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Rice fortification: Potential for improving micronutrient intake and steps required for implementation at scale

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Abstract
Food fortification has been used historically to improve the nutritional quality of the food supply. Deficiency diseases such as goiter and rickets that were widespread at the turn of the century rarely occur in the general US population because of fortification programs. The Food and Drug Administration (FDA) in the 1940s and1950s established standards of identity for enriched staple foods (e.g., flour, bread, rice, corn meal) and specified levels of thiamin, riboflavin, niacin, and iron to be added for reducing deficiencies of certain B vitamins and iron to achieve the target of good public healthy early 1950.
These cereal-grain products were considered to be appropriate vehicles for fortification because they were consumed by most of the US population and provided a significant percentage of the daily energy intake. Guidelines for food fortification have evolved as interest in adding nutrients to foods has shifted from prevention of deficiency diseases to broader issues of improving overall health and as concerns have been raised regarding over-fortification of the food supply with nutrients such as iron.
In part as a result of debates about increased iron fortification the FDA stated that decisions relative to food fortification should be based primarily on clinical and biochemical data rather than on dietary data alone, as had been the basis of earlier proposed fortifications.
Food fortification can lead to relatively rapid improvements in the micronutrient status of a population, especially of vulnerable groups. It comes at a very reasonable cost, especially if advantage can be taken of existing technology and local distribution networks. Furthermore, it does not require any behavioural change on the part of the consumer. Salt is a classic example. By making it mandatory by law to add iodine to all salt meant for human consumption, India is making significant progress toward sad dressing iodine deficiency disorders.

Keywords: rice fortification, nutrients and micronutrients, vitamins, minerals

Introduction
Fortification is the process by which one or more micronutrients are added to food during processing to increase the level of specific nutrient(s) or to restore nutrients lost during food manufacturing (e.g., by washing and milling). Food fortification has been highlighted as a very cost-effective way to address micronutrient deficiencies in the general population [1, 6] as micronutrient malnutrition or "hidden hunger" remains a large public health problem, affecting more than 2 billion people worldwide [1, 30] and common in developing countries such as Asia, Africa and the Pacific. There are several deficiencies and their effects which are discussed as below

(a)Vitamin A deficiency
Vitamin A deficiency can lead to diseases such as xerophthalmia, Bitot's spot, conjunctival xerosis, corneal lesion, xerosis, ulcer, scars and keratomalacia. All of these deficiency conditions can lead to poor vision or total blindness if left [7, 29]. For example, during the year 2000, in India 5,049,139 people were affected out of a total population of 841,523,272 [14].

(b) Iron deficiency
India continues to be one of the countries with a high prevalence of iron deficiency anaemia (IDA). National Health Family Survey (NHFS, in 1998-1999) revealed that about 70-80% of children, 70% of pregnant women and 24% of adult men were suffering from IDA [15].

(c) Folic acid deficiency
Folic acid is one of the important B-complex vitamins essential for biosynthesis of DNA, and for purine and amino acid inter-conversions. It cannot be synthesized by the body and

therefore it needs to be obtained from dietary sources. Folic acid deficiency leads to cardiovascular diseases, major depression, schizophrenia, Alzheimer's disease, and some carcinomas such as colorectal, uterine, cervical, lung and oesophageal. Various studies have shown that adequate intake of folate during early pregnancy reduces the risk of abnormalities in early embryonic brain development and specifically the risk of malformations of the embryonic brain/spinal cord, collectively referred to as NTDs [18, 19].

2. Why rice fortification?

Rice is a rich source of macro and micronutrients in its un-milled form i.e. rich source of vitamins B1, B6, E, and niacin [30]. During rice milling the fat and micronutrient-rich bran layers are removed to produce the commonly consumed starch-richi.e. white rice and we losses the majority (75–90%) of these vitamins. Only Parboiling may keep more than 50% of the water-soluble vitamin levels of brown rice remain, and this is due to their migration from the outer layers to the endosperm [24]. White rice is the number one staple food in southeast and northeast Asia, one of the most densely populated regions in the world where 90% of world's rice production, is grown and consumed. On average, 30% of calories come from rice and this can increase to more than 70% in some low-income countries [13] and in these regions, the words for rice and food are synonymous.

Rice is therefore a potentially excellent product for delivering micronutrients to a very large number of people and has the potential to significantly alleviate micronutrient deficiencies but will work only as long as fortified rice is economically accessible to people at the bottom of the income pyramid. However, this will only achieve the desired result as long as the sensory characteristics of the end product are not discernibly changed and people do not object to incorporating fortified rice into their daily diet.

Table 1 Rice intake (grams and kilocalories per person per day), percentage of calories from rice, prevalence of stunting among children under five years old, prevalence of anemia among preschool children, vitamin A deficiency among preschool children, and proportion of the population with insufficient iodine intake in some countries where rice is the main staple food

	Rice intake/person/day		Calories from rice	Stunting among children under five years old	Anemia among preschool children	Vitamin A deficiency among preschool children	Insufficient iodine intake
Country	g	kcal	%	%	%	%	%
Bangladesh	475	1,727	83	43	47	22	71
Lao People's Democratic Republic	454	1,465	71	48	48	45	27
Cambodia	439	1,530	74	40	63	22	NA
Viet Nam	387	1,390	67	31	34	NA	84
Myanmar	386	1,204	58	35	63	37	38
Thailand	365	1,323	64	16	25	16	35
Indonesia	349	1,259	61	37	45	20	64
Philippines	338	1,213	59	32	36	40	65
Guinea	290	1,068	52	40	79	46	64
Madagascar	289	1,074	52	50	68	42	NA
Sri Lanka	284	1,004	49	17	30	35	31
Guinea-Bissau	271	991	48	32	75	55	NA
Liberia	263	968	47	42	87	53	4
Sierra Leone	253	897	43	36	83	75	NA
Guyana	224	796	38	18	48	NA	27
Republic of Korea	223	883	43	0	17	NA	NA
Nepal	218	760	37	49	78	32	35
Brunei Darussalam	211	749	36	0	24	NA	NA
China	209	794	38	10	20	9	16
Democratic People's Republic of Korea	209	744	36	32	32	28	NA
Malaysia	203	731	35	17	32	4	57
Senegal	196	707	34	19	70	37	76
India	187	676	33	48	74	62	31
Timor-Leste	184	607	29	58	32	46	NA

Source: Food and Agriculture Organization [12], UNICEF [23], De Benoist *et al.* [8, 9], World Health Organization [28].

3. Micronutrients: selection and suitability

The selection of micronutrients depends on their legal status, price, expected bioavailability, stability, and sensory acceptability. It also depends on the product forms fitting the applied fortification technology as in some technology, water-soluble forms may be suitable, and in others water insoluble or even oily forms may be suitably preferred.

(a) Minerals

Zinc deficiency is often an important public health issue. Zinc oxide in rice fortification is doubtless the product form of choice unless a highly water-soluble product form is needed. Zinc oxide does not cause taste issues, has a good bioavailability, is cheap, and has no effect on color. There is also no effect at the levels used on vitamin Astability. Zinc sulphate works as well, but it is more expensive and there might be a negative effect on vitamin A stability when used together [21].

Iron is considered one of the most limiting micronutrients, especially in diets based mainly on polished rice. Unpolished rice contains about 2.6 mg iron/100 grams. The native molar ratio of phytate to iron (>10) might inhibit absorption. In polished rice the iron level can be as low as 0.4–0.6 mg/ 100 grams [25]. Considering the already low bioavailability of iron

in unpolished rice due to the amount of phytate [16], the physiological effect of the reduction of intrinsic iron from milling is expected to be low. Iron fortification and polishing of rice improves the phytate: iron ratio. Thus, bioavailability studies based on the active substance alone have to be considered with care. Fortification of rice with iron is only indicated if other suitable vehicles for iron fortification are not available in the food basket.

Ferric pyrophosphate is often used in rice fortification. It is nearly white or off-white, and due to its low solubility at the pH of rice, interaction with other rice components and other nutrients is low. Thus, the effect on color during storage of rice kernels is minimal. There is alsominimal effect on the promotion of rancid fat or degradation of vitamin A. Regular ferric pyrophosphate has a mean particle size of about 20 µm and shows a relatively low interaction with the food matrix; however, the bioavailability of this grade is the lowest among the ferric pyrophosphates. Milled ferric pyrophosphate has a mean particle size of about 2–3µm; it has a higher bioavailability than regular ferric pyrophosphate, and it shows more interaction with the rice matrix [22, 26]. Nanoparticles of ferric pyrophosphate in an emulsifying matrix are not water soluble, but are reported to have a bioavailability comparable to ferrous sulphate due to the very small particle size. However, this depends heavily on the food matrix, and in rice this has proved not to be the case. It has been shown that in hot-extruded rice the relative bioavailability (RBV) of ferrous sulphate from micronized dispersible ferric pyrophosphate is only 24%. If added to rice without extrusion, the RBV is only 15%. Thus, the hot-extrusion process increases the RBV by 60%. In absolute terms the availability is only at 3%. Emulsified nanoparticles are expensive and the high cost from this formulated product might be an obstacle [15]. In some countries, such as the United States, ferric orthophosphate is used in rice fortification, but this nearly white powder has an even lower bioavailability than ferric pyrophosphate [18, 19].

Ferrous sulphate should only be used in special cases due to its interaction with the rice matrix. Only dried ferrous sulphate is useful and the product is limited to use in only a few technologies. It might be used in dusting and in some coating techniques; however, it can turn brown over time when converting to ferric sulphate. In addition, the water solubility of ferrous sulphate is an issue. Washing and cooking rice leads to high losses of this iron form, especially if excess water is drained after cooking. Ferrous sulphate has a metallic taste, and its taste and color effects depend on the quality of the ferrous sulphate used, even when specifications might be identical.

Iron ethylenediamine tetra acetic acid sodium salt (NaFeEDTA) would be a product form of choice in rice fortification due to the high iron bioavailability in the presence of absorption inhibitors, such as phytate.

Ferrous fumarate is widely used in cereal fortification; however, in rice fortification it is not recommended because of its effects on color and taste. Elemental iron, though cheap, is also not recommended. It does not work in dusting and in extruded kernels as it leads to gray discoloration and its bioavailability is low.

Neither unpolished nor polished rice are rich sources of calcium. Calcium carbonate ($CaCO_3$) is a suitable calcium source and has a whitening effect, which might be useful in hot extrusion if more opaque kernels are needed (levels up to 30% $CaCO_3$ occur in fortified kernels). Hot extrusion at high mechanical energy input leads to glossy, semi-transparent kernels that resemble parboiled kernels. Other calcium sources are calcium chloride or calcium lactate gluconate. Calcium chloride has limitations due to the effect on taste. Rice fortification techniques require highly soluble forms and, in these cases, calcium lactate gluconate is recommended. However, to achieve any real fortification with calcium, large quantities of $CaCO_3$in the portion are required. Considering inclusion rates of only 0.5–1% of fortified kernels (extruded or coated), the kernels will hardly have sufficient carrier capacity to supply nutritional, meaningful calcium quantities. A negative effect on iron absorption at these quantities of calcium is not likely.

(b) Vitamins and other nutrients

Vitamin A palmitate, stabilized with antioxidants such as butylatedhydroxytoluene (BHT) and/or butylatedhydroxyanisole, is the most frequently used form of vitamin A in grain fortification. Vitamin A is the most sensitive among the most frequently used micronutrients in rice fortification. It is sensitive to light, elevated temperature, trace elements, and oxygen, as well as to low pH. The presence or absence of iron has a large effect on stability of vitamin A. Processing, washing, and cooking losses of vitamin A are moderate, though storage losses, especially at elevated temperatures, can be substantial (4–10% per month at least depending on temperature, product form, and fortification technology [4]). High-quality vitamin A has a light yellow color and has no color effect on the fortified kernels.

Vitamin E acetate can be used either as a dry preparation or a pure oily form, again depending on the technology as vitamin E is very stable in its acetate form. The product is white or colorless. Vitamins D and K are not currently used in rice fortification. Brown (unpolished) rice is an excellent source of thiamine and white rice is not, it was logical to consider the addition of this nutrient to white rice. Thiamine mononitrate is the form most often used. It is less soluble and less hygroscopic than thiamine hydrochloride. The use of hydrochloride makes sense only in techniques where high water solubility is needed., Thiamine modulates taste; it is sensitive to heat above 70 °C and has processing losses and long-term storage losses of 30–40%. Riboflavin and riboflavin 5-phosphate are both colorants and water-soluble vitamins. Fortification with this riboflavin is possible but leads to intensely colored kernels in cases where coating or extrusion technologies are used. Sice processing losses are close to 50%, in most cases fortification with this vitamin is not done.

The following four B vitamins are highly stable during processing and storage. The first is vitamin B3, also known as vitamin PP, nicotinic acid, or niacinamide. The latter is the form of choice for fortification. Nicotinic acid is less suitable as it is a strong irritant and the handling is critical. Second, vitamin B6 is a colorless, tasteless water-soluble vitamin; the suitable application form is pyridoxine hydrochloride. Third, folic acid (vitamin B_9) is a yellow/orange–colored vitamin, which is used in small quantities so as to minimize effect on color; and there is no effect on taste. For physiological reasons, it is highly recommended to apply folic acid in combination with the fourth vitamin B, vitamin B_{12}, which is a pink-colored substance that has nearly no effect on color because of the low level in final food products, and is neutral with respect to taste.

Vitamin C, as either ascorbic acid or sodium ascorbate, is suitable for rice fortification but requires special formulation techniques. Both of the above forms may lead to a color

change of the fortified kernels (to orange/light brown) but they work well in combination with _-carotene (pro vitamin A). The combination of carotene and vitamin C yields attractive orange kernels. The processing and storage losses of vitamin C are in the range of 30– 50%.

It is a very stable form of a vitamin A when protected with an antioxidant (e.g., ascorbate); however, the conversion of_-carotene to retinol depends on the vitamin A status, the amount of fat in the diet.

Rice is a good source of amino acids except for lysine, another essential nutrient of interest. Biological value of rice protein can be increased substantially by supplying additional lysine with a rice-based diet. One option is fortifying rice with lysine hydrochloride; although highly water soluble, the majority of coextruded lysine will survive washing and cooking of rice [11].

4. Technologies

Successful vitamin and mineral fortification of rice is a technological challenge, but the fortification of wheat flour or maize meal does not cause serious issues except for the potential stability issues of low-quality vitamin A forms. This is due to the size difference between rice kernels and micronutrients, which is much greater than that between flour and micronutrients. Simply mixing rice kernels with a micronutrient blend will lead to micronutrient separation, in homogeneity, and losses during production, transport, and further rice preparation, especially rice washing. One form of intrinsic micronutrient improvement in rice, rather than fortification, was the introduction of parboiling. Before removing the bran, rice kernels are soaked, steamed, and dried again. During these steps, the content of vitamins B1, B6, and niacin in the endosperm increases three fold due to their migration from the bran into the endosperm [30]. The total daily need of these vitamins might be covered. However, other micronutrients, such as iron and zinc, are not elevated in white rice after parboiling; this is why other means of micronutrient fortification are advisable.

(a) Dusting

It is observed only in the U.S., involves dusting the polished rice grains with the powder form of the micronutrient premix. During dusting, micronutrients in the form of fine particles are blended with the bulk rice. But, there is a segregation risk [3]. This method makes use of the electrostatic forces between the rice surface and the micronutrients. Washing and/or cooking in excess water leads to significant losses due to draining. These losses are so extensive that in the United States, a warning has to be printed on the label not to rinse the rice before cooking or not to cook in excessive water.

(b) Coating

Micronutrient losses through washing is prevented by adding high concentrations of micronutrients to a fraction of the rice and to subsequently coat the rice kernels with water resistant edible coatings, and then mix the coated kernels with normal rice in ratios ranging from 1:50 to 1:200. Several coating layers, usually alternated with layers of coating material alone, are added by spraying the suspension through nozzles into a rotating drum containing the rice kernels to be fortified. The same drum is generally used during drying of the kernels by means of a hot air current. Many different coatings have been tried, including waxes, acids, gums (e.g., agar), starches, and cellulosic polymers (e.g., hydroxypropyl methylcellulose, ethyl cellulose, and methylcellulose [5, 27]. When cooking with an excess of water, the majority of water-soluble nutrients will be lost (60–90%) [27]. The major problems encountered with coating technologies are related to color, taste, and a loss of micronutrients during washing and cooking also, if the coating is not resistant to cooking. The micronutrient layer will come off leaving the vitamins more exposed to heat and moisture. Some commercially available coated rice fortification premixes claim to be stable during washing and cooking. It is advisable to stress-test these materials before incorporation into national fortification programs. Coating technologies generally imply a lower initial financial investment than extrusion technologies, but the cost per metric ton of fortified rice is relatively comparable. Coating is practiced in the United States, Costa Rica, and the Philippines.

(c) Extrusion processing

These processing consists of hot extrusion and Cold extrusion.

Hot extrusion passes dough made of rice flour, a fortificant mix, and water through a single or twin screw extruder and cuts it into grain-like structures that resemble rice kernels. This process involves relatively high temperatures (70-110 °C) obtained by preconditioning and/or heat transfer through steam heated barrel jackets. It results in fully or partially pre-cooked simulated rice kernels that have similar appearance (sheen and transparency) as regular rice kernels. The teams visited two companies in China and one in the Philippines that used this technology.

Cold extrusion, a process similar to one used for manufacturing pastas, also produces rice-shaped simulated kernels by passing a dough made of rice four, a fortificant mix, and water through a simple pasta press. This technology does not utilize any additional thermal energy input other than the heat generated during the process itself, and is primarily a low temperature (below 70 °C), forming process resulting in grains that are uncooked, opaque, and easier to differentiate from regular rice kernels. One of the firms visited in Costa Rica uses this process.

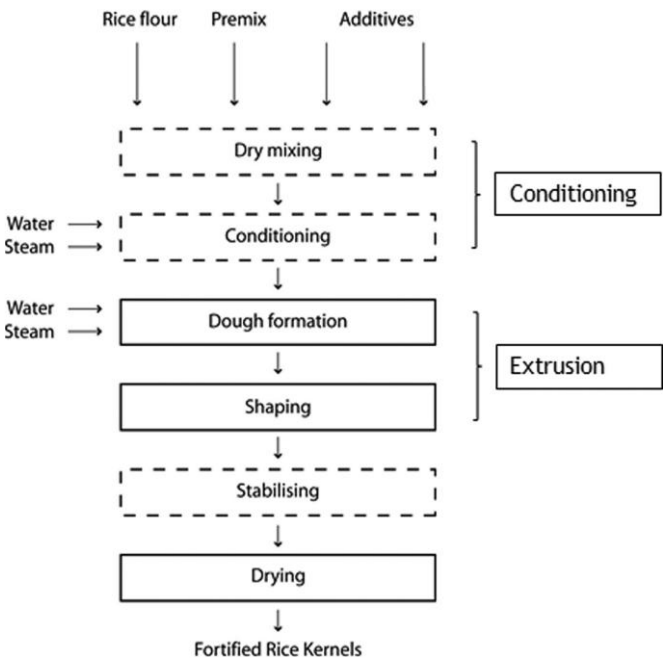

Fig 1: Different unit operations during extrusion processing of fortified rice kernels. Dashed boxes represent optional processing steps

5. Implementation Scale

Fortification of folic acid (100 to 150 µg/day) of cereal grain products resulted in decrease in NTDs in the United States and Canada [4, 5]. It has been observed that with the widespread consumption of wheat flour-based acid fortification should be adapted as a public health initiative in Europe [22]. In Australia, 2 per thousand live births are affected by NTDs attributed to folic acid deficiency. As a result, fortification of bread making flour with folic acid has been mandatory in Australia since September 2009 [27]. Although fortification of staple foods, oil, salt, and condiments is an effective means of addressing micronutrient deficiencies in the adolescent and adult population, fortification levels are determined as a function of the dietary needs of a healthy adult and will, therefore, usually fall short of meeting the requirements of groups with relatively high needs, such as young children and pregnant or lactating women [1]. These groups, therefore, often require specially fortified foods, such as complementary foods for young children, iron–folate tablets for pregnant and lactating women, or home fortification with micronutrient powder or small quantities of lipid-based nutrient supplements in addition to a diet that includes foods fortified for the general population [6, 10].

6. Conclusion

The biggest challenge in rice fortification is the development of a more efficient iron fortification strategy. The bioavailability of the presently used product forms in a rice matrix is low due to the intrinsic presence of phytate. An optimal product should have high bioavailability in the presence of inhibitors and, at the same time, low reactivity with the rice matrix, which otherwise leads to color change.

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