and string beans are similarly blanched in boiling water. Tomatoes, sweet potatoes, and beets are usually blanched in steam or steam under pressure to facilitate peeling (Cruess, 1958).

The type of blanching method used has a decided and variable influence on the retention of ascorbic acid, niacin, thiamin, and riboflavin in vegetables. Tables 2 and 3 demonstrate some of these effects. Water blanching of spinach for 2¾–5 minutes at temperatures in the range of 160–204°F resulted in the retentions of these four vitamins of 64–95 percent, with ascorbic acid being affected to the greatest extent. In

TABLE 2 Retention of Various Vitamins in Certain Vegetable Products After Canning

Product	Vitamin	Average Retention Value (%)
Whole grain yellow corn	Carotene	97
	Thiamin	34
	Riboflavin	97
	Niacin	86
Peas	Ascorbic acid	72
	Carotene	97
	Thiamin	54
	Riboflavin	82
	Niacin	65
Green beans	Ascorbic acid	55
	Carotene	87
	Thiamin	71
	Riboflavin	96
	Niacin	92
Asparagus	Ascorbic acid	82
	Thiamin	67
	Riboflavin	88
	Niacin	96

SOURCE: Cameron *et al.*, 1955.

contrast, steam blanching of spinach for 2–2¾ minutes permitted retentions of these four vitamins ranging from 88–100 percent (Guerrant *et al.*, 1946; Lamb *et al.*, 1947). Unfortunately, at the boiling point, blanching of spinach results in loss of green color due to decomposition of chlorophyll to phaeophytin to form a yellowish-green color. This loss does not occur in spinach blanched at 170°F in hot water, possibly due to greater loss of acid from the vegetable so there is less hydrolysis of chlorophyll to phaeophytin (Cruess, 1958).

An inmersion blanch for 45 minutes in 160°F water resulted in 94 percent loss of ascorbic acid in spinach (Cameron, 1949). Under these conditions, thiamin losses were 35 percent. Large losses of ascorbic acid are likely due to oxidation as well as by leaching during the long period in the blancher. Enzyme-catalyzed oxidation could also play a role, since temperatures of 160–170°F may possibly not be adequate

TABLE 3 Retention of Vitamins in Canning of Tomato Juice

Vitamin	Retention (%) Max.	Min.	Ave.
Ascorbic acid	90	35	67
Thiamin	100	73	89
Riboflavin	100	86	97
Niacin	100	83	98
Carotene	74	60	67

SOURCE: Cameron *et al.*, 1955.

for rapid inactivation of enzymes. Retentions of niacin, thiamin, and riboflavin during commercial blanching of spinach, asparagus, green beans, and peas are approximately equivalent. The mean retention of these vitamins in these vegetables is about 88 percent after blanching (Cameron, 1949).

After studying the effects of various blanching procedures upon retention of water-soluble nutrients in vegetables, it becomes obvious that high-temperature, short-time blanches are more favorable for the retention of these nutrients and that present commercial blanching methods might well be modified to improve retention of nutrients without sacrificing quality (Heberlein *et al.*, 1950). A closer check on product quality, however, would undoubtedly have to be maintained if blanching methods were modified to conserve water-soluble nutrients, since the margin of safety for adequate blanch would be reduced.

PRODUCTION AND THERMAL PROCESSING OF FRUIT AND VEGETABLE JUICES

Fruit and vegetable juices are important in the diet as sources of fluids, carbohydrates (sugars), vitamins, and minerals. The principal vitamins of relative importance are the water-soluble B vitamins, ascorbic acid, and provitamins A in certain colored fruits and vegetables. Processing methods responsible for affecting the nutritional properties of fruit and vegetable juices include:

- Method of extracting, straining, or clarifying juice.
- Method of de-aeration.
- Method of heating, cooling, and packaging.
- Storage conditions.

Factors involved in juice extraction and straining that relate to retention of nutritional value include enzyme action, oxidation, and time and temperature of heating. For example, tomatoes must be heated before or during juice extraction or most of the ascorbic acid will be lost by enzymatic changes. Contact of fruits and vegetables with pro-oxidants such as copper, iron, and zinc will also hasten the ascorbic acid destruction.

Published data on the effect of canning on nutrients in fruits and vegetables have been primarily concerned with total changes during processing. It can safely be said that "no significant losses of nutrients during extraction and de-aeration of juices have been reported that could not be avoided by application of properly adapted procedures now generally employed in industry" (Harris and Von Loesecke, 1960).

With regard to thermal processing of fruits and vegetables and their juices, published data indicate that, regardless of the method of heating, the effect of heating depends on the following factors:

- Time and temperature of heating.
- Amount of oxygen present during heating.
- pH of the juice or blend.
- Presence of metallic salts and other prooxidants.

During retorting of canned nonacid vegetables, the loss of thiamin is appreciable. For example, studies by Cameron *et al.* (1955) indicated that samples of spinach retained 77 percent of their original content after blanching and only 23 percent after retorting. Peas showed a retention of 73–92 percent in blanching and only 39–64 percent after retorting. These investigators also reported a retention of ascorbic acid in peas of 47–82 percent, the principal losses occurring in blanching through leaching. Niacin retention in peas ranged from 50 to 94 percent (see also Table 2).

The data in Table 3 illustrate that thiamin and niacin retentions are greater in the relatively high-acid tomato juice than in the low-acid vegetables in Table 2.

From the data in Table 2, it is apparent that carotene is well retained in most thermally processed vegetables. The principal losses of vitamin A are due to conversion of all trans-carotenes to *cis*-isomers of lower activity (Sweeney and Marsch, 1971). For example, Table 4 shows the biopotency values of carotene steroisomers based on all-trans-β carotene.

Sweeney and Marsch (1971) evaluated the effects of various processing methods on provitamin A in vegetables and estimated that the

TABLE 4 Biopotency Values of Carotene Stereo-isomers

Isomer	Biopotency
Neo-β-carotene U	38
All-trans-β-carotene	100
Neo-α-carotene U	13
Neo-β-carotene B	53
All-trans-α-carotene	53
Neo-α-carotene B	16

SOURCE: Zechmeister, 1962.

vitamin A value of the average cooked green vegetable would be decreased by about 15 to 20 percent. They further stated that for yellow vegetables, because of the presence of α-carotene and its isomers, the decrease might be as large as 30–35 percent.

Schroeder (1971) analyzed various leguminous, root, and green vegetables for vitamin B_6 and pantothenic acid and found that mean losses of vitamin B_6 were 57–77 percent in canned vegetables compared with those in the raw state. Mean losses of pantothenic acid were 46–77 percent. In contrast, Krehl and Cowgill (1950) reported little change in biotin, folic acid, pyridoxine, and inositol in grapefruit juice during canning and storage for 6 months.

The canning of foods would not necessarily be expected to result in losses of trace minerals except perhaps in the fluid in which the foods were kept or in the cooking water. Analyses by Schroeder (1971) have shown differences from the raw materials. For example, canned spinach apparently lost 82 percent of the manganese, 71 percent of the cobalt, and 40 percent of the zinc found in raw spinach. Zinc losses amounted to 60 percent in canned beans and 83 percent in canned tomatoes. Canned carrots, beets, and green beans lost 70, 67, and 89 percent, respectively, of the cobalt found in raw foods.

Cameron *et al.* (1955) summarized published data on the retention of some nutritive factors in commercially packed foods during storage. Their findings indicated that canned vegetables decreased in content of ascorbic acid more rapidly at 80°F than at 50° and 65°F. Losses of carotene, thiamin, and riboflavin during storage were much less than for ascorbic acid. Similarly, losses of ascorbic acid and thiamin in commercially packed fruit juices were greater at 80°F than at 50° and 65°F (see Table 5).

TABLE 5 Loss of Ascorbic Acid and Thiamin in Juices During 12 Months' Storage

Juice	Storage Temp. (° F)	Loss (%) Ascorbic Acid	Thiamin
Grapefruit	50	5	1
	65	9	0
	80	25	7
Orange	50	3	0
	65	8	2
	80	23	11
Pineapple	50	0	7
	65	0	7
	80	7	13
Tomato [a]	50	0	0
	65	8	6
	80	26	23

SOURCE: Cameron *et al.,* 1955.
[a] 24 month's storage.

EFFECTS OF FREEZING ON FRUIT AND VEGETABLE NUTRIENTS

Several studies have compared the composition of foods before and after processing by freezing and other methods of processing (Watt and Merrill, 1950; Burger *et al.,* 1956). Results of these studies indicate that losses are comparable to those incurred in blanching and that the actual freezing process does very little to alter the nutrient composition of fruit and vegetables. Since most frozen vegetables are blanched before freezing, this process will generally account for the majority of the losses of vitamins, minerals, and carbohydrates.

The speed of freezing will affect the texture of foods; water-soluble nutrient losses will be less in a food that has been sharp-frozen than one that has been slow-frozen (Harris and Von Loesecke, 1960). Storage times and temperatures will also have an effect on nutrient losses. At zero or lower temperatures, losses of ascorbic acid from frozen asparagus, peas, and lima beans are negligible after 6 months' storage, while losses exceed 50 percent at 16°F.

THE EFFECT OF FREEZE-DRYING ON MATERIALS

Inspection of the literature on the subject has shown that this method does very little damage to the nutrients of fruits, vegetables, or other foods so treated. Suffice it to say that the losses incurred in the preparation of the product for processing will not be further increased by the preservation method. In fact, since all the product is consumed when properly rehydrated, the net yield of vitamins is probably greater in this instance than, for example, in drained canned products. Gram for gram, the net return of water-soluble vitamins would be greater with freeze-drying.

EFFECT OF DRYING AND DEHYDRATION ON FOOD NUTRIENTS IN FRUITS AND VEGETABLES

The nutrients affected by conventional, forced air-type, tunnel dehydrators are the same as those affected by other processing methods involving heating. Losses of B vitamins from vegetables, which can be attributed directly to the drying process, are generally slight. Losses of thiamin, riboflavin, niacin, and pantothenic acid from green and yellow vegetables generally are between 3 and 6 percent (Harris and Von Loesecke, 1960). Thiamin is destroyed, however, by sulfite, which is sometimes added to certain vegetables (*e.g.,* cabbage) as an aid in protecting against nonenzymatic browning. For example, destruction of thiamin is three to five times greater during dehydration of sulfited than of nonsulfited cabbage.

Ascorbic acid content during drying can be expected to be considerably reduced, amounts depending on the uniformity of the raw material and such drying conditions as the type of drying trays used, time, and temperature. Losses may vary from 10 to 100 percent, but usually are nearly 50 percent during blanching and drying (Harris and Von Loesecke, 1960). A further factor involved in the loss of ascorbic acid in dehydrated vegetables involves the formation of furfural from ascorbic acid, which is responsible for browning of certain vegetables and fruit juices (Braverman, 1963). This phenomenon can be moderately reduced by sulfiting and/or reduction of the air temperature as complete dryness is approached (Hendel *et al.,* 1955).

Losses of carotene in vegetables can be severe during dehydration of unblanched vegetables, but blanching exerts a protective effect as shown in Table 6.

The major nutrients lost in dehydration of vegetables are also lost in conventional dehydration of fruits. As with vegetables, treatments with

TABLE 6 Effect of Blanching on Carotene Loss in Dehydrated Vegetables

	Carotene Loss (%)	
Vegetable	**Unblanched**	**Blanched**
Spinach	27	0
Peas	50	0
Mustard greens	26	20

SOURCE: Cruess, 1958.

sulfite cause severe losses of thiamin. Also, drying will result in moderate-to-severe losses of carotene and ascorbic acid, but sulfuring and dehydration are effective in reducing the losses.

EFFECTS OF FERMENTATION ON VEGETABLE NUTRIENTS

Fermented foods such as olives, pickles, relishes, and sauerkraut in general are poor sources of vitamin A, thiamin, riboflavin, ascorbic acid, and minerals. These foods supply salt, bulk, lactic acid, and virtually nothing else. The leaching process to which vegetables are subjected in a pickling operation is responsible for the removal of sugar, ash constituents, soluble proteins, and the majority of the water-soluble vitamins. Carotene is retained in almost all fermented vegetables with little loss.

EFFECT OF FOOD SERVICE OPERATIONS

LaChance *et al.* (1973) noted, as have others, the increased patronage of the food service industry to the extent that about 25 percent of our meals are consumed away from home. This important segment of the industry is concerned with the effect of time and duration of cooking and holding on nutrients. Any thought directed towards nutrification of these foods must consider the data provided by LaChance *et al.* For example, they show reduced ascorbic acid in canned peas, beans, and sweet corn to be almost negligible after reheating to 180°F. Assays of frozen commercial samples of the vegetables also showed low values that were further reduced upon heating to 180°F. Even when products were nutrified with ascorbic acid, frozen, and heated to and held at 180°F, the loss of total vitamin C ranged between 9 and 23 percent, depending upon the method of cooking.

FORTIFICATION

Having examined the effect of food processing *per se* on the retention of vitamins and minerals, let us now turn our attention to fortification or nutrification of fruits and vegetables. Clausi (1973) provides an excellent statement on guidelines for nutrification. He states that fortification of convenience foods is a good practice if care is taken to build the right levels of nutrients into the right foods—and only those that have some nutritional rationale. One must fortify foods that enjoy general consumption rather than specialized foods of restricted use. He further states that when food analogs are formulated they should be fortified with only those nutrients the food is normally expected to provide, and one should not become bogged down in "the morass of nutritional detail."

Clausi goes on to state two important principles:

1. "A nutritionally-modified food should have a balance in its important nutrients at least equal to the foods it may replace in the diet," and
2. "Nutrition must be put into the foods people eat—not just those that experts feel they 'ought to eat'."

Clausi suggests that it will be a long time before the consumer really understands or cares to know very much about nutrition. In addition, regulatory and technological problems face the manufacturer. Among the latter are:

- Sources of knowledge on macro- and micronutrients and trace substances in foods.
- Problems of taste, product performance, and processing brought on by the use of certain nutrients.
- Problem of storage life on nutritionally modified products.
- Problem of continued biological availability of added nutrients.

Aylward and Morton (1970) and LaChance (1973) have suggested fortification to cover (1) the addition of nutrients that have been lost during processing; (2) the addition of a nutrient, not normally present, to a food to make it equal to another; and (3) the addition of a nutrient not normally present wherein the "food" simply acts as the most logical carrier of the nutrient.

Fortification is practiced in infant foods, dietetic foods, specialty foods, and in foods for general consumption, i.e. breads, milk.

Baurenfeind (1970) lists the following fruit and vegetable commodities as being amenable to fortification:

Product	Nutrient	Comments
Fruit gelatin powders	Ascorbic acid	Fruit associated—a good carrier
Noncitrus juices, fruit beverages, citrus juices, and like products	Ascorbic acid	Variable level, good carrier
	β-carotene	Adds color and vitamin A value
Potato products		
Chips	Thiamin	
	Riboflavin	As an enrichment
	Niacin	
	Pyridoxine	Low natural level
	Vitamin A	High unsaturated fat level
Instant	Ascorbic acid	Restoration
	Vitamin A	Good carrier
Soups	Water and fat soluble vitamins	Enrichment
Tomato juice	Ascorbic acid	Natural content varies

Examination of fortified foods available in other countries by type of food and vitamin reveal the route(s) of improving the availability of nutrients.

Beverage	Nutrients
Milk base with wheat–chickpeas–lentil	A, B_2, D, Ca
Milk base with soy–corn starch	A, B_1, B_2, B_6, C, D, niacin, minerals

Cereals	Nutrients
Macaroni	B_1, B_2, B_6, B_{12}, D, niacin
Wheat–peanut flour	A, B_1, B_2, niacin, Fe, Ca, lysine
Bread	Lysine, vitamins
Rice	B_1, B_2, lysine, minerals

No fruit or vegetable carriers are included in the extensive listing provided by Baurenfeind of 26 milk-base beverages and 22 cereal bases that are fortified.

Examination of the local supermarket shelves for fortified fruit and vegetable products reveals the following:

Frozen orange drink fortified with β-carotene, ascorbic acid
Dry citrus juice mixes fortified with ascorbic acid, A, B_1
Grape drinks fortified with ascorbic acid
Certain soups fortified with ascorbic acid

USDA (1971) data provide the following on the nutrients available in our food supply on a per capita per day basis. These data show for 1971:

		Percent Contributed			
		Fruits		Vegetables	
	Total Available per Capita	Processed	Fresh	Processed	Fresh
Vitamin A	7800 IU	2.5	5.2	16.4	20.1
Thiamin	1.84 mg	2.0	1.9	3.1	4.8
Riboflavin	2.28 mg	0.7	1.3	2.1	3.6
Niacin	22.50 mg	1.2	1.4	3.5	3.1
Ascorbic acid	109.00 mg	22.8	13.9	11.0	26.6
Calcium	0.94 g	1.0	1.0	2.1	4.2
Phosphorus	1.53 g	0.9	0.9	2.3	3.2
Iron	17.20 g	2.1	2.1	5.9	5.0

This tends to put things in perspective as to the "relative" importance of processed fruits and vegetables as contributing to the nutritional availability. Suffice it to say that they contribute significant quantities of ascorbic acid and vitamin A.

If one is going to consider fortification, the "vehicle" is all important. First of all it must be available, liked, and used by the consuming public. Also it should be one that is consumed in its entirety. Foods like juices, applesauce, rehydrated freeze-dried portions, and the like are totally consumed as opposed to the liquid portion of canned vegetables that may or may not be discarded. One way to select likely vehicles is to look at per capita consumption patterns available from USDA (1971) data (see Table 7).

Inspection of these data show potential vehicles, i.e., citrus juices, tomato products and juice, frozen potato products, corn, and peaches among others. With respect to fortification, it would be folly to fortify products where part of the contents (i.e., packing media) would be discarded. From the above list we can eliminate certain carriers, i.e., pickles, canned peas, beans, and whole-kernel corn. All of the rest of

TABLE 7 Canned and Frozen Fruits and Vegetables (Per Capita Consumption, lb)

Fruits		Juices		Vegetables	
Peaches	5.4	Citrus	29.1	Potato	12.9
Apples	3.6	Catsup, sauce	10.2	Pickles	7.6
Pineapple	3.3	Tomato juice	4.0	Corn	7.4
Cocktail	2.7	Apple	3.3	String beans	6.8
Pears	1.9	Pineapple	3.0	Peas	5.9
Strawberries	1.4				

the processed products would more often than not be entirely consumed.

Next we must look to the compatability of the added nutrients with the flavor, mouth feel (grittiness), texture, and odor of the vehicle. There is no shortcut to this—it is a "cut and try" method. One has to use a logical approach. We must consider that we cannot fortify everything with all RDA nutrients. We do not expect to make it possible that "no matter what one eats, 100 percent of the RDA will be ingested." We are constrained by existing laws (standardized products), technological feasibility, and good common sense in fortification.

Once we decide upon the vehicle, the specific nutrients, in terms of compatibility, solubility, level, and reactions with food components, we then approach the application.

Dr. Borenstein (1972) has presented the important chemical considerations, i.e., solubility, pH dependency, color, flavor, influence of reducing/oxidizing agents, and light, of the vitamins and minerals with which we are to deal. We find that thiamin is highly soluble, stable at pH <5 in the presence of heat and oxidizing agents, and may be a flavor problem; that riboflavin suffers some lack of solubility, is stable to oxidation in acid media, is degraded by light, and imparts color; and that niacin is stable.

Returning to our "likely vehicle" candidates, one must examine them in the light of whether or not solubility is afforded, and the reactions and stability in the food. Again Borenstein (1972) has provided an excellent review of the problem areas in fortification. One must examine each of the vitamins with respect to its potential stability in a particular product, giving detailed consideration to the effect of the process, packaging, and storage on the vitamin after its addition. One should add labile nutrients as late in the process as is practical and commensurate with achieving uniform distribution in the product.

With beverages, the later in the processing procedures one can add the nutrients the better.

Dry-mix products may present a problem with segregation and clumping due to changes in hygroscopicity of added compounds.

The addition of calcium salts must be approached cautiously. Graininess and grittiness may be induced, the viscosity of the product may be affected, and the texture may be significantly altered due to the calcium–pectin reactions. Iron may cause some color problem and possibly promote rancidity.

Experimental packs to determine overages necessary to comply with the regulations for Class I foods become absolutely necessary. Not only must the process *per se* be assessed but also the effects of storage and distribution.

Further consideration of potential vehicles indicates the possibility of nutrifying canned fruits, in accordance with sound technological principles, just prior to closing the container. Here one could use a liquid, dry mix, or pelletized combination of the appropriate nutrients.

Possibilities lie in the fortification of fabricated products, e.g., extruded products, commensurate with the final processing step. This assumes that uniform distribution of the micronutrients is possible. Products such as frozen vegetables in sauces are amenable to fortification. Here nutrification of the sauce is indicated. Should nutrification of freeze-dried items be considered, the inclusion of a "nutrification pellet" to be added and dissolved in the rehydration media offers a route.

In approaching nutrification of foods, one must have answers to the following questions:

- Is the product under consideration widely consumed?
- Are there possibilities for introduction of both water and lipid-soluble vitamins to the product?
- To what level, percent of USRDA, should the nutrients be added?
- Will there be potential flavor, color, odor, texture, and stability problems? If so, they should be defined.
- Depending upon product composition and process, what are the solubility limits within the food matrix for the nutrients?
- Which nutrients are normally expected in the product? Which naturally occurring nutrients are lost in the process and could be added back?
- At what point in the process could nutrients be added?
- What is the expected stability of the nutrients in the product under normal storage and distribution patterns?
- What is the overage requirement in order to comply with label declarations for Class I foods?

- What are the economics of the enrichment program? Is the product one that can carry "added" costs?
- What are present legal restrictions to fortification of certain foods and can they be changed?

The answers to these questions will, in part, enable considered judgment by management of the propriety of entering the arena of nutrification.

Not all answers to the questions are in. There is need for bench work for the particular product(s) under consideration. Certainly, new benchmarks will have to be obtained.

It seems highly appropriate that some research be funded to enable a new look at nutrient stability patterns of food in the market. The last definitive research was in the 1950's. Certain updates have been obtained with a few specific products in the intervening years. A whole new profile of "foods" is now available in the market basket on which we have relatively little definitive but considerable speculative data on nutritional aspects of these foods as manufactured, stored, and distributed.

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DANIEL ROSENFIELD

Fortification of Analogs

I will begin by quoting two paragraphs from The Report of Task Force II from a "Symposium on Vitamins and Minerals in Processed Foods." This Symposium, held March 22–24, 1971, was cosponsored by the Council on Foods and Nutrition of the American Medical Association and the AMA–Food Industry Liaison Committee. The pertinent paragraphs are:

> We recommend that a fortification program take into consideration the impact that micronutrient additives might have on flavor, texture, color, and stability, all of which are food characteristics important to consumer acceptance of food. All foods do not provide equal fortification opportunities due to the fore-mentioned characteristics. Therefore, it will be important to identify appropriate groups of foods which can provide opportunity for selective fortification.
>
> Current technology will permit selective fortification, and we recommend that special problem areas be identified so the technology can be developed where necessary to permit micronutrient additions where important. Some technological problems may take time to solve. This should be recognized in fortification recommendations and procedures and should be outlined whereby the necessary development work can be accomplished.

In my opinion, today's workshop is fulfilling a need as indicated by the above. I have personal experience of a specification for a nutrient addition to a food product that was technologically impractical. At the USDA, we developed nutrient specifications for so-called "Formulated Grain-Fruit Products" for the School Breakfast Program. The specifications were checked with the FDA prior to issuance. The minimum level of magnesium was initially set at 45 mg for a minimum unit weight of 2 ounces of product. Manufacturers demonstrated to us that products such as sponge cake developed a bitter flavor and volume was diminished, thereby giving an unappetizing texture. After consultation with a number of food companies and further laboratory studies by them, the specification was changed to 30 mg. This level did not interfere with the organoleptic quality. In retrospect, we should have consulted with people familiar with the technology of fortification of baked products prior to issuing specifications based mainly on nutritional considerations.

In view of all I have said, I am pleased that this workshop has been convened and that I have been asked to participate. My subsequent remarks will briefly review how analogs are prepared. I will then describe what is being done to fortify analogs and how our program was developed. Finally, I will close with a discussion of the possible use of nutrients that might be required in the future for fortification of analogs if they are not to be considered nutritionally inferior to traditional foods.

ANALOGS

For this chapter, I propose a simple definition of analogs. They are products made from plant, yeast, and egg protein; vegetable fats and oils; corn syrup and starch; emulsifiers and stabilizers; nutrients; colors, flavors, and seasonings; and they simulate, completely or partially, the appearance, flavor, color, and texture of meat, fish, and poultry. The principal protein source is plant; generally, soy is predominant, though wheat may be in some products. I will discuss analogs that are intended for total replacement of an animal food at any given meal, as opposed to plant protein products that are designed to be used in combination with a meat, fish, or poultry item. Combination ingredients are not analogs *per se,* since they need not simulate all organoleptic qualities of the foods with which they are to be combined.

Analog preparation can be considered to consist of four major unit operations, though others might list more. The first is *mixing* of all the ingredients. An important fact in determining final product texture is how the soy protein was processed prior to mixing. It is generally agreed that soy fibers in themselves, which are prepared by the so-called "spinning" process, simulate the texture of animal products to a greater degree than extruded soy ingredients. But it should be pointed out that the texture of the analog at consumption is dependent on a number of factors including other ingredients, method of processing, and home cooking. The second step is *forming* the mixture into a desired shape.

The third step is *cooking* to "set" the product into the final form. This "setting" is generally due to coagulation of the egg albumin. The product, after cooling, can then be sliced, diced or ground, if needed. The fourth major operation is a final processing by canning, freezing, air-drying, or freeze-drying. Depending on the end product desired, one can vary or omit any of the major or minor processing operations.

A FORTIFICATION PROGRAM

What we are doing represents a pragmatic approach to the fortification of analogs. The meaningful genesis of our fortification program was the FDA proposal of December 5, 1970, on textured protein products (*Federal Register,* 1970a). The FDA proposed that "if such food in finished form is intended or is represented as a significant protein source food and is represented or suitable for use so that a serving of the food as customarily or usually prepared for consumption provides 100 or more calories, the food shall also contain in the quantity which supplies 100 calories : 1.25 milligrams of iron, 0.10 milligram of thiamin, 0.10 milligram of riboflavin, 2.0 milligrams of niacin, 0.10 milligram of Vitamin B_6, and 1 microgram of Vitamin B_{12}." Though no final action has ever been taken on this proposal, the decision was made to fortify to these levels our product line. Rather than have a multitude of vitamin–iron premixes specific for the various products, it was hoped that one premix would be possible. When our formulations were studied, it was seen that 40 g of most products were approximately equivalent to 100 calories. Thus, a premix was specified to add the FDA proposed levels to 40 g of product.

One of the first problems we ran into was the need to modify analytical techniques. Those that are used for our vitamin supplements were not satisfactory, nor were those found in the AOAC. Suffice it to say, successful modification was accomplished. We checked on the accuracy of our modified techniques by sending samples of fortified foods to the vitamin manufacturers for their analysis. Prior to large-scale fortification, work was done to determine processing losses and effect on quality. We were fortunate to find that there was no effect caused by the vitamins and iron we were adding on the color, flavor, or texture. We did find that average loss during the cooking process was 20 percent of amounts calculated to be present from both naturally occurring and added quantities. Our people thought this would be higher, since the destructive effects of heat and water are well known. Our results indicate that losses in those products that are retorted after canning can be as high as 50 percent.

Conversely, products that are frozen rather than canned show little, if any, loss during freezing and frozen storage.

Fortification of our products was begun in 1971. Our labels only list the vitamins and minerals in the ingredient statement. Thus, while we add an "overage" of premix to reach the FDA proposed levels, there is no pressure to meet any labeling claim in terms of quantities or percentages of Minimum Daily Requirements.

On the other hand, we are currently test marketing in Southern California, Arizona, and Florida, a line of frozen breakfast-style analogs. Percentages of minimum daily requirements for the vitamins and iron are given in terms of serving size. For example, the label states that three breakfast links contain the following percentage of adult Minimum Daily Requirements:

Iron (as ferrous sulfate)	17%
Niacin	30%
Thiamin	20%
Riboflavin (B_2)	20%
Pyridoxine (B_6)	0.2 mg (MDR not estab.)
Cyanocobalamin (B_{12})	2.0 μg (MDR not estab.)

It is imperative that we have sufficient overage to account for any processing and storage losses to meet our label claims. Products are checked on a routine basis as part of our quality assurance program. We find the vitamin B_{12} assay can be used as a single test of our fortification procedure.

We are currently gathering analytical data on all of our products after processing and storage, in order to be able to comply with the FDA's nutrition labeling regulation beginning January 1974 (*Federal Register,* 1970b). Obviously, the label described in terms of MDR's, will no longer be satisfactory.

From our experience with fortifying analogs with iron, niacin, and vitamins B_1, B_2, B_6, and B_{12}, it is reasonable to conclude that there should be no detrimental effects from these nutrients on appearance, flavor, texture, or color of the analogs prepared in a conventional manner. However, there are losses in vitamins and minerals, especially during processing. Analysis must be made for added nutrients immediately after analog preparation and stability tests must be carried out to determine where losses occur and how significant they are. The Nutrition Labeling Regulations make routine nutrient testing of products a necessity.

POSSIBLE USE OF ADDITIONAL NUTRIENTS

No remarks on fortification of analogs would be complete without some mention of adding other nutrients in addition to those listed in the FDA proposal of December 1970. The nutritional rationale for use of additional nutrients was clearly expressed in a report by an international working group sponsored by The International Union of Nutritional Sciences, International Union of Food Science and Technology and National Academy of Sciences–National Research Council (*Food Technology,* 1971). This group met in Washington in August 1970. The following is part of its comments on the philosophy and guidelines for fortification of analogs:

> So-called "substitute" or "imitation" foods such as substitute milk or meat products sold or used in the place of the traditional food must supply at least the nutrients present in significant amounts in the food displaced. The amounts supplied should be in the upper range given in food composition table. Where feasible it is desirable that fabricated foods be nutritionally complete. It should be kept in mind, however, that certain nutrients must not be present in excessive or imbalanced amounts.

A 1968 Joint Policy Statement of the American Medical Association's Council on Food and Nutrition (Improvement of nutrition quality of foods, 1968) and the Food and Nutrition Board of the National Academy of Sciences included the following recommendation:

> The imitation or fabricated food should contain at least the variety and the amounts of important nutrients contained in the food which it replaces.

The central issue regarding the implementation of these recommendations is what one considers a significant amount of a nutrient and possibly what is an important nutrient from the standpoint of fortification. FDA has addressed itself to this issue in its Food Labeling Regulations by considering that an analog that is not "nutritionally inferior" to the product that it resembles or imitates may be marketed without the use of the word imitation. FDA then defines "nutritional inferiority" as a reduction in any essential vitamin, mineral, or protein that amounts to 10 percent of the USRDA. Thus, in practice, if the traditional food that the analog simulates does not contain 10 percent of the RDA's in a serving size, then the analog need not be fortified with the nutrient. Of course, an analog may naturally contain more than 10 percent of the RDA.

This concept, though not all aspects of the regulation, is similar to Canadian guidelines that state: "A food sold or used as a substitute for a traditional food that normally provides, in a reasonable daily intake of the food, at least 10% of the daily requirement of a nutrient (including calories) should contain an equivalent amount of that nutrient" (*Food and Drug Directorate,* 1971).

As with any government action, there have been favorable and adverse comments regarding all sections of the FDA's Food Labeling regulations. Labeling of analogs is no exception. Those who have criticized Section 1.8 of the regulations feel many important foods do not supply 10 percent of the USRDA per serving. Thus a food analog prepared in the style of the conventional food would not have to contain the essential nutrient. Today's workshop is not the forum to discuss this issue. I must admit that I have not formed any personal opinion and would welcome the comments of the workshop participants. All I want to say at this juncture is that any changes in the FDA regulations as the result of continuing discussion of the issue could lead to the fabrication of analogs with other nutrients such as zinc, biotin, pantothenic acid, copper, and magnesium. This could be necessary to prevent analogs from being considered "nutritionally inferior" and thus required to be labeled "imitation." I am uncertain as to what technological problems, if any, might be encountered if other nutrients have to be added to analogs.

Finally, the FDA in the *Federal Register* (1973) of July 26 finalized its regulation concerning the use of amino acids in foods. Beginning January 1974, DL-methionine and L-methionine will be allowed to be added to foods, provided certain conditions are met. The critical area with respect to amino acid fortification of meat, fish, and poultry analogs prepared primarily from soybeans is that the food must furnish, in a reasonable daily intake, at least 6.5 grams of "naturally occurring primarily intact protein" and the finished food after amino acid fortification must have a PER of 2.5 or more. I note this new regulation because of the objectionable flavor associated with the use of methionine in human food. I have heard that some technology has been developed to make possible methionine use in food, but I have no definitive information. Your comments on latest developments would be appreciated. If there is still a problem, then obviously no food manufacturer will add methionine to products other than infant formulations as is currently the case. However, promulgation of this regulation could lead to intensified efforts to overcome any remaining flavor problems.

I want to conclude with two observations. There is no doubt that processors of analogs will be changing the composition and quantities of fortification nutrients to meet changing nutrition concepts. Based on past experience and with the possible exception of methionine addition, I do not foresee major technological difficulties in fortifying meat, fish, and poultry analogs.

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R. FENTON-MAY

Fortification of Beverages

In recognition of the worldwide distribution of a variety of beverage products ranging from 100 percent natural fruit juice through fruit-juice drinks, to conventional carbonated soft drinks, we have been seeking for several years a rational policy for use of these products as vehicles for nutrient fortification. Development work on fortified beverage products has led to a number of technological problems, outlined below, some of which are now solved, and some of which remain to be solved.

In examining the technological problems attendant to fortification, we have viewed beverages in three groups, namely:

- Fruit-juice-containing drinks
- Engineered beverages
- Conventional soft drinks described by the existing soda water standard of identity

A short discussion of each of these product categories follows.

FRUIT-JUICE-CONTAINING DRINKS

For a number of years, we have successfully marketed a line of non-carbonated fruit drinks fortified with vitamin C. This line has been of value in bringing to the consumer a palatable and acceptable source of vitamin C. As presently marketed, all flavored products contain at least 10 percent fruit juice (calculated on a single-strength basis), and the product is enriched with vitamin C so that each 6-fluid-ounce serving contains 100 mg of vitamin C. Conceivably, such products could also be enriched with the other micronutrients associated with pure fruit juices, namely vitamin A, vitamin B_1, iron, and, possibly, folic acid. We are investigating the possibility of developing acceptable formulations incorporating these additional micronutrients.

In recognition of the fact that some consumers prefer carbonated beverages, we have proposed to the FDA the establishment of a definition and standard of identity for a category of products to be designated "carbonated fruit drinks." Such a product is currently undergoing a test market in two midwestern locations. These products also contain not less than 10 percent, but less than 35 percent fruit juice (calculated on a single-strength basis). The product is enriched with vitamin C so that each 6-fluid-ounces of finished beverage contain not less than 60 mg.

The fruit juice content of the above products inevitably leads to a price premium over conventional carbonated soft drinks. We believe that this attendant price premium will tend to reduce consumption of these products below soft-drink levels, thus minimizing excessive consumption of vitamin C.

The storage losses of vitamin C in liquid systems such as fresh, single-strength, orange juice have been well documented. The bibliography provides literature on this subject. Our work on the processing and storage losses of vitamin A and vitamin B_1 in noncarbonated, fruit-juice-containing systems continues. Vitamin B_1 and iron both present organoleptic problems, neither of which has yet been completely overcome. Vitamin A palmitate with a suitable overage has been found to be satisfactory and stable in our manufacturing process.

In regard to vitamin C, we have found only slight losses in the beverage base, which is transported frozen. There is a loss during the hot packing of the reconstituted beverage and then a slow decrease in the level of vitamin C in the product itself during storage. The following example in Table 1 is given for the product when the beverage base is first manufactured in one location and then shipped frozen to a canning plant, where it is reconstituted and hot-packed into cans at about 190°F and cooled.

Table 2 shows the results of typical 8-month ambient-temperature storage tests on the product—a slow loss of vitamin C with time.

Similar results have been noted with chemically preserved carbonated fruit-juice drinks. As an example, typical results for grape beverage base stored under ambient conditions and at 100°F are shown in Figure 1. When stored under ambient conditions, losses from the original level (90 mg/6 fl oz of reconstituted beverage, or 50.7 mg/

TABLE 1 Typical Vitamin C Levels[a] During Product Manufacture

Base Manufacturing			Drink Hot-Packaging			
Added Level	Minimum Spec.	Loss [b]	Minimum Spec.	Loss [b]	Label Claim	Total Loss [c]
76.50	75.50	1.31	71.5	5.30	56.36	26.33

[a] Values are in mg/100 ml of final beverage.
[b] % loss during manufacturing and hot-packing, respectively.
[c] % total loss of quantity added.

100 ml) after 1, 2, and 3 months are 5.6, 8.3, and 12.2 percent, respectively.

After the bottling of the beverage base, there is a further loss of vitamin C that is a function of both the packaging (whether glass or can) and the flavor. Typically, for grape flavor, the percent loss of vitamin C 3 months after bottling was independent of the syrup age, and was 6.7 for a canned product and 23.4 for a bottled product. For a product bottled from 3-month-old syrup and stored under ambient conditions, the vitamin C level 3 months after bottling was 67 percent of the original level in the fresh syrup, or 60 mg per 6 fl oz which is the claim. In the equivalent canned product, the level was 82 percent of the level in the fresh syrup. It has, therefore, been concluded that an overage of 50 percent is satisfactory in order to ensure meeting the label claim.

ENGINEERED BEVERAGES

We have developed various different beverage systems that incorporate protein, vitamins, and minerals into good-tasting beverages. Thus far

TABLE 2 Stability of Vitamin C in Product After Canning (Product Stored Under Ambient Conditions)

	Vitamin C in mg/100 ml			
Flavor	Added	After 2 Months	5 Months	8 Months
Orange	67.51	66.1	62.4	54.2
Florida punch	67.51	66.1	61.2	—
Grape	67.51	68.1	65.0	58.9
Lemon lime	67.51	68.1	66.6	60.7

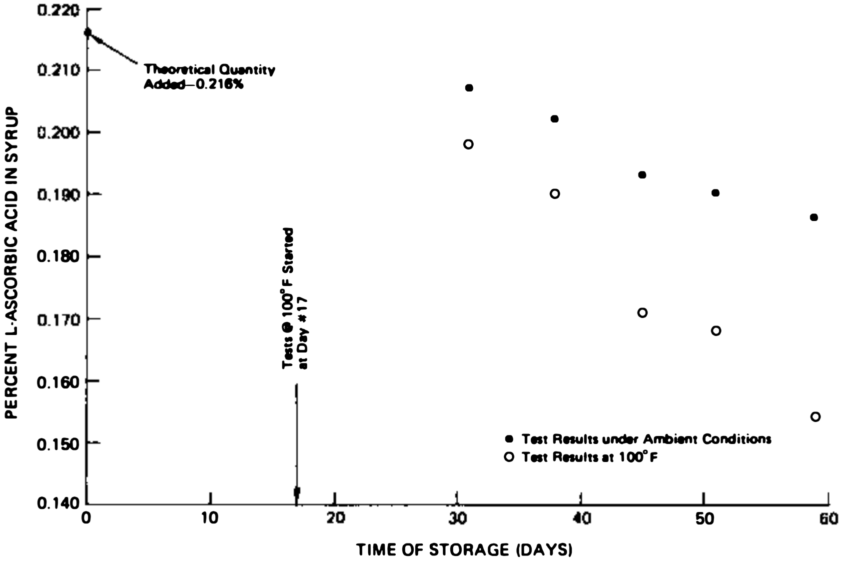

FIGURE 1 Vitamin C Loss in Fruit-Juice Beverage Syrup—Grape Flavor

we have worked on beverages containing casein, whey protein, and soy protein. These products can be grouped into three classes according to the method of preservation:

Sterilized, Liquid, Noncarbonated Beverages

We have undertaken extensive work on two such systems: one, a soymilk, which was test-marketed in Rio de Janeiro, Brazil; and a second, casein-based, which is being test-marketed in Surinam, South America. Both of these products are sterilized in a rotating retort after bottling. Sterilization time is 240°F for 17 minutes.

Each product contains vitamins A, D, B_1, B_2, B_6, B_{12}, and niacin at a level of about 25 percent MDR. Losses on sterilization have been found to be approximately as shown in Table 3. In addition, for bottled beverages, one must take due regard to the light sensitivity of vitamin A and vitamin B_2. After exposure to sunlight, in flint and amber bottles for 9 hours, we found typically that the vitamin losses in one product would be as shown in Table 4. In order to protect vitamin A and vitamin B_2 from the sunlight, it is therefore desirable to use either full-depth

TABLE 3 Vitamin Losses on Sterilization of Liquid Noncarbonate Beverages

Vitamin A	6–10%	Vitamin B_1	10–40%
Vitamin D	10%	Vitamin B_2	0–10%
Niacin	negligible	Vitamin B_6	0–5%
		Vitamin B_{12}	negligible

cases for transportation, or amber bottles, or green bottles with ultrasorb (a proprietary ultraviolet absorbing compound in the glass).

The use of full-depth cases has the secondary advantage of protecting the seal between the crown liner and the locking ring in handling after the sterilization process. A vacuum is created in the bottle during sterilization (by the expulsion of air). If the crown seal is broken after sterilization, air will be sucked into the bottle and airborne microorganisms may then cause product spoilage. The protection of this seal is, therefore, a major quality assurance consideration in the design of sterilization equipment and in methods for handling sterilized bottled products in normal distribution and trade channels. No work has been done on mineral fortification of these beverages.

By use of varying overages, shown in Table 5 for one product, we can usually guarantee the vitamin claims for up to 6 months on a product stored under normal market conditions without abusive handling (such as excessive sunlight exposure). Note that these overages do not

TABLE 4 Vitamin Stability to Sunlight

		Percent Loss of Vitamin After Exposure	
Vitamin	Bottle	Flavor I (light)	Flavor II (dark)
A	Amber	4[a]	0
	Flint	42	6
B_1	Amber	0	0
	Flint	0	0
B_2	Amber	0	3[a]
	Flint	21	3[a]

[a] Less than maximum analytical error.

include the separate overages incorporated in the premix by the manufacturer.

Acid-pH Beverages

These products typically contain whey protein or a vegetable protein hydrolysate. They could be carbonated or noncarbonated, and preserved either chemically or by pasteurization (say 160°F for 15 minutes). Our major developmental effort in this area to date has been with a chemically preserved, carbonated beverage.

This beverage contains 1½ percent whey protein from a whey protein base produced by ultrafiltration. It also contains about 25 percent MDR of nine vitamins. Basically, in the development of this beverage we have had to address ourselves to the following problems:

1. The difficulty is to chemically preserve this product. Basically the product is a concept designed to be adaptable to as many soft drink bottling operations as possible. Most soft drink bottling plants, unlike breweries, do not have in-bottle continuous pasteurizers, and the expense of these (even if space for their large bulk were physically available) would discourage the widest distribution of this product. One therefore needs as low a pH as possible, with as high a level of benzoate and sorbate as can be tolerated by organoleptic and/or human metabolic considerations. In addition to these beverage additives, one must observe very strict bottling line cleaning procedures to prevent spoilage or cross-contamination of conventional soft drinks. Our present sanitation procedures call for 1½-hour cleanups before and after bottling on a standard filling line.

TABLE 5 Vitamins in Sterilized Bottled Nutritional Beverage

Vitamin	Form	Claim Per 200 ml	Added Overage (%)
A	250–SD	1000 IU	100
B_1	Mononitrate	0.25 mg	50
B_2	Type S	0.30 mg	50
B_6	Hydrochloride	0.50 mg	20
B_{12}	In gelatin	1.25 μg	60
Niacin	Niacinamide	100 IU	20
D_2	500–CWS	2.50 mg	100

2. We have found that vitamin A palmitate is not stable in this beverage system at pH 2.95. There is a complete loss of vitamin activity shortly after bottling. β-carotene (10 percent beadlets), with a 50 percent overage show more promise of being a stable source of vitamin A activity.

3. Ascorbic acid appears to promote browning in the beverage, especially after short periods of sunlight exposure. To date we have not been able to find a stabilized vitamin C formulation that is acceptable for more than 6 weeks, and vitamin C is not included in the beverage marketed in Brazil.

4. Aside from the quantity present endogenously in the whey base, we have not included extra iron and calcium in the formulation, because both buffer the system and therefore increase the pH for a given quantity of added acid. This increase in pH is unacceptable from the standpoint of microbiological stability, and extra acid cannot be added because of organoleptic considerations. Iron in addition in aqueous solution quickly oxidizes essential oils in the flavor system.

The present beverage formulation, including the following vitamins, with claim levels and added overages, are shown in Table 6. The typical stability of these vitamins after 3 and 7 months is shown in Table 7.

We have also examined the variation during aging of PER and available lysine in the product. There is very little change. Typically the PER, depending on the source of the whey protein base, will be between 3.0 and 3.4. In one sample, the PER of the whey base and the corresponding beverage were 3.4 and 3.3, respectively. After 1 year the

TABLE 6 Vitamins in Product

Vitamin	Form	Claim (per 200 ml)	Added Overage (%)
A	10% β-carotene	1000 IU	50
B_1	Mononitrate	0.25 mg	20
B_2	Type S	0.30 mg	50
B_6	Hydrochloride	0.50 mg	20
B_{12}	In gelatin	1.25 μg	60
D_2	500—SD	100 IU	100
Niacin	Niacinamide	2.50 mg	20
Folacin	Folic acid	0.025 mg	20
Pantothenic acid	Calcium salt	2.50 mg	50

TABLE 7 Vitamin Stability in Product

Vitamin	Claim	Added	3-Month	7-Month	7-Month Loss (%)
A	1000 IU	1500 IU	[a]	[a]	[a]
B_1	0.25 mg	0.30 mg	0.30 mg	0.34 mg	0
B_2	0.30 mg	0.45 mg	0.44 mg	0.33 mg	27
B_6	0.50 mg	0.60 mg	0.52 mg	0.47 mg	22
B_{12}	1.25 μg	2.00 μg	3.0 μg	2.5 μg [b]	[b]
D_2	100 IU	200 IU	178 IU	—	—
Niacin	2.50 mg	3.0 mg	2.8 mg	2.9 mg	0
Folacin	0.025 mg	0.03 mg	—	0.027 mg	10
Pantothenic acid [c]	2.50 mg	3.0 mg	1.7 mg	1.3 mg	48

[a] Results variable; this subject is still under investigation.
[b] High because of the high endogenous level in the whey base.
[c] Results with increased overage (to 50%) not yet available.

PER of the beverage was 3.1. Available lysine after one year by the trinitrobenzene sulfonic acid (TNBS) method of Kakdale and Liemer (1969) was 8.5 g per 16 g of nitrogen, which was identical, within experimental error, to the level in the original whey powder base, which contained 68 percent protein, dry basis.

Beverage Powders

After 4 years of experience with various bottled beverages, we have turned our attention to the development of a corresponding range of instantized nutritional beverage powders. These powders can be reconstituted on a drink-by-drink basis in the home or in bulk for institutional dispensing purposes.

One very major advantage of the dry-powder concept is that it overcomes many of the disadvantages alluded to earlier, chiefly, the problems involved in preserving liquid nutritional beverages. Most of our work to date has been on whey-based beverage powders with a composition similar to that already described. The powder concept has the advantage that the problems mentioned above are overcome, as there are no major technical or organoleptic problems associated with the incorporation of vitamin A, vitamin C, or minerals into the powders.

Our present concept calls for a product with 10 percent USRDA of protein (PER 3.0 +), calcium, phosphorus, and iron, and 25 percent USRDA of all the vitamins mentioned in the nutritional labeling guidelines. This product, in a slightly different formulation based on the National Academy of Sciences–National Research Council allowances for a 10–12-year-old, has been extensively tested both in the United States and in the bottled form in Brazil.

Five-month storage in a polyethylene bag (1 lb 10 oz per bag) at 110°F, and at 50 percent relative humidity has caused the percent losses of vitamins added, shown in Table 8. In the same period of time the PER did not change significantly (multiple analyses vary from 2.98–3.34). Available lysine results are not yet conclusive; the value was 8.48 g per 16 g of nitrogen, and any change during storage appears to have been minimal.

There was a marked organoleptic deterioration after 4 months of storage at 110°F, 50 percent relative humidity, regardless of the type of packaging used. When stored at room temperature, however, the product is quite acceptable for a year.

SOFT DRINKS

These are products defined by the existing standard of identity for carbonated soda water. We believe that such products should be treated as a pure refreshment and should not be the subject of fortification,

TABLE 8 Vitamin Stability in Nutritional Beverage Powder Stored at 110°F, 50 Percent Relative Humidity

		Percent Loss After	
Vitamin	Added[a]	3 Months	5 Months
A	2300 IU[b]	0[b]	10.9[b]
B_1	0.47 mg	0	0
B_2	1.05 mg		21.9
B_6	0.55 mg		0
B_{12}	2.86 μg		6.3
Niacin	6.13 mg		2.1
Folacin	0.128 mg		12.5
C	63 mg	8.4	19.0
D_2	[c]		[c]
E	6.8 IU		35.3[c]

[a] Includes added vitamins and those endogenously present in whey—all analyses by Wisconsin Alumni Research Foundation (WARF).

[b] Results from different analytical groups vary significantly from 1600 IU to 2300 IU (WARF). However, percentage losses agree approximately.

[c] Analyses variable; results inconclusive.

especially when the items above are available in the market as alternatives. For this reason, on which our views concur with those expressed earlier by the Food and Nutrition Board of The National Academy of Sciences, we have not worked on the addition of nutrients to soda water; but rather we have directed our attention to producing palatable alternatives.

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DISCUSSION

Dr. Robinson asked if any food products had been omitted that should have been included.

Dr. Birdsall pointed out that some areas of fortification not discussed were food fat, food snacks, legumes, and alcoholic beverages. These might well be considered at another time. Further, the hot-air blanching of vegetables mentioned by Dr. Cain should be expanded on. Dr. Cain noted that there are limited data available; however, data exist on beans, beets, and spinach.

Dr. Robinson noted that the rationale of nutrification had been touched on in all the presentations and that there seemed to be two points of view: those who want to fabricate a food to be a complete diet and those who want to fortify only to replace the nutrients lost in processing. The technological point of view notes the specific instances in which certain nutrients cannot be put into certain products, even though some would like to see them there. The workshop report should emphasize these points, particularly the technological problems of fortification. For example, it is very difficult to put vitamins A and B into cereal products; it is difficult to get or retain the flavor in fruit juices when vitamin B_1 is added. Iron salts may be added to cereal but not to fat products. A great deal more information is needed, and good common sense must be applied to all our efforts.

Time and time again the need for assays was emphasized in the presentations, i.e., for vitamin K, folic acid, even assays of protein efficiency ratio. The interactions that take place between the added nutrients and the food product are not completely understood. For example, in brine-making in the canning industry the addition of sodium chloride causes surges in iodide due to preferential solubility, thus causing nonuniform distribution in the solution.

Dr. McIntire pointed out the need to fortify in order to take care of the variations in the natural products, the deficiencies in the natural product, and the losses due to processing and storage of the natural product. Dr. Borenstein suggested that in the refining of natural vegetable oils one removes considerable vitamin E, and these microconstituents need to be replaced, that is, fortified to the original level.

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Summary and Perspective

The research needs have been outlined very well in the individual papers. A few areas needing further attention deserve emphasis here:

1. The potential for nutrient variability due to genetic variation among food sources is not fully clarified. Qualitative changes in protein content have resulted from deliberate genetic alteration, as in high-lysine corn. The natural content of carotenoids is an inheritable characteristic. Other nutrient components may well come under genetic control. Plant breeders should be alerted to check new varieties for major nutrient composition as well as for potential toxicants.
2. Great care must be taken in generalizing about nutrient stability or lability. Specific nutrients under specific, well-defined conditions with specific processes must be considered in most cases. Fortification is neither inherently good or bad. It needs to be evaluated in each specific circumstance in terms of nutrients, need, and the logical alternative nutrient sources. This must be recognized more fully by nutrition educators and public health nutritionists.
3. The final preparation of food for consumption is a significant step that was not adequately treated in this workshop. We really need to consider the total food system. The nutrient content of foods as consumed relates to all processing, storage, and handling variables that precede consumption. Therefore, a total food-delivery system should be con-

sidered when we attempt to evaluate the nutritional significance of processing, preservation, storage, and final preparation for consumption.

4. The toxicological aspects of the degradation products resulting from vitamin breakdown are not well known. The paucity of data in this area raises enough of a question to alert us to possible problems. More work is needed on the interactions of both vitamins and minerals at the food-processing level. We need to know where the materials go and how they are bound if they are bound. These interactions obviously affect not only the chemical form but also the bioavailability. If we embark on any large-scale enrichment and experience concurrent losses in processing, we are producing a considerable amount of degradation products in the food materials. We know very little about these degradation products and their interactions in the food supply. Obviously, any large-scale change in fortification or enrichment should be approached cautiously and then only after much study.

5. Methodology for nutrient measurements leaves much to be desired. One clear example is protein quality determinations, which are not reliable when applied to various protein sources, as has been demonstrated by Dr. Hegsted of Harvard. The determination of vitamin and mineral content of processed foods also is exceedingly difficult in many cases. Better assay methods are needed.

6. Regulatory agencies need to recognize that in the future meats may need to be enriched. This may be addition of meat analogs to extend an increasingly short supply, or the addition of micronutrients appropriate to this particular food group. Negative attitudes toward fortification of meat products have discouraged research and development in this area in the past.

7. Formulated foods provide an excellent opportunity for future innovations that will help meet nutritional needs. Two basic questions remain: What to fortify? and, How much to fortify? Certainly the fortification criteria of the Food and Nutrition Board and the Council on Foods and Nutrition of the American Medical Association are useful guidelines.

8. In studies designed to maximize nutrient retention, appropriate balance must be maintained with other quality attributes. Risks related to the microbiological safety of foods must always be minimized. For example, microbiological safety considerations obviously supersede retaining 5 percent more thiamin by a slight reduction in heat processing.

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