Opportunities for Micronutrient Interventions

Rice Fortification For Developing Countries

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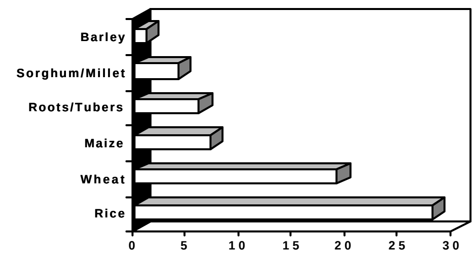
Introduction

One of the most fundamental decisions underlying food fortification schemes is selecting appropriate foods to be fortified with the essential micronutrients lacking in a population's diet. Criteria to identify potential food fortification vehicles generally include selecting a food that is commonly eaten by the target groups, is affordable and available all year long, and is processed in such a manner that fortification is technically feasible and can be done economically. Staple foods such as wheat flour and sugar have been popular foods to fortify in order to address micronutrient deficiencies in several developing countries. This document provides an overview of the importance of rice as a staple food and food vehicle for fortification in countries where populations suffer from micronutrient deficiencies. Available technology and current rice enrichment and fortification[1] practices are reviewed. Limitations and opportunities for expanding rice enrichment and fortification programs in developing countries are identified.

Rice: An Important Staple Food in Developing Countries

Rice is the most popular cereal worldwide, serving as a staple food for 39 countries and nearly half of the world's population (Juliano 1993). Globally rice accounts for 22 percent of total energy intake (Bierlen et al. 1997). For populations living in many developing countries, rice contributes the greatest percentage of calories and protein (See Figure 1). Trends in rice consumption are closely linked to rice production in a number of rice-producing countries as illustrated in Table 1.

Figure 1. Percent Calories Contributed by Staple Foods to Diets - All Developing Countries



Source: FAO/ESS, 1996 (Averages 1992-1994)

Nutrition Problems in Rice-Consuming Countries

Low energy and protein intakes are common nutritional problems for people in rice-consuming countries. FAO estimates that about half the people of South Asia do not have adequate energy intakes to lead healthy active lives. Nutrition indicators compiled for 34 rice-consuming countries indicate that the incidence of low birth weight, infant mortality, mortality of children under five years of age, and prevalence of underweight children are considerably higher in these countries than in other countries (UNICEF 1991).

Micronutrient deficiencies of global public health concern include nutritional anemia due to iron deficiency, vitamin A deficiency in children, and iodine deficiency disorders. All are common in many countries where rice is the staple food. For example, micronutrient deficiencies, particularly of vitamin A, are common in Bangladesh, India, Indonesia, Myanmar, Nepal, the Philippines, Sri Lanka, and Vietnam (See box on opposite page). Other micronutrient deficiencies, including those of thiamin, riboflavin, calcium, vitamin C, selenium, magnesium, and zinc, also exist but have been less well-documented.

[1]Codex defines fortification or enrichment as "the addition of one or more essential nutrients to a food, whether or not it is normally contained in the food for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups" (FAO/WHO 1994).

Table 1: Percent Change in Rice Consumption and Rice Production in Selected Countries

Country	Percent Change in Per Capita Rice Consumption 1961-65 to 1981-85	Percent Change in Total Rice Production 1961-1985
Taiwan	-39	6
Japan	-29	-8
Malaysia	-17	63
Nepal	-17	27
Thailand	-14	77
India	-3	63
Bangladesh	1	46
Sri Lanka	4	142
South Korea	5	54
Philippines	12	102
China	33	160
Indonesia	47	166

Source: Howarth Bouis, 1996. Changing Food Consumption Pattern in Asia and Prospects for Improving Nutrition: Implementation for Agricultural Production Policies. IFPRI, Washington DC.

Rice Production

Rice can be grown in a wide range of environmental and soil conditions and is produced in over 100 countries and on every continent except Antarctica. About 95 percent of the world's rice is produced in developing countries, 92 percent of it in Asia (Juliano 1993). In contrast, only 42 percent of wheat (the second most popular staple) is grown in developing countries (Juliano 1993). In 1996, China was the principal rice producer (35.7 percent), followed by India (21.3 percent), Indonesia (8.9 percent), Bangladesh (4.9 percent), Vietnam (4.5 percent) and Thailand (3.9 percent) (USDA/ERS 1996). Irrigated lands account for two-thirds of the total rice production while about 20 to 25 percent is from less favorable environments (deep-water and tidal lowland, rain-fed lowland, upland). Of the major rice producers, only Pakistan, United States, and Egypt had 100 percent irrigated rice (Juliano 1993).

Less than five percent of the world's rice production enters international markets. In 1996, the major rice exporters were Thailand, Vietnam, United States, India,

Micronutrient Deficiencies Common in Rice-Consuming Populations

Vitamin A deficiency is widespread in rice-consuming countries of tropical Asia and is most serious in Bangladesh, India, Indonesia, Myanmar, Nepal, Philippines, Sri Lanka, and Vietnam. The deficiency is also common in northeastern Brazil. Vitamin A deficiency in children can lead to corneal lesions which can result in partial or total blindness. Of the total three million children worldwide estimated to be suffering from xerophthalmia, one-third live in India. Mild vitamin A deficiency is more common and is associated with reduced resistance to infectious disease and increased morbidity and mortality.

Nutritional anemia from iron deficiency is widespread in rice-consuming countries. The highest overall occurrence of anemia in developing countries occurs in South Asia and Africa. Anemia lowers work performance, has been linked to reduced resistance to infection, and severe anemia is a significant cause of maternal deaths. Mild anemia may also affect cognitive development and psychological function in young children.

Iodine deficiency disorders (IDD) are prevalent in many rice-eating populations, particularly in mountainous regions of Brazil, China, India, Indonesia, and Malaysia, where the iodine content of the soil, water, and food is low. IDD is also common in Bangladesh because frequent flooding washes iodine from the soil. Most people at risk of IDD live in Asia. Iodine is essential for normal growth, fetal development, and normal physical and mental activities in adults.

Thiamin and riboflavin deficiencies still exist in many parts of Asia. Beri-beri (thiamin deficiency) is common where polished rice is consumed. It is rarely seen when rice is parboiled or undermilled since thiamin is not removed. As economic conditions improve and diets become more varied, beri-beri has tended to disappear. However, beri-beri in breastfed infants is still seen sporadically in many places. In Thailand, for example, new mothers restrict their diet and the resulting low thiamin content of breastmilk predisposes infants to beri-beri. Riboflavin deficiency is frequently seen in young children and pregnant and lactating women in rice-eating populations of Bangladesh, India, and Thailand.

Source: Juliano 1993

Various Rice Forms

Few of the world's grains are available in as many forms as rice. These include:

Rough Rice: Also called paddy rice. Rice kernels are still enclosed in an inedible, protective hull which must be removed.

Brown Rice: Rice which has only the hull removed. The bran layers and rice germ remain, giving the rice a brown color.

Parboiled Rice: Rice that has been steam-pressurized to gelatinize the starch within the rice kernel, resulting in a firmer, more separate grain that is more stable and less susceptible to overcooking than regular-milled white rice.

Regular-Milled White Rice: Sometimes called milled rice, polished white rice, or polished rice. Hulls, bran layers, and germ have all been removed.

Precooked Rice: Regular-milled white rice, parboiled milled white rice, and brown rice can be precooked and dehydrated before packaging. Precooked rices include quick-cooking rice, instant rice, and boil-in-the-bag rice.

Individually Quick Frozen (IQF) Rice: Cooked rice grains are individually frozen before packaging.

*Crisped/Puffed/Expanded Rice: K*ernels can be processed in a number of different ways and shapes to meet particular manufacturing need.

Source: USA Rice Federation, Houston, Texas

Pakistan, and the European Union. The leading importers were the European Union, Iran, Brazil, Indonesia, and China (USDA/ERS 1996).

Rice Milling and Nutrient Loss

Milling of rice is different from other cereals since the objective is to produce a maximum yield of unbroken milled grains rather than a flour or meal as with most other cereal grains. Processing the unhulled rice grain, also called paddy or rough rice, involves cleaning, milling to remove the hull, germ, and bran layers, and sizing to produce white uncoated rice. A coating of talc and glucose may be added to improve appearance; however, this is not permitted in some countries including the United States. Various forms of rice available are outlined in the box on this page.

Milled or white rice represents 40 to 76 percent extraction of rough rice. The B vitamins and iron are found primarily in the germ and bran layers, and are therefore removed in the milling process. It has been estimated that in the course of milling brown rice to white rice approximately 80 percent of the thiamin is removed (Kik 1945). Other nutrients contained in the bran layer are also lost, including niacin, iron, and riboflavin. The loss of vitamins and minerals in milling are noted in Table 2.

Nutrients can be preserved in the rice grain by parboiling. Parboiling transfers the nutrients contained in the bran layer to the inner endosperm layer prior to milling and removal of the bran. The parboiling process involves soaking of rough rice and applying heat and then drying and milling. Parboiled rice is produced in India, Bangladesh, Burma, Thailand, Sri Lanka, and other Asian countries by both traditional and modern parboiling processes (Pillaiyer 1990). Parboiling may require expensive equipment and can result in a golden color rice that is often not acceptable to consumers. Converted rice was developed with a similar process but uses pressure to transfer nutrients to the inner endosperm layer.

Enrichment methods have been developed to add synthetic vitamins and minerals to rice to replace those lost in milling. Primarily iron, thiamin, niacin, and riboflavin are added, although other nutrients, including pantothenic acid, B_6, calcium, and folate have also been included in some

Table 2: Influence of Milling on Vitamin and Mineral Content of Rice

Extraction Rate (%)	100*	82**	72***
Mineral Content			
calcium (mg/g)	0.3	0.1	0.1
phosphorous (mg/g)	3.1	3.2	1.5
zinc (ppm)	24	33	18
iron (ppm)	38	8.8	4.1
copper (ppm)	2.8	2.7	2.2
Vitamin Content (ug/g)			
thiamin	2.8	2.4	1.6
riboflavin	0.5	0.3	0.2
niacin	29.6	29	6
pyridoxine	5.1	5.1	1.9
folate	0.5	0.3	0.1
biotin (ng/g)	91	48	43

Source: Adapted from Bauernfiend, 1991
* Rough Rice
**Brown Rice
*** Milled Rice

enrichment premixes. In addition, rice has been used as a vehicle for vitamin A fortification in various pilot programs. The current technology of these enrichment and fortification methods are briefly described below.

Current Available Technology

There are two types of rice enrichment processes currently in commercial use: powder and whole grain enrichment. Powder enrichment uses a preblended powder mixture of B vitamins (thiamin, riboflavin, niacin, or niacinamide), and iron (ferric orthophosphate–white iron; ferric sulfate–yellow iron, or reduced iron). Ferric orthophosphate is recommended for rice because it is relatively water insoluble and white in color (Hoffpauer 1992). In powder enrichment, a pre-blended mixture of vitamins and minerals is added to the rice. For parboiled rice, the premix is added soon after milling as the heat and moisture on the grain surface at that point facilitates the powder adhering to the grain. Powder enrichment is less expensive than other types of enrichment; however, higher nutrient losses occur if the rice is rinsed before cooking. It is estimated that 20 to 100 percent of the enrichment will wash off rice depending on the amount of water used and cooking time (Hoffpauer 1992). In the United States, the statement "To retain vitamins, do not rinse before or drain after cooking" is required on the label if less than 85 percent of the nutrients are retained after rinsing.

The second and most common type of enrichment is known as "grain" type, generally referred to in the industry as "premix." Vitamins and minerals are applied to the rice grain followed by coatings of a water insoluble substance so they will not rinse off. Usually these premix grains have high concentrations of nutrients. These grains are then blended with unenriched milled rice, usually at a ratio of 1 enriched grain to 200 unenriched to attain the desired enrichment levels in the final product. Several grain type methods have been developed over the past 50 years.

The first patented premix method in the United States was developed by Hoffmann-La Roche in the 1940s. This involved spraying a sulfuric acid solution containing thiamin (thiamin hydrochloride) and niacin (nicotinamide); drying; and applying a protective coating followed by application of talc and iron (ferric orthophosphate).

Some improvements have been made over the years to the Hoffmann-La Roche method (Clarke 1995). Merck Company patented a similar rice premix concentrate in 1955 using different acidic solutions and coatings. A combination of the Hoffmann-La Roche and Merck methods has been developed by the Wright Enrichment Company. The Hoffmann-La Roche method was also revised and simplified by Ricegrowers Co-operative Ltd. (RCL) in Australia (Bramall 1986). Developers of the RCL method report that the problem of browning in the Hoffmann-La Roche method due to formation of ferric sulfates was eliminated with the use of an alternative acid

Standard of Identity for Enriched Rice in the United States

The current standard of identity for rice requires that each pound of milled rice, if enriched, must contain:

- not less than 2.0 and not more than 4.0 mg thiamin;
- not less than 16 and not more than 32 mg of niacin or niacinamide;
- not less than 13 and not more than 26 mg iron;
- if riboflavin is used it is limited to not less than 1.2 and not more than 2.4 mg
- if vitamin D is used it must be not less than 250 and not more than 1000 IU
- if calcium is used it must be not less than 500 and not more than 1000 mg

Source: 21 CFR Part: 137.350 Enriched Rice, revised as April 1, 1993

Effective January 1998, each pound of rice, if enriched, must contain not less than 0.7 mg and not more than 1.4 mg folic acid. [0.14mg (140ug) folic acid per 100 grams]. The folic acid content of rice varies from 0.036 mg/lb for white rice to 0.090 mg/lb for brown rice.

Source: Federal Register, Tuesday March 5, 1996. 21 CFR Part 137.50. Food Standards: Amendment of Standards of Identity for Enriched Grain Products to Require Addition of Folic Acid; Final Rule.

solution. The cost of the RCL method is reportedly lower since the number of raw materials is reduced, simplifying the processing and reducing labor costs.

Another method of grain type enrichment currently being tested is the development of enriched simulated/ synthetic rice grains. Vitamins and minerals are added to artificial grains made from rice flour extruded to form a rice-shaped kernel. These fortified grains are then mixed with regular milled rice to provide the target fortification levels in the final product. Artificial rice grains have provided an opportunity to increase the number of nutrients that can be added. This method is currently not in commercial use, but studies continue, as mentioned below, to investigate the feasibility of using this technology for vitamin A fortification. Although there is optimism that this technology has great potential, concerns have been noted regarding the blending of the simulated grains with natural products and their consistency after cooking (Hoffpauer and Wright 1994).

A simple procedure has been developed to fortify rice with calcium (Lee et al. 1995; Hettiarachchy et al. 1996). It consists of infusing calcium salts into the rice grain through controlled steaming technology. The fortification process met the U.S. standards for calcium-fortified rice (110-220mg/100g) and resulted in minimal washing losses of calcium.

History of Rice Enrichment and Fortification and Current Programs

The first attempts to fortify rice focused on adding thiamin. Awareness of the importance of thiamin in the diet dates back to 1890 when a Dutch physician, Eijkman, observed that chickens fed a diet of polished rice developed symptoms common to beri-beri patients. Later, it was discovered that feeding rice polishings could reverse the symptoms of beri-beri in both fowl and humans. The compound was later identified as thiamin. It became economical to enrich rice when technological advances made it possible to commercially synthesize large quantities of thiamin and riboflavin.

In the United States, regulations adopted in 1958 established a food standard for enriched rice. Regulations did not require enrichment, but specified the quantities of specific vitamins and minerals to be added if manufacturers chose to enrich. As the intent of the regulations was to return the milled rice to the nutritional level of brown rice (unmilled rice), levels of riboflavin, thiamin, niacin, and iron to be added were specified. Riboflavin, however, is not generally added since it causes a yellow color in the cooked rice. Addition of vitamin D and calcium is optional (See box on opposite page). The levels of nutrients to be added are similar to those specified for other enriched cereal and grain products including enriched wheat flour, cornmeal, and pasta. Although enrichment of rice is only voluntary, most rice sold in the United States is enriched. A recent regulation requires that folic acid also be added to enriched rice. This regulation was adopted due to public health concern over low folate levels in the diets of young women and related increased risk of neural tube defects in infants born to folate deficient mothers.

In Canada, enrichment of precooked rice is also voluntary. If the product is labeled enriched, then thiamin, niacin, and iron must be added. Addition of B_6, folic acid, and pantothenic acid is optional. In Japan, a multinutrient-enriched rice has been on the market since 1981. Pantothenic acid, vitamin E, and calcium are added in addition to thiamin, niacin, riboflavin, and iron. The enriched rice, known as *Shingen* (meaning "brown rice in the new age") is considered an important step in combating high rates of iron deficiency anemia in Japanese women (Hunnel et al. 1985).

Enrichment of rice with iron and thiamin in the Philippines has a long history, as summarized in the box on this page. Although a law exists mandating the enrichment of all rice in the Philippines, it is currently not enforced. Attempts were made to fortify rice with vitamin A; however, the 10 to 20 percent nutrient loss due to washing was considered unacceptably high (Florentino and Pedro 1990; Murphy et al. 1992). Studies are currently underway in the Philippines to fortify rice with iron using ferrous sulfate.

Studies are also underway to test the feasibility of marketing and distributing vitamin A-fortified rice in Indonesia, where vitamin A deficiency is common (Lotfi 1997). The fortified rice grains are made from rice flour extruded to form a rice kernel shape matching the appearance of local rice. These fortified grains are then blended

Fortification of Rice in the Philippines

Rice enrichment has a long history in the Philippines. It had its beginnings in the 1940s with research by Dr. Robert Williams, a scientist who determined the chemical structure of thiamin, and the support of Dr. Juan Salcedo, who was Secretary of Health of the Philippines at the time. The process for adding thiamin, niacin, and iron to rice was developed by Hoffmann-La Roche. Beri-beri was a major public health problem in the country and the development of rice fortification technology with thiamin seemed a viable solution.

Experiments on rice fortification began in 1946. Feeding trials were conducted to test the acceptability of enriched rice in regard to color, taste, odor, palatability, and digestibility. A large-scale pilot test was then conducted in the province of Bataan. It involved enrichment of rice at the mill and household level. After the second year, there were virtually no deaths due to beri-beri. The success of the Bataan enrichment experiment led to the enactment of the Rice Enrichment Law in 1952. It required all rice millers and wholesalers to enrich the rice they milled or traded. However, the rice millers saw the law as a way that their total production, and therefore their income, could be monitored and consequently they did not comply. Political will to enforce the law wavered since the millers were a formidable force in the political structure. The law, however, has not been repealed.

Attempts were made to fortify rice using ferrous sulfate as a fortificant in the 1980s. The rice was rated acceptable after six months of storage at room temperature. Iron absorption studies showed that about 12 percent of the iron was absorbed. Later studies were conducted on fortifying extruded rice grains with both iron and vitamin A for a product called "ULTRA RICE ™." Despite extensive trials with two different premixes, unacceptable losses of vitamin A occurred during storage and cooking.

Currently, the technology developed in the early 1980s is being improved upon to further test iron fortification of rice. Because rice mills in the Philippines vary considerably in size and sophistication, appropriate low-cost technology is being developed. Both commercial and home-scale enrichment schemes are being tested.

Source: Florentino 1995

with regular unfortified rice to reach target levels of vitamin A in the final product. Results so far suggest that the fortified rice is marketable and acceptable to Indonesian households. The rice is known as *beras VitA*. Study results indicate that it is feasible to distribute the rice mix to millers for blending with unfortified rice. Further work is being carried out on appropriate quality control measures that will be needed to ensure proper storage and proper blending of the fortified rice premix. Additional field studies will be conducted on the stability of vitamin A in the rice after cooking under local conditions. Feasibility trials were successfully conducted using vitamin A-fortified rice in Brazil (Flores, et al. 1994); however, further work is still needed to document levels of vitamin A lost during cooking.

As part of an early USAID study to investigate enrichment and fortification of grains in selected countries, a field trial was conducted in Thailand to investigate the nutritional impact of fortifying rice with lysine, threonine, thiamin, riboflavin, vitamin A, and iron (Gershoff 1977). Although the trial did not result in a measurable nutritional impact, data were collected on stability of added nutrients and insights were gained into promoting rice fortification among millers.

Currently, the annex of the draft Codex standard for rice (FAO/WHO 1995) states that vitamins and minerals may be added in conformity with the legislation of the country in which the product is being sold. Countries accepting the standard should determine the fortification levels based on the nutrient needs of the population.

Nutrient Stability

Nutrient stability of added nutrients in enriched rice varies by the enrichment process utilized and by storage, washing, and cooking conditions. Early estimates of nutrient losses due to rinsing/washing, including those of iron in unenriched milled rice, have been estimated at about 60 percent because after milling the remaining nutrients are close to the grain's surface (Furter et al. 1946). Nutrient loss is high in powder enrichment since much of the dusted vitamins and minerals easily react with other food components and are washed away with rinsing.

Coating procedures used in grain enrichment have improved nutrient stability. Using the Hoffmann-La Roche method and the Wright method for adding thiamin, pyridoxine, niacin, vitamin E, folic acid, iron, calcium, and zinc, cooking losses were reported to be less than one percent (Cort et al. 1976). The exception has been for vitamin A where cooking losses have varied from 10 to 30 percent depending on the coating procedure (Rubin et al. 1977; Peil et al. 1981). Cooking in excess water resulted in more than 80 percent loss of vitamin A using only the Hoffmann-La Roche method (Rubin et al. 1977). The loss of vitamin A added to simulated grains has reportedly been high after storage. Losses due to rinsing were minimal as were those following cooking for five minutes (Murphy 1992). Additional studies on the stability of vitamin A added to extruded rice grains in Brazil indicated vitamin A losses of approximately 25 percent during storage, and similar losses occurred under normal cooking conditions (Flores et al. 1994).

Attempts to fortify artificial rice grains with both vitamin A and iron showed that vitamin A was oxidized by iron, resulting in a discolored product (Murphy 1996). Combination of two separately produced simulated rices—one with vitamin A and one with iron—is possible but will require considerable work to prevent discoloration due to added iron (Murphy 1996).

Bioavailability of Nutrients

Absorption of added nutrients, particularly iron, varies widely depending on the fortificant used. Selection of the form of iron to be used as a fortifying agent requires consideration of the chemical and physical properties of both the fortifying agent and the food to be fortified

(Whittaker and Dunkle 1995). Bioavailable forms of iron are usually chemically reactive and often produce undesirable effects in the food. For this reason, inert iron compounds are commonly used but they are often poorly absorbed (Cook and Ruesser 1983). For example, ferric orthophosphate is currently the preferred form of iron for rice enrichment in the United States because of its white color and water insolubility. This compound, however, is not readily available for absorption by the body. Reduced iron has been used but is not preferred since it is sensitive to the magnets used in processing to remove tramp metal (Whittaker and Dunkel 1995). In Japan, eight iron compounds are permitted in foods. However, ferric pyrophosphate is most often used for rice since it does not affect the appearance, aroma, and flavor of cooked rice (Hunnel et al. 1985). Ferrous sulfate is more bioavailable than ferric orthophosphate but can produce undesirable sensory changes in cereals during storage. Electrolytically reduced iron has also been used because of its increased bioavailability (Peil et al. 1981).

Sensory Evaluation

The appearance, texture, taste, and aroma of enriched rice must be evaluated to assess consumer acceptability. A number of sensory studies conducted in Japan on *Shingen* enriched rice showed that the addition of nutrients did not affect the appearance, aroma, or taste of the cooked rice (Misaki and Yasumatsu 1985).

A recent investigation on the sensory quality of rice fortified with vitamin A indicates that further research is needed to determine the effect of oxidation, light, and heat on vitamin A added to rice (Walker 1997). Given the significance of recent regulations in the United States requiring folic acid to be added to enriched rice, a study examining the sensory quality of rice fortified with folic acid is currently underway at the University of Arkansas.

Benefits of Rice Fortification on Micronutrient Status

The highly successful study conducted in the Philippines in 1948-50 demonstrated the value of rice fortification in preventing beri-beri (Salcedo 1950). Demonstrating biologic impact of rice enrichment, as in any food fortification scheme, is complex. Providing scientific substantiation for the effectiveness of food fortification has been identified as a scientific barrier to food fortification (ILSI 1996). For example, iron status does not change rapidly with iron fortification (Cook and Ruesser 1983). It is recognized that changes in iron status must take into consideration other potential factors including parasitism, malabsorption, and chronic infection. Results from clinical studies in Japan indicated that consumption of enriched rice resulted in improved hemoglobin status (Koyanagi et al. 1982). The bioavailability of vitamin A in artificially produced rice kernels was assessed in a field trial conducted in Brazil (Flores et al. 1994). Results indicated that the serum retinol levels improved in children consuming the fortified rice.

Constraints and Opportunities

Although food fortification can be an effective means of improving micronutrient status, constraints exist in countries where micronutrient deficiencies are common. Obstacles to the successful introduction of rice enrichment using the premix method were identified many years ago (FAO 1954). These included the need for appropriate quality control at mills; nutrient losses due to cooking in excess water; and lack of information on nutrient loss in storage. Decades of research on rice enrichment and fortification practices have provided a better understanding of the technology needed; however, some technical problems remain. Some of these can be addressed through additional research on iron-rice interactions and the development of functionally suitable and bioavailable iron fortificants. More attention also needs to be directed to improving stability of added nutrients. Given the progress made to date in vitamin A fortification, continued research is warranted to address some of the remaining technical difficulties identified for fortifying rice with vitamin A (Murphy 1996).

Programmatic barriers to implementing rice enrichment were identified in rice fortification studies in Thailand (Welsch et al. 1979). These included concerns related to production, milling and marketing systems, storage facilities, millers' attitudes, fees, and consumer acceptability. These concerns will vary from country to country. One concern is the number of rural and urban rice millers in the country. For example, in the Philippines most rice is cultivated on small farms and milled in over 10,000 mills throughout the country (Florentino 1995). Some farming households cannot afford milling fees and still rely on home pounding to remove the rice hull. Consequently, coverage of standardized fortification efforts may be limited. Some countries may have many small-scale millers in rural areas but the majority of the grain is milled in a few centrally located mills in urban areas. One consideration is to operate fortification programs through government agencies responsible for controlling the rice supplies. For example, in the Philippines the National Food Authority controls rice supply in the country and distributes about six percent of the total rice consumed in the country. This rice is distributed primarily to low-income groups and disaster groups likely to be affected by nutrient deficiencies.

Conventional wisdom has held that to be administratively feasible, the fortified food must be centrally processed. However, some early field trials have suggested otherwise (Austin 1978). Studies in Guatemala and Thailand have illustrated that village-level fortification was operationally feasible (Gershoff et al. 1975; Welsch et al. 1979). Decentralized milling may lend itself to geographic targeting of fortification programs to areas where deficiency problems exist (Austin 1978).

Shortcomings of many fortification programs in the past have been due to failure to establish an adequate quality assurance program (Clarke 1995). Ensuring that the premix is added in correct proportions at the mill has been identified as an obstacle. Quality assurance systems and quality control measures need careful consideration, particularly if a large number of mills are involved. Reference methods have been established to analyze levels of added nutrients, and protocols are currently being developed by FAO/WHO to determine reliable analytical tests.

Cost is considered a most basic consideration in promoting food fortification programs. Costs incurred generally include costs of the fortificants; transport; equipment; equipment maintenance; production labor; quality assurance, including assays; any special packaging needed; monitoring and evaluation; and enforcement and legislation (Nestel 1993). With the exception of vitamin A, the cost of the added nutrients to cereal grains is negligible. Ranges from 1.5 cents per person per year for added iron to 29 cents per person per year for added vitamin A have been reported (Lotfi et al. 1996). Commercial vitamin-mineral premixes can reduce the quality control costs by providing uniform nutrient levels. The capital costs of launching a food enrichment/fortification program, however, must be balanced against the cost of not implementing a program which may result in public health problems, increased medical costs, and decreased productivity due to resulting deficiencies. USAID/OMNI has investigated the cost-effectiveness of various strategies to improve micronutrient status, including food fortification programs.

Program planners can learn from the decades of experience in rice fortification technology. Applying known rice fortification technology in rice consuming countries where deficiencies are common provides an opportunity to reduce the economic and social burdens that are placed on the population due to micronutrient deficiencies. The benefits to the producer and the miller of adding value to rice by improving its nutritional quality needs to be determined to promote food fortification programs. Applied research to address these considerations will contribute to tailored programs that are appropriate for specific rice milling situations and nutritional needs within a given country.

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