Chapter

Food Fortification through Innovative Technologies

Vlaic Romina Alina, Mureşan Crina Carmen, Muste Sevastita, Mureşan Andruța, Muresan Vlad, Suharoschi Ramona, Petruț Georgiana and Mihai Mihaela

Abstract

The chapter aims to approach food fortification naturally as a result of the need for nutritional improvement and therefore underlines sustainable activities that would facilitate effective fortification. The need to fortify food is due to the close link between human, health, and food. The WHO and FAO and other internationally recognized organizations have recognized that there are over 2 billion people worldwide suffering from a variety of micronutrient deficiencies. The interest in the fortification of foods is largely due to bioactive compounds, such as vitamins, minerals, sugars, organic acids, dietary fiber, phenolic compounds, essential amino acids, and antioxidants. The most effective and accessible way of securing the population with vitamins and micronutrients is to fortify additional food and consumer products daily. At the same time, the technology for the fortification of bakery products will also be presented.

Keywords: food, fortification, nutrients, advanced technologies

1. Introduction

In accordance with the *General Principles for the Addition of Essential Nutrients to Foods* [1] Codex, the term *fortification* or *enrichment* is synonymous to the addition of one or several essential nutritional elements for a food product, regardless of whether it is or not habitually contained in foods, toward the prevention or correction of proven deficiencies in one or more nutrients, either for the entire population or certain specific groups. The General Principles Codex further states as the primary condition mentioned in the fulfillment of any such fortification program to be the initial demonstration of the requirement for an increase in the nutrient intake essential to the population or to the target group. This demonstration can rely on real clinical or subclinical studies of deficiency, estimates of the low levels of nutrient intake, or possible deficiencies triggered by changes in standard food products [1].

Food fortification has been implemented for a long period of time in industrialized countries to achieve the successful control of vitamin A and D deficiencies, several B vitamins (thiamine, riboflavin, and niacin), as well as iodine and iron. Salt irrigation was introduced in the early 1920s both in Switzerland [2] and the United States [3] and has progressively expanded worldwide since salt iodine is presently used in most countries. Since the early 1940s, the fortification of cereal products with thiamine, riboflavin, and niacin has become a common practice. Margarine was fortified with vitamin A in Denmark, while milk was fortified with vitamin D in the United States. Foods for young children were fortified with iron, thus substantially reducing the risk of iron-deficiency anemia in this age group. In recent years, folic acid fortification has become widespread in America, a strategy undertaken by Canada and around 20 Latin American countries [4]. These approaches have proven to be effective in reducing the prevalence of many diseases due to deficiencies, such as goiter (iodine), xerophthalmia (vitamin A), rickets (vitamin D), and anemia (iron). Foods from around the world have begun to be fortified with calcium, iron, phosphorus, and vitamins (especially A, B, C, and D), depending on the chemical composition of the basic foods [5].

The need for food fortification is also presented by the WHO and FAO, among many other nationally recognized organizations. They have acknowledged the micronutrient deficiencies of more than 2 billion people, largely caused by a dietary deficiency of vitamins and minerals. The importance of these deficiencies for public health depends on their magnitude and spread, but the most vulnerable are pregnant women and young children, as fetal and child development, cognitive development, and resistance to infections are affected. Although the entire world population suffers from various nutritional deficiencies, people with low incomes are the most affected, particularly in developing countries, due to unsafe food consumption. Poverty, the lack of access to a variety of foods, and the lack of knowledge on appropriate dietary practices represent major drawbacks for socio-economic development while also contributing to a vicious circle of underdevelopment. As such, long-term effects on health, learning, and productivity are significant, while they also generate a high level of social and public costs from reduced work capacity due to high rates of illness and disability [4].

It was also in less industrialized countries that fortification has become more and more appealing in recent years, so much that the planned programs have advanced more rapidly throughout the implementation phase than initially estimated. Bearing in mind the success of the relatively long program to fortify sugar with vitamin A in Central America, where the prevalence of vitamin A deficiency has been greatly reduced, there are similar initiatives in other regions of the world. Currently, the first attempt to fortify sugar in South Africa is taking place in Zambia, and if successful, it will be implemented elsewhere. Darnton-Hill and Nalubola [5] identified at least 27 developing countries that could benefit from programs to fortify one or more foods.

According to research conducted by Svetlana [6], the most efficient and accessible way of providing the population with vitamins and micronutrients is their additional fortification using these substances in consumer food products and daily foods, especially flour and bakery products. The fortification of foods should not diminish their nutritional qualities and quality, especially not to substantially alter the taste or assimilation of other nutrients contained therein, not to reduce shelf life or to change product harmlessness characteristics.

2. Biofortification

People require at least 22 mineral elements for their well-being [7]. These micronutrients can be delivered through a proper diet. However, over 60% of the world's population is estimated to be iron-deficient(Fe), more than 30% are zinc-deficient (Zn), while 30% are iodine-deficient and 15% selenium-deficient (Se). In addition, calcium (Ca), magnesium (Mg), and copper (Cu) deficiencies are common in many developed and developing countries [8]. These deficits influence many biochemical pathways directly or indirectly [9]. This is due to the production of crops in areas with low mineral bioavailability and/or (sporadic) crop consumption with inherent tissue mineral concentrations, accompanied by the lack of fish or food products [7] or low-micronutrient crops [10]. At present, mineral malnutrition is considered to be one of the most serious global challenges that is active but avoidable [11]. Mineral malnutrition can be addressed by dietary diversification, mineral supplements, food fortification and/or increased mineral concentration in edible crops (biofortification).

The term *biofortification* refers to the increase of the micronutrient concentration in the edible part of the plant and can be achieved both by using fertilizers and by stimulating the absorption of these minerals in the plant [12], while the use of micronutrient fertilizers was effective in increasing the micronutrient content in plants [13].

Practically, the fortification of food is closely linked with the biofortification of plants (raw materials for food); the higher the nutritional value of the raw material, the smaller the need for fortification. Thus, from increasing the productivity of the cultivated varieties nowadays, the necessity of obtaining varieties with high nutritional value has become a very important task for agronomists, as almost half of the world population suffers from deficiencies in zinc, iron, and selenium [14].

In some countries, selenium wheat biofortification is achieved by using selenium-based fertilizers, as wheat is considered a major source of selenium for our daily diet [15]. As such, selenium is considered to be an essential micronutrient for the human body, which can reduce the risk of degenerative diseases, including cancer [16]. A study by Wu [17] based on the consumption of common wheat biscuits biofortified with selenium through fertilization showed that although the levels of selenium in blood plasma increased, there were no significant changes of degenerative disease-specific biomarkers and of the health condition in general. Another method of biofortification that aimed at the development of wheat varieties enriched with some micronutrients was based on interactions between genotypes and environmental factors and led to good iron and zinc levels in humans [18, 19].

3. Food fortification

Government agencies, as well as food policy makers, support food enrichment and fortification to different degrees, in order to lower the deficiency rate in populations on a large scale, this proving to be an efficient approach [20]. It is estimated that 2 billion people worldwide suffer from micronutrient malnutrition [21]. From a public health standpoint, it is estimated that micronutrient deficiencies account for approximately 7.3% of global diseases.

The most important elements used for food fortification are:

3.1 Iron

The greatest part of the iron in the human body is found in erythrocytes as hemoglobin, where its main function is to carry oxygen from the lungs onto the tissues. Iron deficiency causes anemia, the most common and widespread nutritional disorder in the world and a public health problem in both industrialized and nonindustrialized countries [22]. As a component of myoglobin, a protein that supplies oxygen to the muscles, iron supports metabolism [23]. Additionally, iron is necessary for growth, development, normal cellular function, and the synthesis of hormones and the connective tissue [23]. Dietetic iron has two main forms: heme and nonheme [24]. Iron-fortified plants and foods contain only nonheme iron, while meat, seafood, and poultry contain both heme and nonheme iron [23].

People normally lose small amounts of iron through the urine, feces, gastrointestinal tract, and skin. Losses are higher in menstrual women due to blood loss. Hepcidin, a circulating peptide hormone, is the key element in regulating iron absorption and iron distribution in the body, including plasma [23–25].

Hemoglobin concentrations lower than 13 g/dL in men and 12 g/dL in women indicate the incidence of iron-deficiency anemia (IDA) [26].

The Recommended Dietary Allowance (RDA) is shown in **Table 1**; RDA for vegetarians is 1.8 times higher than for those who eat meat. This is because iron from meat is more bioavailable than the iron in herbal foods, while meat, poultry, and seafood increase iron absorption through nonheme [26].

The richest sources of heme iron in the diet include lean meats and seafood. Dietary nonheme iron sources include nuts, beans, vegetables, and fortified cereal products. In the United States, about half of the food is derived from bread, cereals, and other cereal products [23, 26]. Breast milk contains highly bioavailable iron but in quantities that are not sufficient to meet the needs of infants over 4–6 months [23, 32]. In the United States, Canada, and many other countries, wheat and other types of flour are fortified with iron [33]. Also, infant formulas are fortified with 12 mg iron per liter [32].

According to EFSA average iron intake ranged between 2.6 and 6.0 mg/day (0.9–1.9 mg/MJ) in infants ($<$ 1 year, four surveys), between 5.0 and 7.0 mg/day (1.2–1.6 mg/MJ) in children aged 1 to $<$3 years (five surveys), between 7.5 and 11.5 mg/day (1.1–1.7 mg/MJ) in children aged 3 to $<$10 years (seven surveys), between 9.2 and 14.7 mg/day (1.1–1.7 mg/MJ) in children aged 10 to $<$18 years (seven surveys), and between 9.4 and 17.9 mg/day (1.2–2.1 mg/MJ) in adults ($\geq$ 18 years) (eight surveys). Average daily intakes were in most cases slightly higher in males (Appendix D) than in females (Appendix E), mainly owing to larger quantities of food consumed per day [34]. Tolerable upper intake levels for iron fall between 40 and 45 mg [26].

A study conducted in the United States, for example, revealed that iron supplements during pregnancy have reduced the number of premature births or the incidence of low birth weight [35]. In Vietnam, fortifying fish sauce with iron and consuming 10 ml per day of the sauce fortified with 100 mg iron (as NaFeEDTA) for 100 ml significantly improve the iron deficiency of the group of women tested, compared to the placebo group after just 6 months [36]. In China, a series of studies have been carried out to evaluate the efficacy of fortifying soy sauce with iron (as NaFeEDTA). The daily consumption of 5 mg or 20 mg of iron in fortified sauce has been reported to be very effective in the treatment of iron-deficiency anemia in children; positive effects were recorded within 3 months of starting the study or 6 months on a sample of 10,000 children and women suffering from anemia [37]. In a South African iron deficiency group, fortifying the curry powder with NaFeEDTA led to significant improvements in blood hemoglobin and the prevalence of iron-deficiency anemia in women declined from 22% to just 5% during the 2 years of study [38].

3.2 Vitamin A

Vitamin A is the name of a group of retinoids soluble in fats, including retinol, retinal, and retinyl esters. Vitamin A represents an essential nutrient, thus necessary in small amounts for the normal functioning of the visual system in

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Age/nutrient		Iron (mg/d)	Vitamin A (μg/d)	Iodine (μg/d)	Folate (μg/d)	Vitamin B12 (μg/d)	Thiamin (mg/d)	Riboflavin (mg/d)	Niacin (mg/d)	Vitamin B6 (mg/d)	Vitamin C (mg/d)	Vitamin D (μg/d)	Calcium (mg/d)	Selenium (μg/d)	Total fiber (g/d)	Protein (g/d)	Fat (g/d)
Infants	0–6 months	0.27	400	110	65	0.4	0.2	0.3	2	0.1	40	10	200	15	ND	9.1	31
	6–12 months	11	500	130	80	0.5	0.3	0.4	4	0.3	50	10	260	20	ND	11	30
Children	1–3 years	7	300	90	150	0.9	0.5	0.5	6	0.5	15	15	700	20	19	13	ND
	4–8 years	10	400	90	200	1.2	0.6	0.6	8	0.6	25	15	1000	30	25	19	ND
Males	9–13 years	8	600	120	300	1.8	0.9	0.9	12	1	45	15	1300	40	31	34	ND
	14–18 years	11	900	150	400	2.4	1.2	1.3	16	1.3	75	15	1300	55	38	52	ND
	19–30 years	8	900	150	400	2.4	1.2	1.3	16	1.3	90	15	1000	55	38	56	ND
	31–50 years	8	900	150	400	2.4	1.2	1.3	16	1.3	90	15	1000	55	38	56	ND
	51–70 years	8	900	150	400	2.4	1.2	1.3	16	1.7	90	15	1000	55	30	56	ND
	70+ years	8	900	150	400	2.4	1.2	1.3	16	1.7	90	20	1200	55	30	56	ND
Females	9–13 years	8	600	120	300	1.8	0.9	0.9	12	1	45	15	1300	40	26	34	ND
	14–18 years	15	700	150	400	2.4	1	1	14	1.2	65	15	1300	55	26	46	ND
	19–30 years	18	700	150	400	2.4	1.1	1.1	14	1.3	75	15	1000	55	25	46	ND
	31–50 years	18	700	150	400	2.4	1.1	1.1	14	1.3	75	15	1000	55	25	46	ND
	51–70 years	8	700	150	400	2.4	1.1	1.1	14	1.5	75	15	1200	55	21	46	ND
	70+ years	8	700	150	400	2.4	1.1	1.1	14	1.5	75	20	1200	55	21	46	ND
Pregnancy	14–18 years	27	750	220	600	2.6	1.4	1.4	18	1.9	80	15	1300	60	28	71	ND
	19–30 years	27	770	220	600	2.6	1.4	1.4	18	1.9	85	15	1000	60	28	71	ND
	31–50 years	27	770	220	600	2.6	1.4	1.4	18	1.9	85	15	1000	60	28	71	ND

Age/nutrient		Iron (mg/d)	Vitamin A (μg/d)	Iodine (μg/d)	Folate (μg/d)	Vitamin B12 (μg/d)	Thiamin (mg/d)	Riboflavin (mg/d)	Niacin (mg/d)	Vitamin B6 (mg/d)	Vitamin C (mg/d)	Vitamin D (μg/d)	Calcium (mg/d)	Selenium (μg/d)	Total fiber (g/d)	Protein (g/d)	Fat (g/d)
Lactation	14–18 years	10	1200	290	500	2.8	1.4	1.6	17	2	115	15	1300	70	29	71	ND
	19–30 years	9	1300	290	500	2.8	1.4	1.6	17	2	120	15	1000	70	29	71	ND
	31–50 years	9	1300	290	500	2.8	1.4	1.6	17	2	120	15	1000	70	29	71	ND
References		[26]	[26]	[26]	[27]	[27]	[27]	[27]	[27]	[27]	[28]	[29]	[29]	[30]	[31]	[31]	[31]

ND—not determined.

Table 1.
Nutrient RDA by age.

human beings, maintenance of cell growth function, epithelial cell integrity, immune function, and reproduction. Dietary vitamin A requirements are normally provided by a combination of preformed vitamin A (retinol), which is present in food of animal origin, and provitamin A carotenoids, which are derived from foods of plant origin, which have to be converted into retinol by tissues such as the intestinal mucosa and the liver, in order to be used by cells [39–41]. Vitamin A deficiency is based on a frequent evaluation of serum or plasma retinol [42], and a deficit affects visual function, as vitamin A status indicators have traditionally been based on visual changes, especially night blindness and xerophthalmia [43]. The World Health Organization (WHO) estimated that over 254 million preschool children worldwide have low serum retinol levels, and therefore these indicators may be considered clinically or subclinically deficiencies in vitamin A [42].

Two forms of vitamin A are available in the human diet: preformed vitamin A (retinol and its esterified form, retinyl ester) and provitamin A carotenoids [26, 39–41]. Preformed vitamin A is found in food from animal sources, including dairy products, fish, and meat (especially the liver). The most important provitamin A carotenoid is beta-carotene; other provitamin A carotenoids are alpha-carotene and beta-cryptoxanthin. The body transforms these pigments into vitamin A. Both provitamin A and preformed vitamin A should be metabolized intracellularly within the retina and retinoic acid, the active forms of vitamin A, to support the vital biological functions of the vitamin [40, 41]. Other carotenoids found in foods, such as lycopene, lutein, and zeaxanthin, are not turned into vitamin A.

Commonly, vitamin A deficiency occurs with a diet low in vitamin A sources (e.g., dairy products, eggs, fruits, and vegetables), poor nutritional status, and a high rate of infection, especially measles and diarrheal diseases. The best sources of vitamin A are foods of animal origin, especially liver, eggs, and dairy products containing vitamin A in the form of retinol, a form that can be easily used by the body. In fact, it is difficult for children to meet their vitamin A requirements if their diet is low in foods of animal origin [26, 40] and, similarly, if their diet is low in fat. Fruits and vegetables contain vitamin A in the form of carotenoids, the most important being β-carotene. In a mixed diet, the conversion rate of β-carotene to retinol is about 12: 1. The conversion of other carotenoids to retinol is less effective, the corresponding conversion rate being 24: 1. Different food preparation techniques, such as cooking, grinding, and adding oil, can improve the absorption of synthetic β-carotene food carotenoid in the oil, also widely used in vitamin A supplements. The latter has a conversion ratio of 2: 1 to retinol, while the synthetic β-carotene forms, commonly used to fortify foods, have a conversion ratio of 6: 1.

Analyses have shown that high-dose vitamin A supplements can reduce measles mortality by up to 50%. Another analysis found that improving vitamin A deficiencies, either by supplements or by fortification, decreased mortality by 23% in children aged 6 months to 5 years, irrespective of the cause [44]. Another study on a group of preschoolers who consumed 27 g of vitamin A-fortified margarine for 6 months reported a reduction in the prevalence of low serum retinol concentrations from 26 to 10% [45].

A plasma retinol concentration lower than 0.70 micromoles/L (or 20 micrograms/mcg/dL) reflects vitamin A deficiency in a population, whereas concentrations of 0.70–1.05 micromoles/L could be marginal in some people [5]. RDA for men and women is 900 and 700 μg retinol activity equivalent/day. Tolerable upper intake levels for preformed vitamin A in adults are set at 3000 μg [26].

3.3 Iodine

Iodine is present in the body in small amounts, mainly in the thyroid gland, while its only confirmed role is in the synthesis of thyroid hormones. Iodine deficiency is a major public health problem for populations around the world but especially for young children and pregnant women. In some areas, it is a significant threat to national, social, and economic development, as the devastating result of iodine deficiency is mental retardation: currently one of the main causes of cognitive impairment that can be prevented. This is the primary reason behind the current global mission to eliminate iodine deficiency-related disorders [4].

Iodine is an essential component of thyroid hormones, thyroxine, and triiodothyronine. Thyroid hormones regulate many important biochemical reactions, including protein synthesis and enzymatic activity, as critical determinants of metabolic activity [26, 46]. These are also necessary for an adequate development of the central nervous system and skeletal system in the fetus and infants [46].

Food iodine and iodine salt are present in several chemical forms, including sodium and potassium salts, inorganic iodine, iodate, and iodide, the reduced iodine form [47]. Iodine rarely appears as an element but rather as a salt. For this reason, it is called iodide and not iodine. Iodine is rapidly and almost completely absorbed in the stomach and duodenum. Iodate is reduced in the gastrointestinal tract and absorbed as iodide [26, 48]. When the iodide enters the circulation, the thyroid gland concentrates it in quantities adequate for thyroid hormone synthesis, and most of the remaining amount is excreted in the urine [26]. Healthy adults with sufficient iodine amounts exhibit approximately 15–20 mg of iodine, 70–80% of which are contained in the thyroid [49].

Average urinary iodine concentrations of 100–199 mcg/L in children and adults, 150–249 mcg/L in pregnant women, and > 100 mcg/L in nursing women indicate adequate iodine intake. Values lower than 100 mcg/L in children and adults who are not pregnant indicate insufficient iodine intake, although iodine deficiency is not classified as severe until the urinary iodine level is lower than 20 mcg/L [47].

One of the best sources of iodine is marine algae, but its content is variable according to species [48]. Other good sources include seafood, dairy products, cereal products, and eggs [50]. Iodine is also present in human breast milk [26, 48] and in infant formulas.

3.4 Folate (vitamin B9)

Folate (vitamin B9) is important in the synthesis and methylation of nucleotides that intervene in cell multiplication and tissue growth. Its role in protein synthesis and metabolism is closely interrelated to that of vitamin B12.

The main sources of dietary folate are leafy vegetables, fruits, yeast, and liver [4]. The total body content of folate is estimated at 10–30 mg; about half of this amount is stored in the liver [51, 52], while the rest in the blood and body tissues. A serum folate concentration is commonly used to assess folic acid status, with a value greater than 3 ng/ml being adequate [26, 51]. The follicular erythrocyte concentration above 140 ng/ml indicates an adequate folate status [26, 53], although some researchers have suggested that superior values are optimal for preventing neural tube defects [54].

Folate is naturally found in a wide variety of foods, including vegetables (especially leafy green vegetables), fruits and fruit juices, nuts, beans, peas, dairy products, poultry and meat, eggs, sea food, and cereal. Spinach, liver, yeast, asparagus, and brussels sprouts are among the foods with the highest levels of folic acid [52, 55].

In January 1998, the US Food and Drug Administration (FDA) began to require producers to add folic acid to enriched bread, cereals, flour, corn, pasta, rice, and other cereal products [56]. Since cereals are widely consumed in the United States, they have become very important contributors to folic acid intake for the American diet. The fortification program was designed to increase the folic acid intake in the United States by about 100 mcg/day but eventually succeeded an increase of about 190 mcg/day [57]. In April 2016, the FDA approved the voluntary addition of folic acid to corn meal at levels compatible with other enriched cereal products [58]. The Canadian Government has also called for the addition of folic acid to many cereals, including white flour, enriched pasta, and corn flour, as of November 1, 1998 [59]. Other countries, including Costa Rica, Chile, and South Africa, have also established compulsory programs for the folic acid fortification [60].

3.5 Vitamin B12

Vitamin B12 (cobalamin) is a cobalt-containing vitamin that is synthesized by microorganisms and exists in various chemical forms in food, particularly that of animal origin, such as milk, cheese and eggs, as well as artificially fortified foods [61]. B12 deficiency can cause neurological damage, megaloblastic anemia, increase of homocysteine in plasma, and possibly impairment of the immune function. In infants and young children, it can cause serious developmental delays [4]. Approximately 56% of an oral B12 dose of 1 mcg is absorbed, but absorption decreases drastically when the intrinsic factor capacity is exceeded (for 1–2 μm of vitamin B12) [62].

Vitamin B12 is systematically evaluated through B12 serum or plasma levels. Approximate values below 170–250 pg/ml (120–180 picomoles/L) for adults [26] indicate a vitamin B12 deficiency. Increased levels of methylmalonic acid (values>0.4 micromole/l) could be a more reliable indicator of vitamin B12 status, as they indicate a metabolic change that is highly specific to vitamin B12 deficiency [26, 32–64].

Vitamin B12 is naturally found in animal products, including fish, meat, poultry, eggs, milk, and dairy products. Generally, vitamin B12 is not present in plant foods, but fortified breakfast cereals are an available vitamin B12 source with high bioavailability for vegetarians. Some nutritional products from yeast also contain vitamin B12 [26, 65].

3.6 Other B vitamins (thiamine, riboflavin, niacin, and vitamin B6)

In recent years, due to increased evidence that some B vitamins can prevent the occurrence of developmental disorders, as well as chronic degenerative and neoplastic diseases, special attention has been paid to their possibilities of employment [66]. Moreover, vitamin B complexes are of utmost importance for energy metabolism. Specifically, thiamine (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), and vitamin B6 are required for decarboxylation, transamination, acylation, oxidation, and reduction of substrates that are ultimately employed in energy consumption. One or several of these vitamins are also important for amino acid, fatty acids, cholesterol, steroid, and glucose synthesis [67]. In fact, thiamine plays a critical role in energy metabolism and hence in cell growth, development, and function. Important sources can be found in wheat germs and yeast extracts, the edible organs of most animals, legumes, and green vegetables [68]. The main sources of riboflavin are milk and dairy products, bread and bakery products, mixed meat-based foods, ready-to-eat cereals, and mixed grain-based foods [27, 69]; good sources of niacin are liver, meat and meat products, fish, peanuts, and whole grains [70]. The richest sources of vitamin B6 include fish, beef liver and other organs, potatoes, and other starchy vegetables, and fruits (other than citrus fruits) [27, 71]. Fortification of foods for nutrient recovery such as the vitamin B complex is effective in basic foods or spices [72], in wheat flour [73, 74], fish sauce [75], and rice [76]. RDAs are presented in **Table 1**.

3.7 Vitamin C

Vitamin C is a redox system composed of ascorbic acid and dehydroascorbic acid, which acts as an electron donor. Its main metabolic function is to maintain collagen formation. Additionally, it functions as an important antioxidant. Vitamin C is widely available in food of plant and animal origin, but the best sources are fresh fruits and vegetables and the edible organs of animals. However, since vitamin C is unstable when exposed to an alkaline environment or to oxygen, light, and heat, losses can be substantial during storage and cooking [4]. Foods fortified with vitamin C include milk and baby food [77], juices [78], jelly, and candies [79].

Acute vitamin C deficiency leads to scurvy. Scurvy evolution time varies with vitamin C levels, but signs may occur within 1 month after the decrease or absence of vitamin C consumption (below 10 mg/day) [80].

3.8 Vitamin D

Vitamin D deficiency can lead to musculoskeletal diseases such as rickets and osteomalacia, but vitamin D supplements and fortified foods can prevent extraskeletal disorders such as respiratory tract infections, asthma exacerbations, pregnancy complications, and premature death. Vitamin D has a unique metabolism as it is mainly synthesized in the skin under the influence of sunlight (i.e., ultraviolet radiation-B), while nutritional intake traditionally plays a relatively minor role. The recommended target concentrations range from ≥25 to ≥50 nmol/L (≥ 10–20 ng/ml), corresponding to a daily vitamin D dose of 10–20 μg (400–800 international units). Worldwide, vitamin D food fortification has already been introduced in the United States, Canada, India, and Finland with effective results [81]. As such, foods recommended to be fortified with vitamin D include milk, dairy products, and margarine [82].

Very few natural foods contain vitamin D. Fatty fish (such as salmon, tuna, and mackerel) and fish liver oils are among the best sources [28, 65]. Small amounts of vitamin D are found in beef liver, cheese and egg yolks, and certain mushroom varieties [83].

In the American diet, fortified foods provide most of the vitamin D intake [28, 83]. For example, almost all US milk is voluntarily fortified with 100 IU/cup. (In Canada, milk is fortified by law with 35–40 IU/100 ml, similar to margarine with ≥530 IU/100 g.) In the 1930s, a milk fortification scheme was implemented in the United States to fight rickets, considered to be a major public health problem. Other dairy products such as cheese are generally not fortified. Ready-to-eat breakfast snacks often contain vitamin D, similar to some brands of orange juice, yoghurt, margarine, and other foods. Both the United States and Canada require vitamin D-fortified formula for infants: 40–100 IU/100 kcal in the United States and 40–80 IU/100 kcal in Canada [28].

3.9 Calcium

Calcium is an essential element for the growth, activity, and maintenance of the human body [84]. Bone health is a major public concern. Each year, approximately

9 million people worldwide suffer from fractures due to osteoporosis [85]. Insufficient calcium and vitamin D absorption, an inadequate lifestyle, food choices, and genetics play an important role in the development of osteoporosis. Calcium absorption is controlled homeostatically by vitamin D regulation. Calcium deficiency can also lead to reduced blood clotting conditions, weak teeth, and some other symptoms [86]. People with lactose intolerance have decreased calcium intake due to absent dietary intake of calcium-dairy products [87], while the availability of calcium from nondairy sources is affected by the presence of the phytic acid, oxalic acid, and fiber [88]. Calcium is used for fortification in the form of calcium carbonate, calcium lysinate, and tricalcium phosphate in foods such as rice extrudates and noodles [89], tuna bone powder crackers [90], cookies [91], biscuits [92], yoghurt [84], etc.

The percentage of calcium absorbed depends on the total amount of elemental calcium consumed at one time; as the amount increases, the absorption percentage decreases. The absorption is highest in doses ≤500 mg. For example, someone who takes 1000 mg of calcium daily as supplements could divide the dose and take 500. The average dietary calcium intake for men over 1 year old is between 871 and 1266 mg/day, depending on the age group, while for females the interval is between 748 and 968 mg/day mg at two separate times during the day [29].

3.10 Selenium

Selenium (Se) is an essential micronutrient for both humans and animals. It forms an important component of glutathione peroxidase, a well-known antioxidant that counteracts cellular oxidative destruction. Furthermore, it plays an important role in catalyzing the production of the active thyroid hormone [93, 94], and it is required to improve human immunity and sperm motility [95]. Epidemiological studies have indicated that Se deficiency is positively correlated with the incidence of cancer [96]. The average daily recommended dose for an adult is 60 μg/day [97]. Selenium content in foods of plant origin varies with soil selenium content [98]. The most prevalent selenium fortification is that of the cooking salt, which significantly reduced the prevalence of Keshan disease in China [99], but there are other foods that can be fortified with selenium, such as yoghurt [100].

3.11 Fibers

Constipation has a negative impact on the quality of life and is defined as a difficult evacuation accompanied by discomfort and pain, while long-term constipation entails serious health problems. This is due to a decrease in dietary fiber consumption, which is directly proportional to excessive food processing [101].

Food fibers can be classified as soluble and insoluble fibers. Both types of fiber have many health benefits including maintaining intestinal and overall health integrity, lowering blood cholesterol levels, controlling blood sugar levels, and providing a non-caloric volume that can help weight loss by replacing caloric food components such as fat. According to the Dietary Guidelines for Americans, dietary fiber is consumed by most adults indicating that fortification of fiber foods might bring health benefits. Numerous studies [102–105] have shown that sausage fiber fortification (2–3 g/portion) can be achieved without any negative impact on sausage sensory quality. Alongside the increased fiber intake, products also come with other advantages such as fat replacement, increased water holding capacity, and improved oxidative stability when the fiber source is associated with phenolic antioxidants [103, 106], bran bread [107], and fiber-containing yoghurt [108].

3.12 Proteins

Proteins belong to a category of biologically active compounds that are essential to life through their specific action. They are the building blocks for the formation of tissues in the human body (cell walls, muscles, blood, hair, internal organs such as the heart and the brain, etc.), hormones, enzymes and antibodies, and replacement of waste cells. The essential amino acids are those that the body cannot produce by itself, and thus, they must be secured from food. Nonessential amino acids are amino acids that can be synthesized by the human body from essential acids or by cleavage of proteins [109]. The quality of plant proteins (vs. those from animal sources) has become a very debatable topic due to the consumption of plant products, which is increasingly promoted in the "world of nutrition." As the presence of essential amino acids in the body is of utmost importance, nutritionists recommend the right combination between the two sources (plant and animal). An advantage can be found in the addition of a vegetable matrix to meat preparation. This improves the mineral profile of the product and brings a supply of vitamins to the finished product, for example, mushroom sausages, meat products with soy protein isolate, and whey or wheat protein [110, 111], but also the fortification of plant products with plant proteins, for example, the fortification of wheat flour with cottonseed, chickpeas, amaranth, quinoa, and lentils [12].

3.13 Fatty acids

Essential fatty acids are important nutrients for the human body, especially for maintaining the health of the cardiovascular system. Several sources of information suggest that human beings have evolved on a diet that included a ratio of omega-6 to omega-3 fatty acids (EFA) of ~ 1, while western diets include a ratio of 15/1–16.7/1. Western diets exhibit omega-3 fatty acid deficiency, while they also include excessive amounts of omega-6 compared to the diet that human beings have evolved on and which set the foundation for their genetic patterns [112]. Products fortified with fatty acids in balanced proportions include meat, oil, jelly, various sauces, etc.

3.14 Multiple fortifications

Based on what is known about the prevalence of individual micronutrient deficiencies, there are generally multiple deficiencies of common micronutrients or in different population groups. Micronutrient deficiencies are more common in people on a diet low in foods of animal origin and therefore low in iron and bioavailable zinc intake, as well as calcium, retinol (vitamin A), vitamin B2 (riboflavin), vitamin B6, and vitamin B12 intakes. Commonly, poor diets, lacking fresh fruits and vegetables, yield deficiencies of vitamin C (ascorbic acid), β-carotene (provitamin A), and folic acid. Grain milling eliminates several nutrients, especially iron and zinc, various B complex vitamins (i.e., thiamine, riboflavin, and niacin), and folate. People on refined grain diets are at increased risk of deficiency in all these micronutrients. [4] Thus, fortifications are cumulated, such as vitamin A and iron, the vitamin B complex, calcium, and vitamin D, if micronutrients are separated. If fortification is achieved with the addition of different raw or auxiliary materials, the finished product will benefit from multiple fortifications, for example, the fortification of bread or sausages with mushrooms—this product will additionally have the nutritional value for protein and fiber content [110], while bakery products with the addition of nut paste come with a high intake of lipids, fibers, and minerals [12]. Most of the products fortified with unprocessed vegetable additions exhibit multiple fortifications.

4. Advanced applied technologies for the fortification of bakery products

The lentil flour was obtained by grinding the lentils, thus obtaining a fine consistency; then flour mixtures were created according to **Figure 1** [113].

Several aspects need to be taken into account throughout the technological process of obtaining fortified bakery products. This process of obtaining different types of fortified bread, including lentil bread, can be achieved through a single-phase process, since the amount (10–30%) of lentil flour is always introduced into the process by uniform distribution in the flour mass before adding the wet components (**Figure 1**) or through a two-phase process [113].

The use of compressed yeast as suspension in water facilitates the even distribution of yeast cells in the dough, thereby contributing to the improvement of product quality. As such, preparing the compressed yeast involves performing several operations such as suspending, filtering the suspension, and activating the yeast [114, 115]. The dosing aims at obtaining the dough with the optimal rheological properties and the appropriate composition of the product. The dosing of the raw materials used for dough preparation is performed taking into account their physical characteristics [113].

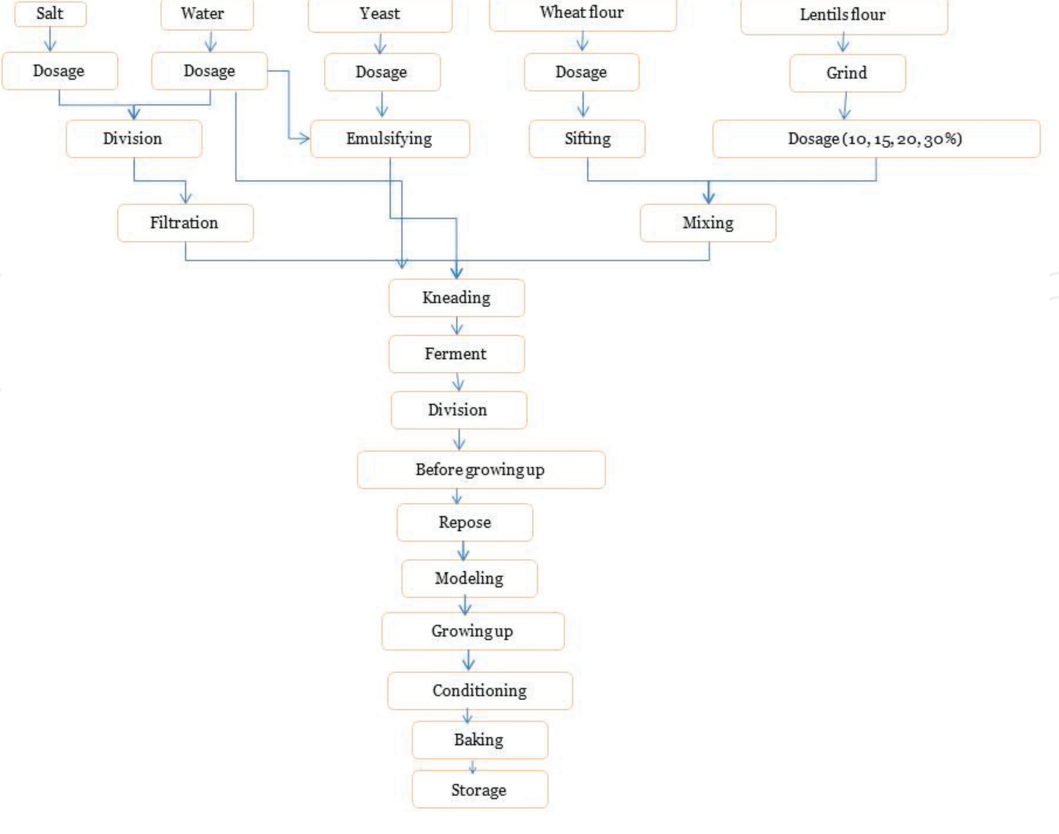

Figure 1.
The technological chart for the production of bread fortified with lentil flour, according to [113].

During the kneading process, an amount of air is included in the dough, required to meet its rheological attributes. The physical processes that take place in the dough at its kneading are the mechanical action during the kneading that ensures the water penetration into the flour mass and the temperature increase of the dough [116]. During the process of kneading itself, wet clumps of flour stick together under the influence of the mechanical kneading action, surface water penetrates deep, proteins become hydrated, the amount of bound water increases, and the dough increases its consistency and gradually acquires its elastic properties [117].

The fermenting operation is aimed at obtaining a risen dough that would produce suitable well-risen products with the right volume, as well as a porous and elastic core. Therefore, during this operation, various dough substances are accumulated in the dough, which impart the taste and aroma of bakery products. During dough fermentation, the yeast multiplication process continues, the predominant process being alcoholic fermentation, which releases carbon dioxide, ethyl alcohol, and a small amount of heat [116].

A well-risen product can only be obtained if the dough forms large amounts of gas. Ultimate leavening is the operation where the leavening of the dough reaches the maximum. The gases formed affect the gluten skeleton and thus the porosity of the dough by increasing or decreasing mesh size [116]. The biochemical processes formed during fermentation are hydrolysis of starch and gluten amylolysis or proteolysis, respectively. The microbiological processes refer to the multiplication of yeasts and their fermentative activity, as well as that of lactic bacteria that make up dough microbiota. Colloidal processes are the continuation of the gluten-forming process and gluten peptization [115].

Some of the gas present in the dough is lost during modeling, and as a result, the spongy structure of the dough is largely destroyed, the internal surface is reduced, and its specific weight increased [115].

A significant part of the carbon dioxide accumulated in the dough is eliminated during the division and modeling operations. Therefore, the dough must be subjected to a new fermentation for the restoration of its porous structure. As such, the products rise and the volume develops [116]. The main goal of the final leavening of the dough is the rise by the accumulation of carbon dioxide that is formed during yeast alcoholic fermentation and conditions the volume and structure of the porosity of products [115].

Colloidal processes condition the dough to be transformed into the inner crumb and modify the water binding state so that the crumb, although exhibiting a higher moisture than the initial humidity of the dough, appears dry due to thermal hydrophilic modifications. During coagulation, protein clotting and the gelatinization of starch occur [116]. The protein coagulation process starts at temperatures slightly above 50° C and proceeds at a maximum speed of 60–70° C, thus accelerating to continue the heating of the dough. After coagulation, proteins become more easily attackable by enzymes, both digestive enzymes and the proteolytic ones in the dough. The gelatinization of the starch takes place in two stages: granule swelling and gelatinization itself. Swelling occurs due to the penetration of water groups within the starch granule that distances the protein chains. This is achieved by increasing the kinetic energy of water molecules by heating the dough. The gelatinization is accomplished by breaking the existing H2 bonds between the amylose and amylopectin chains and dispersing these chains between the molecules of water previously penetrated into the granule. Biochemical processes formed during baking are amylolysis and proteolysis. Microbial processes during baking include alcoholic fermentation and lactic fermentation [117].

5. Results obtained in food fortification

After lentil flour was employed in 10%, 15%, 20%, and 30% proportions for the fortification of bread, the increase in mineral elements was found to be up to 4 times the control sample, and protein content increased from 6.55% to 10.50% and fibers from 0.6% to 4.7%, while the ratio of ω-6 and ω-3 fatty acids decreased from 16.66 to 7.86 [113].

For 10%, 20%, and 30% flax fiber fortified biscuits, the results showed that the total content of polyunsaturated fatty acids increased significantly from 10.50% to 20.50%, while the total content of saturated fatty acids decreased significantly from 48.22% to 40.20%, showing that the omega-3 content of fortified flax seed biscuits was significantly higher than biscuits lacking flax seeds, while the ω-6/ω-3 dropped significantly from 8.50 to 1.00. Furthermore, the calcium content increased significantly from 25.6 mg/100 g for the control sample to 168.3, 175.0, and 179.1 mg/100 g, respectively [92].

Examples may continue for different products: mushroom sausages [110], mushroom powder pastes [118], marc bread [119], chestnut flour bread [120], spirulina paste [121], inulin- and lactobacilli-fortified juice [122], tortillas fortified with iron and folic acid [123, 124], bread fortified with zinc and iron [19], etc.

6. Conclusion

The benefits of food fortification positively impact the entire life cycle of mankind. Thus, food fortification may be one of the most effective ways to overcome malnutrition and various diseases, especially in children and pregnant women and their children, preventing the birth of intellectually impaired children with malformations or deficiencies. Efforts to fortify food must be integrated in the context of each country's public health and nutrition plans and as part of a comprehensive strategy to include different micronutrients in staple foods to meet the social, physiological, and economic goals of millions of people worldwide.

Author details

Vlaic Romina Alina[1], Mureşan Crina Carmen[1]*, Muste Sevastita[1], Mureşan Andruța[1], Muresan Vlad[1], Suharoschi Ramona[2], Petruț Georgiana[1] and Mihai Mihaela[2]

1 Department of Food Engineering, Faculty of Food Science and Technology, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Cluj-Napoca, Romania

2 Department of Food Science, Faculty of Food Science and Technology, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Cluj-Napoca, Romania

*Address all correspondence to: crina.muresan@usamvcluj.ro

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