24. Microencapsulation for food fortification

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The United Nations Member States, in 2015 had adopted the 2030 Agenda for Sustainable Development which provides a framework of 17 Sustainable Development Goals for achieving peace and prosperity for people and the planet. All nations recognize that ending poverty should align with strategies that improve health and education, reduce inequality, and stimulate economic growth- and at the same time, tackle climate change and work to preserve our oceans and forests.

Sustainable Development Goal 2 aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030. The triple burden of malnutrition – undernutrition, hidden hunger and overweight – threatens the survival, growth and development of children and young people. Well-nourished children are better able to grow and learn, to participate in their communities and to be resilient in the face of disease, disaster and other emergencies.

According to the WHO, 690 million people (8.9 per cent of the world's population) were hungry in 2019. Children, adolescents and young adults from the poorest and most marginalized communities bear the greatest burden of all forms of malnutrition. Worldwide, nearly half of all deaths in children under 5 are attributable to undernutrition. In 2019, 144 million children under 5, or 21.3 per cent were stunted, 47 million or 6.9 per cent, were wasted (of which 14.3 million were severely wasted) and 38 million, or 5.6 per cent, were overweight. Malnutrition during pregnancy can also affect nutrition outcomes in children, notably one third of females aged 15 to 49 years worldwide were affected by anemia in 2016, with no notable change over the last 2 decades. Central to all of the nutrition-related disorders and disease conditions is hidden hunger or micronutrient (mineral and vitamin) deficiencies. Widespread consumption of poor-quality food leads to hidden hunger, which ravages economies and worsens poverty, according to International Food Policy Research Institute. Globally, more than 2 billion people are micronutrient deficient not because they do not have access to food, but because they fail to receive enough micronutrients from the poor-quality food they eat which makes them sick with various deficiency conditions.

Hunger and consequences.

Hunger in all forms poses a serious challenge to sustainable development as hungry

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people tend to be less productive and are easily prone to diseases. While global progress on curtailing chronic hunger has been seeing considerable improvement, progress on improving hidden hunger has been much slower. Ironically, undernutrition has been on the rise globally since 2015 after showing a significant downward trend for decades. This trend has been essentially due to major setbacks in food production and distribution systems due to climate change; locust infestation in East Africa, Arab Peninsula, the Indian subcontinent and South America; conflicts and war; and the very recent global crisis of the COVID pandemic. These stresses on food systems very easily impact the most poor and susceptible sections of the population, drastically reducing their purchasing power and cutting off their access to food, driving them into an abyss of hunger.

Chronic Hunger and Hidden Hunger

Chronic hunger is a consequence of undernourishment or inadequacy of calories or of one or more nutrients and is also referred to as undernutrition. The four consequences of chronic hunger are: (i) **being underweight** for one's age, defined as *low weight for age* in children and *BMI lower than 18.5* in adults; (ii) **stunting** and **(iii) wasting** in children defined as *being too short for one's age* and *being dangerously thin for one's height* respectively; and (iv) **hidden hunger** or **micronutrient malnutrition**-*being deficient in micronutrients or vitamins and minerals*.

Hidden hunger develops when there is low intake or absorption of vitamins and minerals essential for proper health and physical and mental development in children and normal productive functioning in adults. Particularly susceptible are women and children specifically those from marginalized communities as they have stages of life when there is a surge in physiological need for micronutrients during periods of menstruation, pregnancy and lactation in women and period of spurt in growth in children. Causes include inadequate wholesome diets and frequent occurrence of disease especially in infancy and childhood and enhanced physiological needs that are summarily not met. Children exposed to grave levels of hidden hunger right from the time of conception to infancy and early childhood which is within the crucial window of 1000 days of existence are crippled for life as a consequence of severe physical and cognitive impairments. They are never quite able to resuscitate themselves from the viscous cycle and outcomes of micronutrient deficiency and grow in to adults who underperform in society curtailing the country's socioeconomic development. Undernourished and micronutrient deficient girls become young women who contribute to intergenerational undernutrition by bearing low birthweight children that suffer from both undernutrition and hidden hunger from birth.

Hotspots of hidden hunger

Micronutrients deficiency is a major threat for more than half of the world population living in the developing countries. The two regions considered to be hotspots where prevalence of hidden hunger is the highest are the sub Saharan Africa and South Asia. The most commonly recognized vitamin and mineral deficiencies deemed responsible for hidden hunger in the order of incidence are iodine, iron, zinc, vitamin A, calcium, vitamin D and B vitamins. Of the 3.1 million child deaths that occur globally each year, a whopping 1.1 million are caused by hidden hunger. Iron deficiency is the most common and widespread nutritional disorder in the world and it makes a public health problem in both industrialised and non-industrialised countries. In severe cases, iron deficiency causes anaemia. Anaemia is the outcome of a reduced haemoglobin level in blood causing mental disorders, severe pregnancy problems, and premature delivery. In addition, iron deficiency leads to impaired motor development, anemia, low energy, pregnancy and childbirth-associated morbidities. Worldwide, about 18 million babies are born with brain damage each year due to maternal iodine deficiency. Anemia also causes over 50000 maternal deaths during child birth, in addition to causing preterm births, low birthweight and infant deaths. Iron deficiency has left about 40% of women low on energy in the developing world. In India, over 50% of women are anemic contributing significantly to its burden of disease. Folic acid deficiency causes megaloblastic anaemia, increases the susceptibility to cancer, leads to neural tube defects and vascular diseases.

Most of the vitamin A deficiencies occur in the developing countries and are common in South and South East Asia. Women, being the most susceptible group, are influenced by vitamin A deficiency (VAD) during pregnancy and lactation. VAD affects normal functioning of the visual system, cell function, epithelial cellular integrity, immune function, and reproduction. VAD has affected over two million people, especially pregnant women and young children, in the developing countries. Vitamin A and zinc deficiency in children impair the immune system causing increased susceptibility to disease.

Zinc deficiency reduces growth and leads to stunting in children. Lack of iodine and iron in diet causes cognitive impairment. Zinc interferes with the cell division, protein synthesis, and growth which indicates its need for infants and pregnant and lactating women. Zinc deficiency affects infants, pregnant and lactating women, and also leads to growth retardation and cognitive impairment. The consequences of iodine deficiency include goitre, cretinism, paralysis, and deaf-mutism.

Food fortification has contributed effectively to improving the micronutrient status in adults and children in several countries across the globe. According to WHO, in most regions in the world, bread consumption is high in most countries and flour fortification offers an opportunity to deliver adequate levels of iron. Fortification with micronutrients of staple foods like wheat flour, ubiquitously used condiments like salt is strongly recommended to overcome the related nutrient deficiencies. Micronutrient fortified foods have certain technical limitations which must be considered on the priority basis to make this program successful.

Micronutrients fortification: unencapsulated vs. microencapsulated forms

Whole wheat flour when fortified with ferrous sulphate, zinc sulphate, zinc oxide, the following observations on were made on the flour quality. Due to elemental iron and zinc oxide moisture content and protein content of flour decreased compared to unfortified flour. Quality attributes of fortified chapatti like flexibility, texture, and chewiness were reduced up to 15% as compared to unfortified flour. Fortification had deteriorative effects on the chemical stability of flour as well as on the texture attributes of the product. Also, the biologically active form- the ferrous form was converted to ferric, which affected bioavailability. Since whole wheat flour has significant levels of phytic acid, absorption and bioavailability of unencapsulated fortificants like iron, zinc is significantly reduced. Softness of Naan (a kind of food prepared from wheat flour) was reduced significantly by the electrolytic effect of iron on the dough proteins. Biscuits prepared from flour fortified with ferrous sulphate showed unpleasant sensory attributes, grey colour and disagreeable taste compared to the unfortified ones. At room temperature, the unencapsulated ferrous sulphate caused oxidation in the biscuits and deteriorated the quality of the fat in the product. Finger millet flour has also been used as a vehicle for ferrous fumarate and ferric pyrophosphate fortification. Bio-accessibility of both fortificants was significantly reduced mainly due to the presence of large quantities of phytate, tannin, and calcium in millet flour which inhibit the absorption of iron. The disadvantages associated with unencapsulated iron and other micronutrient fortificants can be overcome with encapsulation techniques.

In a study, milk was fortified with unencapsulated iron and encapsulated iron. Thiobarbituric acid (TBA) absorption which measures the fat oxidation products and is a measure of stability, was higher in milk fortified with unencapsulated iron. Similarly, microencapsulated iron whey protein complex was used to fortify yogurt, which had good sensory quality and suppressed the oxidised flavour of iron. Whereas, high TBA absorption was observed in yogurt fortified with unencapsulated iron. This was due to the interaction of iron with casein of milk and the presence of oxygen acted as pro-oxidant and triggered lipid oxidation. When oxidation occurs, free fatty acids accumulate and ultimately TBA absorption increases which is an indicator of oxidative rancidity.

A Water/Oil/Water emulsion: Emulsion of water in corn oil with Tween 60 as an emulsifier was prepared to encapsulate iron in the inner aqueous layer to overcome oxidation. Encapsulation efficiency of iron was 99.75% and TBA reactive substances (TBARS) production was negligible showing that encapsulated iron prevented the oxidation reactions that led to increased formation of TBARS. Another type of encapsulated iron uses a stable form of iron (iron pyrophosphate) which was encapsulated by spray drying using palm oil with 1% lecithin. When iron microcapsules of variable sizes were prepared and evaluated for their bioavailability, the highest bioavailability was observed with the microparticles with smallest particle size.

In a study, three kinds of yogurt-plain, yoghurt fortified with ferrous sulphate, yoghurt with iron whey protein complex, and yoghurt with microencapsulated iron whey protein complex were compared for stability and sensory characteristics. Yogurt fortified with ferrous sulphate was highly oxidised and metallic taste developed. The flavour and overall quality of yogurt fortified with microencapsulated iron-whey protein complex were similar to those of unfortified yogurt and were well accepted by the sensory panellists. In another study, ferric ammonium sulphate microcapsules were prepared using airless paint sprayer method. In this method, the emulsion of polyglycerol monostearate and iron salt was nebulised into a chilled solution tween 60. The resultant mixture was centrifuged and microcapsules were obtained. The encapsulation efficiency of microcapsules was 75%. Chemical lipid oxidation rate was high in milk fortified with unencapsulated iron. TBA absorption increased in milk fortified with unencapsulated iron after 12 days of storage.

Microcapsules containing ferric pyrophosphate, potassium iodide, and retinyl palmitate were prepared by using spray chilling technique. In this, ferric pyrophosphate (40% w/w) and lecithin (1% w/w) in hot molten palm fat were filled in spray tower, iodine salt, and retinyl particles were also added into the mixture. This mixture was transferred immediately to pre-cooled spray tower to avoid oxidation and the atomised particles were solidified. The size of microcapsules was 132 μm. The microcapsules were added in salt to prepare Triple fortified salt (TFS). There was no difference in colour or taste, and the overall acceptability was good.

Microencapsulation technique

Microencapsulation may be defined as the process of enclosing a substance inside a miniature capsule. Extremely tiny droplets, or particles of liquid or solid material, are packed within a second material or coated with a continuous film of polymeric material for the purpose of shielding the active ingredient from the surrounding environment. All three states of matter (solids, liquids, and gases) may be microencapsulated. core materials may be encapsulated so that the core material will be released either gradually through the capsule walls, known as controlled release or diffusion, or when external conditions trigger the capsule walls to rupture, melt, or dissolve. The substance that is encapsulated may be called the core material, the active ingredient or agent.

The material encapsulating the core is referred to as the coating, membrane, shell, or wall material. Microcapsules may have one wall or multiple shells. These capsules, which range in size from one micron to several 100 microns. Terms applied to the coating of the microcapsules include the wall, shell, external phase or membrane. Advantages of Microencapsulation: The primary reason for microencapsulation is either for sustained or prolonged drug release or to increase bioavailability. This technique has been widely used for masking taste and odour of many drugs to improve patient compliance. This technique can be used for converting liquid drugs into a free-flowing powder.

Microencapsulation protects encapsulated nutrients from oxidation due to exposure to moisture, light and other prooxidants. Incompatibility among the components of fortificant and food vehicle can be prevented by microencapsulation. Vaporization of many volatile bioactive compounds can be prevented by microencapsulation. Also, microencapsulation reduces toxicity and GI irritation. Alteration in site of absorption can also be achieved by microencapsulation. Microencapsulated vitamin A palmitate was reported to have enhanced stability. Microencapsulation decreases evaporation rate of the core material and also enables targeted delivery.

Composition and characteristics of microcapsules provides definite flexibility and utilization of these features often allows effectual design and development of the desired microcapsule properties. Controlled release of nutrients from microcapsule is achieved under specific conditions. Coating Materials: The coating material should be capable of forming a film that is cohesive with the core material, be chemically compatible and non-reactive with the core material and provide the desired coating properties, such as strength, flexibility, impermeability, optical properties, and stability. Film-forming, pliable, tasteless, stable. Non-hygroscopic, no high viscosity, economical. Soluble in an aqueous media or solvent, or melting. The coating can be flexible, brittle, hard, thin etc. Examples of coating materials: *Water soluble resins*- Gelatin, Gum Arabic, Starch, Carboxymethyl-cellulose, Hydroxyethylcellulose, Polyvinylpyrrolidone, Methylcellulose, Arabinogalactan, Polyvinyl alcohol, Polyacrylic acid. *Water insoluble resins* — Ethylcellulose, Polyethylene, Polymethacrylate, Polyamide (Nylon), Poly (Ethylene Vinyl acetate), and Cellulose nitrate, Silicones, Poly (lactidecoglycolide). *Waxes and lipids* — Paraffin, Carnauba, Spermaceti, Beeswax, Stearic acid, Stearyl alcohol, Glyceryl stearates. *Enteric resins*- Shellac, Cellulose acetate phthalate, Zein.

The process variables for effective encapsulation are as follows: Density, surface area, melting point, solubility, friability, volatility, crystalline nature, flowability of the core material, concentration and application rate of coating material, volume of air required to fluidize and support the core material, inlet and outlet temperatures. Evaluation of microencapsulation is done by the following methods- Surface morphology of the microcapsules by Scanning electron microscopy, bioactive compound content and activity determination, determination of % ingredient entrapment, bulk density, particle size, studies on in vitro dissolution, diffusion and stability.

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