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Innovative technologies in food fortification: A bamboo perspective

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1. Introduction

Globalization and urbanization have changed food availability, food environments, and food practices. Millions of families have left the countryside and moved to cities, leaving behind traditional diets for processed foods that are frequently high in salt, sugar, and saturated fat, and are low in essential nutrients and fibre. This has led to the increase in micronutrient deficiency or hidden hunger which is a major cause of concern globally, and many individuals, especially women and children, suffer from the serious and widespread negative health consequences. More than two billion people suffer from micronutrient malnutrition particularly iron, zinc, iodine, selenium, and vitamin A leading to a decline of the physical and cognitive capacity of millions of people especially children in the low and middle income countries (Kurmi et al. 2023). Needed in low amounts, micronutrients are vital for growth, brain development, bone health, fluid balance, blood clotting, immune function, energy production, illness prevention and have many other functions in different cellular and enzymatic reactions (Mattar et al. 2022). Overall, it has been estimated that micronutrient deficiencies account for about 7.3% of the global burden of disease, and iron and vitamin A deficiency rank among the 15 leading causes of the global disease burden, contributing to the deaths of over one million children annually. Rapid urbanization and fast moving pace of life especially in the cities have driven people to depend more on processed foods which are generally devoid of nutrients while undergoing processing and packaging. Keeping in mind the global issue of micronutrient deficiency, various methodologies are being proposed to add these micronutrients to food and the most popular method is food fortification which is defined as the practice of adding vitamins and minerals to consumed food to increase their nutritional value. Food fortification is a sustainable, scientifically proven and the most cost-effective long term strategy for improving diets and for the prevention and control of micronutrient deficiencies (Thakur et al. 2023). In the past two decades, due to the serious health problems caused by micronutrient deficiencies, governments, industry and non-governmental decision makers are increasingly emphasizing to fortify widely consumed staple foods such as cereal flour, salt, sugar, oil and many more. Removing these deficiencies not only improve health but also help in economic growth and national development (Chadare et al. 2019). Meta-analysis of large scale food fortification programs have revealed that such programs were able to reduce anemia by 34% and goiter by 74% as a result of increased iron and folate intake respectively.

2. Contemporary food fortification

Traditional or contemporary food fortification refers to practices that improve the nutritional value of foods through natural means, often passed down through generations. The earliest practice is fermentation which is the process of using microorganisms like bacteria and yeast to break down complex carbohydrates into simpler forms, making them more digestible and increasing the bioavailability of certain nutrients e.g. fermented vegetables like kimchi, sauerkraut bamboo shoots, pickles, yogurt and many more.The most common form of food fortification applied on a large scale is the addition of synthetic ingredients. The most commonly fortified foods include salt, milk, sugar, oils and rice, wheat and maize flour. Fortifying flour is one of the best and simple ways because the nutrients available in powdered form can be successfully mixed with flour. Rice is one of the most important staple foods in developing countries and is the best food vehicle for food fortification regarding a population-level intervention. Fortification of rice flour with iron, zinc and folate was able to improve the growth micronutrient status of children less than five years (Hettiarachchi et al. 2004). There are three types of conventional food fortification, the first is biofortification involving traditional breeding techniques and/or biotechnology to create micronutrient-dense staple crops. The most popular example of this approach is the transgenic 'Golden Rice' containing twice the normal levels of iron and significant amounts of beta-carotene. Microbial biofortification involves using probiotic bacteria (mostly lactic acid bacteria), which ferment to produce beta carotene either in the foods we eat or directly in the human intestine. The second type is industrial fortification which involves fortifying commercially available products such as flour, rice, cooking oils, sauces, butter etc. with micronutrients and the process occurs during manufacturing. It has been practiced since the 1930s to target specific health conditions such as iodine deficiency through the iodisation of salt, anaemia through the fortification of cereals with iron and vitamins, and neural tube defects through the fortification of wheat flour with folic acid. It is usually possible to add multiple micronutrients without substantially increasing the total cost of the food product at the point of manufacture. Home fortification is the third type which is a merger of supplements and fortification and consists of supplying deficient populations with micronutrients in packages or tablets that can be added when cooking/consuming meals at home.

3. Conventional food fortification

Though food fortification has been used since the 1930s to combat micronutrient deficiencies; the main challenge for successful implementation is the combination of the bioavailability, affordable fortificant with the best food vehicle as a carrier to reach at-risk populations (Matter et al. 2022). Three innovative methods namely encapsulation, nanoparticulation, and chelation have been explored, which aim to overcome problems associated with conventional fortification, especially those affecting organoleptic properties and bioavailability.

3.1. Encapsulation

Encapsulation involves the incorporation of food ingredients, enzymes, cells or other materials in small capsules to protect the encapsulated materials from moisture, heat or other extreme conditions, thus enhancing their stability and maintaining viability (Gibbs et al. 2009). It involves entrapping a functionally active core material into a matrix of an inert material. In the food industry, encapsulation masks the undesirable color, flavor, taste, preservation of unstable constituents, incorporation of additional functional and nutritional components and site-specific release of encapsulated ingredients at a controlled time and rate (Timilsena et al. 2020). A wide variety of foods is encapsulated- flavouring agents, acids, bases, artificial sweeteners, colourants, preservatives, leavening agents, antioxidants, agents with undesirable flavours, odours and nutrients, among others. At the onset, food grade proteins and polysaccharides were used to encapsulate sensitive and bioactive food ingredients including highly unsaturated edible oils, vitamins, enzymes or various flavours for enhancing their shelf-life and/or masking the undesirable flavor or taste. Freeze drying, spray drying, coacervation, liposome entrapment, extrusion, fluidized bed drying and in-situ polymerization are some commonly used microencapsulation technologies Though encapsulation technique is advanced in the pharmaceutical industry, more understanding is required to harvest its application in the food industry.

3.2. Nanoparticulation

Nanoparticulation is revolutionizing the food industry by offering innovative solutions across various aspects (Singh et al. 2023). These tiny particles, typically sized between 1-100 nanometers, possess unique properties due to their high surface area-to-volume ratio. In food packaging, nanomaterials can enhance barrier properties, extending shelf life and reducing food spoilage. Nanomaterials are used as ingredients and additives (e.g., vitamins, antimicrobials, antioxidants) in nutrients and health supplements for enhanced absorption and bioavailability. They can also be incorporated with antimicrobials for active packaging, combating foodborne pathogens. Additionally, nanosensors embedded in packaging can monitor freshness and detect contamination. Research is also underway to utilize nanoparticles for nutrient delivery, improved bioavailability of nutraceuticals, and taste modification. While the potential of nanoparticulation in food is vast, ongoing research is crucial to ensure its safety for consumption

3.3. Chelation

In the food industry, chelation plays a vital role in preserving the quality and extending the shelf life of various products (Ghasemi and Azarikia 2023). Chelating agents, also known as sequestrants, are additives that bind to metal ions like iron and copper. This binding action offers several benefits: it prevents these metals from participating in reactions that cause discoloration or off-flavors. For instance, chelation can hinder enzymatic browning in fruits and vegetables, a process often triggered by metal ions. Additionally, chelators can impede metal-catalyzed fat oxidation, which contributes to spoilage in fatty foods like baked goods. Common chelating agents in food include citric acid, tartaric acid, and EDTA (Ethylenediaminetetraacetic acid). Their use is generally safe and regulated by authorities like the FDA, making chelation a valuable tool for food manufacturers.

4. Bamboo shoot as a Food fortificant

Bamboo mainly the juvenile shoots shows promise as a new player in the world of food fortification (Nirmala and Bisht 2017; Chongtham and Bisht 2020; Santosh et al. 2022). This is due to its rich nutrient content including proteins, essential amino acids, minerals and vitamins, high content of bioactive compounds like phenols, dietary fibers and phytosterols are the precursors of many pharmaceutically active substances. Different forms of processed bamboo shoots such as paste, sun dried, oven dried, freeze dried and fermented can be used for food fortification.

4.1. Novel bamboo shoot fortified food products

Food-to-food fortification (FtFF) is an emerging food-based strategy that can complement current strategies in the ongoing fight against micronutrient deficiencies, but it has not been defined or characterized (Kruger 2020). Natural fruits and vegetables with high mineral as well as ascorbic acid and β-carotene contents are used as fortificants. Bamboo shoots with rich nutrients and bioactive compounds are potential fortificants. Fortified bamboo shoot products have enormous potential as a health food and a good source for nutraceutical and pharmaceutical products (Santosh et al. 2021). Various food-to-food fortified products have been developed utilizing bamboo shoots some examples of which are given below.

- **i) Biscuits and cookies:** Richer in nutrients and bioactive compounds, better shelf life, improved texture and improved mouth feel.
- **ii) Nuggets:** Chicken and pork nuggets with better physicochemical and shelf life, improved flavor, aroma, taste, and texture and sensory and microbial qualities.
- **iii) Chips:** Reduction in acrylamide level, safe for consumption in terms of microbiological analysis and good sensory acceptability.
- **iv) Salted snacks:** Significant improvement in the antioxidant activity.
- **v) Tart:** Improved sensory and widely accepted.
- **vi) Milk pudding:** Fortified with bamboo fiber and was observed to have better rheological and texture properties due to the improved elasticity.
- **vii) Candy**: Good sensory acceptability in terms of color, flavor, aroma, taste, and texture.
- **viii) Yoghurt**: high protein with improved functional properties, including higher appearance, texture, aroma, and taste.

Along with the nutrients, the bamboo shoots fortified of food products enhanced the contents of bioactive compounds including phenols and phytosterols in namkeens, biscuits, and nuggets. The development of food products with enhanced bioactive compounds has several health benefits due to which different processed bamboo shoots are being used to fortify food products.

4.2. Bamboo nanoparticles

The innovative technologies used in food fortification has not yet been used in developing food products from bamboo but have been used in packaging food products and pharmaceuticals Bamboos have gained particular attention of researchers because of their unique class of functional compounds that make them an ideal candidate for the formulation of nanoparticles. Nanoparticles have gained attention in the development of new pharmaceutical and cosmetic products, biosensor materials, composite fibres and electronic components. Different parts of bamboo such as leaves, bamboo cellulose, bamboo hemicelluloses and bamboo pulp are used for the synthesis of silver nanoparticles and it has been found that the phytochemicals present in bamboo extracts play a role as significant reducing, stabilizing and capping agents (Nirmala et al. 2024). Nanomaterials used for food packaging provide many benefits such as detection of microbial contamination and potentially enhanced bioavailability of nutrients. Silver nanoparticles are playing a key role in medicine and healthcare as they possess anti-inflammatory, anti-fungal, anti-angiogenic, antibacterial and anti-diabetic activities (Oladipo et al. 2020). . Research is also needed to assess the antimicrobial efficacy of AgNPs in the field of agriculture and food industry. This should be focused on ascertaining the optimal threshold concentrations of AgNPs that effectively reduce the occurrence of diseases in plants, while avoiding any negative effects on non-target organisms and soil.

Hence, bamboo shoot with high nutrient content and health-promoting bioactive components has the potential to be utilized as a natural source of fortificant for food-to-food fortification to address the micronutrient inadequacy issues that the twenty-first century is currently experiencing.

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