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Food Fortification: Global Experience, Importance, Challenges and Potential in Nepal

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Abstract

Micronutrient deficiencies are a significant global health concern, especially in developing countries like Nepal. This review explores the effectiveness, challenges, and strategies of food fortification in combating these deficiencies. Drawing from diverse sources, including government reports, academic literature, and international organizations, we analyze the types of fortification, their implementation, and their impact on public health. This review highlights significant improvements in health outcomes through food fortification initiatives, such as a 32% reduction in anemia and a 58% decrease in vitamin A deficiency, as evidenced by global studies. In Nepal, fortification efforts, particularly salt iodization, have successfully reduced iodine deficiency disorders. However, challenges remain in ensuring coverage, quality control, public awareness, and stakeholder collaboration. Key considerations such as monitoring, quality control, consumer acceptance, and sustainability are examined. The review underscores the importance of fortified foods in improving nutrition and highlights successful interventions. The review provides detailed recommendations for future initiatives, emphasizing the need for enhanced multi-sectoral cooperation, rigorous quality assurance protocols, and comprehensive public education campaigns to ensure the long-term success and sustainability of fortification programs

Keywords: *Micronutrient deficiencies, food fortification, public health, nutritional interventions, iodine deficiency, anemia reduction*

Introduction

Micronutrients, which are necessary for growth, brain development, and immunity, must be obtained from the diet or through supplements. Micronutrient deficiencies, known as hidden hunger, affect 2 billion people in developing and developed countries, resulting in various health issues such as learning disabilities, reduced work capacity, illness, and even mortality (Mason et al., 2005, Tulchinsky, 2010). Micronutrient deficiencies (vitamin A and zinc) are responsible for over one-third of under-five child deaths and 11% of the global total disease burden in developing countries (Bhutta, et al., 2013). These populations are often affected by multiple forms of hidden hunger, which are not mutually exclusive but rather complement each other. Solutions to hidden hunger include supplementation (in the form of tablets, capsules, and syrups), public health measures, food fortification, and other food-based approaches such as biofortification. Supplementation with high doses of micronutrients is a short-term measure to address severe deficiencies, and its use is expected to decrease as longer-term measures are established. Food fortification, on the other hand, is a medium- to long-term solution that provides a cost-effective means of addressing specific nutrient deficiencies in a population. It involves adding measured amounts of vitamins and minerals to commonly consumed foods during processing (Olson et al., 2021). The control of vitamin and mineral deficiencies is one of the most remarkable scientific advances related to development in recent years (Latham, 2003). Iron supplementation, iron-folic acid, multiple micronutrients (MMN) supplementation, and large-scale fortification significantly reduce the risk of anemia in children and adults (Allen, et al., 2009; Christian, & Tielsch, 2012; Tam et al, 2020). MMN supplementation during pregnancy reduces the risk of low birth weight, small-for-gestational age, and anemia (Allen, et al., 2009; Christian, & Tielsch, 2012; Darnton-Hill & Mkparu, 2015). Vitamin A supplementation is effective in reducing all-cause mortality among children (Bailey & Black, 2015; Tam et al, 2020). Zinc supplementation decreases the incidence of diarrhea, a major cause of mortality in children under five (Bailey & Black, 2015; Tam et al, 2020). Large-scale fortification with iodine significantly reduces the odds of goiter (Díaz et al., 2003; Keats, et al, 2019). Lipid-based nutrient supplementation (LNS) and MMN supplementation improve growth outcomes, including stunting and underweight, in children, and also improve cognitive and motor development in children (Allen, et al., 2009; Christian, & Tielsch, 2012; Tam et al., 2020). Fortification with folic acid significantly reduces the odds of neural tube defects (Darnton-Hill, & Mkparu, 2015; Keats et al,2019). Perhaps no other technology available today offers such a significant opportunity to improve lives and expedite development at such a low cost and within a short time frame (Mannar, 2017). Fortified foods typically include staple foods like cereals, oils, fats, sugar, salt, and sauces, which ensures broad coverage and requires minimal behavioral change from consumers. These fortified foods are designed to provide approximately 30-50% of the daily adult requirements of micronutrients with normal consumption of the food products (Keats et al., 2019). The objective is to offer meaningful nutrient levels at regular food consumption rates, prioritizing safety and impact. In Nepal, micronutrient deficiencies, particularly among women and children, continue to be a health and well-being concern. Food fortification is a critical intervention in Nepal, providing several benefits such as wide reach, passive intervention, and cost-effectiveness.

Globally, food fortification has significantly improved public health, with successful programs such as iodized salt fortification. Food fortification with multiple micronutrients has been shown to reduce anemia by 32%, iron deficiency anemia by 72%, iron deficiency by 56%, vitamin A deficiency by 58%, vitamin B_2 deficiency by 64%, vitamin B_6 deficiency by 91%, and vitamin B_{12} deficiency by 58% based on 43 studies involving 19,585 participants (17,878 children) conducted in both high-income countries and low- and middle-income countries (LMICs) indexed in Cochrane, MEDLINE, Embase, and 20 other databases, including clinical trial registries (Das et al., 2019). Successful fortification programs rely on strong political commitment, involvement of the private sector, support from the public sector, financial assistance, and consumer education (Durotoye et al., 2023). Nepal's efforts to combat micronutrient deficiencies can benefit from fortified foods as well as the development of biofortified crops. Challenges in implementation include ensuring coverage, quality control, public awareness, and collaboration among stakeholders (Bhandari & Banjara, 2015; Nestel et al., 2006). However, successful implementation of food fortification ensures improved nutritional status, reduced prevalence of deficiency-related diseases, enhanced cognitive function, and improved economic productivity (Freeman et al., 1977; Martorell et al., 2010). Food fortification offers promising strategies to address hidden hunger in Nepal, but their success requires coordinated efforts from the government, non-governmental organizations (NGOs), and the private sector.

Importance of Food Fortification in Nepal

Food fortification is a critical component of integrating food systems, nutrition, and health in Nepal. The importance of food fortification can be highlighted in the following ways:

- Addressing Micronutrient Deficiencies: Despite some progress, Nepal still faces widespread deficiencies in key micronutrients such as iron, vitamin A, iodine, and zinc, particularly among vulnerable groups. For instance, 28% of children aged 6-59 months suffer from iron deficiency, 4% have a vitamin A deficiency, and 21% have a zinc deficiency. Additionally, 1% of children in this age range experience folate deficiency. Among non-pregnant women aged 15-49 years, 20% have iron deficiency anemia, 4% have a vitamin A deficiency, 12% have anemia, 24% have zinc deficiency, and 5% have RBC folate deficiency. The prevalence of RBC folate deficiency ranges from 1% in the Far-western region to 8% in other regions. Similarly, among pregnant women aged 15-49 years, 27% suffer from anemia and 14% have iron deficiency. Additionally, in non-pregnant women of the same age range, 24% have zinc deficiency (Ministry of Health and Population, et al., 2018).

- Food fortification serves as a medium to long-term strategic intervention in addressing these deficiencies and providing essential micronutrients to combat conditions such as iron-deficiency anemia, goiter, neural tube defects, and other health conditions (Allen et al., 2006).
- Improved Cognitive Function and Development: Adequate intake of micronutrients through fortification supports optimal brain development in children and consequently enhances cognitive function and academic performance (Iannotti et al., 2006).
- Effective Strategy: Fortifying commonly consumed foods in Nepal enables the bridging of nutritional gaps without requiring significant dietary changes. Notably, fortification of staple foods like wheat flour and salt has proven successful in reducing iodine deficiency disorders (Gharibzahedi & Jafari, 2017).
- Multi-Sectoral Approach: Successful implementation of food fortification programs requires collaboration among various sectors, including the establishment of regulatory frameworks, quality control measures, and public-private partnerships. Strengthening these partnerships, utilizing a multilevel systems approach, and employing both quantitative and qualitative methods can enhance the efficacy and reach of fortification programs (Bryson et al., 2015).
- Context-Specific Interventions: The effectiveness of interventions such as large-scale food fortification and supplementation varies based on local food consumption patterns and implementation factors (Bhutta et al., 2013; Keats et ak., 2019).
- Sustainability and Scale-Up: There is a need for sustainable and scalable interventions that address food insecurity and poverty, which are underlying causes of micronutrient deficiencies (Bhutta et al., 2013; Darnton-Hill & Mkparu, 2015).

Technology of Food Fortification

Micronutrient deficiencies are a significant global health concern, and addressing them necessitates the implementation of effective fortification programs. This review examines the technological considerations that are crucial in developing successful fortification strategies.

Types of Food Fortification

Food fortification encompasses various strategies that aim to address nutritional deficiencies in populations. Understanding the different types of fortification is essential for the implementation of effective interventions.

Mass Fortification

Mass fortification is a public health intervention to address widespread nutritional deficiencies by fortifying commonly consumed foods. An example of this is the addition of iron and folic acid to flour, which is a widely practiced method to improve nutrient intake across entire populations (Bruins et al., 2015). This approach targets staple foods that are consumed by a large segment of the population, making it an effective way to provide essential nutrients to those at risk of deficiency.

Targeted Fortification

On the other hand, targeted fortification focuses on specific subgroups of the population with unique nutritional needs, using a risk-benefit approach to balance

health benefits and potential risks (Bruins et al., 2015). This approach acknowledges that certain groups, such as infants and young children, may require additional nutrients for optimal growth and development. For instance, fortified complementary foods designed specifically for infants can help bridge nutrient gaps during critical stages of growth (De Pee, 2017). Moreover, home fortification using micronutrient mixes in sachets offers an alternative method to ensure nutrient intake, particularly in regions where access to centrally processed foods is limited (Nguyen et al., 2016).
There have been successful examples of targeted fortification, such as fortifying milk with vitamin D for children. Vitamin D is crucial for bone health and calcium absorption, and since children, particularly in areas with limited sunlight exposure, are at a higher risk of vitamin D deficiency, fortifying milk, a staple in their diet, effectively addresses this issue (Lappe and Heaney, 2008). Another example is fortified complementary foods for infants and young children. These foods, like cereals and purees, provide balanced amounts of essential nutrients, including iron, zinc, and other crucial vitamins and minerals, to support healthy growth (Allen et al., 2006).

Market-Driven Fortification

Market-driven fortification is initiated by consumer demand and market incentives. Food manufacturers respond to the preferences of consumers by fortifying products such as breakfast cereals, milk, and yogurt. This voluntary fortification expands the availability of fortified foods, offering consumers a wider range of options to meet their nutritional requirements (Detzel & Klassen-Wigger, 2020). Market-driven fortification aligns with consumer preferences and can help address specific nutrient deficiencies based on dietary patterns and individual preferences. The creation of demand and communication interventions aimed at changing social behavior can increase the adoption and consumption of fortified foods, thereby reducing micronutrient deficiencies (Van Liere & Shulman, 2018). Successful examples of market-driven fortification include:

- Fortified breakfast cereals: Numerous breakfast cereals are enriched with essential vitamins and minerals in order to cater to health-conscious consumers seeking a nutrient-rich start to their day (Drewnowski, 2009).
- Fortified milk and yogurt: In addition to vitamin D, milk and yogurt can be fortified with calcium and other nutrients, which enhances their nutritional value and appeals to consumers who are focused on bone health and overall well-being (Nicklas et al, 2008).

Each form of fortification presents unique advantages and challenges. Mass fortification addresses public health risks on a large scale, but its effective implementation may depend on policy and regulatory support. Targeted fortification permits tailored interventions for specific population groups but requires careful targeting and distribution mechanisms. Market-driven fortification responds to consumer demand and preferences, but it may require clear labeling and consumer education to ensure informed choices. Understanding the different types of food fortification is crucial for designing comprehensive strategies to combat malnutrition and improve public health outcomes. By leveraging the strengths of each approach and addressing associated challenges, fortification programs can effectively enhance nutrient intake and promote overall health and well-being.

Food Vehicles for Fortification

There is a global trend towards fortifying staple foods such as flour, oils, and sugar with essential micronutrients, with over 63 countries implementing such programs. Mandatory fortification of cereal flour has been successfully implemented in regions such as the Middle East, North Africa, and Africa, reaching millions of consumers. This has led to significant reductions in anemia, neural tube defects, and under-five child mortality, with an estimated economic value of $31.8 billion annually in 18 low-income countries (Akhtar et al., 2019; Bégin et al., 2001; Kancherla et al., 2021). The success of sugar fortification in addressing vitamin A deficiency in Latin and Central America highlights the potential benefits of such initiatives (Dary, 2002). Various innovative approaches have been implemented to address malnutrition and improve public health outcomes using fortified staple foods and innovative delivery methods. For instance, the World Food Program has adopted on-site milling and fortification, as well as fortified rice kernel (FRK) fortification, to ensure access to fortified foods during emergencies (Van Den Briel et al., 2007). Targeted programs have also been successful in reducing anemia rates, such as providing fortified milk to infants in Chile. Complementary food supplements have been introduced as a convenient way for mothers to incorporate essential micronutrients into their cooking or infant feeding practices. In countries like India, fortified lozenges have been distributed to simplify the intake of micronutrients for specific demographic groups.

Several food vehicles have been identified as key options for fortification:

- Cereals: Staple grains like rice, wheat, and maize are commonly milled at centralized locations and serve as vehicles for multiple nutrients. However, challenges arise when cereals are milled at the community level due to quality and safety constraints (Dodson et al., 2015). Innovations like simulated rice-shaped premixes have been developed to facilitate fortification of whole grain cereals, expanding the reach of essential nutrients (Saha & Roy, 2020).

- Fats and Oils: Cooking fats and oils are ideal for delivering fat-soluble vitamins such as vitamins A and D. However, loose unbranded forms pose challenges due to the need for protection against vitamin degradation. Thus, opaque packaging is necessary to preserve the nutritional content of these products.

- Condiments: Salt, sugar, spices, and sauces serve as attractive carriers for fortification due to their widespread use and regular consumption. Double fortification of salt with iron and iodine has shown promise in addressing multiple deficiencies (Li et al., 2011; Melse-Boonstra et al., 2000).
- Dairy Products: Milk processed in dairies offers an opportunity for fortification with both vitamins and minerals, benefiting populations with regular dairy consumption (Bonjour et al., 2013; Woźniak et al., 2022).
- Value-Added Products: The shift towards urban areas globally has increased the consumption of commercially processed foods and value-added products. However, vulnerable populations may have limited access to these higher-priced products, resulting in sporadic consumption.

Fortification Methods

Various techniques facilitate nutrient addition based on food processing methods, each optimizing nutrient retention and distribution (Mannar, 2017):

- Dry Mixing: Common for cereal flours, powdered beverages, and milk, ensuring even distribution of nutrient premix (Hoppe et al., 2008).
- Dissolution: Employed in liquid milk, beverages, and bread-making water, ensuring homogeneity (Ahmad & Ahmed, 2019).
- Spraying and Adhesion: Utilized in salt iodization and sugar fortification, ensuring micronutrient adherence. They involve spraying liquid micronutrient solutions onto flour during mixing for good homogeneity, requiring precise control to avoid clumping (Gogia, 2005; Mudambi and Rajagopalan, 2001).
- Coating and Dusting: a straightforward method involving the application of micronutrient powders onto flour particles, is cost-effective and versatile, but it often struggles to achieve uniform nutrient distribution. Despite its simplicity, challenges arise from the potential for nutrient loss during handling and processing (Gogia, 2005; World Health Organization, 2016).
- Fluid Bed Coating: employing a fluidized bed to suspend flour particles while micronutrients are sprayed onto them, offers improved nutrient distribution but at a higher cost and with the requirement for specialized equipment. (Jafari, 2017).
- Co-Milling: entails milling premixes of micronutrients and flour together, resulting in fortified flour with excellent nutrient homogeneity, making it suitable for large-scale fortification but necessitating dedicated milling facilities (WFP (World Food Programme), 2004; World Health Organization, 2016).
- Extrusion: Utilized in rice fortification, creating simulated rice-shaped premix for even distribution (Li et al., 2010; Moretti et al., 2005).
- Encapsulation and Micronization: Applied in double fortification of salt, enhancing nutrient stability and bioavailability (Andersson et al., 2008).

Technical Considerations

Fortification strategies encompass a range of food vehicles and methods tailored to address specific nutrient deficiencies in diverse populations, emphasizing collaboration between governments, food industries, and public health organizations (Tam et al., 2020). Several crucial factors such as cost, bioavailability, sensory acceptability, and storage stability should be considered for effective food fortification programs (Wirakartakusumah & Hariyadi, 1998). Some of the technological considerations are:

- Consistency in Consumption: The chosen food vehicle should be consumed consistently to ensure accurate fortification dosage calculations (De-Regil et al., 2014).
- Centralized Processing: Foods selected for fortification should undergo centralized processing to enable controlled fortification (Horton, 2006).
- Compatibility and Nutrient Retention: Micronutrient addition should harmonize with existing production and distribution systems, ensuring minimal nutrient loss during processing and storage while preserving food quality (Horton, 2006).
- Maintaining Product Characteristics: Fortification should not alter the taste, appearance, or color of the final product, preserving consumer acceptability (Mehansho, 2006).
- Affordability: Fortified foods should remain affordable, especially for low-income groups vulnerable to malnutrition (Wimalawansa, 2013).

According to Darnton-Hill and Nalubola (2002), key features of successful fortification programs include:

- Strong political commitment and the ability to enforce regulations in a facilitative manner.
- Early private sector involvement and willingness to comply with regulations.
- Public sector backing including endorsement by professional medical organizations.
- Financial support by donors.
- Active consumer education to raise awareness and promote demand.

Selection of Nutrient Form

The chemical form of added nutrients, or fortificants, significantly affects the fortified food's bioavailability, stability, appearance, and uniformity (Greger, 1987). This choice considers factors such as solubility in gastric juice and sensory impact on the food. Iron compounds serve as illustrative examples of this concept (Hilty et al., 2011; Kumari & Chauhan, 2022). These compounds range from highly soluble in water to insoluble, influencing both bioavailability and sensory properties (Boccio & Monteiro, 2004; Steiger et al., 2014). For instance, while highly water-soluble compounds like ferrous sulfate offer excellent bioavailability, they may cause taste and color issues in moist or fatty foods. In such cases, less soluble forms are preferred to ensure consumer acceptance (Cook & Reusser, 1983). Recently, chelated iron forms, such as sodium iron EDTA, ferric sodium ethylene diamine tetra-acetic acid (NaFeEDTA), have gained recognition for their high bioavailability, making them ideal for fortifying specific foods like soy sauce and whole wheat flours (Allen et al., 2006). Alternatively, less soluble forms are chosen to ensure consumer acceptance. Recent advancements, such as the use of chelated iron form sodium iron EDTA (NaFeEDTA), are gaining recognition for their effectiveness in specific food products like soy sauce and whole wheat and maize flours (Andang'o et al., 2007; Chen et al., 2005; Kloots et al., 2004).Ongoing research and development efforts aim to enhance fortification effectiveness. For example, in the case of vitamin A, strategies are being developed to reduce nutrient loss during storage by incorporating antioxidants and stabilizers (Sharma et al., 2020). Improved refining techniques and packaging methods have notably enhanced the stability of iodine compounds in salt and vitamin A in cooking oils (Diosady et al., 2002; Yoshida et al., 1999; Zimmermann et al., 2004). Similarly, for iron fortification, stabilizers and absorption enhancers can be added alongside fortificants to maintain absorbable forms or enhance absorption (Ballot et al., 1989). Furthermore, modifying the structure of iron compounds holds potential for improving absorption rates (Davidsson et al., 2001).

Extrusion Method for Food Fortification

The extrusion method is a versatile food processing technique widely used to fortify several food products with essential nutrients (Choton et al., 2020). The intricacies of extrusion fortification, its advantages, challenges, and considerations are discussed below.

Process of Extrusion Fortification

- Pre-treatment of Raw Materials: Raw ingredients like grains or legumes are pre-treated for optimal moisture content and particle size.
- Mixing: Pre-treated materials are blended with fortificants, ensuring homogeneous distribution.
- Extrusion Cooking: The mixture undergoes high temperature, pressure, and shear forces in an extruder, creating a viscous, homogenous mass.
- Shaping and Cutting: Extruded mass is shaped through a die and cut into desired lengths or forms.
- Drying and Cooling: Products are dried to reduce moisture content and cooled to ambient temperature.
- Packaging: Fortified products are packaged for distribution and consumption (Choton et al., 2020; Offiah et al., 2019).

Organoleptic and Functional Properties Fortified Foods

Several studies (Table 1) have shown that fortifying flour with micronutrients does not significantly alter the sensory qualities or baking attributes of food products like bread, noodles, and tortillas. For instance, fortification with various forms of iron, folic acid, and other nutrients did not affect instant noodles and tortillas' sensory acceptability or shelf-life stability. Consumers generally accepted fortified products, indicating minimal organoleptic differences compared to non-fortified ones.

Table 1: Studies on organoleptic and functional properties of fortified foods

Country	Product Tested	Fortificants	Rfsults	Reference
India	Bread	Ferrous sulphate, calcium carbonate, vitamins (thiamine, riboflavin, niacin, folic acid)	Addition of premix (1%) increased iron and calcium content 4-6 times compared to control. No alteration in bread-making quality.	Sudha et al., 2008
Thailand	Instant noodles	Ferrous sulfate (FS), NaFeEDTA, encapsulated H reduced elemental (EEI) iron	No significant change in sensory properties or shelf-life. NaFeEDTA least affected color and flavor.	Kongkachuichai et al., 2007
Pakistan	Flour	NaFeEDTA, elemental iron, ZnSO4, ZnO	Slight deteriorative effect on flour's chemical composition and chapattis' texture.	Akhtar et al., 2008
Mexico	Tortillas	Vitamin B1, B2, zinc (ZnO), iron (elemental reduced iron)	Fortified tortillas well accepted by Mexican adults.	Rusado, 2005
Pakistan	Naan	Ferrous iron, folic acid	Naan with 50 ppm ferrous iron had the best overall characteristics in sensory evaluation.	Alam et al., 2007
U.K.	Bread	Thiamin, niacin, riboflavin, iron, vitamins (A, B6, folic acid), calcium, magnesium, zinc	Vitamins retained well; no detrimental effect on bread structure, appearance, or color.	Emodi et al., 1980
United States	Bread & noodles	Iron sulfate, zinc sulfate, zinc oxide	Zinc oxide less preferred than zinc sulfate. Zinc-fortified products well-liked overall.	Lopez de Romaña et al., 2002
Malaysia	Noodles, sandwich bread, roti canai	Electrolytic iron, ferrous fumarate, ferrous sulphate, folic acid, vitamins B1, B2	Fortified wheat flour with ferrous sulphate had undesirable organoleptic properties. Premix produced comparable quality to control.	Food Fortification Initiative, (n.d., a)
Thailand	Angel cake, cookies, alkaline noodles	Ferrous sulfate, ferrous fumarate, elemental iron, H-reduced EI, electrolytic EI, folic acid	Elemental irons more appropriate due to insignificant effects on sensory quality. Folic acid stable during storage.	Food Fortification Initiative, (n.d., c)
Senegal	Complementary foods, bread	Iron alone, iron and zinc, iron and folic acid	Products accepted by participants. Adults detected taste differences with certain zinc levels.	Aaron et al., 2011
China, India, Malaysia, Sri Lanka, Philippines	Noodles and bread	Iron, folic acid, (some: B12, vitamin A, thiamin, riboflavin, zinc)	No deterrent to acceptability due to organoleptic differences. Micronutrients retained during preparation.	Food Fortification Initiative, (n.d., b)

Advantages of Extrusion Fortification:

- Uniform Nutrient Distribution: Ensures consistent nutrient intake with each serving due to homogeneous fortificant distribution (Brennan et al., 1999)
- Enhanced Bioavailability: High temperature and pressure can increase nutrient bioavailability by breaking down complexes and improving solubility(Ilo et al., 2015).
- Improved Stability: Encapsulates fortificants within the food matrix, enhancing stability during storage (Dhurandhar et al., 2014).
- Product Versatility: Can fortify a wide range of food products with various shapes, textures, and flavors (Fellows, 2009).
- Cost-Effectiveness: Relatively cost-effective compared to other fortification methods, particularly at large scales (Bechtel et al., 1974).

Challenges of Extrusion Fortification:

- Nutrient Stability: Some nutrients may degrade during extrusion due to heat and pressure, requiring careful selection and optimization of fortificants (Schubert, 2011).
- Sensory Changes: Fortificants can alter taste, color, or texture, necessitating sensory evaluation and optimization for consumer acceptability (Kokini, 2003).
- Equipment and Processing Costs: Extrusion equipment can be expensive, and energy input is significant, though cost-effectiveness improves with scale (Harper, 1981).

Extrusion emerges as a highly effective and versatile method for fortifying food products with essential nutrients. While offering numerous advantages such as uniform distribution and enhanced bioavailability, challenges like nutrient stability and sensory changes must be addressed through careful optimization and selection of appropriate fortificants (Abilmazhinov et al., 2023; Singh et al., 2007).

Wheat Flour Fortification

Wheat flour fortification is vital for addressing nutritional deficiencies, especially given its widespread consumption in various forms like bread and instant noodles (Akhtar et al., 2019). In Nepal, both large-scale roller mills and small village mills contribute to flour production, posing challenges for consistent fortification. Initiatives led by organizations like the Micronutrient Initiative (MI) have supported fortification efforts, but challenges remain in ensuring the bioavailability of fortified nutrients. Adjusting the composition of vitamin and mineral premixes is essential to optimize nutritional impact, although it may increase the cost of fortification. Options for premixes vary in composition and cost, with considerations for different iron sources and nutrient levels. The key components and considerations involved in wheat flour fortification are considered below.

Micronutrients Commonly Added:
Micronutrients such as iron, folic acid, vitamin B12, vitamin A, and zinc (Table 2) are commonly added during fortification to combat deficiencies that lead to various health issues like anemia, neural tube defects, impaired cognitive development, and weakened immune systems (WHO, 2006).

Table 2. Number of micronutrients fortified in wheat flour

Micronutrient	Amount Added (ppm)
VitaminA, as Retinyl Palmitate, cold water-soluble	1
Iron, electrolytic powder	60
Folic Acid	1.5

Note: ppm: parts per million

Source: World Bank, 2012

Wheat Fortification Process:
The wheat fortification process involved several steps (Food Fortification Initiative, n.d.), which are:

- Intake of Raw Materials: Wheat grains undergo inspection for quality upon receipt.
- Cleaning: Removal of impurities like stones and dust from wheat grains.
- Milling: Cleaned grains are milled to produce flour.
- Premix Preparation: Micronutrient premix is formulated as per specifications.
- Fortification: Premix is accurately added to the flour stream using specialized dosifiers.
- Blending: Thorough blending ensures uniform distribution of added micronutrients.
- Packaging: Fortified flour is packaged for distribution and consumption.
- Quality Control: Rigorous quality control measures ensure the final product meets required standards.

Cost of Wheat Flour Fortification:
The cost of food fortification varies significantly depending on several factors, including the type and quantity of micronutrients used, the scale of operation, the technology employed, and the specific country context. Estimates indicate a broad range, typically spanning from US $0.25 to US $2.00 per metric ton of wheat flour for fortification, as reported by the Food Fortification Initiative (n.d.). In the context of developing countries, fortifying wheat flour with essential micronutrients like iron and folic acid comes at an approximate cost of US $0.02 per person per year, according to the Copenhagen Consensus Center (2012). Despite these costs, food fortification remains a highly cost-effective intervention, given its potential benefits in improving public health and enhancing economic productivity.

However, the increased cost of a new vitamin and mineral premix has implications for the flour price. Using a premix with different iron sources and more vitamin A and folic acid will have higher costs ranging from $3.83 to $4.90 per Metric Ton (MT) of flour compared to the current premix cost of $1.67 per MT of flour (Table 4) (World Bank, 2012).

Table 4: Premix Options for Flour Fortification

Options	Vitamin A (ppm)	Folic Acid (ppm)	Iron (ppm)	Iron Type	Fortification Cost ($ per MT)
Current Premix	1	1.5	60	Electrolytic	$1.67
Option 1	3	2.6	60	Ferrous Fumarate	$3.83
Option 2	3	2.6	40	NaFeEDTA	$4.90

Source: World Bank, 2012

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Wheat Flour Fortification Equipment and Mixing Methods

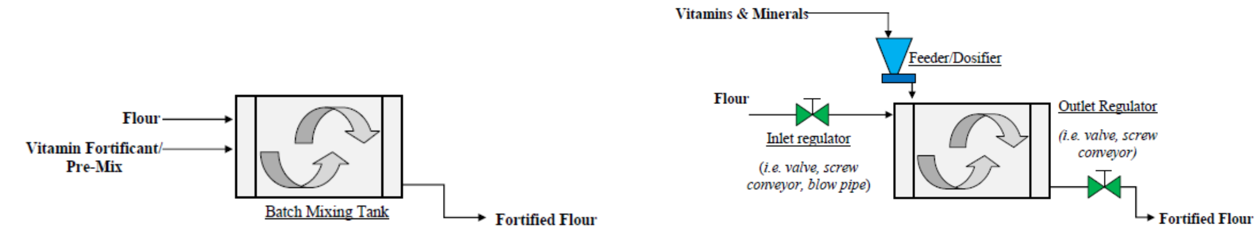
Fortifying flour with essential vitamins and minerals demands precise equipment and mixing techniques. The details of different mixing methods and the equipment required for fortification are:

Mixing Methods:

The four methods of mixing flour and vitamin premix offer various options suitable for different production needs and capacities.

Batch Mixing Method:

This method involves mixing flour and vitamin premix in a batch using simple agitation tanks operated manually or electrically (Figure 1A). It is ideal for small companies prioritizing low cost over short mixing time or automation (Muthayya et al., 2012).



A B

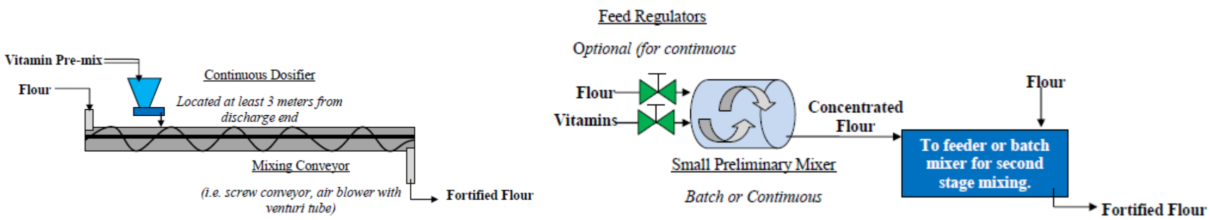
Figure 1: Different flour and premix mixing methods. (A) Batch Mixing Method (B) Continuous Mixing Method

Continuous Mixing Method

Flour and vitamin premix are continuously mixed under a continuous flow of both ingredients (Figure 1B). This method requires equipment such as feeders and agitation tanks, making it suitable for companies willing to invest in higher processing rates with accuracy.

1.1.1.1 Continuous Metering Method

Premix is continuously fed into the flour flow using precision micro ingredient powder feeders (Figure 2A). This method requires equipment for metering, agitation, and flow rate adjustment, making it fast, easy, and reliable, particularly for factories with existing screw conveying mechanisms.



A B

Figure 2: Different flour and premix mixing methods. (A) Continuous Metering System (B) Two Stage Mixing System

Two-Stage Mixing Method

This method involves a two-stage process where a premixing step is incorporated before the final mixing stage (Figure 2B). It helps reduce mixing time and ensure uniformity, making it suitable for companies with variable flour flow that require high accuracy.

Each method offers distinct advantages and is recommended based on factors such as company size, budget, processing rate, and desired accuracy. Integrating these methods into production processes can optimize efficiency and product quality.

Fortification Equipment:

Feeders/dosifiers are essential for the controlled and continuous addition of vitamins to the flour matrix, offering various types for different precision needs:

Volumetric Feeders

These operate on the principle of adding a consistent volume of media, such as vitamins, which equates to a constant mass. Common types include screw feeders, revolving disk feeders, and drum feeders.

Gravimetric Feeders

Adding precision to the feeding process, gravimetric feeders compare discharge weights to set-point values and adjust accordingly. Examples include loss-in-weight or gain-in-weight feeders, which measure weight loss or gain of the substance being added, enhancing accuracy.

Pneumatic Feeders

Suitable for factories equipped with air blowers, pneumatic feeders can be placed in any location with the use of a venturitube to control flow rate.

Screw Feeder

The most commonly used feeder, the screw feeder deposits consistent volumes of vitamins along a rotating screw, ensuring controlled additions with precision (Figure 3).

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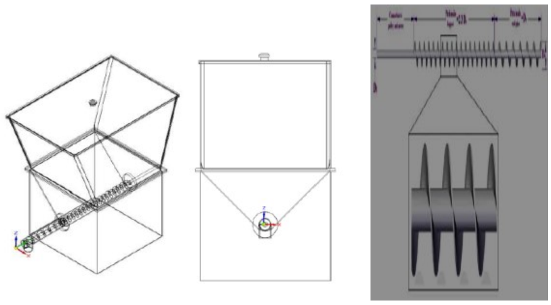
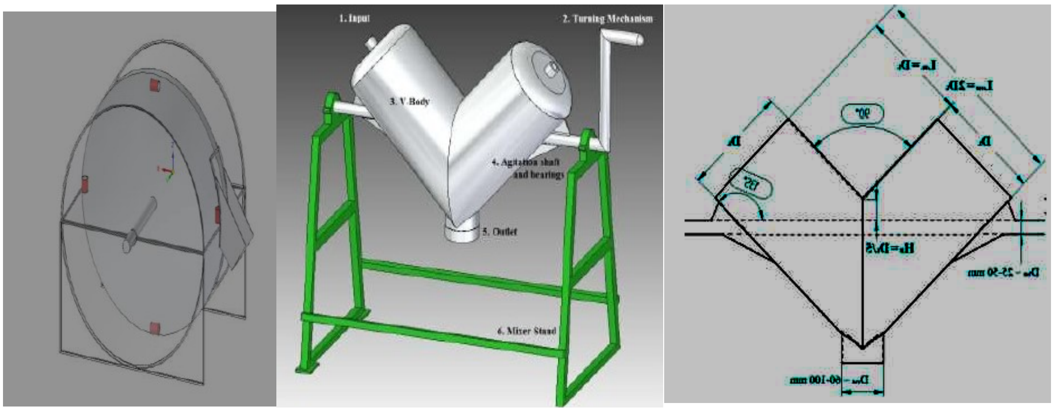


A B C

Figure 3: Screw Feeder (A) Angled and Front Views (B) Screw Dimensions for Screw Feeder (C)

Rotating Cup Feeder

Cost-effective and suitable for low-cost machinery, the rotating cup feeder scoops up small amounts of vitamin premix and dumps them out as they rotate (Figure 4A). Although less precise than screw feeders, they offer continuous flow operation and easy maintenance.



A B C

Figure 4: Different types of feeders and mixers (A) Rotating Cup Feeder (B) Manual V-Mixer for Flour Fortification Assembly (C) Schematic diagram

Each type of feeder offers distinct advantages, catering to different production needs and budgets. Proper placement and maintenance of these feeders are essential for efficient and accurate fortification processes.

Mixers and Blenders

The following machines have been tested and proven feasible for local manufacturers to produce, ensuring uniform mixing of the vitamin premix with the food vehicle:

Batch-fed V-Mixer for Dry Flour Mixing:

In this flour fortification process, flour and vitamins/minerals are added through separate legs of the V-body, with lids preventing leakage. Rotation, whether manual or motorized, ensures thorough mixing for uniform fortification (Figure 4, B, C). The V-body, made of stainless steel or aluminum, facilitates efficient mixing. An agitation shaft and bearing support rotation, with external stability, supports as needed. Fortified flour e xits through controlled valves at the V-body's vertex, while a sturdy mixer stand supports the entire setup. These components combine to fortify flour effectively.

These batch-fed V-mixers offer a cost-effective solution for mixing dry flour with vitamin premix, suitable for both small-scale and larger automated operations. Proper design and maintenance ensure efficient mixing and consistent fortification of food products.

Batch or Continuous Horizontal Mixer with Pin-Type Agitator for Wet Flour Mixing:

In batch or continuous horizontal mixers with pin-type agitators for wet flour mixing, several components and features play crucial roles: For batch operations, water and powders are added through simple lid openings, while continuous operations utilize feeders or densifiers for powder addition and valves for water flow control. The tank lid fits firmly to prevent leakage, secured by hinges and latches, often made of thick transparent plastic for visual inspection during mixing (Figure 5). The agitator, supported by housed ball bearings, features tapered blades alternating through four orientations, ensuring efficient mixing without extraneous movement. The tank body, fabricated from stainless steel or aluminum sheet metal, features horizontal support beams for larger mixers.

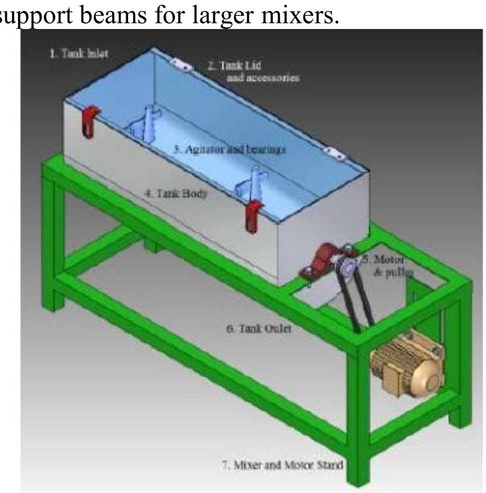


Figure 5. Sample System for Water-Flour Mixer for Pasta or Bread Making.

The motor turns the agitator via pulleys, with options for different pulley sizes or a gearbox for speed control. Safety measures include housing the motor assembly and installing metal guards. For batch operations, manual

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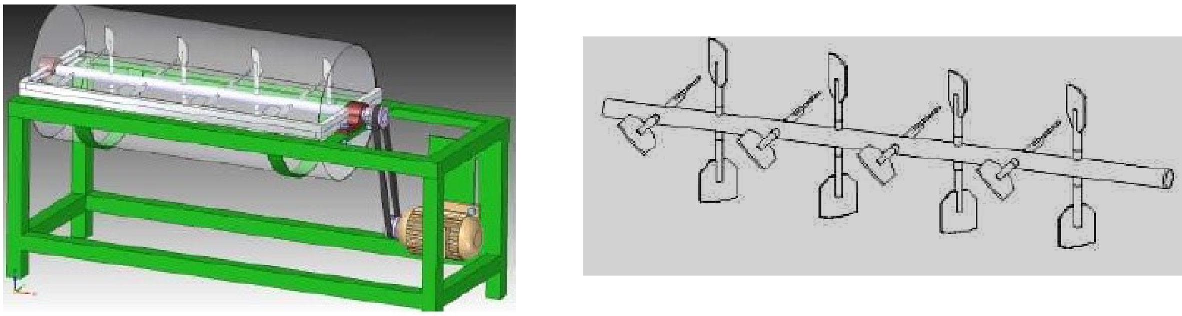


A B

cleaning is required, while continuous operations feature an outlet hole with a screw conveyor for dough removal.

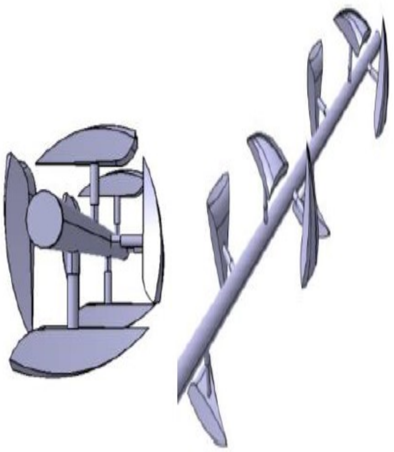
Horizontal Mixer with Paddle-Type Agitator for Dry Flour Mixing:

The horizontal mixer with a paddle-type agitator is a specialized system crafted for the precise mixing of dry flour. Its design revolves around a horizontally oriented cylindrical tank that houses the unique paddle-type agitator (Figure 6). This agitator is strategically positioned within the tank, with paddles set at 45° angles in each cardinal direction, ensuring thorough and efficient mixing. The tank itself opens conveniently in the middle, facilitating easy removal and cleaning of the agitator while maintaining a tight seal to prevent any flour spray. For larger tanks, the option to accommodate two paddle agitators further enhances mixing efficiency, making this system an ideal choice for industries requiring consistent and high-quality dry flour mixing.

Figure 6. Paddle-Type Agitator for Dry Powder Mixing (A) Example Setup (B) Paddle setup

Horizontal Mixer with Plow-Type Agitator for Dry or Wet Flour Mixing:

The horizontal mixer with a plow-type agitator offers versatility for both dry and wet flour mixing applications. Its design includes a horizontally oriented cylindrical tank with a central opening for convenient maintenance. Within this tank, the plow-type agitator is positioned to efficiently scrape the edges in each cardinal direction, ensuring thorough mixing of the flour (Figure 7). This configuration allows for effective blending of dry ingredients or the incorporation of liquids into the flour mixture, making it a practical choice for various industrial mixing needs.



A B

Figure 7: Plow-Type Agitator (A) Front View (B) Angled View

Horizontal Mixer with Double Ribbon/Helical Agitator for Dry Flour Mixing:

The horizontal mixer with a double ribbon/helical agitator is a preferred choice for dry flour mixing applications. Its design features helical blades arranged in a double ribbon configuration, effectively scraping flour from the tank edges (Figure 8). With one screw being right-handed and the other left-handed, they work in tandem to push flour sections in opposite directions, ensuring thorough mixing throughout the tank. This design promotes consistent blending of dry ingredients, making it well-suited for various industrial mixing processes requiring precise flour mixing.

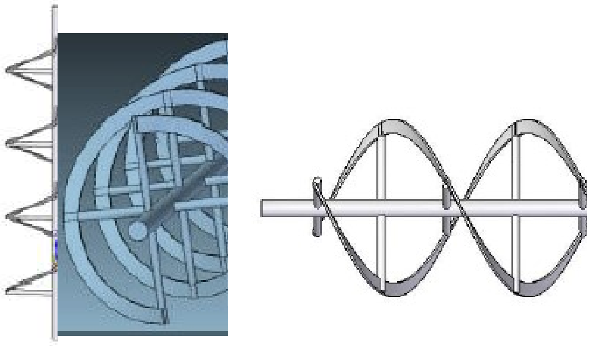


Figure 8. Various Views of Double Ribbon/Helical Agitator.

Rice Fortification

Rice fortification, as indicated by Pyo, Tsang, and Parker (2022), is a strategic intervention aimed at addressing micronutrient deficiencies, particularly in regions where rice is a staple food. This process involves enriching rice

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with vitamins and minerals, significantly enhancing the diet's nutritional quality without altering eating habits with costs between 1.5% to 3% of the current retail price of rice (Muthayya et al., 2012). The retention of micronutrients during the cooking process, according to Pyo et al. (2022), is crucial for successful rice fortification. Research suggests that both extrusion and coating fortification technologies are comparable in terms of micronutrient retention. However, Pyo et al. (2022) warn that cooking fortified rice in excess water can lead to increased micronutrient loss for both technologies.

The organoleptic properties, including taste, texture, and appearance, are vital for consumer acceptance. Pyo et al. (2022) found that fortified kernels containing ferric pyrophosphate, zinc oxide, or zinc sulfate have shown the most positive results in maintaining these properties. Pyo et al. (2022) stated that consumer acceptability is influenced by the sensory attributes of fortified rice and its resemblance to unfortified rice. The current practice of fortifying rice with ferric pyrophosphate provides high micronutrient stability and results in rice with organoleptic properties and consumer acceptance levels comparable to those of unfortified milled rice (Pyo et al., 2022).

Despite the potential benefits, challenges hinder the widespread adoption of rice fortification. Beretta Piccoli et al. (2012) state that these challenges include high initial investment, lack of government leadership, and consumer hesitation due to variations in rice characteristics or perceived higher prices without understanding the benefits. In conclusion, rice fortification presents an untapped opportunity to improve micronutrient intake among populations heavily reliant on rice as a dietary staple. With the right blend of technology, government support, and consumer education, as suggested by Pyo, Tsang, and Parker (2022), rice fortification can be a viable solution to address micronutrient malnutrition.

Rice Fortification Technologies

Rice fortification technologies are devised to enhance rice with vital vitamins and minerals post-harvesting, aiming to boost its nutritional content. Some of the primary technologies employed are:

Extrusion Technology

Extrusion technology entails producing fortified rice kernels by blending rice flour, micronutrient premix, and occasionally other ingredients. These fortified kernels are then mixed with natural rice in a ratio typically ranging from 1:50 to 1:200. The extrusion process ensures that the fortified kernels closely resemble the size, shape, and color of natural rice grains (Roelofsen, 2024).

Coating Technology

Coating technology involves applying a micronutrient mix to the surface of rice grains. This can be achieved by dusting dry micronutrient powder onto the grains or spraying a liquid solution containing the micronutrients (World Health Organization, 2006). The grains are often coated with a protective layer to seal in the nutrients. This method allows for rice fortification without significantly altering its cooking properties.

Hot Start/Cold End Technology

This method incorporates adding a micronutrient premix to rice during the cooling phase after parboiling and drying. The nutrients adhere to the warm grains, which are then cooled and polished, resulting in fortified rice that retains the added vitamins and minerals (World Health Organization, 2006).

Wash-Resistant Technology

Certain fortification methods focus on rendering the added nutrients resistant to washing and rinsing, common practices before cooking rice. This ensures that the micronutrients are not lost during pre-cooking preparation (Food Fortification Initiative, 2021).

Each of these technologies presents its advantages and challenges. For instance, extrusion and coating technologies are effective but may necessitate significant initial investment and consumer education for acceptance. The selection of technology hinges on various factors, including the dietary habits of the target population, local rice milling infrastructure, and specific micronutrient deficiencies being addressed. For a successful rice fortification program, it is essential to consider these factors alongside the technical feasibility and cost-effectiveness of the fortification method.

Current Status of Food Fortification in Nepal:

Salt Iodization

Nepal initiated its salt iodization program in 1973, with the "Iodized Salt (Production and Distribution) Act 2055 (1998)" later ratified by the government. Salt iodization is mandatory for all types of salt whether domestically produced or exported resulted high coverage rates attained swiftly through centralized distribution, especially in remote areas where iodized salt is subsidized. Despite challenges, Nepal achieved significant progress, with 82.5% of households having access to iodized salt by 1998 and reaching 90.7% in 2016 with mean iodine level in salt of 44.2 mg/kg (ppm) (Ministry of Health and Population, 2018), leading to adequate iodine levels assessed through urinary iodine excretion (UIE) levels. Median Urinary Iodine Concentration (UIC) increased from 143.8 µg/L in 1998 to 202.8 µg/L in 2007, and 286.2 ug/L in non pregrnant and lactating women of 15-49 years (Ministry of Health and Population, 2018), indicating satisfactory iodine status.

The "Iodized Salt (Production & Distribution) Act 1999" mandates salt iodization, overseen by the Ministry of Health and Population (MoHP) and monitored by the Department of Food Technology and Quality Control (DFTQC) with mandatory concentration for iodine fortification of 50 ppm (Government of Nepal, 2001). Challenges persist, including inadequate storage facilities leading to reduced iodine levels due to moisture absorption and informal salt importation, potentially introducing improperly iodized or non-iodized salt into the market. Despite these hurdles, ongoing efforts are needed to enforce salt iodization standards effectively and ensure sustained progress in addressing iodine deficiency disorders in Nepal.

Wheat Flour Fortification

Wheat flour constitutes a significant portion of Nepali diets, consumed directly through staples like chapattis and indirectly through processed foods like biscuits, bread, and instant noodles. The consumption of processed foods, especially instant noodles, has been rising steadily, particularly in urban areas. While detailed data on the milling industry is limited, it's estimated that a significant portion of wheat flour is milled in large-scale commercial roller mills, with the remainder processed in small-scale village mills.

Mandatory fortification of roller mill flour was initiated in August 2011, with support from organizations like the Micronutrient Initiative (MI). MI provided training, technical assistance, free fortification premix, and machinery to facilitate fortification efforts. The success of MI's initiatives prompted further support from entities like the Asian Development Bank (ADB) for fortification in small-scale mills. The fortification of wheat flour, whether domestically produced or exported, became mandatory in 2011 (Nepal Government, 2011) resulting 36.8% of total wheat flour in Nepal being fortified in 2016 (Ministry of Health and Population, 2018). However, challenges remain, particularly regarding the bioavailability of iron in the current premix used for roller mill fortification, especially in products like noodles and atta flour. Adjustments to fortification levels, particularly for iron, vitamin A, and folic acid, may be necessary to enhance effectiveness. These adjustments, while beneficial, come with increased costs, ranging from $3.83 to $4.90 per Metric Ton (MT) of flour compared to the current cost of $1.67 per MT.

Various premix options have been proposed, each with different combinations of vitamin A, folic acid, and iron compounds. For instance, options include ferrous fumarate and NaFeEDTA as alternative iron sources. The increased costs associated with these options necessitate careful consideration, although potential offsets like VAT elimination on flour could help mitigate these expenses. Additionally, hydrogenated vegetable oil has been fortified with vitamin A to ensure nutritional supplementation in the Nepali diet. These efforts collectively aim to improve the nutritional quality of wheat flour and related products, thereby addressing prevalent deficiencies and promoting better public health outcomes.

Fortification of hydrogenated oil

Hydrogenated vegetable oil has been fortified with vitamin A at a level of not less than 25 International Units (IU), as 1 IU is the biological equivalent of 0.3 µg retinol, of the final weight (Government of Nepal, n.d).

Fortification of Rice

Fortification of rice is carried out with the addition of "fortified rice kernel (FRK)", which has been enriched with additional nutrients, at the rate of 0.5 -2 % to polished rice (Government of Nepal, n.d). Additionally, fortified rice must adhere to the quality factors outlined, including taste and odor standards. The amount of fortified nutrients in FRK comprises essential micronutrients at mandatory concentrations such as iron: 39 to 72 parts per million (ppm) at dry basis (DB), zinc: 32 to 59 ppm, vitamin A: 0.89 to 2.21 ppm, folic acid: 0.24 to 0.59 ppm, vitamin B12: 0.007 to 0.020 ppm. Sources of fortified nutrients in fortified rice include Ferric Pyrophosphate for iron, zinc oxide for zinc, retinyl palmitate or retinyl acetate for vitamin A, and cyanocobalamine for Vitamin B12. Similarly, thiamin (vitamin b1) at 2.3-5.6 ppm, niacin (vitamin b3) at 20.5-50.7 ppm, pyridoxine (vitamin B6) at 1.9 -4.8 ppm can be voluntarily added in FRK by adding thiamin mononitrate, nicotinamide, and pyridoxine hydrochloride, respectively (Government of Nepal, n.d).

Rice as a vehicle for food fortification has an immense opportunity as rice is the main staple of Nepali; the coverage of total rice produced and industrially produced is 100% and 59.6 %, respectively (Ministry of Health and Population, 2018) with daily availability of 242 g/capita/day (FAO, n.d.). Furthermore, low-cost high-quality plant protein, either in the form of concentrate or isolate, can also be incorporated to develop protein-micronutrient enriched FRK (PMFRK) by using extrusion technology to tackle protein-energy and micronutrient deficiencies together. To create a food-based approach to nutritional security and related health interventions, the National Food Research Centre, a subsidiary institution of Nepal Agricultural Research Council, an apex governmental body of agricultural research and development, is researching to develop PMFRK.

Costs of Food Fortification

The capital costs for initiating fortification programs vary based on the equipment required. For flour mills with a capacity exceeding 50 metric tons of wheat ground per 24-hour period, a volumetric manual operation feeder costs from US $3,000 to $10,000 (Food Fortification Initiative, n.d.). Alternatively, an automatic feeder with linked microprocessor control can cost between US $15,000 to $35,000. Flour millers typically bear the costs of purchasing premixes, which are then passed on to customers. The cost increase for bakers can be as low as US$ 0.10 per 50 kilograms of flour, while for consumers, it can amount to US$ 0.10 per loaf of bread or 0.01 per five kilograms of flour.

The premix cost primarily depends on the number and quantity of vitamins and minerals included. Notably, vitamin A is the most expensive nutrient to fortify flour with, significantly impacting premix costs. The estimated cost range per Metric Ton (MT) of flour for different nutrient combinations is given in Table 5:

Table 5. The cost of different forms of premixes

Nutrients in Premix	Cost Range per Metric Ton of Flour (US dollars)
Iron and folic acid	$0.85-$3.00
Iron, folic acid, B group vitamins	$1.60-$3.90
Iron, folic acid, B group vitamins, and vitamin A	$2.85-$9.90

Source: Food Fortification Initiative (n.d., d)

While fortification is feasible even in micro mills, ensuring consistency poses challenges. In countries like the Kyrgyz Republic, successful fortification has been implemented in mills with capacities ranging from 10 to 30 metric tons per day. These mills use small feeders that adequately fortify flour consistently.

Cost Comparisons

Tables 6, 7, 8, and 9 provide estimated costs for a V-Mixer and stand-still agitation tank, respectively, scaled according to specific dimensions. These estimations allow for a comparison of costs associated with different equipment types. The estimated prices for V-Mixers and stand-still agitation tanks vary based on factors such as volume and material composition. For instance, the estimated prices for V-Mixers range from $308 to $2058 for stainless steel bodies and $239 to $1465 for aluminum bodies. Similarly, the estimated prices for stand-still agitation tanks range from $462 to $3398 for stainless steel bodies and $361 to $4670 for aluminum bodies.

Table 6. Scaleup Values for V-Tumbler

Empty volume (L)	20	50	100	300	500	1000	2000	3000	4000
Empty Volume (ft^3)	0.71	1.77	3.53	10.59	17.66	35.31	70.63	105.94	141.26
Production Capacity (kg/batch)	4	10	20	60	100	250	600	1000	1350
Leg diameter (mm)	211	287	361	521	618	778	981	1123	1236
Outer Leg Length (mm)	391	530	668	964	1143	1440	1814	2077	2286
Inner Leg Length (mm)	180	244	307	443	525	662	834	954	1050

Source: Head & Getachew, 2014

Table 7. Estimated Cost of V Mixer

Empty Mixer Volume (L)	Estimated Price	
	Stainless Steel (SS) Body (USD)	Aluminium (Al) Body (USD)
20	308	239
50	411	317
100	518	398
300	740	560
500	900	679
1000	1163	866
2000	1522	1110
3000	1807	1300
4000	2058	1465

Source: Head & Getachew, 2014

Table 8. Scaleup Values for Stand Still Agitation Tank

Empty volume (L)	50	100	200	300	500	1000	2000	3000	4000
Production Capacity (kg/batch)	11.2	22.4	44.9	67.3	112	224	449	673	898
Diameter (m)	0.30	0.38	0.48	0.55	0.68	0.86	1.19	1.37	1.50
Length(m)	0.70	0.89	1.12	1.28	1.37	1.72	1.79	2.05	2.25
No Agitator Blades	8	10	13	15	16	20	21	24	27

Source: Head & Getachew, 2014

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Table 9. Estimated Costs for Locally Built Stand-Still Agitation Tank

Empty Mixer Volume (L)	Estimated Price	
	SS Body (USD)	Al Body (USD)
20	462	361
50	515	424
100	681	548
300	848	684
500	1100	885
1000	1551	1590
2000	2271	2575
3000	2846	3559
4000	3398	4670

Source: Head & Getachew, 2014

These cost comparisons provide insights into the financial considerations associated with implementing fortification programs, allowing stakeholders to make informed decisions regarding equipment selection and budget allocations.

Monitoring and Evaluation of Food Fortification:

As food fortification programs expand globally, monitoring the quality of fortified foods and evaluating their impact on alleviating micronutrient deficiencies becomes increasingly vital. Monitoring activities aim to ensure fortified products contain adequate micronutrients and reach the target population. Quality assurance at the production level is essential, while periodic monitoring at various distribution chain levels, from production to household consumption, is also crucial.

Biological impact evaluations, conducted approximately every 2 to 3 years, assess whether fortified nutrients are well-absorbed and effectively reduce micronutrient deficiencies in the population. These evaluations may reveal unforeseen issues; for instance, while folic acid fortification has improved the nutritional status of women, certain segments may benefit less due to increased risk of Vitamin B12 deficiency. To mitigate this, adding Vitamin B12 alongside folic acid during fortification has been recommended.

Adherence to quality measures, routine analysis of results, and prompt problem-solving ensure maximum health impact of fortification programs, involving both food control and program monitoring. The government, alongside the milling industry, shares responsibility for ensuring correct and consistent fortification. Government responsibilities include developing fortified flour standards, enforcing regulations, conducting analytical testing, and evaluating program impact.

External Monitoring System

External monitoring involves inspection and auditing at production centers and importation sites to ensure compliance with standards and regulations. While Nepal has modernized its food control infrastructure with external assistance, limited resources prioritize control of foods with immediate public health hazards over fortified foods. The reliance on finished product testing neglects consistent processing procedures and control measures, contrasting with global trends favoring comprehensive food production inspection and Hazard Analysis and Critical Control Points (HACCP) systems. Currently, the Department of Food Technology and Quality Control (DFTQC) focuses on testing fortified foods with mandatory standards, particularly salt. With mandatory fortification of flour in roller mills, DFTQC is expected to increase efforts in analyzing fortified flour. Enhancements in inspection practices are necessary to improve coverage, refocusing on food industry companies and providing adequate training in all aspects of the food control system.

Internal Monitoring System

Internal monitoring involves quality control and assurance practices by producers, importers, and packers. While the large-scale food industry has established quality assurance and Food Safety Management Systems (FSMS), support for internationally accredited third-party laboratories is lacking due to the absence of accreditation systems in Nepal. Most of the food processing in Nepal occurs in small-scale industries not covered by the current Food Act, posing challenges to FSMS oversight. Local governments have a role in monitoring small-scale food services but are currently not fulfilling it, potentially undermining the effectiveness of FSMS in Nepal. Balancing the nutritional needs of the population with maintaining food quality and safety requires robust monitoring systems and a comprehensive understanding of fortification's effects. By implementing effective monitoring practices and addressing regulatory gaps, Nepal can ensure the success and sustainability of its food fortification programs.

Issues and Challenges for Food Fortification

Food fortification faces various challenges that must be addressed for effective implementation. For instance, ensuring compliance among small-scale salt producers remains difficult, hindering efforts to achieve universal salt iodization. Additionally, the dispersed nature of processing facilities in developing countries prolongs the time needed for fortification interventions to take effect. Challenges also arise in increasing iron intake due to the low bioavailability of dietary iron, especially from plant sources. Moreover, differing perceptions about fortification, including concerns about foreign substance addition and potential toxicity, create barriers to its widespread acceptance.

While acknowledging these challenges, a balanced approach is necessary to address nutritional deficiencies effectively. Efforts should focus on fortification interventions while simultaneously tackling underlying causes of deficiencies, such as improvements in sanitation and vaccinations. Collaboration between stakeholders is essential to ensure the success and sustainability of fortification programs. Key challenges include establishing robust monitoring and quality control systems, addressing consumer acceptance issues, ensuring equitable access to fortified foods, and securing long-term financial and logistical support. Overcoming these challenges is crucial to maximize the health impact of food fortification and improve the well-being of vulnerable populations. Addressing these challenges requires a multifaceted approach involving stakeholders at all levels, from policymakers to consumers. By prioritizing monitoring and quality control, promoting consumer acceptance, ensuring equitable access, and fostering sustainable partnerships, food fortification

programs can effectively combat nutritional deficiencies and improve public health outcomes.
To address these challenges, several strategies are suggested:

Improving Compliance:

- Strengthen regulations for mandatory fortification and regular monitoring. India has implemented mandatory fortification of staple foods like rice and wheat flour, improving compliance rates.
- Provide financial incentives or subsidies to encourage compliance. Brazil offers tax exemptions to companies participating in fortification programs, enhancing compliance.

Enhancing Bioavailability of Nutrients:

- Innovative Techniques: Use microencapsulation and nanotechnology to improve nutrient bioavailability. The United States uses these techniques to enhance the stability and absorption of iron and other micronutrients.
- Fortifying Appropriate Foods: Choose foods that naturally enhance nutrient bioavailability. For example, combining vitamin C with iron-fortified foods improves iron absorption, as successfully implemented in Bangladesh.

Increasing Consumer Acceptance:

- Public Awareness Campaigns: Educate the public about the benefits of fortified foods through mass media and community programs. Tanzania's campaigns have increased the acceptance and consumption of fortified foods.
- Engaging Stakeholders: Involve local communities, healthcare providers, and influencers in promoting fortified foods. Uganda's collaboration with local leaders and healthcare workers has garnered community support for fortification initiatives.

Case Studies from Other Countries

- India: Mandatory fortification of staple foods and financial incentives have improved industry compliance.
- Brazil: Tax exemptions for compliant companies have increased the availability of fortified foods.
- United States: Microencapsulation techniques have enhanced the bioavailability of nutrients like iron.
- Bangladesh: Combining iron-fortified foods with vitamin C sources has effectively addressed iron deficiency.
- Tanzania: Public awareness campaigns have significantly increased consumer acceptance of fortified foods.
- Uganda: Engaging local leaders and healthcare providers has improved community acceptance of fortification programs.

By learning from these examples, Nepal can adopt strategies to overcome its unique challenges in food fortification, ensuring improved public health outcomes through better compliance, enhanced bioavailability, and increased consumer acceptance.

Way Forward and Recommendations for Food Fortification

Food fortification stands as a crucial strategy in addressing widespread nutritional deficiencies. To ensure its effectiveness and sustainability, the following short and long term pririoties are recommended:

Short-Term Priorities

1. Strengthen Regulatory Framework:

Enforce Mandatory Fortification: Implement and enforce regulations for the mandatory fortification of staple foods.

Regular Monitoring and Evaluation: Establish systems for regular monitoring and evaluation to ensure compliance and effectiveness.

Enhance Public Awareness:

Public Education Campaigns: Launch mass media and community-based education campaigns to raise awareness about the benefits of fortified foods.

Stakeholder Engagement: Involve local leaders, healthcare providers, and influencers in promoting fortified foods to enhance community acceptance.

2. Improve Quality Control:

Capacity Building for Producers: Provide training and support to food producers to ensure high standards in fortification practices.

Quality Assurance Systems: Develop and implement robust quality assurance systems to monitor the fortification process.

Long-Term Priorities

1. Expand Fortification Coverage:

- Diversify Fortified Foods: Increase the range of fortified foods to include more staple items and reach a broader population.
- Target Vulnerable Groups: Focus on fortifying foods that are commonly consumed by vulnerable groups, such as children and pregnant women.

2. Sustainability and Funding:

- Secure Long-Term Funding: Establish sustainable funding mechanisms to support fortification programs.
- Public-Private Partnerships: Foster partnerships between the government, private sector, and non-governmental organizations to share resources and expertise.

3. Research and Innovation:

- Invest in Research: Support research initiatives to identify new fortification technologies and improve existing methods.
- Innovative Fortification Techniques: Encourage the adoption of innovative techniques like microencapsulation to enhance nutrient bioavailability.

By prioritizing these short-term and long-term recommendations, Nepal can effectively strengthen its food fortification programs, ensuring improved public health outcomes and sustainable nutrition security.

Conclusion

Food fortification is essential for addressing nutritional deficiencies, especially in regions where staple foods like rice are central to diets. It offers a safe, cost-effective, and sustainable way to improve public health. Nepal can combat malnutrition by expanding fortification coverage, strengthening quality control, raising public awareness, and fostering collaborative partnerships. Rice fortification enhances the nutritional value of a staple food consumed by millions. Despite challenges like high initial investment and consumer hesitation, the right blend of technology, government support, and consumer education can make it a viable solution. Strengthening regulatory frameworks to enforce mandatory fortification, alongside regular monitoring, and evaluation, will ensure compliance and effectiveness. Public awareness campaigns and community-based education are essential for increasing acceptance of fortified foods. Training food producers and developing quality assurance systems will further improve the fortification process. Expanding the range of fortified foods, particularly those consumed by vulnerable groups such as children and pregnant women, will enhance the program's impact. Securing long-term funding and fostering public-private partnerships will ensure sustainability. Supporting research on innovative techniques like microencapsulation and nutrient interactions with local diets will improve nutrient bioavailability and overall program success. Future research should focus on evaluating the long-term health impacts of fortification programs and understanding consumer acceptance to develop effective education and marketing strategies. Enhancing collaboration among government agencies, the private sector, and NGOs will strengthen resource sharing and expertise. Comprehensive public awareness campaigns involving local communities and influencers are crucial for promoting fortified foods and increasing their acceptance. Identifying specific areas for further research and suggesting policy changes are crucial. Future research should also investigate innovative fortification techniques like microencapsulation and nanotechnology to improve nutrient bioavailability and study nutrient interactions with local diets to optimize absorption. Longitudinal studies are needed to assess the long-term health impacts of fortification programs and evaluate their effectiveness across various population groups. Researching consumer behavior towards fortified foods will help develop targeted education and marketing strategies, considering socio-cultural influences. Policy implications include developing and enforcing stricter regulations for mandatory fortification and establishing robust monitoring frameworks to ensure compliance and effectiveness. Multi-sectoral collaboration between government agencies, the private sector, and NGOs will enhance resource sharing and expertise. Encouraging public-private partnerships will provide financial and technical support for fortification initiatives. Securing long-term funding mechanisms and exploring innovative financing options, such as leveraging international aid, will ensure program sustainability. Comprehensive public awareness campaigns and the involvement of local communities, healthcare providers, and influencers are essential to promote fortified foods and increase their acceptance. By bolstering existing programs, expanding fortification efforts, ensuring quality control, and fostering consumer awareness, Nepal can make significant strides in improving public health. Embracing food and rice fortification as key public health strategies can lead to a healthier, more nourished population and a brighter future for generations to come. A multi-faceted approach combining regulation, education, innovation, and collaboration is essential for the success and sustainability of Nepal's fortification programs.

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