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Fortification of common salt with iron: use of polyphosphate stabilisers

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Fortification of common salt with ferrous sulphate and sodium hexametaphosphate appears to be a satisfactory method for the production of iron-fortified salt. There was no discoloration of the fortified salt. Iron stability was satisfactory. Iron distribution was uniform (1000 ± 50 ppm). Iron absorption was better than with the old formulae of iron-fortified salt. It was readily acceptable in place of common salt. Large scale production in factories was smooth and economical. These observations indicate that the production of iron-fortified salt by 'dry mixing' is suitable for a tropical country like India.

INTRODUCTION

Iron deficiency anaemia (IDA) is a major public health problem in developing countries (Baynes & Bothwell, 1990; WHO, 1990). The prevalence of IDA in the Indian population is high and ranges from 40 to 70% depending upon age and sex (Report, 1982). Use of iron fortified salt (IFS) has been shown to be the simplest and cheapest method of controlling IDA (Pichmani Subramanian, 1989). Increasing the iron content of the diet by IFS was shown to be an effective public health approach for the control and prevention of IDA in India (Report, 1982). A successful method for the fortification of salt with ferric orthophosphate as the iron source and sodium acid sulphate as an absorption promoter was reported earlier by Narasinga Rao and Vijayasarathy (1975). As the cost of fortification was high, an alternate process was developed by Narasinga Rao and Vijayasarathy (1978) using the less expensive ferrous sulphate as the iron source, along with orthophosphoric acid as the stabiliser and sodium acid sulphate as the absorption promoter. Although this process was acceptable in terms of stability and bioavailability of iron in the laboratory, several problems were encountered during the large scale manufacture of the fortified salt in factories. One of the problems was the discoloration of the fortified salt. The IFS turned yellow within a few days of fortification and the colour persisted whether it was stored as a heap or in bags of 1 kg and 50 kg capacities. It was possible to decolorise the IFS by adding an extra amount of orthophosphoric acid. However, this incurred additional expenditure to the manufacturer. Orthophosphoric acid is corrosive by nature and handling large quantities always poses problems. Furthermore, it is hygroscopic, and so there is a risk of adding less than the necessary quantity to the salt during fortification. Aqueous sodium acid sulphate solution is strongly acidic. Large scale manufacture in the factories at Tamil Nadu and Andhra Pradesh (India) showed that the repeated use of orthophosphoric acid and sodium acid sulphate during fortification damaged the inner parts of the fortification plant as corrosion took place. The manufacturer was forced to spend more money in replacing the damaged parts of the plant. All these factors finally increased the cost of production of the IFS. Attempts were, therefore, made to develop an alternative formula for salt fortification using ferrous sulphate and polyphosphates which have high iron chelating ability.

MATERIALS AND METHODS

Common salt was obtained from Tuticorin, Tamil Nadu (India). Food grade ferrous sulphate ($FeSO_4 \cdot 7H_2O$) and the polyphosphates were obtained from M/s Abhyudaya Chemical & Scientific Corporation, Hyderabad (India). Radioactive iron-59 and iron-55 were obtained from Bhabha Atomic Research Centre, Bombay (India) and Amersham International Inc. (UK). Radiolabelled ferrous sulphate was prepared according to the method of Steinkamp *et al.* (1955).

Common salt was fortified with ferrous sulphate at the 0·5% level (equivalent to 1000 ppm of iron) and different polyphosphates: sodium hexametaphosphate (SHMP), sodium tripolyphosphate (STPP), and tetrasodium pyrophosphate (TSPP) at the 0·5% and 1% levels. A stainless steel ribbon blender with a capacity to hold 100 kg salt was used for fortification. First, polyphosphate and ferrous sulphate were mixed well and the mixture was used to fortify the common salt by a 'dry mixing' process with a mixing time of 10 min. After the fortification of each batch of 100 kg, several samples of the IFS were drawn randomly and the distribution of iron was tested by the thiocyanate method (Wong, 1965). The random selection was done according to the ISI Handbook (1978). The effect of storage on the stability of iron at room temperature and at high humidity (76% RH) as well as discoloration of the IFS were tested.

Iron bioavailability was studied by the in-vitro method of Narasinga Rao and Prabhavathi (1978). Iron absorption was measured in 16 apparently healthy male volunteers aged 20–40 years. None of the subjects gave a history of disorders that might affect the absorption of iron from the gastrointestinal tract. They had normal haematological status. Their Hb was 13·5–17·0 g/100 ml with a mean Hb of 15·6. All the subjects were in good health and gave written informed consent before participating in the study, which was carried out in accordance with the Ethical Committee of the National Institute of Nutrition, Hyderabad, India. The IFS externally spiked with radio iron was given along with a rice- or wheat-based meal. The extrinsic tag method for dietary iron absorption has been validated by a number of workers (Cook *et al.*, 1972; Bjorn-Rasmussen *et al.*, 1973; Layrisse *et al.*, 1973). About 100 g of the IFS was labelled with a radioactive iron (^{59}Fe) compound. After an overnight fast, these subjects were given a rice- or wheat-based lunch. Doses of 5 g of ^{59}Fe-labelled IFS, providing 5 mg of iron, was incorporated into the meal in the same way as salt is normally used. The next day, 5 mg of iron in the form of freshly prepared ferrous sulphate labelled with a second isotope ^{55}Fe was given in a similar way. About 5 μCi of ^{59}Fe and 10 μCi of ^{55}Fe were administered. Body retention of iron was determined in blood after 12 days by measuring ^{55}Fe and ^{59}Fe activities by a modification of the procedure of Eakins and Brown (1966) in which the final precipitation of the white complex of Fe was carried out directly in the liquid scintillation counting vial (Narasinga Rao & Vijayasarathy, 1975).

Acceptability of the IFS was studied by distributing both the IFS and the unfortified salt to 60 families drawn from different socio-economic backgrounds. The families did not know which salt was the IFS. They were requested to use both types of salt in their food preparations, each one for a period of 10 days, and their observations were recorded with respect to organoleptic properties, such as colour, taste, smell and texture.

Large scale production of IFS was tested in the factories of M/s Sundar Chemicals Pvt Ltd, Madras (India), M/s Jaybharathi Salts Pvt Ltd, Hyderabad (India) and Mariyur Valinokkam Salt Complex, Valinokkam, of the Tamil Nadu Salt Corporation (India).

RESULTS

Colour formation

Both STPP- and TSPP-added salts turned orange-red after 2 days of fortification (Table 1). SHMP-added salt did not develop any colour throughout the study period of 1 year.

Iron stability

The effect of storage on the stability of iron in the IFS was satisfactory. The iron remained stable at the initial level of 1000 ppm up to 1 year of storage. Iron stability was quite satisfactory even in high humidity conditions.

Iron distribution

Analysis of hundreds of samples showed that the distribution of iron in the IFS was uniform, approximately 1000 ppm with a range of 950–1050 ppm.

Bioavailability of iron

Iron was available in a soluble form even at the end of 1 year. The in-vitro bioavailability of iron was 40% and no significant change was observed after 1 year of storage. The results of absorption studies in human volunteers are given in Table 2. The percentage iron absorption ranged from 6·0 to 9·0% with an average value of 6·9% for the rice meal and 3·0–6·4% with an average value of 4·0% for the wheat-based meal. The ratio of absorption of iron of the IFS to ferrous sulphate for the rice-based meal was 1·2–2·5 with a mean value of 1·6 and for the wheat-based meal it was 1·3–2·9 with a mean of 2·0. The iron absorption of the IFS was significantly high ($p < 0{\cdot}001$) as compared to ferrous sulphate.

Table 1. Effect of storage on the colour of the iron-fortified salt

Stabiliser	Level	Colour of the fortified salt	Time of colour change
STPP	0·5% and 1%	Orange-red	<2 days
TSPP	0·5% and 1%	Orange-red	<2 days
SHMP	0·5% and 1%	White	—

Table 2. Iron absorption from iron-fortified salt when given with a meal

No.	Subject		Percentage absorption		Ratio (A/B)
	Wt (kg)	Hb (mg/dl)	^{59}Fe IFS (A)	^{55}Fe ferrous sulphate (B)	
Rice based meal					
1	70	17·0	6·6	4·9	1·4
2	75	15·5	7·1	3·4	2·1
3	50	15·9	8·7	4·1	2·1
4	47	16·4	6·3	2·5	2·5
5	71	15·8	6·1	5·3	1·2
6	60	15·6	6·2	6·1	1·0
7	61	13·5	6·0	5·1	1·2
8	65	16·4	8·1	5·5	1·5
Mean	62·4	15·8	6·9[a]	4·6[a]	1·6
± SEM	±3·53	±0·37	±0·36	±0·42	±0·20
Wheat based meal					
9	69	14·5	3·5	2·6	1·3
10	71	14·2	3·1	1·6	1·9
11	52	16·0	6·4	2·7	2·4
12	49	15·5	4·0	2·4	1·7
13	75	14·7	3·0	2·0	1·5
14	61	15·0	3·6	1·3	2·9
15	59	16·7	4·4	2·1	2·1
16	66	16·5	4·2	2·0	2·1
Mean	62·8	15·4	4·0[b]	2·1[b]	2·0
± SEM	±3·24	±0·33	±0·38	±0·17	±0·18

[a,b] $P < 0{\cdot}001$.

Acceptability of the IFS

The results showed that the IFS was readily acceptable to the families who participated in the acceptability trials. It was as good as unfortified salt in normal cooking with most commonly used food preparations according to observations made by the participants. The IFS did not change the colour or taste of the food preparations.

New formula

The addition of SHMP at the 0·5% or 1% level did not change the stability, bioavailability or acceptability of the IFS. The new formula has the following composition: 100 kg salt + 0·5 kg SHMP + 0·5 kg ferrous sulphate ($FeSO_4 \cdot 7H_2O$).

Factory production

Production of the IFS by the new formula did not pose any problem in the factories. The IFS retained the original colour of the unfortified salt whether it was stored as a heap or in bags of different capacities. Prolonged use of SHMP and ferrous sulphate did not damage the inner parts of the fortification plant. The IFS was free-flowing. Uniform distribution of iron was observed in the factory as the iron content was 1000 ± 50 ppm when several tonnes of the IFS were produced and samples were analysed periodically from the bulk (Table 3). The pH values of a 5% aqueous solution of SHMP, ferrous sulphate and the IFS were 5·3, 3·2 and 3·3 respectively. SHMP was freely soluble in water and the weight percentage of P_2O_5 was 70%.

Cost of the IFS

The cost of SHMP used in the new formula was less (18 paise/kg IFS) than the combined cost of orthophosphoric acid and sodium acid sulphate used in the old formula (35 paise/kg IFS).

Table 3. Analysis of randomly selected iron-fortified salt

Test	Result
Colour and appearance	White crystalline solid
NaCl content	98% on dry weight basis
Moisture	2% by weight
Iron	950–1050 ppm
Phosphorus	1500–1600 ppm
pH of 5% aqueous solution	3·3
Magnesium (water soluble)	0·04% by weight
Sulphate	0·3% by weight
Water-insoluble matter	0·4% on dry weight basis
Acid (HCl) insoluble matter	0·3% on dry weight basis
Water-soluble matter other than NaCl	1% on dry weight basis

DISCUSSION

IDA is a global nutritional problem. The magnitude of this problem is much greater in countries like India than in developed countries. Fortification of foods with iron has been considered as an effective means of preventing this disorder (WHO, 1975; INACG, 1977). Although bread has been traditionally used in the industrialised countries as a vehicle for iron fortification, it is not suitable for Indian conditions since its consumption is not universal in India. Common salt is considered to be a suitable vehicle in India for iron fortification as it satisfies all the criteria of an ideal vehicle. Salt is produced in a few centres. A well established salt distribution system exists in India. Salt is consumed by all segments of the population, rich or poor, irrespective of the socio-economic background. Salt consumption lies within a narrow range of 10–15 g per day. Salt is a cheap commodity and easily available. Furthermore, the usefulness of the IFS in controlling and preventing IDA has been clearly demonstrated in the country (Report, 1982).

Although earlier studies have shown the feasibility of the production of the IFS by using either ferric orthophosphate (Narasinga Rao & Vijayasarathy, 1975) or ferrous sulphate (Narasinga Rao & Vijayasarathy, 1978), the commercial production of the IFS was hampered by problems such as the discoloration of the IFS and the corrosion of the plant. Inorganic polyphosphates are used extensively in the food industry as stabilisers, anticaking agents, sequestrants, rancidity preventers, and antimicrobial agents (Ellinger, 1972; Zoller *et al.*, 1980; Suwanik, 1980). They form soluble complexes with iron and thereby promote iron absorption. The use of polyphosphates was, therefore, suggested for improving the iron availability and several investigators have shown that polyphosphates increase the absorption of essential minerals such as iron (Chapman & Campbell, 1957; Dymsza *et al.*, 1959; WHO, 1964; Ellinger, 1972; Subba Rao & Narasinga Rao, 1985). No adverse physiological effects were observed. These studies indicated adequate absorption and utilization of iron with both high (3·5%) and normal (0·9%) levels of polyphosphates. Earlier studies with various polyphosphates have shown that SHMP has higher iron-chelating ability compared to STPP and TSPP. The chelate retained more than 90% iron in a soluble form at pH 7·5. When these polyphosphates were added to foods they increased the ionisable iron 3–7 fold at pH 7·5 (Subba Rao & Narasinga Rao, 1983, 1985). However, SHMP was found to be less effective than TSPP.

When STPP and TSPP were added to common salt along with ferrous sulphate, the IFS turned orange-red within a few days of fortification. Though STPP and TSPP could increase the ionisable iron significantly, the discoloration of the IFS rendered them unsuitable for salt fortification. On the other hand, the addition of SHMP did not change the colour of the IFS even after 1 year of storage. The stability of iron in the IFS was quite satisfactory after 1 year, either in room conditions or in high humidity conditions. Analysis of several hundreds of the IFS samples showed that the iron content was approximately 1000 ppm.

The observed iron absorption for the rice-based meal (6·9%) was higher than the values (<4%) reported earlier for the IFS in India (Narasinga Rao & Vijayasarathy, 1975, 1978). In the present study, better values were observed in the case of the wheat-based meal also (Table 2). The inter-individual variation was not great for either type of meal. The maximum spread was 3% irrespective of the meal type (6–9% for the rice meal and 3–6% for the wheat meal). The absorption ratio of the IFS to ferrous sulphate was relatively constant, but highly significant. The mean ratios of 1·60 and 2·00, for the rice and wheat meals respectively, indicated that the absorption of iron from the IFS was approximately double that of ferrous sulphate. The absorption ratios were higher than the values reported earlier (0·7–0·8%) for the IFS (Narasinga Rao & Vijayasarathy, 1975, 1978).

The acceptability trials showed that the IFS was as good as the unfortified salt. The factory production was smooth and economical. The production of the IFS did not damage the salt mixing unit, whether it was done at the sea coast (Madras and Valinokkam, India) or inland (Hyderabad, India). Addition of SHMP did not increase the cost of the IFS. At present, SHMP is manufactured in small quantities according to demand. The large scale manufacture of the IFS may create a greater demand for SHMP which in turn will further reduce the price of SHMP and also the IFS.

The FAO/WHO Expert Committee on Food Additives studied the toxicological aspects of polyphosphates and recommended an unconditional acceptance level of <30 mg/kg body weight per day and a conditional acceptance level of 30–70 mg/kg body weight per day (Joint FAO/WHO, 1982). The unconditional acceptance level is considered safe in any of the diets known in the world, while the conditional level is acceptable only when the dietary calcium level is higher than 1 g/day. The maximum tolerable daily intake of phosphorus, through the intake of SHMP from regular diets, is 70 mg/kg body weight (FAO/WHO, 1984, 1985; Joint FAO/WHO, 1986). The Acceptable Daily Intake code for SHMP is FU which means full or unconditional and the evaluation of SHMP is considered to be complete.

The rich sources of phosphorus in Indian diets are cereals, pulses, nuts and oil seeds. However, much of the phosphorus (40–80%) in these foods, particularly in cereals, is present as a component of phytin, which is not available to the body. The results of animal feeding studies reported in the literature indicate that levels of

0·5% of the phosphates could be tolerated in the diet without adverse physiological effects. This level of phosphate is highly unlikely in human diets (Ellinger, 1972). In the Indian situation the total phosphorus intake from the SHMP formula IFS would be much lower than the permitted level.

Thus the present study shows that the addition of SHMP at a level of 0·5% to salt, along with ferrous sulphate, may be suitable for manufacturing the IFS on a large scale.

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