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Fortification and Supplementation: Strategies for Addressing Mineral Deficiencies

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Mineral fortification is a key public health strategy aimed at preventing micronutrient deficiencies by adding essential vitamins and minerals to commonly consumed foods. Fortification can be categorized into mass fortification, targeted fortification, and market-driven fortification, each addressing specific population needs. Household and biofortification approaches further enhance accessibility and sustainability. Common fortificants include vitamins A, D, E, C, B-complex, iron, iodine, and other minerals, each requiring careful selection to maintain stability, bioavailability, and sensory quality. Fortification offers several advantages, including rapid improvement in nutritional status, low cost, and compatibility with existing dietary patterns.

Supplementation complements fortification by providing concentrated nutrient doses through tablets, syrups, and capsules, especially targeting vulnerable groups like children, adolescents, and pregnant women. National programmes like the Reproductive and Child Health Programme emphasize iron and folic acid supplementation to combat anemia and developmental issues in children and women. Together, fortification and supplementation form an integrated approach to improving population health outcomes.

Mineral Fortification

Food fortification refers to the process of adding one or more essential nutrients to food, regardless of whether the food originally contains these nutrients, to prevent or address nutrient deficiencies in the general or specific population groups (FAO/WHO, 1994). Other related terms include restoration, which involves replacing essential nutrients lost during manufacturing, storage, or handling, restoring the food's original nutrient levels (FAO/WHO, 1994). Enrichment is often used synonymously with fortification but typically refers to replenishing vitamins and minerals lost during food processing (Hoffpauer and Wright, 1994).

Forms of Food Fortification

Food fortification can be implemented in different ways. It may involve adding essential nutrients to foods that are commonly consumed by the entire population (mass fortification), enriching foods specifically designed for certain groups like young children or displaced individuals (targeted fortification), or allowing food companies to voluntarily add nutrients to products sold in the marketplace (market-driven fortification).

1. Mass Fortification

Mass fortification refers to the process of adding one or more essential micronutrients to staple foods that are regularly consumed by the majority of people, such as milk, cereals, and condiments. Typically, this type of fortification is introduced, regulated, and overseen by government authorities. It is also known as universal fortification.

This approach is most suitable when a large segment of the population is at significant risk of developing micronutrient deficiencies. In some cases, these deficiencies are clearly measurable through low nutrient intake or biological markers, while in other situations, even if clinical deficiencies are not yet evident, fortification can still provide substantial public health benefits.

2. Targeted Fortification

Targeted fortification focuses on increasing the intake of specific nutrients within particular groups rather than the whole population. This is achieved by fortifying foods specially intended for those groups, such as:

- Complementary foods for infants and toddlers
- Meals provided in school feeding programs
- Special fortified snacks like biscuits for children and pregnant women
- Blended foods or emergency rations for displaced communities or refugees

3. Market-driven fortification

The term "market-driven fortification" is applied to situations whereby a food manufacturer takes a business-oriented initiative to add specific amounts of one or more micronutrients to processed foods. Although voluntary, this type of food fortification usually takes place within government-set regulatory limits. Market-driven fortification can play a positive role in public health by contributing to meeting nutrient requirements and thereby reducing the risk of micronutrient deficiency.

Other type of Fortification

1. **Household and community fortification:** Efforts are under way in a number of countries to develop and test practical ways of adding micronutrients to foods at the household level, in particular, to complementary foods for young children. In effect, this approach is a combination of supplementation

and fortification, and has been referred to by some as "complementary food supplementation"

2. **Biofortification of Staple Foods:** The biofortification of staple foods, i.e. the breeding and genetic modification of plants so as to improve their nutrient content and/or absorption is another novel approach that is currently being considered. The potential for plant breeding to increase the micronutrient content of various cereals, legumes and tubers certainly exists; for instance, it is possible to select certain cereals (such as rice) and legumes for their high iron content, various varieties of carrots and sweet potatoes for their favourable β-carotene levels, and maizes for their low phytate content (which improves the absorption of iron and zinc).

Vitamin and Mineral Fortificants

Prudent handling of vitamin and mineral additives in food processing requires a sound understanding of the characteristics of these compounds: their stabilities to various unit operations, solubilities and reactivities with other compounds. Many forms of these nutrients have been developed to render them more suitable for use under a wide range of applications.

Properties of Micronutrient Compounds

1. **Vitamin A:** In vivo, this vitamin is generally found as the free alcohol or esterified with a fatty acid. The vitamin is available in pure form by chemical synthesis as vitamin A palmitate or the acetate, or recovered from molecularly recovered fish oil. It is a yellowish oily material which may crystallise into needlelike crystals (Parman and Salinard, 1981). Provitamins which are then converted to their active form, serve not only as nutrifyng compounds but also as colourants and anti-oxidants. The most common of these is beta-carotene.

   In dehydrated foods, vitamin A and provitamin A are highly susceptible to loss by oxidation (Labuza et al., 1978). The extent of this loss depends on the severity of the drying process, protection provided by packaging materials and conditions of storage. Vitamin A in pure form is unstable in the presence of mineral acids but stable in the presence of alkali. Naturally occurring vitamin A is insoluble in water but soluble in oil. In this form the vitamin has limited applicability. Vitamin A fortificants are commercially available in a wide range of forms adapted for use under various conditions. For use in fat or oil based foods such as margarines, oils and dairy products, vitamin A as the acetate or palmitate have been used. They are stabilised with a mixture of phenolic antioxidants or with tocopherols. For mixing with dry products, a dry form of the fortificant was required with the appropriate size and density. Encapsulation of the vitamin in a more hydrophilic coat is commonly practised in order to achieve a more water dispersable product. Two materials used in encapsulation are gum acacia and gelatin. These dry forms of the vitamin are also stabilised using tocopherols or phenolic antioxidants.

2. **Vitamin D:** The principal forms of the vitamin are D_3 and D_2. They are white, crystalline fat-soluble vitamins, formed by irradiation of the appropriate

sterol followed by purification procedures. These compounds are sensitive to oxygen and light, with the D_3 form of the vitamin being slightly more stable. Trace metals such as Cu and Fe act as pro-oxidants.

As with vitamin A, commercially available forms include fat-soluble crystals for use in high fat content foods, and encapsulated, stabilised versions of the fortificant, suitable for use in dry products to be reconstituted with water. As was stated for vitamin A, at the levels of water activity which exist in dehydrated foods, these fat-soluble vitamins are most susceptible to oxidative loss.

3. **Vitamin E:** Vitamin E is a slightly viscous, pale-yellow oily liquid obtained from molecular distillation of by-products from vegetable oil refining or by chemical synthesis. The naturally occurring form of the vitamin is the d-isomer. The synthetic compound is a racemic mixture of the d and 1 isomers. The 1-isomer doesn't have the full biological activity of the d-isomer, but due to the stability of the racemic mixture and the ease of purification, the IU of vitamin E has been defined as 1 mg dl-a tocopheryl acetate. The free alcohol form of the vitamin is highly unstable to oxidation and is therefore widely used in foods as an antioxidant to stabilise the lip id component of foods. Esterified forms of the vitamin, commonly the acetate, are much more stable. For this reason, fortificants are usually of this form. As with the other fat soluble vitamins, cold water soluble forms have been produced by encapsulation within a suitable matrix.
4. **Vitamins of the B Complex:** Vitamin B_1, or thiamine, is a white crystalline solid with a characteristic yeast-like odour and a slight bitter taste. Thiamine is produced by chemical synthesis as the hydrochloride and mononitate salts. The hydrochloride is soluble to the extent of 50% in water as compared with 2.7% for the mononitrate (Bailey, 1991). Thiamine is one of the most unstable vitamins. Its stability to heat and oxidation is greatest at a pH range of 6 and below. At higher values of pH it becomes increasingly unstable. Thiamine is susceptible to nucleophilicattack, therefore it is degraded by some mineral salts in aqueous foods. Thiamine hydrochloride is the fortificant of choice in cases where dissolution in aqueous media is required. In most other cases the mononitrate is used due to its lower hygroscopicity. Thiamine is also commercially available in a coated form using mono- and di-glycerides of edible fatty acids.

Biotin is a white crystalline powder of low water solubility. It is generally commercially available in diluted form as the physiological requirement for this vitamin is so low. Hoffmann-La Roche sells a 1 % mixture of this vitamin with dicalcium phosphate dihydrate. Biotin is fairly stable to heat, air and light. Vitamin B_2, riboflavin, is of an intense orange colour and low water solubility. A commercially available more water soluble form of this vitamin is the sodium salt of riboflavin 5'-phosphate. Riboflavin is generally stable under most processing conditions, but is unstable in alkaline medium. It is very sensitive to light, particularly in the presence of ascorbic acid.

Pantothenic acid, is a pale yellow, viscous, hygroscopic liquid which is very unstable. The most commonly used commercially available form is calcium pantothenate. This is a slightly hygroscopic white powder with no smell but a slightly bitter taste. Stability of this compound is greatest at pH values between 5 and 7. Vitamin B_6, pyridoxine, is available commercially as the hydrochloride. Coated forms are also available as with all of the B-vitamins. This vitamin is quite stable to heat and atmospheric oxygen and heat, but degradation is catalysed by metal ions.

Niacin in the form of either nicotinic acid or nicotinamide, can be used in nutrient addition to foods. At very high levels, nicotinic acid has been shown to cause unpleasant side effects such as flushing and 'pins and needles'. This has led to some preference for nicotinamide. Both forms of the vitamin are stable to atmospheric oxygen, heat and light in the dry state as well as in solution.

Cyanocobalamin, the most important compound with vitamin B_{12} activity, is commercially available as a crystalline, dark red, hygroscopic powder. Human requirements for this vitamin are very low and it is commonly sold highly diluted by a carrier. In the preparations sold by Hofmann-La Roche, for instance, it can be purchased diluted with mannitol or a mixture containing modified starches, citrate, citric acid, benzoate, sorbic acid and silicon dioxide. The selection of preparation depends, of course, on the end use. In solution it is most stable between pH values 4-7. It is unstable to oxidising and reducing agents and exposure to sunlight, but is fairly stable to heat (Bailey, 1991).

Folic acid is a yellow-orange, odourless, tasteless crystalline substance. It is moderately stable to heat and atmospheric oxygen. In neutral solution it is quite stable, but instability increases with a shift in pH in either direction. Folic acid is unstable to heat, light, sunlight, oxidising and reducing agents.

5. **Vitamin C:** Vitamin C or ascorbic acid is an odourless, white, crystalline compound which is stable in its dry form. Due to its high water solubility, losses due to leaching can be a problem in some processing procedures. Ascorbic acid is readily oxidised. In dehydrated citrus juices the degradation is dependant on both temperature and water activity. Other factors as well can influence the degradation behaviour of vitamin C, these include salt and sugar concentration, pH, oxygen, metal catalysts and ratio of ascorbic: dehydroascorbic acid.

Vitamin C addition to foods is commonly practised for reasons other than fortification. Commercially available forms of this vitamin include the free acid and the sodium and calcium salts of these, in powder as well as crystalline or granular form. For mixing with dry products, particle size and density are of course important considerations. A fat coated form of ascorbic acid is also available for enrichment purposes. Ascorbylpalmitate, is a form of the vitamin used for purposes other than fortification. It is used as an antioxidant in fats and oils and has also emulsifying properties (Anon. 1985). Other areas of food processing for which vitamin C has application are the prevention of browning in fresh and canned fruit and vegetables, acidification, curing of meat and prevention of haze formation in brewed products (Borenstein, 1987).

6. **Iron Fortificants:** Iron compounds used in food fortification are commonly classified according to their solubility. Selection of an appropriate iron fortificant for any given application is based on the following criteria: organoleptic considerations, bioavailability, cost and safety (Hurrell and Cook, 1990).

The colour of iron compounds is often a critical factor when fortifying light coloured foods. For example white iron, ferric orthophosphate, is often the fortificant of choice in the enrichment of rice. The use of more soluble iron compounds often leads to the development of off-colours and off-flavours due to reactions with other components of the food material. Infant cereals have been found to turn grey or green on addition of ferrous sulphate. Off-flavours can be the result of lipid oxidation catalysed by iron. The iron compounds themselves may contribute to a metallic flavour. Some of these undesirable interactions with the food matrix can be avoided by coating the fortificant with hydrogenated oils or ethyl cellulose.

Bioavailability of iron compounds is normally stated relative to a ferrous sulphate standard. The highly water soluble iron compounds have superior bioavailability. Bioavailability of the insoluble or very poorly soluble iron compounds can be improved by reducing particle size. Unfortunately this is accompanied by increased reactivity in deteriorative processes.

Sodium iron EDTA is less well absorbed than ferrous sulphate from foods which contain few inhibitors to absorption. In the presence of these inhibitors, however, the EDTA complex is better absorbed. Sodium iron EDTA also participates to a lesser extent in deteriorative reactions. The use of this compound reduces the problem of precipitate formation in foods such as fish sauces and tea. The use of this compound is not advised in developed countries where the population already receives close to the recommended acceptable daily intake of EDTA (Hurrell and Cook, 1990).

The problem of low bioavailability of some of the less reactive forms of iron is often circumvented by the use of absorption enhancers added along with the fortificant. Examples of such enhancers are ascorbic acid, sodium acid sulphate and orthophosphoric acid.

7. **Iodine Compounds:** The most commonly used compounds in the iodisation of foods are the iodides and iodates of sodium and potassium. These are the additives allowed by Codex Alimentarius in the iodisation of salt. The iodide compounds (Bauernfeind, 1991) are cheaper, more soluble and have a higher iodine content (so that less is needed to achieve the same level of iodisation) than the corresponding iodates. Iodates are more stable under conditions of high moisture, high ambient

temperature, sunlight, aeration and the presence of impurities.

The use of iodate is therefore recommended for use in developing countries. Potassium iodide is well suited in cases where the salt is dry, free from impurities and has a slightly alkaline pH. Otherwise the iodide may be oxidised to molecular iodine and lost through evaporation. If excess water is present the iodide may be separated from the salt in the water film (FAO/WHO, 1991). Loss of iodide can be reduced through the addition of stabilisers such as 0.1% sodium thiosulphate and 0.1% calcium hydroxide combined or 0.04% dextrose and 0.006% sodium bicarbonate (Kuhajek and Fiedelman, 1973). Calcium salts have been used with some report of off-flavour due to the calcium ions (Kuhajek and Fiedelman, 1973). The calcium compound is also much less water soluble than the sodium and potassium compounds and this further limits its applicability.

8. **Other Mineral Additives:** A range of mineral salts are available for fortification with Ca, Mg, P, Zn, Cu and Mn. Prudent selection of mineral compounds is based largely on consideration of mineral reactivity and solubility of the salt. The requirements of the fortificant vary according to the nature of the food product and its end use. To overcome problems of flavour, texture and colour deterioration due to addition of minerals, some companies have engineered new fortificant preparations which generally involve the use of stabilisers and emulsifiers to maintain the mineral in solution (Anon. 1986).

Advantages of Mineral Fortification

- Potentially rapid improvements in micronutrient status of population.
- Reasonable cost, especially with existing technology and local distribution networks.
- Requires no changes in existing food patterns or in individual compliance.
- Fortified food consumed in adequate amounts by target population.
- Fortificants that are stable and well absorbed, but do not affect sensory properties of foods.
- Preferably, centrally processed food vehicles.
- Government and food industry partnership.

Supplementation

- Food supplements are concentrated sources of nutrients or other substances with a nutritional or physiological effect, with the purpose of supplementing the normal diet.
- Food supplements are highly concentrated vitamins and minerals produced by pharmaceutical manufacturers in the form of capsules, tablets or injections and administered as part of health care or specific nutrition campaigns.
- Food supplements can be in the form of pills, tablets, capsules or liquids in measured doses.
- Supplements may be taken in order to correct nutritional deficiencies or maintain an adequate intake of certain nutrients. However, in some cases an excessive intake of vitamins and minerals can be harmful to health. Therefore maximum levels are necessary to ensure their safe use in food supplements.

- Reaching out to vulnerable groups (particularly children and women of childbearing age) with vitamin and mineral supplements in the form of tablets, capsules and syrups.
- The cost can be as low as a few cents per person per year.
- Under Reproductive and Child Health Programme : Young children and adolescent girls are given iron and folic acid.
- Children 6-24 months old are at the greatest risk of the irreversible long term consequences of iron deficiency namely impaired physical and mental development.
- They are given 20mg elemental iron and 100 microgram of folic acid in syrup form. Children below 5 years are given 20mg of elemental iron and 100 microgram of folic acid.
- Adolescent girls on attaining menarche should consume weekly dosage of IFA tablet containing 100 mg elemental iron and 500 microgram of folic acid.
- All pregnant mothers are given 60mg of elemental iron and 500 microgram of folic acid. Low birth weight infants need iron supplementation from the age of 2 months.

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