Chapter 21

Microencapsulation for food fortification

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Micronutrient deficiency

Micronutrient deficiencies are the cause for widespread health problems, especially in developing countries. The deficiencies in vitamin A, iron, and iodine have been identified as the greatest concern, as they affect over one third of the world's population (WHO, 1995). In addition, these micronutrients interact with each other, i.e., synergistic effects between iodine deficiency disorder (IDD) and iron deficiency anemia (IDA), or between vitamin A deficiency (VAD) and IDA to deepen their negative impacts (Lonnerdal, 2004; Lynch, 1997; Zimmermann et al., 2004). Deficiencies typically coexist in children in developing countries (Zimmermann et al., 2000).

70% of people in India do not consume enough micronutrients such as vitamins and minerals. About 70% of pre-school children suffer from anaemia caused by iron deficiency and 57% of preschool children have sub–clinical Vitamin A deficiency. Neural Tube Defects (NTDs) are the most common congenital malformation with an incidence that varies between 0.5-8/1000 births. It is estimated that 50-70% of these birth defects are preventable. One of the major causes is deficiency of folic acid. Thus, micronutrient deficiency also known as "hidden hunger", is a serious health risk. Unfortunately, those who are economically disadvantaged do not have access to safe and nutritious food. Others either do not consume a balanced diet or lack variety in the diet because of which they do not get adequate micronutrients. Often, there is considerable loss of nutrients during the processing of food.

Addressing micronutrient deficiencies

Micronutrient deficiencies can be addressed in three ways namely by making changes in the diet, through supplementation, and by means of fortification of food with selected nutrients. While dietary modification is desirable, it is a long-range solution and may require changes in food preparation practices and social customs. Supplementation is an effective and rapid approach, but it requires appropriate medical infrastructure/administration and thus it is costly. Food fortification is a cost-effective intervention that does not require any

conscious action by the consumer, and needs no changes in the dietary habits of the target populations. Moreover, it is readily adapted into existing food production and distribution systems.

Food fortification has been extensively used for many years as a cost-effective strategy for combating micronutrient deficiencies. It is the addition of key vitamins and minerals such as iron, iodine, zinc, Vitamin A & D to staple foods such as rice, milk and salt to improve their nutritional content. Fortification strategy is the best long-term approach and the cheapest way to initiate and maintain the desired micronutrient levels in the diet.

Advantages of fortification

1. Since staple foods that are commonly consumed are enriched with nutrients, this is a splendid method to improve the health of a population with lesser effort.

2. Fortification is a safer way of ensuring better nutrition among people. Since fortification is done as per guidelines in accordance with approved standards, an overdose never occurs.

3. It is not necessary for people to make changes in their routine food habits.

4. It is a socio-culturally acceptable way to deliver nutrients to people.

5. Food characteristics are not altered by fortification.

6. Implementation of fortification programs can be swiftly done . The positive impact on nutritional status is quickly evident too.

7. If the existing technology and delivery platforms are taken advantage of, fortification can be very cost-effective.

8. It has a high benefit-to-cost ratio. The Copenhagen Consensus estimates that every rupee spent on fortification results in a benefit of Rs nine.

Fortification programs worldwide

Many fortification programs have been implemented worldwide, including universal iodization of salt and enrichment of B vitamins in wheat flour. 70% of the world's population consumes iodized salt now significantly reducing the incidence of iodine deficiency disorders (IDD) over the past three decades (United Nations, 2008). The introduction of folic acid into cereal-grain products in over 40 countries has resulted in

dramatically increased folate status and significant reduction in the risk of neural tube defects in newborns (Buttriss, 2005).

Globally, 87 countries have legislation to mandate fortification of at least one industrially milled cereal grain. In addition, ten countries fortify more than half of their industrially milled wheat or maize flour through voluntary efforts. These include Afghanistan, Democratic Republic of Congo, Gambia, Lesotho, Namibia, Qatar, Swaziland, the United Arab Emirates, Lesotho and Namibia.

Fortification efforts in India

In October 2016, the Food Safety Standards Authority of India published draft standards for food fortification. The draft for wheat flour fortification is in line with global fortification recommendations for iron, vitamin B12, and folic acid. In Haryana, fortifying flour for the mid-day meal, infant child development, and public distribution systems is expected to have a significant health impact. In 2000, Darjeeling in West Bengal was the first place to fortify wheat flour. About 7.6% of the industrially milled wheat flour in India is fortified presently. Fortified rice is available through social safety net programs in the states of Odisha and Karnataka. Rajasthan has taken the lead in fortified oil and fortified milk, which are being sold across the entire state. Flour fortification is supported by the government of India and several state governments. Active involvement of international agencies, national health and nutrition research institutions, and flour milling professionals have contributed toward wheat flour fortification. Most fortified flour in India is distributed in the government's welfare system.

Fortification criteria

All successful fortification programs have some common features, i.e., they are effective in reducing the prevalence of specific micronutrient deficiencies, they are economically viable, and the fortified products enjoy consumer acceptance. To meet these criteria, several technical factors need to be considered, including selection of food vehicles and fortificant forms, determination of fortification levels and quality assurance and quality control of the fortified food products. Among these, food vehicle selection determines whether food fortification programs are effective as an ideal carrier guarantees that the micronutrients reach the largest number of people.

Selection of food vehicle for fortification

Varieties of food or food ingredients have been considered for fortification, including cereal and grain products, milk and dairy products, fats and oils, infant formula and weaning foods, condiments such as salt, sugar, and monosodium glutamate (MSG), as well as a range of processed foods (Lofti et al., 1996). It is generally accepted that staple foods, such as salt, sugar, wheat flour, and rice, are good carriers for fortification, since they are regularly consumed by all of the target population at a fairly constant rate, and are relatively inexpensive so that all segments of the target population could afford them. The global salt iodization is an example of effective programs that improve human nutrition, mainly due to the attributes of the food vehicle – salt. It is universally consumed and is open to a simple fortification technique, which makes the program affordable. In ICAR-Central Institute of Fisheries Technology, fish soup powder was used for fortification. Interestingly, fish is probably the most affordable source to provide almost 40 essential nutrients. Fish soup powder incorporating the nutritional goodness of fish and fortified with iron and calcium by taking into account WHO-recommended RDA values has been developed at ICAR-Central Institute of Fisheries Technology, Kochi. Integrated Child Development Scheme(ICDS), Jowai, West Jaintia District Hills District, Meghalaya and Health Department, Jowai, Child Development Project Officer, Thadlaskein Block, Jowai, and ICAR-CIFT Scientists chalked out a one month program of distributing fortified fish soup to adolescent girls selected to improve their hemoglobin levels and health status. Fifty adolescent girls,age ranging from 11-16 whose blood hemoglobin levels were 9 or below, were recruited for the study. The intervention was closely monitored by ICDS officials which ensured 100% compliance. Blood hemoglobin analysis post intervention showed that all the adolescent girls recorded a statistically significant rise.

Selection of fortificants

Selection of appropriate forms of fortificants is vital. Some vitamins and minerals could be simply added into selected food carriers in powder form, which involves solid-solid blending or solid-liquid mixing. These methods are straightforward and low in cost, but usually ineffective in protecting the micronutrients within the fortified foods. Moreover, the incorporation of these minor ingredients often causes undesirable sensory changes in the fortified foods, such as off-flavours or colors caused either by the additives themselves or the interactions between the additives and the food vehicles. Ignoring sensory effects and physical/chemical properties leads to major concerns regarding product

stability and consumer acceptance that may jeopardize the success of a fortification program. Microencapsulation of nutrients can be effective in delivering fortificants into fortified foods.

Challenges confronted during fortification

A major challenge for food fortification programs is the development of stable forms of micronutrients that overcome the instability of vitamins and the reactivity of minerals. For instance, vitamin A is sensitive to almost all environmental factors, including light, heat, oxygen, and chemical interactions. The difficulty with iron is in finding an appropriate chemical form which is adequately absorbed and yet does not alter the appearance or taste of the food vehicle (Mannar & Gallego, 2002). In addition, the presence of reactive iron compounds significantly affects the stability of other vitamins added in the same food matrix. It is important to prevent interactions between added micronutrients and the food system, and subsequently ensure stability, bioavailability, and sensory properties of the fortified food through production, distribution, retail, and food preparation.

Microencapsulation of nutrients

The best approach for delivering two or more micronutrients simultaneously in a stable and bioavailable form without interaction and degradation, is to microencapsulate them in an inert, but digestible matrix separated from other food components and other added micronutrients. Nutrients are added as concentrated, encapsulated premixes with modified physical and chemical properties, favourable for adding into selected food carriers without greatly reducing their bioavailability. Microencapsulation can also improve the sensory properties of the fortified foods by hiding the undesirable colours and tastes from the fortificants and by preventing the interactions between the fortificants and the food carrier. The microencapsulation-based technology allows the fortificants to be delivered in appropriate forms that resemble the physical characteristics of the selected food vehicles, in terms of shape, size, colour, and appearance. Microencapsulation-based approach allows for multiple micronutrient fortification of a wide variety of staple foods with particle sizes ranging from several hundred microns to several millimeters. To prevent particle segregation, which may result in potential under- or over-dosing, micronutrients must be added in forms that either stick to the food particles, or in agglomerated premixes that match the particle size, and if possible, the particle density of the food. Successful food fortification processes require that the added micronutrients are evenly distributed and are unnoticeable to the

consumer. Thus the complete delivery system must match the food in colour and appearance, and must not alter the food flavour.

Microencapsulation is defined as the application of thin polymeric coating to individual core materials (tiny particles or droplets of liquids and dispersions) that have an arbitrary particle size range from 5-5000 micron (Rawdwick and Burgess 2002). It enables conversion of liquids to solids, which alter colloidal and surface properties, provides protection and controls the release characteristics of different coated materials (Deepak et al. 2013). Encapsulation involves the entrapment of an active compound within another polymeric substance . Microencapsulation finds applications in many areas such as pharmaceutical, nutraceuticals and cosmetic industries (Sanguansri et al., 2013). A large number of core materials like live cells, adhesives, flavors, agrochemicals, enzymes, pharmaceuticals antioxidants, color, pigments, probiotics, aminoacids, essential oils, herb extracts, flavours, sweetners etc., can be encapsulated. The important benefits associated with the encapsulation of bioactive compounds are as follows:

1. For better handling of the bioactive components.
2. The bioactive components which are sensitive to moisture light and oxygen can be protected by microencapsulation.
3. Protection of active components from factors that can cause oxidation and hence a prolonged shelf life.
4. The compounds, which are volatile in nature and vaporize at room temperature, can be prevented by microencapsulation.
5. The microencapsulation process can also help to mask undesirable odours and flavours in the final product.
6. For the controlled release of active components, especially in the case of drug delivery systems.

Structure of a microcapsule

The size of the microcapsule ranges from 5-300 micron in diameter. It has a continuous core region surrounded by a continuous shell called wall material. The wall material may consist of one or more materials. Microcapsules are categorized according to their morphology as mononuclear, polynuclear and matrix. The mononuclear microcapsules contain the wall material layer around the core, polynuclear microcapsules will be having number of cores enclosed within the wall material. In matrix type, there is a homogenous distribution of the core in

the wall material. Since the wall material has an important role to play in many aspects such as encapsulation efficiency, stability as well as the protection of the core compound, a proper selection of the wall material is an important task. Composition of the wall material determines the functional properties of the microcapsule and how it may be used to improve the performance of a particular ingredient.

The wall material selection depends on number of factors such as solubility, molecular weight, glass transition temperature, diffusibility, film forming and emulsifying properties etc. Moreover, the main role of wall material is to protect the core material from oxidation and allow controlled release. Apart from this, the cost of wall material also has to be taken into account because the total process should be economical.

An ideal coating material exhibits the following characteristics:

- Good rheological properties at high concentration during encapsulation.
- Ability to disperse or emulsify the active material and stabilize the emulsion produced.
- Non-reactivity with the material to be encapsulated during processing and storage.
- Ability to seal and hold the active material within its structure during processing or storage.
- Ability to release the solvent used during encapsulation under desolventization conditions.
- Ability to provide protection to the material against oxygen, heat, light, humidity.
- Solubility in solvents acceptable in the food industry (e.g., water, ethanol).
- Chemical non-reactivity with the active core materials.
- Inexpensive, food-grade status.

Commonly used Wall materials or coating materials

- Carbohydrates-Modified starches, Hydrolysed starches (maltodextrins) Starch, chitosan, corn syrup solids, dextran, cyclodextrins, sucrose, Gum Arabic, Modified starch, Agar, Alginates, carrageenan, pectin,
- Cellulose- Carboxymethyl cellulose,methyl cellulose, ethylcellulose, celluloseacetate- phthalate, celluloseacetate butylate-phthalate
- Gum -Gum acacia, agar, sodium alginate, carrageenan

- Fats and waxes- Hydrogenated vegetable oils, Bees wax, paraffin, diacylglyerols, oils, fats

Proteins- Gelatins (types A and B), Sodium caseinates, Whey protein isolate, albumins, peptides, skimmed milk powder

Fortification of foods through Microencapsulation

Conventional way of incorporating the nutrients often alters the physical, chemical and functional properties of the fortified food. Microencapsulation for food fortification is very useful techniques as it delivers staple forms of micronutrient in a bioavaiable form. This technology overcomes the instability of vitamins and reactivity of minerals in the processed products. It maintains the active ingredients in a stable environment, separated from other food components and thereby preventing undesirable changes in fortified foods. This technology can be a best approach for delivering two or more micronutrients simultaneously in a stable and bio-available form.

Microencapsulation Technologies

1. Spray drying

One of the most commonly used microencapsulation technology is spray drying which finds wide range of applications in food and pharmaceutical industries. It is a very economical, flexible, efficient, easy to scale-up technology which produces good quality powder with low water activities that can be easily stored and transported (Ashady, 1993). The process of spray drying involves the dissolution of wall material and core material resulting in the formation of an emulsion, followed by proper homogenization, pumping of the emulsion, atomization of the emulsion and the subsequent dehydration of the atomized droplets to yield microcapsule. The size of microcapsules formed will depend on the concentration of solids content in the dispersion content and accordingly can vary from smaller to larger particles. Apart from this, the viscosity of the emulsion, feed rpm, inlet and outlet temperatures also have an influence on the particle size as well as the oxidative stability of the particles.

2. Freeze drying

Freeze drying is widely accepted as one of the best methods for production of superior quality dried products (Calvo et al., 2011). Though spray drying is the most widely accepted technology for encapsulation, a lower oxidative stability of spray dried products has also been reported. Because of the low temperature employed in freeze drying process and

removal of about 97-98% moisture content and oxygen, this technology is often reported to produce good quality products than spray drying (Minemoto, Adachi, and Matsuno, 2001). The process of freeze drying involves three processes, freezing at a lower temperature of −90 and −40 °C, followed by primary and secondary drying under low pressure. But one limitation of this technology is that it is an expensive process requiring high energy consumption and higher processing time. Moreover, certain researchers have reported spray drying as a better process than freeze drying for fish oil encapsulation (Chen et al., 2013). Taking into consideration the limitations of both freeze drying and spray drying, it can be concluded that the freeze drying can be employed to encapsulate products that are highly sensitive to heat.

3. Coacervation

Coacervation, also known as phase separation is the separation of two liquid phases in a colloidal solution. The phase which is rich in polymer is known as the coacervate phase and that is devoid of polymer is known as equilibrium solution. There are two kinds of coacervation, simple and complex. In case of simple coacervation, there will be only one polymer whereas in complex coacervation, the interaction between oppositely charged polymers is made use of (Ke-Gang et al., 2005). The biopolymers that are being widely employed in the complex coacervation process are gelatin or whey protein and oppositely charged gum arabic, sodium polyphosphate or carboxy methyl cellulose. This method produces microcapsules that are having better and controlled release activities along with heat resistant properties (Jun-xia et al., 2011). The microcapsules thus produced are collected by centrifugation or filtration and further dried by either spray or fluidized bed drying. The size of microcapsules produced depends on a number of factors such as temperature, stirring speed, viscosity and pH (Carvalho et al., 2015). One limitation with this technology is that the coacervates produced are stable over a narrow range of pH and ionic strength.

4. Extrusion

Extrusion process involves mixing of the molten wall material with the core material which is then allowed to pass through a nozzle under high pressure to produce microcapsules of higher density and less porosity (Serfert, Drusch, & Schwarz, 2009). The extrusion microencapsulation includes 3 processes such as centrifugal extrusion (coextrusion), melt injection and melt-extrusion. Centrifugal extrusion, also known as co-extrusion is another extrusion technology that is commonly used for microencapsulation that can produce microcapsules

in the size range of is 500–1000µm. Since the particle size of the extruded powder is more, it can impact the mouth feel. Melt injection process involves dispersion of the core material in a matrix containing starch, anti-oxidants, sugars, emulsifiers and water at about 130°C, extruded thorough a die or filter into a bath filled with organic solvent such as isopropanol which solidifies the sugar matrix. The microcapsules thus formed are collected by filtration or centrifugation (Valentinotti, Armanet, and Porret, 2006). The melt-extrusion process and melt-injection is almost similar, where melt-injection is a vertical screw less process with surface-washed particles, while the melt extrusion is a horizontal screw process with particles that are not surface-washed.

5. Insitu polymerization

In situ polymerization is commonly used for the preparation of microcapsules and functional fibers. The process doesn't include any reactants in the core material and polymerization occurs in the continuous phase itself. By adjusting pH and temperature, the wall material precipitates and distributes evenly over the surfaces of core material. Particles produced by this technology are found to have better encapsulation efficiency, good chemical, thermal and storage stability and controlled release.

6. Liposome entrapment

Liposomes are microscopic, spherical lipid bilayers that can enclose a number of aqueous compartments. The most commonly used encapsulating agents in this method are phospholipids and they are bio compatible and bio degradable substances (Kim &Baianu, 1991). The formation of a lipid bilayer is mainly attributed to the amphiphilic nature of phospholipids. These liposomes can be used to encapsulate omega-3 fatty acids by dissolving them in phospholipid before addition of water. This mixture of phospholipid, omega-3 oil and water is then sonicated to form encapsulated products and oil encapsulated in liposomes is said to have better oxidative stability (Kubo, Sekine, & Saito, 2003). But the limitation of this technology is its high cost and low stability.

7. Fluidized bed drying

This method is restricted mainly to the encapsulation of solid core materials where a coating is applied on the powder particles (Rumpler & Jacob, 1998). Hence this method cannot be used for the direct encapsulation of fish oil, instead it can be considered as a secondary method to provide an additional coating on the already microencapsulated fish oil for better oxidative stability and physicochemical properties. In one

of the patented technology for double encapsulation of fish oil, corn starch was used for coating the already spray dried powder (Skelbaek and Andersen., 1994). In another method, molten hydrogenated palm wax (30% w/w) was used to coat over the already spray dried fish oil powder (Ponginebbi and Publisi, 2008).

Advantages and Disadvantages of Some Encapsulation Methods:

Encapsulation Method	Principle	Advantages	Disadvantages
Spray drying	Dispersion of the core material in a entrapment material, followed by atomization and spraying of the mixture in a hot air desiccant into a chamber	a) Low process cost; b)Wide choice of coating material; c)Good encapsulation efficiency; d) Good stability of the finished product; e)Possibility of large-scale production in continuous mode	a) Can degraded highly temperature sensitive compounds; b) Control of the particle size is difficult; c) Yields for small batches are moderate
Spray cooling/chilling	The same of as the spray drying differing only that the air desiccant is cold	Temperature-sensitive compounds can be encapsulated	a) Difficult control of the particle size; b) Moderate yields for small batches; c) special handling and storage conditions can be required
Simple extrusion	Forcing a core material in a molten wall material mass through a die (laboratory scale) or a series of dies of a desired cross section into a bath of desiccant liquid. The coating material hardens on contacting liquids, entrapping the active substances	a) The material is totally surrounded by the wall material; b) Any residual core is washed from the outside; c) It is a relatively low-temperature entrapping method	a) The capsule must be separated from the liquid bath and dried; b) It is difficult to obtain capsules in extremely viscous carrier material melts
Centrifugal extrusion	Similar as simple extrusion differing that the core material and coating material form a unified jet flow only at the end through a nozzle with a coaxial opening (coextrusion) by centrifugal force	The same of simple extrusion	The same of simple extrusion
Coacervation	The entrapment is due to the deposition of a liquid coating material around the core material by electrostatic attraction	Can be used to encapsulate heat-sensitive ingredients due to done at room temperature	a) Toxic chemical agents are used; b)The complex coacervates are highly unstable; c) There are residual solvents and coacervating agents on

			the capsules surfaces; d) spheres low size range; e)expensive and complex method
Liposome entrapment	Phospholipids are dispersed in an aqueous phase spontaneously formation a liposome. A core material is entrapment into a liposome	a) Either aqueous or lipid soluble material can be encapsulated; b) suitable to high water activity applications; c) efficient controlled delivery	Mainly used on a laboratory scale
Fluidized bed coating	This technique relies upon by nozzle spraying the coating material into a fluidized bed of core material in a hot environment	a) Low cost process; b) It allows specific capsule size distribution and low porosities into the product	Degradation of highly temperature- sensitive compounds
Lyophilizaton/ Freeze drying	The entrapment occurs by lyophilization of an emulsion solution containing a core material and a coating material	Thermosensitive substances that are unstable in aqueous solutions may be efficiently encapsulated by this technique	a) Long processing time; b) expensive process costs; c) expensive storage and transport of the capsules
Inclusion complexation	Particular apolar molecules are entrapped through a hydrophobic interaction inside the β-Cyclodextrin cavity replacing water molecules	Very efficient to protect unstable and high added value apolar compounds such as flavors	a) Encapsulation restricted to apolar compounds with a suitable molecular dimensions; b) β cyclodextrin price is expensive; c)frequently undesirable release of the formed complex

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