Fortification of Cereals and Cereal Products with Proteins and Amino Acids

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Fortification of staple cereals with protein concentrates or pure amino acids improves their nutritive value and may aid in alleviating malnutrition in developing countries. Concentrates from peanuts, cottonseed, and coconut can be utilized. Soya concentrates can encourage a valuable new crop. Protein isolates from these sources provide fortification flexibility and a base for a variety of acceptable nutritious foods. Fish protein concentrates have high nutritive value, are potentially the cheapest animal protein supplement, and enable greater use of existing fish resources. Milk powder is a valuable protein for fortification, particularly if indigenous milk production is increased. Single-cell protein, grown on petroleum or other low-cost substrates, has potential for animal and human feeding. Economic syntheses of pure amino acids make fortification of cereals with limiting amino acids practical and provide greater utilization of the cereal protein. Protein choice, fortification method, and economic factors are important in fortification.

Vitamin fortification of cereals has been one of the success stories of applied nutrition. It has made a significant contribution to the improvement of nutrition in the United States, and its wider use in the developing countries could greatly alleviate vitamin deficiency diseases still prevalent in many areas.

Protein fortification of cereals is a logical and needed extension of the successful fortification principle. The purpose of this paper is to bring attention to the need for protein fortification of cereals, to discuss the rationale, and to summarize the fortification ingredients currently or potentially available, and the caveats of the fortification approach.

NEED FOR DIETARY PROTEIN

The need for additional dietary protein occurs largely in the developing countries. Literally hundreds of millions of people in these countries are living on dangerously low protein intakes. Elimination of malnutrition will require a 45% increase in the total supplies of protein for the period from 1960 to 1975 (Abbott, 1966).

Children are particularly vulnerable to protein malnutrition because their need for protein is several times that of adults on a unit weight basis. Too often in the developing countries the child grows normally as long as he is breast-fed, but at weaning he is given the same low-protein diet eaten by his parents and his growth decreases markedly. If protein intake is very low, he will develop kwashiorkor, the disease of extreme protein deficiency. The International Conference on Prevention of Malnutrition in the Pre-School Child (National Academy of Sciences, 1966) established that protein calorie malnutrition is basically responsible for the early deaths of millions of children, that it permanently impairs physical growth and probably causes irreversible mental and emotional damage, and that it is a serious deterrent to progress in the developing countries, weakening the productive capacities of adults surviving from the irreparable damages received in early childhood.

The need for more protein in the diets of the developed countries would appear, on the basis of over-all consumption figures, to be remote. However, the need of special groups in our population, such as old people, for more protein must be considered. Actually, we are fortifying much of our white bread with protein in the form of nonfat dry milk. This has had a beneficial effect on the nutrition of many low-income groups.

The paradox in the need for additional protein in the diets of so many people is that there is probably no shortage of protein in the world. The FAO (1964) reviewed the extent of the protein problem and came to this tentative conclusion. Further expansion of existing sources and development of sources now in the research stage probably can keep up with world needs well into the future. The paradox stems from poor distribution of the available supplies to supply human needs, and these in turn are caused in great part by the lack of wide acceptability of man's protein resources as human foods.

Diets in the developing countries tend to be limited in variety and are invariably based primarily on cereal grain or on some form of carbohydrate such as tapioca, manioc, or yams. Dietary habits also tend to be highly conservative. Introducing a new food concept in the form of high-protein foods, whether for adults or children, is a slow, time-consuming process (Belden *et al.*, 1964). Nutrition education to encourage the use of a wider variety of food inevitably meets strong resistance to the new tastes and the new cooking methods. It is important that we try to introduce new foods in the developing countries and to foster the use of a greater variety of foods to meet long-term needs. However, immediate measures to meet the present need for more dietary protein must also be considered. Fortification of the basic cereals and other carbohydrate sources offers an approach to this need.

A prime reason for the success of vitamin fortification of cereals is that fortification does not interfere with the organoleptic qualities of cereals. Enrichment made white bread more nutritious, and the B vitamin intake of the individual was improved, but the bread did not taste any

Agency for International Development, Washington, D. C. 20523

different. There was no consumer resistance; the consumer had his cake and ate it, too. The lack of any significant effect on the taste and appearance of the cereals was made possible by the availability of the vitamins in highly concentrated or pure form.

FORTIFICATION INGREDIENTS

Today, protein concentrates can be made from a variety of sources which can be added to cereals with little effect on taste and flavor and with significant effect on nutritive value. An increasing number of essential amino acids, in pure form, from synthetic or fermentation processes are becoming available at prices which permit them to be considered for broad fortification applications. By fortifying basic cereals with these concentrates or amino acids, singly or in combination, the dietary intake of the needy populations can be increased at minimum cost in time and money and with the least possibility of consumer resistance.

A discussion of protein nutrition is outside the scope and space of this paper, but two examples will show the degree of nutritive enhancement that can be achieved by protein fortification of cereals. The addition of 5% fish protein concentrate to whole wheat increased the protein efficiency ratio (PER) from 0.78 for the wheat to 1.42 for the mixture compared with 2.50 for casein (Stillings, 1967). The addition of 0.2% lysine to a whole wheat raised the PER from 0.98 to 1.45, with the PER of casein at 2.50 (Howe, 1965). Similar results can be demonstrated with other protein concentrates. With suitable mixtures of protein concentrates, PER values approaching or exceeding that of casein are possible.

Because the cereals and other carbohydrate foods are the main staple foods in the developing countries, they are logical carriers for protein. They are consumed in regular and substantial amounts by the population, are traditional foods, and are always acceptable. Additionally, cereals are the main source of protein in the human diet. World wide, the cereals contribute 40,000,000 tons of protein compared with 25,000,000 tons from animal sources and 12,000,000 tons from legumes. Any improvement in the quality or quantity of the protein in cereals will thus have the greatest impact on the widest population.

Protein concentrates, suitable for cereal fortification, can be made from a wide variety of sources, available or potential. In 1966, world protein resources were reviewed in detail (American Chemical Society, 1966).

Oilseeds are the largest single source for production of protein concentrates. Of these, soybeans, in terms of tonnage produced, are the most important source. Properly defatted soybean flour will contain 50% or more of protein. By removing soluble carbohydrates and minerals, concentrates containing up to 70% protein can be prepared, and dispersible isolates containing 90% or more of protein are being made. The isolates are of interest as highly concentrated fortification media and also as bases for a variety of high-protein beverages, desserts, and similar products. Soybean concentrates have the virtue of low cost and good nutritive value. Flavor and palatibility problems can be encountered, but these can be overcome by suitable mixture with other concentrates.

Cottonseed is another important resource but the least utilized for human consumption. Nearly 21,000,000 tons were produced in 1965, much of it in developing countries where protein needs are particularly acute, as in India. By suitably defatting and dehulling cottonseed and treating it to remove or reduce the gossypol content to a suitable level, a bland product containing 50% or more of protein can be produced. Gossypol removal is not readily accomplished, however. Extraction with solvent mixtures shows promise, but more research is needed to make the processing economical. Cottonseed flour is used as the principal protein source in Incaparina, and it is beginning to be used on a small scale in human feeding in India.

An important source of protein concentrates for many developing areas is the peanut. World production is around 15,000,000 metric tons. India raises about 5,000,000 tons annually, and substantial amounts are grown in Africa. Peanuts are poorly utilized as human food largely because of the downgrading of their quality occurring during the extraction of the oil by pressing. When modern solvent extraction of oil is practiced, it is possible to produce an edible peanut flour containing 40% or more protein. Further processing can yield an isolate containing 90% or more of protein. Peanut protein concentrates can be made at low cost, although the nutritive value of the protein is not as good as that of soybeans. A serious deterrent to increased use of peanuts as a protein source in the tropics is aflatoxin, a toxin produced by a mold which grows rapidly on poorly stored peanuts. Research is in progress to develop techniques to remove the toxin. Until these are perfected, production of edible peanut flour in India, for example, is based on use of specially selected, hand-sorted nuts. However, the aflatoxin problem can occur with any oilseed protein in the tropics and is not unique to peanuts. Any practical solution to the problem will have wider applications than to peanuts alone. Despite these limitations, peanuts must be considered as a very important protein source in many developing countries. When feasible, the nutritive shortcomings can be offset by blending with small amounts of other protein concentrates, such as fish protein concentrate or additional amino acids.

Another important, but potential, protein resource for human food use is the coconut. Over 3,000,000 tons of dried copra are produced annually in the southeast Asian area. Nearly all of this is used in the production of coconut oil; the press cake is largely used in animal feeds in the developed countries. Coconut meat has a high oil and fiber content. When it is dried to produce copra, the heat used seriously affects the protein quality. Methods for removing the oil and fiber to produce acceptable food-grade concentrates have been developed but have not reached commercial practice. The white color and bland taste of these concentrates make them especially interesting for cereal fortification. The ability of the coconut palm to produce substantial yields of oil and protein from poor soils and its potential value as a protein source in Southeast Asia and Polynesia make further research on this resource a matter of great importance.

Recently, interesting high-protein products have been processed from wheat milling fractions normally used in animal feeds. Special milling techniques remove much of the fiber to give products containing 25% nongluten protein of good nutritive value. These concentrates are of obvious interest in wheat flour fortification.

Sesame and sunflower are other oilseed resources, but they are of lesser interest because they are not common in most developing countries. Considerable research is going on in the preparation of concentrates from leaves. Very high yields of protein per acre of land can be obtained from such a source, but there are serious taste problems to overcome before such concentrates find use in human foods.

Economical protein concentrates from animal sources are much more limited. The most widely used animal protein concentrate is nonfat dry milk. This product, made by removing fat and water from milk, is an excellent protein product. It is routinely added to white bread in the U.S. in small but significant amounts, a practice which can certainly be called fortification and which contributes to the nutritive value of the bread. Very large amounts have been shipped abroad by the Agency for International Development, UNICEF, and others for use in feeding programs in the developing countries. Nearly all of this has been used in reconstituted milk form, not in any fortification program. Much more could be used in beverage form. It would be desirable if the world supplies could be increased to permit fortification also, but this does not seem possible because of the difficulties of expanding milk production in the developing countries.

A new animal protein resource is fish protein concentrate (FPC) which is made by solvent extraction of whole edible schooling fish. After a rather stormy period of development, FDA approval was given in 1967 to two processes for the preparation of FPC by the solvent extraction of hake. Approval of additional processes and raw materials can be expected.

FPC contains about 80% protein. It has a bland, nonfish taste and a slight nonfishy odor. It provides a way of utilizing the very large protein resources of the oceans more effectively for human feeding. It can use poorly utilized stocks as raw material, it keeps for very long periods without need for special storage conditions, and it can be added to foods at significant levels with little effect on organoleptic properties except color in certain cases. It can be manufactured for 25 cents a pound or less, a price which is about half the cost of nonfat dry milk on a 100% protein basis. The nutritive value, as measured by PER, is about the same as that of milk, and it can replace milk in most nutritive applications.

Plans are under way for extensive testing of FPC in selected developing countries to determine its feasibility as a protein source. Fortification of cereals will undoubtedly be one of the approaches used.

Certain essential amino acids, specifically methionine and lysine, can now be made by synthesis or fermentation, at a cost low enough to permit them to be used for cereal fortification. Threonine also appears capable of being produced at low cost.

These pure nutrients are interesting as fortification ingredients because they are added at very low level and have no effect on the organoleptic properties of the cereal. In this type of fortification, it is the quality of the cereal protein which is being enhanced. The quantity of protein is enhanced, in that more of the protein in the cereal is made available as a result of better amino acid balance, but the degree of quantity enhancement is less than when protein concentrates are used.

The practical value, in human nutrition, of fortification of cereals with pure amino acids needs to be determined. While animal experiments have been clear-cut as to the added value, human experiments have led to some equivocal results. Plans are now being made for tests with lysine-fortified flour on large-scale, long-term human studies in several developing countries to assess the practical nutritional significance of this form of fortification.

Currently, there is much interest in single cell protein (SCP) derived from various microorganisms grown on various substrates, such as petroleum fractions and various wastes. Yeast products are one form of single cell protein which have been used as food protein sources for some time, so the concept is by no means new. Considerable attention has been given to algae as the microorganism as a result of research on providing food for long manned space flights. A spinoff of this research has been some interesting work on growing algae on sewage to provide animal feed materials and to reduce pollution. Whether this could be extended to the growth of food for humans remains to be seen, considering the psychological factors involved.

An important advantage of the single cell protein approach to providing animal feed materials is that it would reduce the competition between man and animal for usable agricultural land.

The techniques of protein fortification are varied. Where cereals are milled into flour or granules such as farina, corn grits, semolina, etc., fortification is done by mixing in the protein concentrate at the proper level. The protein concentrate should be prepared to the same general mesh range as the cereal. Mixing can be done on a continuous basis, using suitable feeders and mixers, or on a batch basis. The latter should not be overlooked as a method in countries where there is wide underemployment and maintenance of sophisticated equipment is a major operation. Amino acids in pure form can be handled in the same way as for vitamin enrichment (Brooke, 1968).

Fortification techniques become more difficult when the cereal is consumed in whole grain form. Rice is particularly difficult because of the almost universal habit of washing the rice before cooking. Unless the fortification ingredients are suitably protected, they will be leached out in the washing process. Crystalline amino acids can be added by using the simulated grain technique used for vitamin fortification. The slight change in the texture of the cooked rice caused by the disintegrated simulated grains will probably not be noticed by the consumer. The simulated grain technique can also be used with protein concentrates. However, the ratio between the rice and the simulated grains would probably be 20 or 30 to 1 instead of 200 to 1, and the larger amount of the simulated grain would undoubtedly cause a noticeable, and probably objectionable, change in the taste and texture of the rice.

A further complication arises where the rice is cooked in an excess of water, as in certain parts of India. The excess is discarded, with resultant loss of a considerable portion of the added nutrients. Some limited experiments by the author (Parman, 1952) indicated that the losses of added B vitamins under these conditions did not exceed 50%, regardless of the amount of excess cooking water used. Whether this would also hold true for added amino acids would have to be determined, but the excess of nutrients required adds substantially to the cost of fortification. The author knows of no simple way to handle all the complexities of the fortification of rice.

Wheat in whole grain form is not washed before use, so fortification is much easier. Graham (1967) has described a number of promising techniques, including coating grains with powdered protein concentrates by tumbling the grains with the powder, steaming, then drying, and also by incorporating the protein in the form of simulated grains. The latter might, unless the grains are well made, cause sufficient change in the appearance of the uncooked wheat sample to arouse consumer suspicion. Lysine and other amino acids have been added by spraying and soaking techniques. More work is needed to determine if the lysine added in this manner will survive normal handling of the grain in milling or home preparation procedures. Addition of the lysine by the simulated grain techniques seems a better approach, although the stability of the added amino acids would still need to be investigated.

There are obviously some limitations to fortification, as exemplified by the foregoing discussion on techniques. A more critical limitation, which is particularly a factor in the developing countries, is that fortification requires that the cereal go through some sort of central handling or processing operation where it can be fortified. The larger these facilities are in terms of tonnage of cereal handled, the better. The author helped set up provision for enriching white rice with B vitamins at several hundred small village rice mills in the Philippines, but the problem of enforcement and control was insurmountable.

In India, the bulk of the indigenous wheat moves from farm to market without going through any sort of silo or bulk storage where amino acids or protein concentrates could be added. The wheat is sold in the market place in whole grain form. It is normally pounded into atta in the home, although the more affluent housewife may pay a small sum to have it ground in a hand-operated coffee-grinder mill. In either case, effective fortification is impossible.

However, the situation is not all bad. A very considerable amount of cereals are milled in central mills, the majority of rice eaters do not cook with an excess of water, and more Indians in the urban areas are turning to commercially milled atta, instead of milling it themselves.

Another critical factor is cost of fortification, which is directly related to cost of the concentrate used. This is a complex question, since it relates to many factors. The protein concentrate used may not be the best, nor the cheapest, but it may be the best and the cheapest available in the particular country and therefore preferable to a cheaper and better concentrate which may have to be imported.

Protein fortification costs will vary generally between 0.5 and 2 cents per pound of cereal. This added cost of fortification may seem small but may be very large to a consumer who has only pennies to spend for food. Conversely, the fortification cost may be minor compared with the normal market price fluctuations for the cereal.

In some countries there may be a distinct advantage in adding considerable quantities of a protein concentrate blended with a cheap carbohydrate source to extend, in effect, the supplies of the cereal as well as to provide more protein, and this may have an important effect on cost. There is no clear-cut answer to the cost problem, but it must be carefully considered in all its aspects when considering cereal fortification, particularly in the developing countries.

If protein fortification is adopted and the protein intake of a population increases, it may also be advisable to give attention to the vitamin intake of the population. Vitamin B_6 may be particularly important in this regard. Rubin (1966) has discussed the relationship between vitamin B_6 and protein intake. In populations where general B vitamin intake is marginal, the load of increased protein intake may precipitate vitamin B_6 deficiency.

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Received for review October 20, 1967. Accepted January 18, 1968. Division of Agricultural and Food Chemistry, Symposium on Enrichment and Fortification of Foods with Nutrients, 154th Meeting, ACS, Chicago, Ill., September 1967.