UNIVERSITY OF TORONTO

DOUBLE FORTIFICATION OF SALT

Phase 2 Final Report

DEPARTMENT OF CHEMICAL ENGINEERING
AND APPLIED CHEMISTRY

DOUBLE FORTIFICATION OF SALT

Phase 2 Final Report

Prepared for
The Micronutrient Initiative, Ottawa
International Development Research Centre ?

by
Levente. L. Diosady, Ph.D., P.Eng.
Professor of Food Engineering
University of Toronto
Department of Chemical Engineering
and Applied Chemistry
200 College St.
Toronto M5S 3E5
Canada

Executive Summary

Over the past decade the magnitude and consequences of global malnutrition have been increasingly recognized. Deficiencies in small quantities of micronutrients, especially iodine and iron, severely affect more than a third of the world's population. In the less developed countries these deficiencies have serious public health consequences, especially for women and young children.

Salt is an ideal carrier of micronutrients. Iodized or iodated salt has long been available in developed countries and the problem of iodine deficiency has been virtually eliminated in North America and most European countries. The double fortification of salt with both iodine and iron is an attractive approach to the reduction of both anemia and IDD. Unfortunately when iron and iodine are both added to salt the iodine is converted to elemental; iodine, which can sublime, and thus it is rapidly lost. Iron is also readily oxidized to the ferric form, which has a lowered bioavailability, an unpleasant taste and unsightly, yellowish brown or rust colour. Despite the apparent chemical incompatibility of iron and iodine, two previously published reports indicated that it may be possible to stabilize iodine on salt in the presence of iron.

In the preliminary stage of our development program we investigated the effect of packaging materials and environmental conditions on the stability of iron and iodine double-fortified salt., and also examined the technological problems associated with the field application of salt double-fortification.

The results clearly indicated that iodine is rapidly lost after initial mixing. Calcium chloride did not have a sparing effect on iodine, despite contrary reports in the literature.

The highest iodine losses were observed at 40° C, 100% relative humidity.

The most important finding of the study was the effect of magnesium chloride, a hygroscopic impurity often found in unpurified salt. It dramatically increased the moisture content of the salt, and resulted in the almost immediate loss of more than 90% of the added iodine.

The work demonstrated that it is important that adsorbed water, iron and iodine do not come into contact on the salt surface. The use of refined (purified) salt is technically feasible, but it would be economically unviable in most developing countries.

We suggested that better results could be achieved by encapsulating the iodine or perhaps the iron compound in an inert carrier that prevents their reactions and degradation. The forming of a physical barrier between the iodine compound, water and iron would stabilize the system. Encapsulating agents could include such stabilizers as sodium hexametaphosphate, dextrin, or even purified salt.

In the present phase of the project we have investigated the effect of encapsulation on the stability of double fortified salt. A total of 83 samples were prepared, and their stability tested over a period of up to one year. A wide range of encapsulating agents, and iron compounds were tested in combination with potassium iodide and potassium iodate as iodine sources.

The program clearly demonstrated that physically isolating the iodine by encapsulation results in acceptable iodine retention under the worst expected storage and distribution conditions. The program found that potassium iodide encapsulated in dextrin is most stable in combination with ferrous fumarate. The organoleptic qualities of this formulation were good, and it will therefore form the basis of in-vivo bioavailability tests in humans, which will be commenced shortly.

In vitro and in vivo tests on rats showed that all of the successful encapsulating systems retained the bioavailability of both iodine and iron, and the application of this technique will not be limited by biological factors.

In the next phase of the program the technology of encapsulation must be further tested on a pilot scale, since laboratory-scale spray dryers use relatively large quantities of encapsulating agents, and their performance is not directly comparable to that of industrial equipment.

Background

Over the past decade the magnitude and consequences of global malnutrition have been increasingly recognized. Deficiencies in small quantities of micronutrients, especially iodine and iron, severely affect more than a third of the world's population. In the less developed countries these deficiencies have serious public health consequences, especially for women and young children.

The lack of iodine in the soil and water and thus, in food, leads to Iodine Deficiency Disorders (IDD) which includes goiter and a wide spectrum of mental and intellectual defects of varying degrees of severity including cretinism, paralysis and deaf-mutism. IDD can also lead to stunted growth and development, miscarriages, still births and infant deaths.

Anemia due to iron deficiency results in a major reduction in work capacity and impaired immune response which leads to a higher incidence of infection, increased risk of maternal and fetal morbidity, and reduction in body growth. The combined impact of these deficiencies results in a severe retardation of social and economic development of entire populations.

The fortification of commonly used foods is an important component of the strategy to combat micronutrient malnutrition. Salt is an ideal carrier of micronutrients in view of its almost universal coverage and uniform regional consumption. Iodized or iodated salt has long been available in developed countries and the problem of iodine deficiency has been virtually eliminated in North America and most European countries. Yet, because the severity and extent of IDD were not widely recognized until recently most of the affected countries begun to take steps towards universal iodization of salt only in the past few years. Many developing countries which now have iodization programs in place, have begun to achieve a significant reduction in IDD.

Encouraged by the progress made in several countries in implementing successful salt iodization programs, efforts have been directed to examining the feasibility of fortifying salt with iron along with iodine. With production and monitoring infrastructure for iodization programs already in place, such an integration and coordination would be the most cost efficient method of ensuring adequate levels of both iron and iodine in the population.

This poses a challenge in developing a formulation in which both the iodine and iron are stable and bioavailable. When attempts were initially made in the mid 1980's to incorporate iodine and iron in salt at the same time, there were problems with the stability of both micronutrients.

Salt can be iodized with either potassium iodide (KI) or iodate (KIO_3). While the former is stable in refined dry salt, the latter shows better stability in low-quality salt in poor packaging. Ferrous iron can oxidize to ferric, which is not as soluble, and therefore the bioavailability of iron is lowered.

When the iron is added as ferrous sulphate to an impure salt, which is hygroscopic, the system becomes acidic. In an acid medium the oxidation of the iodide to iodine takes place rapidly, producing free iodine, which vaporizes, and is lost. Potassium iodate is an oxidizing agent. When it is mixed with ferrous iron it tends to oxidize Fe^{++} to Fe^{+++}, while it is reduced to the volatile I_2 or KI. In order to tackle the problem of incompatibility between iron and iodine salts, two approaches have been proposed: using ferrous sulphate with a chelating polyphosphate stabilizer along with potassium iodide (Rao, N.B.S. 1990); and using ferrous fumarate along with potassium iodide (Venkatesh Mannar et al. 1989).

Narasinga Rao of the National Institute of Nutrition used ferrous sulphate (1000 ppm Fe), potassium iodide (20 ppm I_2) and a stabilizer (a chelating polyphosphate, later reported to be sodium hexametaphosphate). While he has reported that the bioavailability and stability of the double fortified salt under different conditions of storage and acceptability were found to be good, the analysis of salt from a larger-scale test showed less than 3% of the initial iodine levels after distribution. Our own tests showed that SHMP is a good stabilizer, but it fails to protect the iodine under adverse conditions, especially in impure salt

In the preliminary stage of our development program we investigated the effect of packaging materials and environmental conditions on the stability of iron and iodine double-fortified salt., and also examined the technological problems associated with the field application of salt double-fortification.

The results clearly indicated that iodine is rapidly lost after initial mixing. Calcium chloride did not have a sparing effect on iodine, despite contrary reports in the literature.

The highest iodine losses were observed at 40° C, 100% relative humidity.

The most important finding of the study was the effect of magnesium chloride, a hygroscopic impurity often found in unpurified salt. It dramatically increased the moisture content of the salt, and resulted in the almost immediate loss of more than 90% of the added iodine.

The work demonstrated that it is important that adsorbed water, iron and iodine do not come into contact on the salt surface. The use of refined (purified) salt is technically feasible, but it would be economically unviable in most developing countries.

We suggested that better results could be achieved by encapsulating the iodine or perhaps the iron compound in an inert carrier that prevents their reactions and degradation. The forming of a physical barrier between the iodine compound, water and iron would stabilize the system. Encapsulating agents could include such stabilizers as sodium hexametaphosphate, dextrin, or even purified salt.

The following report summarizes the work performed to date on Phase 2.

Objectives

The ultimate goal of the research and development program is to design an industrially and economically viable process for the large-scale double fortification of salt. The object of this second phase of the program was to identify fortifying agents and techniques that result in a stable double-fortified salt under conditions of temperature, humidity and salt purity typically found in the proposed receptor countries.

We proposed to evaluate the stability of iron and iodine in a number of double-fortified salt samples, prepared using dry mixing, wet mixing, encapsulation and chemical stabilization.

Experimental Techniques

Materials

Iron Compounds

Elemental iron, manufacturing grade- SCM Metal Products, Inc.
Ferrous sulphate (278.01), laboratory grade - BDH
Ammonium ferric sulphate, Analar (482.18) - BDH
Ammonium iron citrate , laboratory grade - Aldrich
Ferrous fumarate (169.9), laboratory grade- Sigma
Ferrous lactate (287.97), laboratory grade- Fluka
Ferrous phosphate(357), laboratory grade- Pfaltz & Bauer Inc.
d-Gluconic acid, iron salt dihydrate (482.18),laboratory grade - Aldrich
Iron Atomic Adsorption Standard - SCP Science

Iodine Compounds

Potassium iodide (166), analytical reagent- BDH
Potassium iodate (214), analytical reagent- BDH
Calcium iodate (389.89), laboratory grade - Aldrich

Additional Compounds

Magnesium chloride , hexahydrate (203.30), analytical reagent - BDH
Calcium carbonate (100.09), analytical reagent- BDH
Sodium hexametaphosphate (611.77), laboratory grade - J.T. Baker
Hydrochloric acid (36.46), analytical reagent- BDH
Nitric acid (69.0-71.0%), analytical reagent- - J.T. Baker
Potassium thiocyanate (97.18), analytical reagent - BDH

Sample treatment

Three kg samples of salt were fortified to contain 50 mg/kg iodine and 1,000 mg/kg iron using potassium iodide and ferrous fumarate respectively. The mixtures were blended to ensure uniformity using a 5L ribbon blender (LeRoy Somer - LSTronics).

Four treatment techniques were used as indicated in the following. Each treatment was performed in duplicate.

A. **Powder addition -**

An iodine compound and an iron source were added to the salt as a powders, and blended for 15 min. in a ribbon blender.

B. **Wet mixing -**

An aqueous solution of the iodine compound (about 5% w/v) was added to salt and mixed for 15 minutes. Then the salt was dried at 110 °C for about 10 minutes. Ferrous fumarate powder was then added and the mixture was blended for another 15 minutes.

C. **Hygroscopic Sample -**

An additional series of samples were prepared by the addition of 1% $MgCl_2$ (a naturally occurring hygroscopic contaminant) to the salt. in an effort to determine the effect of this contaminant on the stability of double-fortified salt. First, salt was mixed with an aqueous solution of KI or KIO_3 (5% w/v) for 10 minutes and dried at 110°C for about 10 minutes. Then, the iron compound was added and mixed for another 10 minutes. Finally, $MgCl_2$ was added and mixed again for 10 minutes.

D **Encapsulation -**

An aqueous solution of KI or KIO_3 and the encapsulating agent were spray dried using a Buchi bench-top spray drier. The iodine content of the encapsulated powder was determined, and the required amount of the encapsuleted material, the iron source and the salt were blended for 15 min in the ribbon blender.

Packaging materials

Salt samples were packaged in 500 g portions in open low-density polyethylene bags

Storage conditions

The packages were stored under three conditions:

1. ambient room temperature and humidity (~ 22 °C),

2. elevated temperature and high humidity (~ 40 °C, 100% RH), and

3. elevated temperature and medium humidity (~ 40° C, ~ 60 % RH).

The high temperature and high humidity was maintained by using a controlled temperature oven, in which the air was saturated by exposure to a tray of water. The high temperature / medium humidity conditions were maintained in an environmental chamber manufactured by Associated Environmental Systems Division of Craig Systems Corporation.

ANALYTICAL METHODS

Total iron

Total iron was measured by Atomic absorption analysis

1. Approximately 200 mg sample was weighed accurately into a 40 ml volumetric test tube.

2. Using a Brinkman Instruments dispenser 10 mL digestion solution, consisting of concentrated HNO_3 and HCl (1:1 v/v).

3. Samples were digested by boiling off approximately 75% of the liquid on a hot plate.

4. The digested samples were allowed to cool and then the volume of the solution was made up to 40 mL with deionized water.

5. The absorbance at 248.3 nm was recorded, using a Perkin Elmer Model 703 atomic absorption spectrophotometer with an iron hollow cathode lamp as the light source.

This accuracy and precision of the method were verified by using ferrous fumarate standards.

Moisture

The moisture content was determined gravimetrically. Samples of salt were weighed, then dried at 110°C for 16 hours and reweighed.

Iodine

Iodine was measured by neutron activation analysis.

1. Approximately 1.25 g of salt is accurately weighed into a polyethylene vial. To decrease the interference due to the presence of large concentration of chlorine in the sample, the sample is shielded with cadmium.

2 It is irradiated at 1 kW power using a neutron flux of 5.0×10^{11} cm^{-2} sec^{-1} for 3 minutes using the University of Toronto's SLOWPOKE nuclear reactor.

3. The samples are removed from the reactor, and rested for 6 minutes.

4. After 6 minutes delay the gamma emission at 443 keV is measured using a hyperpure germanium based gamma ray spectrometer.

5. The iodine content is calculated based on a calibration established by a series of spiked samples that covered the range of 5 to 250 mg iodine per kg salt. The relative standard deviation of the analysis was determined to be 2%.

Colour

The colour of the samples were compared visually.

Results

While some 40 runs were proposed, a total of 83 batches of salt were prepared, in addition to many preliminary test and standard samples. The extra work was needed, in order to ensure the success and reliability of the final treatment that will be pilot tested. The experimental parameters for each of these test series is presented in Table 1.

Iron Stability

The results of Phase 1, and a recent series of in vivo tests confirmed that the iron content of the samples remains constant, and the bioavailability of iron in stable treatments is not effected by double fortification. Accordingly, we have not measured the iron content, with the exception of the in vivo and in vitro tests performed on our salt preparations by Professor V. Rao's group.

Table 1. - List of ilt Preparations

DATE mixed	Capsulating material	IODINE source	IRON source	Iodine addition method	Iodine salt to capsule ratio	Magnesium chloride %	SALT
5/9/94	SHMP	KI	SULPHATE		110		Canadian
5/18/94	SHMP	KIO3	SULPHATE		100		Canadian
8/3/94	SHMP	KI	SULPHATE		110		Canadian
8/16/94	SHMP	KI	SULPHATE		20		Canadian
8/16/94	SHMP	KIO3	SULPHATE		200		Canadian
9/5/94	SHMP	KI	SULPHATE		50		Canadian
9/18/94	SHMP	KIO3	SULPHATE		50		Canadian
9/21/94	SALT	KI	SULPHATE		40		Canadian
9/21/94	SHMP	KI	SULPHATE		100		Canadian
9/21/94	SHMP	KIO3	SULPHATE		100		Canadian
9/21/94	SHMP	KIO3	SULPHATE		50		Canadian
9/22/94	DEXTRIN	KI	SULPHATE		40		Canadian
9/27/94	SHMP	KIO3	SULPHATE		100		Canadian
10/2/94	SHMP	KI	SULPHATE		220		Canadian
10/12/94	SALT	KI	SULPHATE		100		Canadian
10/14/94	SALT	KI	FUMARATE		100		Canadian
10/17/94	SALT	KIO3	SULPHATE		100		Canadian
10/17/94	SALT	KIO3	FUMARATE		100		Canadian
10/26/94	SHMP	KIO3	SULPHATE		200		Canadian
10/30/94	SHMP	KIO3	SULPHATE		100		Canadian
10/31/94	SHMP	KIO3	SULPHATE		100	1.0	Canadian
11/2/94	SHMP	KI	SULPHATE		200		Canadian
11/9/94	DEXTRIN	KI	SULPHATE		200		Canadian
11/9/94	DEXTRIN	KI	FUMARATE		200		Canadian
11/15/94	DEXTRIN	KI	FUMARATE		200	1.0	Canadian
11/20/94	DEXTRIN	KIO3	SULPHATE		200		Canadian
11/21/94	DEXTRIN	KIO3	SULPHATE		200	1.0	Canadian
11/22/94	DEXTRIN	KIO3	FUMARATE		200		Canadian
11/23/94	DEXTRIN	KIO3	FUMARATE		200	1.0	Canadian
11/28/94	GELATIN	KI	SULPHATE		100		Canadian
11/29/94	GELATIN	KI	SULPHATE		100	1.0	Canadian
11/29/94	SHMP	KIO3	SULPHATE		90		Canadian

Table 1. - List of lt Preparations

DATE mixed	Capsulating material	IODINE source	IRON source	Iodine addition method	Iodine salt to capsule ratio	Magnesium chloride %	SALT
11/29/94	SHMP	KIO3	SULPHATE		110	1.0	Canadian
12/2/94	GELATIN	KIO3	SULPHATE		100		Canadian
12/3/94	GELATIN	KIO3	SULPHATE		100	1.0	Canadian
12/5/94	GELATIN	KIO3	FUMARATE		100		Canadian
12/6/94	GELATIN	KIO3	FUMARATE		100	1.0	Canadian
12/8/94	GELATIN	KI	FUMARATE		100		Canadian
12/9/94	GELATIN	KI	FUMARATE		100	1.0	Canadian
1/15/95	MONOGL.	KI	SULPHATE		100		Canadian
1/16/95	MONOGL.	KI	SULPHATE		200		Canadian
1/17/95	MONOGL.	KIO3	SULPHATE		100		Canadian
2/17/95	DEXTRIN	KIO3	FUMARATE		200		Canadian
2/18/95	DEXTRIN	KIO3	FUMARATE		200		Indian as is
4/30/95	DEXTRIN	KIO3	LACTATE		100		Canadian
5/1/95	DEXTRIN	KIO3	CITRATE*		100		Canadian
5/2/95	DEXTRIN	KIO3	FUMARATE		100		Canadian
5/3/95	DEXTRIN	KIO3	FUMARATE		100		Indian, dried.
5/3/95	DEXTRIN	KIO3	FUMARATE		100		Indian, as is
5/3/95	DEXTRIN	KIO3	FUMARATE		100		GHANA, dried
5/4/95	DEXTRIN	KIO3	FUMARATE		100		GHANA, as is
6/6/95	SALT	KIO3	FUMARATE		200		Canadian
6/23/95	SALT	KIO3	FUMARATE		200		Indian dried
10/11/95	NEW DEXTRIN	KI	FUMARATE		100		CAN
10/12/95	NEW DEXTRIN	KIO3	FUMARATE		100		Canadian

* ferric ammonium citrate

Table 1. - List of Salt Preparations

STABILIZER AND CONTROL BATCHES - WET OR DRY MIXING								
	SHMP				CaSiO3	MgCl2	DEXTROSE	
	%	IODINE AS	IRON AS		%	%	%	
2/14/94	1.0	KIO3	SULPHATE	DRY MIX				Indian
4/28/94		KI		WET MIX				Canadian
5/2/94		KIO3		DRY MIX				Canadian
5/5/94		KI		DRY MIX				Canadian
6/5/94			SULPHATE	DRY MIX				Canadian
6/8/94		KIO3		DRY MIX				Canadian
6/12/94		KIO3		WET MIX				Canadian
7/4/94	0.5	KI	SULPHATE	WET MIX				Canadian
7/5/94	1.0	KI	SULPHATE	WET MIX				Canadian
7/11/94		KI	SULPHATE	WET MIX				Canadian
7/24/94	1.0	KIO3	SULPHATE	WET MIX				Canadian
7/25/94	0.5	KIO3	SULPHATE	WET MIX				Canadian
8/3/94		KI		DRY MIX				Canadian
8/3/94	1.0	KI	SULPHATE	WET MIX		1.0		Canadian
8/7/94		KIO3		DRY MIX				Canadian
8/7/94	1.0	KIO3	SULPHATE	DRY MIX				Canadian
8/8/94	0.5	KIO3	SULPHATE	DRY MIX				Canadian
8/9/94	0.5	KI	SULPHATE	DRY MIX				Canadian
8/10/94	0.5	KI	SULPHATE	DRY MIX				Canadian
8/14/94	1.0	KI	SULPHATE	DRY MIX				Canadian
12/4/94	1.0	KIO3	SULPHATE	DRY MIX		1.0		Canadian
12/18/94	1.0	KIO3	SULPHATE	WET MIX		1.0		Canadian
1/16/95		KI		WET MIX	0.5		0.05	Canadian
2/13/95	1.0	KI	SULPHATE	DRY MIX	0.5			Canadian
2/19/95	1.0	KIO3	SULPHATE	DRY MIX				INDIAN SALT
3/1/95		KI	SULPHATE	WET MIX	0.5		0.05	WINDSOR
6/19/95	1.0	KI	FUMARATE	WET MIX	0.5		0.05	WINDSOR

83 batches

Both in terms of visual quality, and the iodine content ferrous fumarate seems to be a more stable iron source, and at least initially, it is the preferred iron compound for double fortification.

Iodine stability

The iodine content of the samples were measured after mixing, and at 1,2,3,6,9 and 12 months. Naturally, where the iodine content essentially disappeared at an early stage of storage, the samples were discarded, or not analyzed further. The data on the most stable treatments and representative control treatments are presented in Table 2, together with some relevant observations.

The critical problem with iodine addition is the potential for reducing or oxidizing the iodine in the salt to elemental iodine, or I_2. Elemental iodine readily sublimes, and although its vapour pressure at room temperature, or even at 40°C is low, if there is any air movement, the 40-60 mg/kg present in the sample would readily evaporate. In effect, we can assume that I_2 disappears from the salt as soon as it forms.

The results indicate that most of the iodine loss quickly in systems that are not extensively stabilized. Encapsulated iodine was much more stable than the unencapsulated equivalent treatments, with or without stabilization. The most difficulty was observed with the high temperature-high humidity samples. Still, the encapsulated potassium iodide remained essentially unaffected over the test period.

The Canadian salt, highly purified, and stabilized with dextrose, sodium silicate and sodium hexametaphosphate was stable, but it seems unlikely that this level of purity and stabilizer addition can be achieved in the field.

We found that the distribution of the iron and iodine was very much dependent on the mixing, and subsequent segregation by particle size. It is important therefore, that the encapsulated iodine compound and the added iron be of similar, relatively small, particle size. This ensures that the dosage in the home will be relatively uniform.

The method of encapsulation is still a problem in the laboratory. With spray drying in a small laboratory instrument, the amount of encapsulating agent has to be very high, typically 98-99% of the total. It is hoped that in industrial scale equipment this can be reduced significantly.

We built a small fluid bed drier, which can be also used for encapsulation, and initial results have been very encouraging. A test on spray cooling is now under way. Each of these techniques preserve the principle of establishing a physical air and moisture barrier between the iodine compound and the rest of the system. The success of each of these encapsulating techniques will depend on the integrity of the encapsulating coating. Pilot scale tests will give a much better indication of the best encapsulation technique to be pursued in full scale production.

Table 2, - Summary of best data

Capsulating material	IODINE source	IRON source	Magnesium chloride %	Room Temperature 0	1	2	3 months	6	9	12
SHMP	KIO3	SULPHATE		50.0		44.3	33.1	32.3		
SHMP	KI	SULPHATE		51.9	17.5		44.5	38.6		
SHMP	KI	SULPHATE		44.5	46.8	43.7	38.7		40.9	33.4
SALT	KIO3	FUMARATE		59.6	52.1	56.4	52.1	48.1	49.2	44.5
SALT *	KIO3	FUMARATE		47.9		48.1	42.3			
DEXTRIN	KI	SULPHATE		56.8	55.3	55.8	56.7	55.3	55.3	52.9
DEXTRIN	KI	FUMARATE		56.8	53.4	52.7	54.2	55.0	55.0	47.9
DEXTRIN	KIO3	FUMARATE	1.0	49.4	50.2		47.1	43.0	31.1	
DEXTRIN*	KIO3	FUMARATE		50.9	52.8		54.6	60.2	27.5	
NEW DEXTRIN	KI	FUMARATE		47.7	44.3					
SHMP	KI	SULPHATE		58.1		16.4				
SHMP	KIO3	SULPHATE		56.3		31.8	28.7	32.8		
SALT	KI	FUMARATE		49.4	9.5					
SALT	KIO3	SULPHATE		50.0	3.8					
DEXTRIN	KI	FUMARATE	1.0	55.6	52.0	46.4		47.4	44.9	
DEXTRIN	KIO3	SULPHATE		50.8	52.3		48.6	49.7	22.3	
DEXTRIN	KIO3	SULPHATE	1.0	48.7	45.6		48.9	41.8	26.9	
DEXTRIN	KIO3	FUMARATE		39.9	33.7		41.7	28.9	14.9	
DEXTRIN	KIO3	LACTATE		51.1	56.8		22.2	0.1		
DEXTRIN	KIO3	CITRATE*		53.0	53.1		53.9	33.7		
STABILIZER % SHMP										
	KI	SULPHATE		93.1	85.7	87.0	93.7			
1.0	KI	FUMARATE		81.0		77.4	84.4			
1.0	KIO3	SULPHATE		48.2	34	18.8	41.1			
1.0	KI	SULPHATE		42.4		53.7	48	24.4		

* Indian salt

Table 2, - Summary of best data

Capsulating material	IODINE source	IRON source	Magnesium chloride %	40°C - 60% RH 0	1	2	3 months	6	9	12
SHMP	KIO3	SULPHATE		50		50.0	35.2	16.7		
SHMP	KI	SULPHATE		51.9	11.5		25.3	21.6		
SHMP	KI	SULPHATE		44.5	45.5	42.0	39.6		8.7	3.1
SALT	KIO3	FUMARATE		59.6	50.0	46.4	49.0	47.5	40.7	33.0
SALT *	KIO3	FUMARATE		47.9		44.0	24.5			
DEXTRIN	KI	SULPHATE		56.8	56.7	52.8	56.5	56.6	55.6	44.4
DEXTRIN	KI	FUMARATE		56.8	55.9	54.7	56.1	56.1	59.4	57.9
DEXTRIN	KIO3	FUMARATE	1.0	49.4	53.4		48.5	43.4	21.2	
DEXTRIN*	KIO3	FUMARATE		50.9	51.1		51.9	46.8	0.1	
NEW DEXTRIN	KI	FUMARATE		47.7	49.2					
SHMP	KI	SULPHATE		58.1		15.9				
SHMP	KIO3	SULPHATE		56.3		36.2	32.5	37.6		
SALT	KI	FUMARATE		49.4	7.3					
SALT	KIO3	SULPHATE		50	0.5					
DEXTRIN	KI	FUMARATE	1.0	55.6						
DEXTRIN	*KIO3*	*SULPHATE*		*50.6*	*49.9*		*49.7*	*51.7*	*20.2*	
DEXTRIN	KIO3	SULPHATE	1.0	48.7	42.3		41.5	32.1	17.8	
DEXTRIN	KIO3	FUMARATE		39.9	45.6		43.8	20.7	7.3	
DEXTRIN	KIO3	LACTATE		51.1	41.8		16.4	0.1		
DEXTRIN	KIO3	CITRATE*		53	52.8		49.6	10.7		
STABILIZER % SHMP										
	KI	SULPHATE		93.1	93.7	81.6	91.0			
1.0	KI	FUMARATE		81		77.4	76.0			
1.0	KIO3	SULPHATE		48.2	39.4	19.1				
1.0	KI	SULPHATE		42.4		22.7		36.7		

* Indian salt

Table 2, - Summary of best data

Capsulating material	IODINE source	IRON source	Magnesium chloride %		40°C - 100% humidity 0	1	2	4	6	9	12
SHMP	KIO3	SULPHATE			50		43.8	60.8	56.2		
SHMP	KI	SULPHATE			51.9	38.3		33.2	35.5		
SHMP	KI	SULPHATE			44.5						
SALT	KIO3	FUMARATE			59.6						
SALT *	KIO3	FUMARATE			47.9						
DEXTRIN	KI	SULPHATE			56.8						
DEXTRIN	KI	FUMARATE			56.8						
DEXTRIN	KIO3	FUMARATE	1.0		49.4						
DEXTRIN*	KIO3	FUMARATE			50.9						
NEW DEXTRIN	KI	FUMARATE			47.7	26.1					
SHMP	KI	SULPHATE			58.1		5				
SHMP	KIO3	SULPHATE			56.3		24.9	27.4	20.7		
SALT	KI	FUMARATE			49.4						
SALT	KIO3	SULPHATE			50						
DEXTRIN	KI	FUMARATE	1.0		55.6						
DEXTRIN	KIO3	SULPHATE			50.8						
DEXTRIN	KIO3	SULPHATE	1.0		48.7						
DEXTRIN	KIO3	FUMARATE			39.9						
DEXTRIN	KIO3	LACTATE			51.1						
DEXTRIN	KIO3	CITRATE*			53						
STABILIZER % SHMP											
	KI	SULPHATE									
1.0	KI	FUMARATE			81						
1.0	KIO3	SULPHATE			48.2	37.3	13	0			
1.0	KI	SULPHATE			42.4		43.2	40	10.7		

* Indian salt

Table 2, - Summary of best data

Capsulating material	IODINE source	IRON source	Magnesium chloride %	COMMENTS Room Temperature	40°C	General comments
SHMP	KIO3	SULPHATE		White, nice	White, nice	Excellent
SHMP	KI	SULPHATE				
SHMP	KI	SULPHATE		White, nice	White, nice	
SALT	KIO3	FUMARATE		Nice	Nice	Good
SALT *	KIO3	FUMARATE		Fumarate colour	Fumarate colour	
DEXTRIN	KI	SULPHATE		White	Yellowish	STABLE
DEXTRIN	KI	FUMARATE		White	White	
DEXTRIN	KIO3	FUMARATE	1.0	White	Agglomarated	
DEXTRIN*	KIO3	FUMARATE		Purple discolouration	Agglomarated	STABLE
NEW DEXTRIN	KI	FUMARATE		50 % RETENTION EVEN IN SLURRY - AT 40°C 100% RH		
SHMP	KI	SULPHATE				
SHMP	KIO3	SULPHATE				
SALT	KI	FUMARATE		White, nice	White, nice	BAD COLOUR
SALT	KIO3	SULPHATE		Yellow	Yellow	
DEXTRIN	KI	FUMARATE	1.0	Dark purple	Dark purple	BAD COLOUR
DEXTRIN	KIO3	SULPHATE		Yellow	Yellowish, lumpy	
DEXTRIN	KIO3	SULPHATE	1.0	Purple	Purple	
DEXTRIN	KIO3	FUMARATE		White	White	
DEXTRIN	KIO3	LACTATE		White	Some purple	
DEXTRIN	KIO3	CITRATE*		Yellowish	Gold tinge	
STABILIZER % SHMP						
	KI	SULPHATE		Gold tinge	White	Good
1.0	KI	FUMARATE		Fumarate colour	Fumarate colour	Good
1.0	KIO3	SULPHATE				
1.0	KI	SULPHATE				

* Indian salt

Conclusions and Recommendations

The results clearly indicated that iodine can be stabilized by encapsulating it. The physical barrier formed about the iodine compound prevents its interaction with water and/or iron, and thus it remains stable in the formulation for at least one year. Both sodium hexametaphosphate and dextrin proved to be good encapsulating agents.

The best system consisted of potassium iodide, encapsulated in dextrin, used in combination with ferrous fumarate. The system was stable, and had acceptable colour and taste throughout the test.

The in vitro and in vivo experiments have demonstrated that both the iron and the iodine retain their bioavailability in the double fortified salt. The results obtained by dr. Rao confirm that the bioavailability is not affected by the encapsulation of the iodine compounds, and in terms of availability all of our selected systems are accepted.

Tests are now under way to test human bioavailability in a small number of volunteers in Toronto.

The next logical phase of the program is the initial pilot test, now scheduled for March, at the POS Pilot Plant in Saskatoon. The material produced here will be used in a field test in Ghana.

Assuming that the field tests are successful, we believe that another series of pilot tests must be done before a program of commercial utilization can begin. The technology transfer will depend on the cost and complexity of the final encapsulation system. Pilot tests, and the associated laboratory preparation and evaluation are critical steps in the scale-up and technology transfer. We hope to develop the details of these phases of the program in cooperation with the Micro Nutrient Initiative, after the POS tests in March.

References

1. Narasinga Rao, B.S. Double fortification of salt with iron and iodine to control anaemia and goitre. National Institute of Nutrition, Hyderabad, India (1990).

2. Venkatesh Mannar, M.G., Jayapal, S. and Pandav, C.S. Double fortification of salt with iron and iodine. Proceedings of the Sixth International Nutrition Congress, Seoul (1989).

3. Narasinga Rao, (1994) unpublished communication

4. Zoller, J.M., Wolinsky, I., Paden, C.A., Hoskin, J.C., Lewis, K.C., Lineback, D.R. and McCarthy, R.K. Fortification of non-staple food items with iron. Food Technology. 34, 39-47 (1980).

5. Venkatesh Mannar, M.G. Control of iodine deficiency disorders by iodization of salt: strategy for developing countries. The prevention and control of iodine deficiency disorders. B.S. Hetzel, J.T. Dunn and J.B. Stanbury, eds. Elsevier (1987).

6. Evaluation of certain food additives and contaminants. Thirty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 806 (1991).

7. Hurrel, R.F. and Cook, J.D. Strategies for iron fortification of foods. Trends in Food Science and Technology (Sept. 1990).

8. Gurunath, M.M., Diamond, H.W. and Venkatesh Mannar, M.G. Fortification of salt with iron. Proceedings of the Fourth International Symposium on Salt, Houston, Texas. Northern Ohio Geological Society, Cleveland, Ohio (1973).

9. Narasinga Rao, B.S. and Vijaya Sarathy, C. Fortification of common salt with iron. Effect of chemical additives on stability and bioavailability. Am. J. Clin. Nutr. **28**, 1395-1401 (1975).

10. Nadiger, H.A., Krishnamachari, K.A.V.R., Nadamuni, N., Rao, B.S.N. and Srikantia, S.G. The use of common salt (sodium chloride) fortified with iron to control anaemia: Results of a preliminary study. Br. J. Nutr. **43**, 45-51 (1980).

11. Working Group Report. Use of common salt fortified with iron in the control and prevention of anaemia - A collaborative study. Am. J. Clin. Nutr. **35**, 1442-1451 (1982).

12. Chronology of development of iron and double fortification of salt. UNICEF internal paper. UNICEF, New Delhi, India (1989).

13. Ranganathan S. "Fortification of common salt with iron: use of polyphosphate stabilizers", J. Food Chemistry **45(4)** 263-267 (1992)

14. Rao, B.S.N., Vijayasarathy, C. "An alternative formula for the fortification of common salt with iron", Am. J. Clin. Nutr. **31** (1/2) 93, (1978)

15. Rao, B.S.N., Vijayasarathy, C. "Fortification of common salt with iron: Effect of additives on stability and bioavailability", Am. J. Clin. Nutr. **28** (12) 1395-1401, (1975)