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Editorial

Futuristic Biofortified Foods: How to Ensure their Competence?

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Background

The quality of human growth and development depends mainly on the sufficiency and efficacy of macronutrients and micronutrients. Commonly, they constitute a relatively small part of the diet in different regions of the world. Major insufficiency of those nutrients contributes to underdevelopment and a tremendous type of disease.

Many indexes show that from 24 to 33% of the world population suffer from macronutrient and micronutrient deficiencies, such as vitamins and minerals. The most vulnerable group of the population that is more susceptible to experiencing harm due to a multi-nutrient deficiency under specific circumstances is the geriatric female. However, the elderly people of both sexes and children face the same challenges. People seemed to lack most of the time many compounds, including vitamin A, vitamins B12 and B9, vitamin D, magnesium, iodine, iron, and copper. People around the globe have been working by different means to prevent or correct population health and reduce the level of micronutrient deficiencies by adding essential vitamins, proteins, and minerals to commonly consumed foods. The aim was not to require changes in dietary habits of the vulnerable people; it was rather to focus on improving public health outcomes efficiently and equitably (WHO) through industrial strategic measures to increase nutrient intakes across different categories.

Therefore, the concept of food fortification was initiated, in which industry is allowed to practice the addition of nutrients deliberately (i.e. proteins, vitamins, and minerals) in a food that sounds healthy and fits their culture and religion without any side effects or adverse effects. However, the industry is still neglecting the competence of these products and their economic and health values. The history of fortified foods goes back to the 1930s, as they were marketed to increase dietary intake of vitamins and minerals from commonly consumed foods such as milk, cereals, and bread.

Definition of fortified foods

Foods that are made to contain added nutrients from a natural or manufactured source, whether it be a vitamin, protein, amino acid, fatty acid, mineral element, or probiotic such as bacteria or viruses, including bacteriophages (bacteria eaters). Basically, these foods aim to enhance nutrition and provide additional health benefits.

The purpose and challenges of fortified foods

The main aim of the classical food fortification remains important for addressing specific nutrient deficiencies, but its impact faces challenges and is often limited in many settings that usually rely on cereal-based diets and infants' formulas. Fortified foods play a vital role in reducing nutritional gaps for children, the elderly, pregnant or breastfeeding women, people on specific restricted diets, and poor persons. Fortified food "analogs" with essential amino acids, vitamins, and minerals, such as plant-based milk or meat substitutes, closely resemble their usual food counterparts in nutritional profile. For example, fruit juices may contain calcium and ascorbic acids, and milk is often fortified with vitamin D and calcium. Fortified foods are those that contain nutrients removed during processing or any of the supply chain and then reintroduced or nourished again. Additionally, after processing, many grain flours are refined grains with folic acid, calcium, and iron. The ongoing challenges are quality instability of nutrients, cost of manufacturing, consumers` trust and awareness, possible allergy issues, international approval, and the coexistence of antinutrients. The conventional "one carrier, one nutrient" approach also struggles in communities facing overlapping deficiencies in multiple minerals, enzymes, bioactive peptides, phytochemicals, and some vitamins. The latter challenge has led the scientists to consider biological fortification, which uses microbial processes to enhance multiple nutrients naturally within culturally familiar foods and have nutritional competence.

Classes and types of fortified foods:

1. **Dairy products:**

- Milk: Cow's milk and animal milk-like products (coconut, soy, and almond) are commonly fortified with calcium and vitamin D.
- Yogurt and sharps: Natural yogurt enriched with vitamins and phytochemicals from fruits.
- Cheese: Many cheeses are fortified with calcium and bioactive fats.

2. **Grains and cereals:**

- Breakfast cereals: Corn flakes usually fortified with vitamins and minerals like iron and B vitamins.
- Brown and white breads: They are fortified with nutrients like calcium and iron.
- Wheat flour: Quite often fortified with folic acid and iron.

3. **Drinks and soft drinks:**

- Fruit juices: Some juices are enriched with vitamin D.
- Protein and sports drinks: Some drinks are fortified with added protein, amino acids, vitamins, and minerals like zinc, magnesium, etc.

4. **Specific formulas:**

- Infant formulas: They are the most fortified food that is carefully designed to provide complete nutrition for babies and infants.

5. **Digestive foods:**

- Food bars: Food enriched with fibers, enzymes, and iodine, which is essential for gastrointestinal tract and thyroid health.

6. **Biofortified foods: "New concepts":**

- Fermented food: Some foods are enriched with other fermented foods or parts of fermented foods aimed at fighting different diseases.
- Probiotic food: Food fortified with bacteria that contribute to health, particularly the digestive system.
- Bio-enriched foods: Novel foods fortified with bacteriophages are proposed to help execute pathogens in foods and also provide some extra benefits.

Controlled fermentation illustrates this approach by reshaping the nutritional profile of staple foods. Very often, fermented foods are an exceptional source of beneficial microbes like probiotics "*Lactobacillus, Bifidobacterium, Bacillus*, and *E. coli* and also yeasts, including *Saccharomyces* and *Aspergillus*". The bioactivity of microbial enzymes used in food frees the minerals and improves their bioavailability, including iron and zinc. At the same time, food microbiota synthesizes essential B vitamins, such as folate, biotin, and thiamin, and also vitamin K. Fermentation also improves protein digestibility and energy availability by breaking down complex proteins and starches into bioactive peptides and simple sugars. Beyond enhancing nutrient levels, biofortified foods generate bioactive compounds such as antioxidant, anti-obesity, anti-inflammation, anti-stress, and antimicrobial peptides, which provide functional health benefits regardless of the basic nutritional purpose. Bacteriophages are precise, naturally occurring biological drives that enhance food safety while supporting public health. Those excellent antibacterial viruses infect only pathogenic bacteria. Thus, they pose no risk to humans, animals, or plants neither their products. The power of phages lies in their selectivity: they target pathogens such as *Listeria monocytogenes, Klebsiella, Salmonella,* and *E. coli* without disrupting the beneficial microbes responsible for fermentation, probiotic effects, or desirable sensory qualities. This makes phages fundamentally different from broad-spectrum chemical disinfectants and antibiotics, which often damage the wider food microflora and alter product quality. In recent studies, the bacteriophages already showed exceptional activity against bacteria in meat products. Some studies showed that factors like fat content or surface roughness may influence their performance; however, phage treatments consistently reduce pathogen loads nearly to 96% across a range of foods, including fresh produce (during water treatment as contains phages) that subsidize the ability to extend the shelf life.

Health benefits

Consumers' awareness about biofortified foods can lead to a regular consumption of the fermented foods, which deliver systemic health advantages, mainly through the gut. Food microbiota profoundly supply the body through the food matrix with diverse microbes and metabolites that strengthen the bioavailability of nutrients at the brush border, improve the immune system, reduce cell inflammation, and increase the efficacy of hormones and biochemical reactions. Food combining with probiotics usually targets a specific fortification purpose to create a synergistic effect. This integrated approach produces compounds capable of addressing multiple dietary gaps effectively and sustainably within familiar diet settings and regulations. Combining probiotics with a food matrix acts as a crucial dynamic partner in nutritional fortification. Definitely, this type of combination contributes to the kinetics of nutrients and their competence within the digestive system and in the biological system after being absorbed. The nutrients generated by microbes usually are capable of being absorbed through the enterocytes and soon delivered directly to the circulation system. In different environments, they can lower the intestinal pH, allowing them to produce organic acids, and increase the solubility of iron, magnesium, and zinc. Certain strains also synthesize vitamins such as folate and vitamin K in the colon. Food bioactivities can be tailored to population-specific needs; for instance, children, the elderly, and pregnant's can benefit quite a lot from biofortified foods, which may support gut health and growth, increase nutrient absorption and immunity, and may reduce maternal complications and positively influence infant microbiomes, respectively.

Food combining with probiotics in a synergistic method offers functionally sound foods; this transformation of everyday ordinary food items into functional dynamic products is a potential synbiotic strategy. In our laboratory recently, we worked on a novel biscuit model;

the basic wheat flour was alternated with bean and lentil flours. Those bean and lentil grains were fermented by koji, which contained Aspergillus oryzae, a yeast used in Japanese koji to produce miso. The *in vitro* analyses of the koji biscuit showed a remarkable increase in the protein content and enhanced the antioxidant capacity and antihypertension activity when compared to a classical biscuit. This integrated strategy addresses overlapping micronutrient deficiencies more effectively and sustainably than conventional single-nutrient fortification, especially in populations dependent on cereal-based diets.

Global regularity and familiarity

Usually biofortified food offers a sustainable, precise, and economically practical strategy for improving food safety, enabling the wider distribution of nutritious food, and protecting vulnerable populations within increasingly complex global food systems. In the literature review, renowned regulatory agencies classify robust fermented food as generally recognized as safe (GRAS), which supports their use in minimally processed and organic foods that prioritize clean-label principles. However, every day in the world of food innovation, robust products with novel applications are also emerging: phages can be integrated into functional meat products, beverages, and confectionary products. Although the innovated robust foods are acceptable by pilot studies or well-established research, there is still hard work to be done in terms of validation and certification by regulatory agencies like the FDA, EFSA, WHO, FAO, China's MNPA, and the Codex Alimentarius Commission. Furthermore, the familiarity, palatability, and acceptability to the consumers are other challenges that researchers, industry, academia, and policymakers have to work on. Consumer perceptions also matter quite a lot; skepticism toward structured or unfamiliar fermented foods can slow the intimacy, recognition, and adaptation, even as interest in functional foods grows. Overcoming these barriers requires advanced stabilization technologies, harmonized regulations, and proactive public engagement to align scientific evidence with consumer trust.

Despite the fact, the shift toward food biofortification marks a major change in tackling global malnutrition, moving beyond adding isolated nutrients to enhancing food quality, however, bringing these innovations to the market faces significant interdisciplinary challenges.

Regulatory frameworks are fragmented: agencies like the FDA and EFSA apply different standards for microbial ingredient safety, viability, and efficacy, complicating approvals. The major technical challenges include maintaining probiotic and phage stability, competence, and potency across varied food matrices and storage conditions, particularly in food products without preservatives. Looking forward, the biofortified food industry sits at the intersection of innovation, biotechnology, microbiology, and sustainable agriculture. Promising approaches include strategic green technology to produce biofortified food, which could reduce metabolic disorders and nutrient deficiency diseases. With scalable production models and economic viability, the biofortified food industry may have the potential to redefine nutritional security, merging scientific innovation with ecological and cultural sustainability. Thus, there are still tremendous efforts beyond the research should be conducted to gain the international approval of validation agencies and also the consumers' acceptability to familiarize the nutritional competence of biofortified foods.

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