



Flour fortification for nutritional and health improvement: A review

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ABSTRACT

Deficiencies of micronutrients, essentially vitamins and minerals, have mainly cause several illnesses, especially in children and women worldwide. Governments and world organizations have focused great efforts to address these shortcomings and improve the health of the populations. This malnutrition can be combated by fortifying basic foods that are consumed daily. Thus, flours, especially wheat, maize and rice, are a popular and common food in the world's populations diet and are gaining considerable attention as a suitable vehicle for micronutrient fortification. There are some studies that show the effectiveness of flour fortification in combating micronutrient deficiencies and several diseases and the flour fortification strategies are directed to meet nutritional and health needs of the populations. The main points discussed in this review are food fortification, with great focus in flour fortification, health benefits, and legislative issues. This review also highlights multifaceted issues related to flour fortification to meet nutritional needs and to improve the health of vulnerable populations.

1. Introduction

Vitamins and minerals are essential elements for the growth, metabolism and maintenance of a healthy body and deficiencies of these nutrients have resulted in irreversible physical and cognitive consequences, since these compounds play an important role in the normal functioning of almost all organs (Looman et al., 2019; Wahengbam, Das, Green, Shooter, & Hazarika, 2019). The FAO, IFAD, UNICEF, WFP, and WHO (2018) have estimated that billions of people are deficient in different types of vitamins and minerals. Revealing that in several countries, women and children suffer from severe deficiencies caused by inadequate amounts of vitamins, amino acids and minerals, more precisely vitamin A, vitamin D, iron, zinc and probably other micronutrients. It has also been reported that several micronutrient deficiencies cohabit and are more prevalent in developing countries (Black et al., 2013; Blumfield, Hure, Macdonald-wicks, Smith, & Collins, 2013; Farhat, Lees, Macdonald-Clarke, & Amirabdollahian, 2019; Radziejewska & Chmurzynska, 2019; Ramakrishnan, 2002). A study in pregnant Nepalese women showed vitamin B6 deficiency and in villages in India showed zinc, iron and folate deficiency (Jiang, Christian, Khatry, Wu, & West, 2005; Pathak, Kapoor, Saxena, Kumar, & Gupta, 2004). Moreover, according to WHO, millions of pre-school children worldwide and pregnant women suffer from vitamin A deficiency

(WHO, 2009); otherwise, it is also estimated that, globally, about million people are affected by iodine deficiency (Li & Eastman, 2012).

Micronutrient deficiencies can lead to unfavourable health consequences, such as growth problems, immune competence, mental and physical development, and poor reproductive outcomes. It has also been reported to be related to an increased occurrence, severity and mortality of infectious diseases such as malaria, diarrhoea, pneumonia, among others. These deficiencies have numerous unfavourable results across all populations and age groups, with children and women of reproductive age being more vulnerable (Black et al., 2013; Gibson & Hotz, 2002; Looman et al., 2019).

Many strategies have been used to combat micronutrient deficiencies, such as exclusive breastfeeding during babies first 6 months, control of parasitic infections, food fortification, food diversification, and nutritional supplementation (Black et al., 2013; Hemery et al., 2018; WHO, 2000). Particularly, fortification is a method of incorporating nutrients or non-nutritive bioactive components into food products (Dwyer et al., 2015). Food fortification is one of the methods that has been applied increasingly and addressed to all age groups, being widely used to minimize micronutrient deficiency. By placing micronutrients in food products consumed daily, it reaches target populations, from which daily dietary requirements of micronutrients are scarcely satisfied (WHO & FAO, 2006). It is an impressive public health

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strategy with interesting cost-effectiveness ratios and has the advantage of being installed in the usual dietary patterns, without a major change in eating or health practices and is generally well accepted by the populations (Berner, Keast, Bailey, & Dwyer, 2014; WHO & FAO, 2006).

The development of new products has a strategic role in the food industry, because consumers are increasingly demanding food products with high nutritional value that provide health benefits (Páramo-Calderón et al., 2019). As a staple food common in many countries, flour is often considered one of the most suitable vehicles for multi-micronutrient fortification (Hemery et al., 2018). In addition, fortified flours can be a major source of bioactive compounds, since flour can be fortified with many micronutrients, reducing the risk of multiple deficiencies where they exist and improve health benefits (Akhtar, Anjum, & Anjum, 2011; Oghbaei & Prakash, 2012; Serdula, 2010a, 2010b).

Wheat and maize flours can be fortified with several micronutrients and reduce vitamin, mineral and other micronutrients deficiencies when identified as health public problem. It is estimated that the amount of industrial flour fortified is 97% in the Americas, 21% in Southeast Asia, 6% in Europe, 4% in the Western Pacific, 31% in Africa, and 44% in the Mediterranean area in 2007–2008 (WHO, 2009). Efforts made by some countries to adopt mandatory fortification of flours with some micronutrients are useful in combating these deficiencies. These initiatives are an excellent example for other countries, considering their own programs, however, when it comes to food fortification, appropriate legislation is needed to ensure impact and safety, and the intended benefits to health (Luthringer, Rowe, Vossenaar, & Garretta, 2015; Serdula, 2010a). Therefore, it is necessary to explore how nutrient fortification contributes to the context of the current nutrient intakes. The aim of this review is to evaluate the impact of flour fortification for nutritional and health improvement, detailing the prevalence of micronutrient deficiencies, health consequences, and global trends and experiences regarding flour fortifications.

2. Food fortification

Food fortification has a long history of use in some countries and has successfully controlled micronutrient deficiencies (WHO & FAO, 2006). World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO), defines fortification as the practice of deliberately increasing the amount of a vital micronutrient, i.e. vitamins, minerals, amino acids among others, in a food regardless of whether the nutrients are initially in the food before processing or not, with the intention of improving the nutritional quality of the food and providing a public health benefit with little health risk (Whiting, Kohrt, Warren, Kraenzlin, & Bonjour, 2016; WHO & FAO, 2006). This strategy can lead to relatively rapid improvements in the number of people with food deficiencies within a population, since the benefits are potentially large and consists of very cost-effective public health interventions (Dwyer et al., 2015; WHO, 2009).

The advantages of fortification to public health has been demonstrated over time by the scientific community, helping in the micronutrients deficiency correction and prevention or reduction of these deficiencies in a population, having the capacity to improve nutritional status and dietary intake and consequently improving eating habits and lifestyles (FAO et al., 2018; WHO & FAO, 2006).

To have consolidated results in food fortification, the micronutrient used must have a good availability of absorption by the organism, ideal organoleptic characteristics (not changing the colour and the flavour of the fortified food), be easily accessible, should belong to the usual diet of the population and have a good acceptance.

The most common fortified foods are cereals and cereal products, milk and dairy products, fats and oils, tea and other beverages and various condiments such as salt, soy sauce, sugar and infant formulas (Pacho, Spohrer, Mei, & Serdula, 2015; Whiting et al., 2016; WHO & FAO, 2006). In the early 1920s salt iodization was adopted in Switzerland and the United States of America and today it is used in most

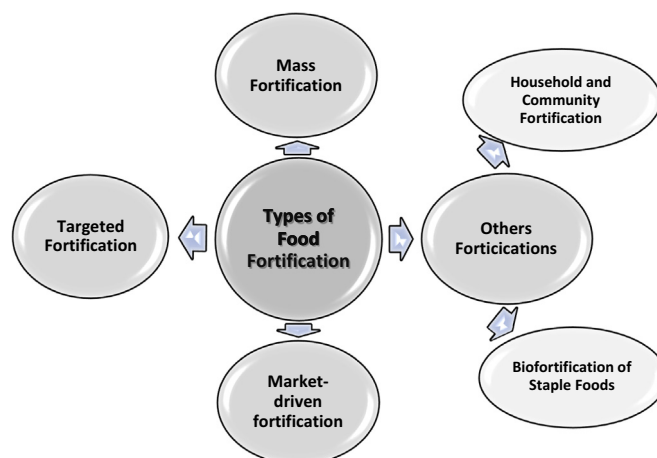


Fig. 1. Different types of food fortification.

countries. From the 1940s, fortification of cereal products with thiamine, riboflavin, and niacin became a common practice. In Denmark, margarine was fortified with vitamin A and in the United States milk with vitamin D. Also, one procedure that significantly reduced the risk of iron deficiency anaemia in young children, was the fortification of foods with iron (Vlaic et al., 2019; WHO & FAO, 2006). Nowadays, fortification of foods with different types of micronutrients has spread throughout the world, for example, folic acid fortification has spread in the Americas, a tactic adopted by the United States and Canada and approximately 20 Latin American countries (FAO et al., 2018; Vlaic et al., 2019).

2.1. Types of fortification

According WHO and FAO, food fortification includes different forms (Fig. 1): i) mass fortification (fortify foods that are quite consumed by the general population), ii) targeted fortification (fortify food targeted to specific population groups, e.g. small children), and iii) market-driven fortification (ensure that food is available in the market). There are other types of fortification such as household fortification (addition of micronutrients to homemade foods, namely a fusion of supplements and fortification) and biofortification of staple foods (breeding and genetic modification of plants to improve the content and the absorption of nutrients) (WHO & FAO, 2006).

Generalizing, mass fortification is often mandatory, targeted fortification is mandatory or voluntary and depends on the importance for public health, and market-driven fortification is always voluntary, but controlled by regulatory limits (Liyanage & Hettiarachchi, 2011; Marques, Marques, Xavier, & Gregório, 2012; WHO & FAO, 2006).

According to Liyanage and Hettiarachchi (2011), commercial and industrial fortification includes available products, such as flour, rice, cooking oils, sauces, butter, etc. and the procedure takes place throughout the manufacturing process. On the contrary, the biofortification encompasses the creation of micronutrient cultures using traditional breeding and/or biotechnology techniques (for example, transgenic “Golden Rice” containing higher amounts of iron and significant levels of beta-carotene (Lonerdal, 2003). There is also microbial biofortification, which includes the use of probiotic bacteria, which ferment to produce β -carotene in foods or directly in the intestine. For example, the use of animal feed enriched with these bacteria (more specific lactic acid bacteria), so that meat, milk and bioproducts are enriched with vitamin A (Liyanage & Hettiarachchi, 2011; Sasson, 2005). Moreover, there is home fortification, where micronutrients obtained from packages or tablets can be incorporated when cooking and or consumed in a homemade meal to fill micronutrient deficiencies in the populations (Liyanage & Hettiarachchi, 2011; Marques et al.,

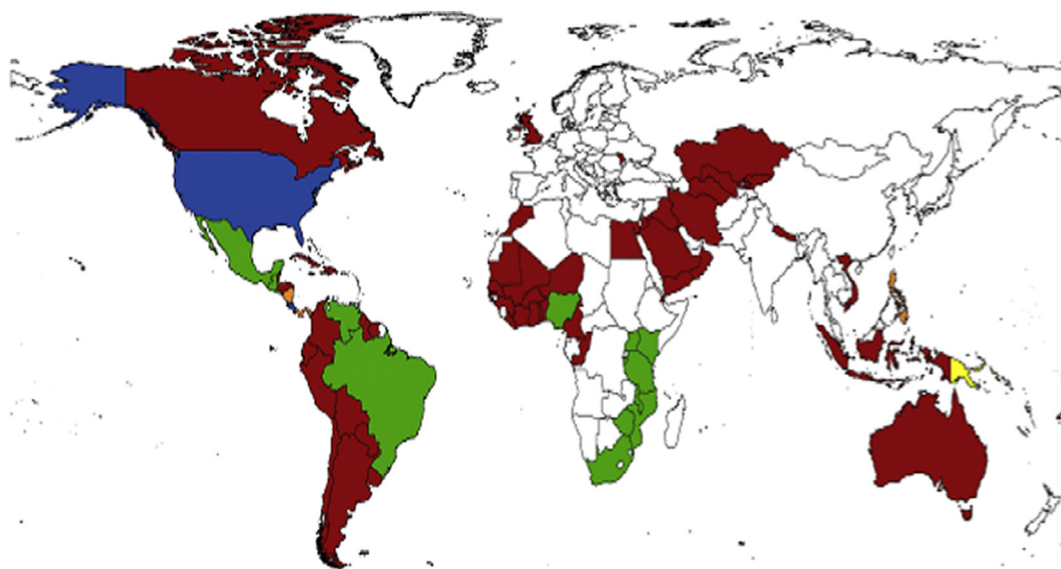


Fig. 2. Mandatory fortification of different types of flour around the world: ● 65 countries – wheat flour, ● 14 countries – wheat flour and maize flour, ● 4 countries – wheat flour and rice (Nicaragua, Panama, Philippines, Solomon Islands), ● 2 countries – wheat flour, maize flour and rice (Costa Rica and the United States), ● 1 country – rice (Papua New Guinea) (FFI, 2019a, 2019b, 2019c, 2019d, 2019e).

2012; WHO & FAO, 2006).

2.2. Issues and challenges of nutrient deficiencies

The greatest modifiable threat to global health and survival is represented by malnutrition, especially among children in the world's poorest countries (Prentice et al., 2008). Given the increasing demands of pregnant and lactating women and young children, this group is among the most vulnerable to micronutrient deficiencies (Black et al., 2013).

WHO reports that worldwide approximately 19.1 million pregnant women are deficient in vitamin A and it is estimated that 82% of these women have zinc intake inappropriate to meet the normal needs of pregnancy; 100 million women of reproductive age have iodine deficiency; 190 million pre-school children are also deficient in vitamin A; iron deficiency is globally found worldwide and approximately 1.62 billion people are anaemic (mostly among pre-school children and pregnant women). Deficiencies of vitamin B6 and B12 have also been observed in many countries (McLean, de Benoist, & Allen, 2008; WHO, 2000, 2009).

Wide spreading of infectious diseases and mortality from pneumonia, malaria, diarrhoea and measles are linked to micronutrient deficiency. Proper nutrition influences health status and helps prevent many diseases, being responsible for providing nutrients (including vitamins, minerals and others nutrients), and contributing to the proper functioning of the body (Jakubowska & Staniewska, 2015). The implications of these shortcomings are not only limited to health standards, but also have effects on the economy, through secondary physical and mental disabilities and modified work productivity (Das, Salam, Kumar, & Bhutta, 2013). Currently the approach to nutritional issues has undergone considerable changes.

Nowadays solutions are already known (such as fortified foods), but require some challenges like political dedication, economic advancement, and scientific research, in order to range a plausible solution. In this sense, several agencies worldwide are focusing their attention on the fight against micronutrient deficiencies, since they are a short-term resolution (FAO, 2017; Prentice et al., 2008). Some challenges, such as choosing appropriate fortification vehicles, having a good policy, targeting populations, avoiding excessive consumption in non-target groups, and monitoring nutritional status, are among relevant factors in improving health and will have the possibility to save billions of lives

(Dwyer et al., 2015; Osendarp et al., 2018; Prentice et al., 2008; WHO & FAO, 2006).

3. Fortification of flour around the world

Worldwide, millions of tons of flours are used for human consumption each year, they are consumed as noodles, breads, pasta and other flour products (Pacho et al., 2015; Serdula, 2010b). In 2016, according to the Food Fortification Initiative, out of the 250 metric tons of industrially milled wheat flour, 26 metric tons of industrially milled maize flour, and 171 metric tons of industrially milled rice, 34%, 57%, and 1%, respectively for each one of the flours was fortified. Between 2016 and 2017, 87 countries have decided to fortify at least one of these cereals (FFI, 2016, 2018; Marks et al., 2018).

The first cereal product to be largely fortified was wheat flour, and the first recommendations about cereals fortification from the World Health Organization (WHO) referred to maize and wheat flour. At the beginning of 2015, 83 countries demanded the fortification of wheat flour, of which 14, required simultaneously the fortification of maize flour. Most of these countries require fortification of wheat flour and maize with at least iron and folic acid, excluding Australia that does not require fortification of flour with iron, and Congo, Nigeria, Philippines, United Kingdom, and Venezuela do not require flour fortification with folic acid (Pacho et al., 2015; WHO, 2009).

Today, just 86 countries worldwide have legislation requiring the fortification of at least one grain of industrially milled cereal, depending on the country the flour is fortified with vitamins, minerals, amino acids and other micronutrients. Within these, 85 countries fortify wheat flour alone or in combination with other grains, taking away the country Papua New Guinea which is mandated only for rice flour fortification (Fig. 2) (FFI, 2019c).

Each country adopts its fortification standard depending on the geographic region, income status, food vehicle(s) and nutrient(s). The total number of nutrients fortified in flours are determined according to the fortification pattern (Table 1) (GFDx, 2019).

Nutrition International directs and supports flour fortification efforts in developing countries through various programs and partners such as: Global Alliance for Improved Nutrition (GAIN), UNICEF, World Food Program (WFP), Food Fortification Initiative (FFI), United States Centres for Disease Control and other organizations, working within different countries (South Africa, Yemen, Iran, India, Pakistan, Nepal,

Table 1
Nutrients in food fortification standards of some country (GFDx, 2019; WHO, 2013).

Country	Food vehicle	Nutrients
Afghanistan	Wheat flour	Vitamin B12, Folate (B9), Iron, Zinc
Bolivia	Wheat flour	Niacin (B3), Riboflavin (B2), Thiamine (B1)
Costa Rica	Wheat flour	Folate (B9), Iron, Niacin (B3), Riboflavin (B2), Thiamine (B1)
	Rice	Folate (B9), Vitamin B12, Niacin (B3), Selenium, Thiamine (B1), Vitamin E, Zinc
	Maize flour	Folate (B9), Iron, Niacin (B3), Riboflavin (B2), Thiamine (B1)
Tanzania	Wheat flour	Vitamin B6, Vitamin B12, Folate (B9), Iron, Niacin (B3), Riboflavin (B2), Thiamine (B1), Vitamin A, Zinc
	Maize flour	Vitamin B12, Folate (B9), Iron, Zinc
Colombia	Wheat flour	Calcium, Folate (B9), Niacin (B3), Riboflavin (B2), Thiamine (B1)
Philippines	Wheat flour	Iron, Vitamin A
	Rice	Iron
Nigeria	Wheat flour	Zinc, Vitamin A, B6, B12, Folate (B9), Iron, Niacin (B3), Riboflavin (B2), Thiamine (B1)
	Maize flour	Zinc, Vitamin A, Thiamine (B1), Riboflavin (B2), Niacin (B3), Iron, Folate (B9), Vitamin B12 And B6
Nepal	Wheat flour	Folate (B9), Iron, Vitamin A
United States of America	Maize flour	Calcium, Folate (B9), Iron, Niacin (B3), Riboflavin (B2), Thiamine (B1), Vitamin D
	Rice	Thiamine (B1), Vitamin D

Bolivia, Central and South America and the Middle East, Indonesia, Nigeria, among others countries). They support and expand fortification programs of flours with different micronutrients to combat the deficiency of these nutrients and improve health disorders (Nutrition International, 2019).

3.1. Types of fortified flours

Since the early days, cereals and cereal products have been the main components of the human diet throughout the world. Major cereal crops include wheat, rice, maize and barley. Maize (or corn) is the most produced, but it is less important than wheat and rice, which are the most important cereals for human nutrition (Preedy, Watson, & Patel, 2011).

Cereals are common staple foods since they are versatile, tasty, always available on the market, accessible and culturally acceptable, are consumed every day by all age groups, being a great fortification vehicle.

Cereals are commonly consumed after being processed by milling industries. When the flours are fortified at the industrial level (flour production), the different produced food products in the food preparation industries (e.g. bakeries) are easier to prepared. This makes the cereal industrial unit much more powerful in this type of fortification, than the a bakery, or even supplements (Johnson, Mannar, & Ranum, 2004; Pachó et al., 2015).

Wheat flour was the first cereal grain product to be extensively fortified and the recommendations of the World Health Organization (WHO) is that fortification of wheat, maize and rice flour are an opportunity to improve health (WHO, 2009). Table 2 presents some types of flours or derived products that have already been fortified and it is found that the work on fortifications has been made mostly in wheat flour.

In the market there are many flours that can be fortified or used to fortify other flours, the following topics highlight the main produced and/or consumed cereals flours worldwide.

3.1.1. Wheat flour

The third largest cereal production in the world is wheat, after maize and rice, and is the second most consumed by the populations after rice. Wheat flour is considered one of the most appropriate vehicles for multi-micronutrient fortification because of its worldwide consumption and given the high consumption of bread and pasta worldwide (Awika, 2011; Peña-Rosas, Field, Burford, & De-Regil, 2014).

The industrial processed fortification of wheat flour, when properly implemented, is an effective, simple and inexpensive strategy to provide vitamins and minerals to the world population, thereby improving

the nutritional quality of food supply and providing a public health benefit (Cardoso et al., 2019; FFI, 2019b; Nuria Mateo Ansón, 2010; Peña-Rosas et al., 2014).

Globally the effort to begin fortifying wheat flour was launched during the 1940s as a way to improve the health of populations (Bishai & Nalubola, 2002). Wheat flour has been fortified with different micronutrients such as iron, folic acid, B-complex vitamins, vitamin A, D and C, zinc, calcium among others, in different parts of the world (Akhtar et al., 2011; FFI, 2019b, 2019c; Johnson et al., 2004; Jungjohann et al., 2015; Marks et al., 2018; Pachó et al., 2015; Peña-Rosas et al., 2014; Rebellato et al., 2017; Serdula, 2010b; WHO, 2009). For example, pasta made with white wheat flour, enriched with *Orzechomys niloticus* L. (high levels of essential amino acids and polyunsaturated fatty acids) flour, improves the nutritional composition of the pasta without compromising its sensorial quality (Monteiro et al., 2019).

3.1.2. Rye flour

Rye is essentially a European cereal and globally the largest production is also centred in Europe. In the baking industry, it is the second most used cereal worldwide, after wheat. In the Middle East, rye is developed as a secondary crop, it has a great wintering capacity and high tolerance to drought, cold, and develops well on low fertility soils. With these characteristics, it becomes a low-risk and economical crop (Cardoso et al., 2019; Carena, 2009; Kaminski, da Silva, do Nascimento Júnior, & Ferrão, 2011; Redant, Buggenhout, Brijs, & Delcour, 2017).

The interest in rye has been increasing because of its nutritional profile, due to its high levels in dietary fibre. Beside its excellent nutritional quality, it also has many health benefits, decreasing the absorption of triglycerides and blood cholesterol levels; reduction in blood glucose; prevention of constipation, and prebiotic effects, among others. These characteristics, allow the classification of rye products as functional foods, proving a relationship between diet and health (Carena, 2009; EFSA Panel on Dietetic Products Nutrition and Allergies (NDA), 2011; Grossmann & Koehler, 2016; Kaminski et al., 2011; Moniz et al., 2018; Preedy et al., 2011; Redant et al., 2017). There are some studies that have presented the fortification of rye flour with cellulose fibre (Fuckerer, Hensel, & Schmitt, 2015, 2016) and with folic acid (Gujska & Majewska, 2005) to increase its health benefits.

3.1.3. Rice flours

Rice is the staple food for more than half the world's population and is the main cereal in many developing countries. In most Asian countries, rice provides between 50% and 80% of the caloric intake. In South and Southeast Asia, most women and children are anaemic and the nutritional value of rice has a significant impact in their health (FFI, 2019e; Preedy et al., 2011; Sasson, 2005; WHO, 2018a).

Table 2
Flour fortification with micronutrients and their health benefits.

Flours	Micronutrients ^a	Health benefits ^b	References
Wheat	Minerals	Increases the content or bioavailability of a specific micronutrients	Chiplonkar et al. (1999), Gujska and Majewska (2005), Towo, Mgoba, Ndossi, and Kimboka (2006), Butt, Arshad, Alam, and Nadeem (2007), Gigante and Victora (2007), Naves et al. (2007), Akhtar, Anjum, Rehman, Sheikh, and Farzana (2008), Pachón, Stoltzfus, and Glahn (2008), Sadighi et al. (2008), Anton, Lukow, Fulcher, and Arntfield (2009), Škrbić, Milovac, Dodig, and Filipčev (2009), Berry et al. (2010), Kaminski et al. (2011), Barbosa, Taddei, Palma, Ancona-Lopez, and Braga (2012), Buzzo et al. (2012), Fares and Menga (2012), Erukainure, Ebuehi, Adeboyejo, Aliyu, and Elemo (2013), Danza et al. (2014), Peña-Rosas et al. (2014), Gawlik-Dziki et al. (2015), Pachó et al. (2015), Prodhon et al. (2015), Muhammad et al. (2016), Sui, Zhang, and Zhou (2016), Bolarinwa, Aruna, and Raji (2017), Kurek, Wyrwiz, Karp, and Wierzbicka (2017), Rebello et al. (2017), Reshmi, Sudha, and Shashirekha (2017), Aranibar et al. (2018), Armellini et al. (2018), Benjakul and Karnjanapratum (2018), Emaleku, Omueti, and Emaleku (2018), Garrod et al. (2019), and Hemery et al. (2018)
	Vitamins	Prevention/reduction/improvement of the incidence of anaemia or specific mineral deficiency	
	Proteins	Functional food with therapeutic protective effects against diabetes and cardiovascular diseases	
	Fibre	Effect on the prevention of colon cancer	
	Fatty acids	Antioxidants activity Prevention of civilization diseases (e.g.: hypertension, obesity)	
Rye	Fibre	Increases the content of a specific micronutrients	Gujska and Majewska (2005), Fuckerer et al. (2015), and Fuckerer et al. (2016)
Maize	Vitamins		
	Minerals	Increases the content or bioavailability of a specific micronutrients	Chiplonkar et al. (1999), Hansen, Bæch, Thomsen, Tetens, and Sandström (2005), Towo et al. (2006), Andango et al. (2007), Gigante and Victora (2007), Naves et al. (2007), Bilgi Boyaci et al. (2012), Buzzo et al. (2012), Pachó et al. (2015), Giménez, Drago, Bassett, Lobo, and Sammán (2016), and Kumar, Xavier, Lekshmi, Balange, and Gudipati (2018)
Rice	Vitamins	Prevention/reduction/improvement of the incidence of anaemia or specific mineral deficiency	Hettiarachchi et al. (2004), Sharif, Rizvi, and Paraman (2014), Igoumenidis, Lekka, and Karathanos (2016), Kumar et al. (2018), and Mounjouenpou et al. (2018)
	Minerals	Antioxidants activity	
Millet	Fibre	Increases the content or bioavailability of a specific micronutrients	Chiplonkar et al. (1999), Tripathi and Platel (2010), Tripathi, Chetana, and Platel (2010), and Tripathi and Platel (2011)
	Vitamins	Antioxidants activity	
Sorghum	Minerals	Increases the content or bioavailability of a specific micronutrients	Tripathi, Platel, and Srinivasan (2012), Tripathi and Platel (2013), and Oluyimika, Kruger, White, and Taylor (2019)
	Proteins		
	Fatty acid		
	Amino acids	Increases the content of protein and fatty acid Antioxidant activity	

^a In this section, the micronutrients have been used directly or they are derived from other foods that are used to fortify the flours.

^b Some of the health benefits that can be found in referenced works.

Such as wheat and maize flour fortification, rice fortification with vitamins, minerals and other micronutrients is a public health opportunity, in order to prevent deficiencies in these compounds and severe diseases (de Pee, 2014; FFI, 2019e; Forsman, Milani, Schondebare, Matthias, & Guyonnet, 2014).

According to GFDx (2019) some countries like Costa Rica, Nicaragua, Panama, Papua New Guinea, Philippines, United States of America, Bangladesh, India and Venezuela fortify rice with zinc, vitamin A, vitamin B1, B2, B3, B6, B9, and B12, iron, calcium, and vitamin D.

However, rice is very difficult to fortify because most of the grains are not processed. Therefore, the alternative is to fortify rice flour instead of rice grain, which can be fortified with the same methods used for the other flours. In Sri Lanka, rice flour is processed, and its cost is approximately equal to wheat flour, leading to a growing interest by the population. Mounjouenpou et al. (2018) fortified rice flour biscuits with 20% baobab (*Adansonia digitata* L.) pulp flour, which has been shown to be very rich in minerals, such as potassium, magnesium, iron and calcium, as also vitamin C and total fibre. According to the authors the biscuits with baobab appears to be a very low cost alternative and an accessible way to combat micronutrient deficiencies in Africa. Fortification of rice flour has been proposed in countries such as the Philippines and Guyana, which have a very significant consumption of this product (Hettiarachchi, Hilmers, Liyanage, & Abrams, 2004; Johnson et al., 2004; Marks et al., 2018).

3.1.4. Maize flours

Maize is grown all over the world and millions of tonnes are produced, actually, different types of maize, varying colours, are cultivated

globally. The United States, China, India, France, Brazil, Argentina, and Indonesia are the main maize producing countries. It is also the main food preferred by billions of consumers in sub-Saharan Africa and Latin America. Tons of maize flours are milled annually, and its consumption is performed in many forms. After wheat and rice, maize is the third most frequently consumed cereal in the world (Sasson, 2005; WHO, 2009).

Around 65% of industrially processed maize in the world is fortified (FFI, 2018, 2019d) and this fortification has been practiced for several years in many countries, where this ingredient is used for the preparation of many common dishes. Between the African and American continent about 16 countries have mandatory legislation to fortify maize flour (Enzama, Afidra, Johnson, & Verster, 2017; FFI, 2019d). Maize flour can be fortified with several micronutrients, such as iron, folic acid, vitamin A and B, zinc, among others; some of them are used to replace nutritional contents and others are used to prevent deficiencies of certain micronutrients relevant to health (GFDx, 2019; WHO, 2016). For example tortilla made from maize flour incorporated with *Moringa oleifera* Lam. flour showed a significantly increased in the protein and lipid content of this food product and an increase in total polyphenolic content as well as its antioxidant activity (Páramo-Calderón et al., 2019).

3.2. Flour fortification as a supplement

Supplementation is a set of substances (vitamins, minerals or other nutrients) that serve to complement your diet when the natural intake of these components is insufficient; this term is used to describe large doses of micronutrients, usually in the form of capsules, tablets or

syrups. It has the advantage of offering the ideal amount of specific micronutrients in an absorbable form and is often the fastest way to combat nutrient deficiency (Bailey, Fulgoni, Keast, Lentino, & Dwyer, 2012; Dwyer et al., 2015; WHO & FAO, 2006).

Worldwide, supplementation programs have been widely used to provide iron, folic acid, vitamin A among other nutrients to pregnant women, infants, children under 5 years, among other groups of individuals (Datta & Vitolins, 2016). However, as for the more water-soluble vitamins and minerals, the populations or target populations need to consume the supplements more often for the control and combat for this type of micronutrient deficiencies. Flour fortification with micronutrients (Table 2) has been widely implemented worldwide, due to the extensive consumption of these foods in different forms and for being a cost-effective and sustainable strategy (Datta & Vitolins, 2016; Marks et al., 2018; Pacho et al., 2015).

As it has been described earlier, there are different types of micronutrients that can be used to supplement food, the following topics highlight the major micronutrients used to fortify flours worldwide.

3.2.1. Vitamins

Vitamins are essential nutrients for growth and maintenance of life, since our organism does not have the capacity to synthesize them, we must guarantee their ingestion through food or supplements. These compounds are present in very small quantities and are linked to various processes related to the transfer and storage of energy, protection and strengthening of the body's defences, protection against various diseases, bone and tissue formation, formation and maintenance of cellular structure and functions, visual system, activity of other nutrients, etc. (Das et al., 2013; Johnson et al., 2004; Verma, 2015).

It has been reported the use of fortified flours with different vitamins to reduce nutritional deficiencies and to prevent and control various diseases. For example, rice has been fortified with vitamin A, to improve the iron status and vitamin A nutrition of populations, while maize flour has been fortified with B vitamins, contributing in the elimination of beriberi and pellagra in many countries, also vitamin B12 added as a fortifier for flour retains high bioavailability when baked in bread, which when consumed contributes in the diminution in this vitamin deficiency (Akhtar et al., 2011; Das et al., 2013; Garrod et al., 2019; Johnson et al., 2004; Peña-Rosas et al., 2014; Serdula, 2010a; WHO, 2018a), vitamin D has been used to fortified chapattis consumed by residents of private sunbeds in Romania, showing higher serum vitamin D levels and significantly increased bone density (Allen, Dangour, Chalabi, & Tedstone, 2015; Ritu & Gupta, 2015; WHO, 2016).

3.2.2. Minerals

Minerals (sodium, potassium, calcium, iron etc.) are nutrients important to the body and are responsible for the proper functioning of metabolism. They favour the balance and maintenance of basic bodily functions such as conduction of nerve impulses, cellular activity and maintenance, and structural functions in the body, nail, tooth, and bone formation (Akhtar et al., 2011; Peña-Rosas et al., 2014; WHO, 2009; WHO & FAO, 2006). The different essential minerals are classified according to their concentration in the body and the requirement in the diet. The differences in the required mineral quantity has a great influence on the cost and on other aspects of mineral fortification of the flours. The main minerals for our organism are calcium, phosphorus, sodium, potassium, chloride and magnesium, while those that are needed in smaller quantities are iron and zinc, and the trace elements needed are iodine, copper and selenium (BNF, 2019; Peña-Rosas et al., 2014; Serdula, 2010a; WHO, 2016).

There are several studies demonstrating the use of minerals to strengthen different types of flours in order to reduce their deficiencies and prevent/control some diseases. Iron deficiency leads to anaemia and is one of the most prevalent public health problems in the world, and for example, in Iran, the fortification of flour with iron is considered a strategy to combat this deficiency (Blanco-rojo & Vaquero,

2019; Sadighi et al., 2008; WHO & FAO, 2006). Currently, every wheat flour sold in many countries are enriched with iron in order to reduce iron deficiency and anaemia caused by low intakes of bioavailable iron (Rebellato, Klein, Wagner, & Lima Pallone, 2018). Zinc is being added to maize flour in South Africa and Mexico and in wheat flour in Mexico, South Africa, Central Asia and Indonesia to address the problem of their deficiency (delayed growth and increased risk of disease), especially in children (Johnson et al., 2004; WHO, 2017; WHO & FAO, 2006). The fortification of calcium in whole wheat flour in Asia has been performed in order to increase the amount of calcium in the body and to combat some diseases, such as osteoporosis (Muhammad et al., 2016; WHO, 2017).

3.2.3. Other nutrients

There are many other micronutrients with health benefits that can be used to fortify flours. Fibre deficiency has a negative impact on quality of life and can lead to serious health problems. Food fibres can be classified as soluble and insoluble fibres. Both types of fibre have several health benefits, including maintaining intestinal integrity and overall health, lowering blood cholesterol levels, controlling blood sugar levels, and providing non-caloric volume that may help in the loss of weight ratio by replacing caloric components. In this sense, fortification of flours with fibre can bring many health benefits (Anderson et al., 2009; Salmean, Zello, & Dahl, 2013).

Proteins belong to a category of compounds that are essential to life through its specific action. They are important for cell walls, muscles, blood, hair, internal organs, such as the heart and brain, among others, also for hormones, enzymes and antibodies, and replacement of waste cells. Essential amino acids can only be acquired through food, because the body cannot produce them by itself. One advantage may be the fortification of products with plant proteins, for example, the fortification of wheat flour with chickpeas, amaranth, quinoa, lentils and mushroom powder, etc. (Preedy et al., 2011; Prodhon, Linkon, Al-Amin, & Alam, 2015).

Essential fatty acids are also an important nutrient, especially for the cardiovascular system. Essential fatty acid deficiency is uncommon, but include scaly dermatitis, alopecia, thrombocytopenia and, in children, intellectual disability. Diets in the West are deficient in omega-3 fatty acids. Although there is not much mentioned about fortified flours with essential fatty acids, there are products derived from flour that have been incorporated with these compounds (e.g.: breads fortified with oils containing omega-3). Nevertheless, there are other products that have been fortified with essential fatty acids that include meat, oil, butter, jelly, different types of sauces, etc. (Preedy et al., 2011; Vlaic et al., 2019).

3.3. Flour fortification with bioactive compounds

The usefulness of food fortification is mostly given to bioactive compounds such as vitamins, minerals, phenolic compounds, essential amino acids, dietary fibre, among other group of compounds. By fortifying day-to-day foods we can guarantee the necessary micronutrients ingestion in order to stay healthy (Del Pino-García, Rico, & Martín-Diana, 2018).

There are many natural sources with bioactive compounds that can be used to fortify flours, a good example could be mushrooms, which can provide relevant amounts of B vitamins, ergosterol (precursor of vitamin D2) and minerals such as selenium, potassium, copper and zinc. Mushrooms are nutritious foods and an excellent source of bioactive compounds, and they have already been used to fortify wheat flour in order to increase the availability of different micronutrients (Cardwell, Bornman, James, & Black, 2018; Prodhon et al., 2015). Moreover, wheat and maize flours have been fortified with egg shell powder as a source of calcium, with finger millet (excellent source of bioactive compounds), due to its high concentration in fibres, minerals, protein, and calcium (Naves, Fernandes, Prado, & Telxreira, 2007; Oghbaei &

Table 3
Some natural sources used as flour fortifiers^a.

Natural sources (origin)	Class of bioactive compounds ^b	References
Mushrooms		
<i>Agaricus bisporus</i>	Carotenoids	Archana and Neetu (2016), Cardwell et al. (2018), Chaudhari, Wandhekar, Shaikh, and Devkatte (2018), Chauhan, Kumar, Kumar, and Kumar (2018), Condé, Oliveira, and Oliveira (2017), Ishara, Sila, Kenji, and Buzera (2018), Mahamud, Shirshir, and Hasan (2012), Prodhan et al. (2015), Sonkar and Singh (2015), and Sulieman et al. (2019)
<i>Pleurotus ostreatus</i>		
<i>Boletus edulis</i>		
<i>Cantharellus tubaeformis</i>		
<i>Pleurotus sajor caju</i>	Phytosterols Tocopherols Flavonoids Phenolic acid	
Plants	Fatty acid	
<i>Aloe vera</i> L.		Bolarinwa, Aruna, and Raji (2019), Izidorczyk and McMillan (2019), Montemurro, Pontonio, and Rizzello (2019), Oyeyinka and Oyeyinka (2018), Preedy and Watson (2019), Preedy et al. (2011), Sonkar and Singh (2015), and Urade (2019)
<i>Artocarpus integer</i> (Thunb.) Merr.		
<i>Avena sativa</i> L.		
<i>Chenopodium quinoa</i> W.		
<i>Hordeum vulgare</i> L.		
<i>Ipomoea batatas</i> Lam.		
<i>Moringa oleifera</i> Lam.		
<i>Pennisetum glaucum</i> (L.) R. Br.		
<i>Abelmoschus esculentus</i> (L.) Moench. (Flour)		
<i>Glycine max</i> (L.) Merr. (Proteins)		
<i>Hordeum vulgare</i> L. (Brewer's Spent Grain)		
<i>Lupinus spp</i> (Lupine Kernel Fibre)		
<i>Malus domestica</i> Borkh. (Pomace)		
<i>Mangifera indica</i> L. (Flours)		
<i>Musa spp</i> (Flours)		

^a The natural sources mentioned are already used to fortify flours or can be used for the same purpose.

^b Classes of bioactive compounds that may be related to plants and/or mushrooms.

Prakash, 2012; Preedy et al., 2011).

Several non-wheat cereal flours are also used for substitution of a portion of wheat flour to improve the micronutrients content in breads, e.g.: rice, maize, amaranth, barley, oat, rye, emmer, buckwheat, spelt and sorghum. There are also other natural source that can be used to fortify flour and develop different types of products, as they contain a large number of bioactive compounds, for example chicken bones, used as a sources of calcium (Muhammad et al., 2016), these natural products, help to decrease micronutrient deficiency, and control/prevent several diseases (Berner et al., 2014). Table 3 shows some of the natural sources, namely plants and mushrooms, used as fortifiers and the class of bioactive compounds that can be targeted.

3.4. Health benefits of fortified flour

Flour fortification in the field of public health is a very attractive tactic and has the advantage of reaching massively a risk populations through existing food distribution systems, without widely changing existent patterns of consumption (Das et al., 2013; Preedy et al., 2011).

The benefits of fortification of flour or derivative flour products (Table 2), act in a positive way over the entire life cycle of the population, especially in children and pregnant women, preventing the birth of children with intellectual disabilities or malformations or deficiencies (Vlaic et al., 2019). It is one of the most efficient ways of combating malnutrition and controlling various diseases linked to vitamin or mineral deficiency (Santos & Pereira, 2007; Vlaic et al., 2019). For example vitamin A fortified cereal flours can be effective to reduce this vitamin deficiency (Ranum, 2001); as previously described, flour fortification with iron is a strategy to combat iron deficiency in Iran (Sadighi et al., 2008); folic acid fortification programs in Chile have resulted in significant declines in the occurrence of pregnancies affected by neural tube defect (Berry, Bailey, Mulinare, Bower, & Dary, 2010).

If consumed regularly, many are the health benefits that can be gained from fortified flour consumption, especially because it can help to maintain body reserves of nutrients in a more efficient way than supplements. Since fortified flours provide nutrients that are similar to those provided by an effective and balanced diet, fortified foods will

contain “natural” amounts of nutrients and this does not happen with supplements by its own (Dwyer et al., 2015; Preedy et al., 2011; Whiting et al., 2016).

Flour fortification has the potential to improve the nutritional status of a large portion of the population, regardless of the social class, as they are a staple food widely distributed and consumed worldwide, and, this fortification does not require changes in existing food patterns of populations, being a very cost-effective method. It is also more efficient in reducing the risk of multiple deficiencies that can result from deficits in food supply or a poor diet. It is a major benefit primarily for women of childbearing age, during periods of pregnancy and lactation (increasing the rate of vitamins and minerals in breast milk and reducing the use of supplements) that need adequate amounts of micronutrients, as well as growing children, which need nutrients daily for growth and development (Berner et al., 2014; Das et al., 2013; Datta & Vitols, 2016; Dwyer et al., 2015; FFI, 2018; Johnson et al., 2004; Preedy et al., 2011). Moreover, it is also usually possible to add one or more micronutrient fortification (multi-nutrient fortification) without adding significantly to the total cost of the flour at the point of manufacture (Das, Salam, Kumar, Lassi, & Bhutta, 2014; Dwyer et al., 2015; Whiting et al., 2016; WHO, 2009).

4. Legislation and major issues regarding quality control

The main objectives of food law are to protect consumer's health, facilitate trade, and protect consumer's fraud. In the case of fortified meals, the population should be protected from consuming toxic levels of micronutrients or nutritionally ineffective. Food fraud is committed to deceive consumers, it often arises from the need for competition between manufacturers, businesses, food establishments and large food retailers. Legislations are applied to require appropriate control in the fortification process to ensure that micronutrient levels are adequately within acceptable limits. The legislation also serves to prevent fortification with nutrients from unsafe or nutritionally unnecessary products, and the constant vigilance of the flours fortification industry, food fraud vulnerability assessments, brings benefits to the industry and ensures the safety and integrity of the supply chain of fortified flours

(Esteki, Regueiro, & Simal-Gándara, 2019; Marks et al., 2018; Spink, 2019).

The wide variety in each country's particularities and the public health goals worldwide have resulted in the development of many different approaches in the regulation of fortified foods. In most countries, fortification standards (in this case flour) are established by law or through cooperative arrangements. In some countries the fortification of food is achieved without any form of management guidance or quality control. With the increase distance between marketing food, whether fortified or not, from its place of production to the final consumer by Global Trade, has made it difficult to track the source of unintentional contamination and quality control concerns, and food safety (Esteki et al., 2019; Johnson et al., 2004). Quality control is performed to evaluate if the fortified product is following the established technical standards, using objective and measurable indicators. It typically consists of collecting samples of fortified food, depending on the production system, and determining its micronutrient content, since it is important to routinely collect and analyse the samples in order to verify and control whether the technical standards are being met. Quality control focuses on purely public health optics and, in this case, concentrates mainly on indicators and criteria that are relevant to the food fortification process (Johnson et al., 2004; Nestel & Nalubola, 2002; Verma, 2015; WHO & FAO, 2006).

The management tools available in order to establish an appropriate level of control over food fortification are food laws and related measures, as well as a broader food control system. This management has the function of protecting public health, being generally recommended that all forms of fortified foods be adequately regulated, to ensure that food fortification is safe and effective for certain population groups, mostly those with micronutrient deficiency risks (Marques et al., 2012; WHO & FAO, 2006). Food fortification techniques follow the principles established by the Codex Alimentarius to ensure food security (FAO & WHO, 2015). Any legislation on food fortification should also include the World Trade Organization (WTO) Agreement on the Application of Sanitary Measures (SPS) and the WTO Agreement on Technical Barriers to Trade (TBT), which have added new values to standards, guidelines, Codex codes and recommendations (FAO & WTO, 2017; Orriss, 1998; WHO & FAO, 2006).

In the legal context, fortification can be classified as mandatory or voluntary, which refers to the level of obligation imposed on producers of fortified foods to comply with the government's purposes evidenced by law (Datta & Vitolsins, 2016; WHO & FAO, 2006). Mandatory fortification is where a manufacturer is legally obliged to add one or more micronutrients to a specific food or food product. Compulsory fortification can reach the general population or a specific group, depending on the consumption criterion of that food. For example, fortification of a staple food, such as flours, would increase consumption of a micronutrient in the general population, while fortification of complementary infant foods would only increase the intake of micronutrients from a target group. In controversy voluntary fortification occurs when a producer freely decides to fortify food, however, it varies depending on the micronutrient and the socio-political and legal environment present. Governments are advised to impose an appropriate degree of control over voluntary fortification, it should not only be consistent with general regulatory objectives but should also consider the General Principles of Codex for the addition of essential nutrients to food. Voluntary fortification is moved by a desire of the industry to promote trade and the consumer to increase consumption of micronutrients as a means to gain health benefits (FAO & WTO, 2017; Hennessy, Walton, & Flynn, 2013; Marks et al., 2018; WHO & FAO, 2006).

In general, and according to the FFI, for wheat flour 82 countries have mandatory fortification and 10 countries have voluntary fortification, for maize flour 16 countries have mandatory fortification and 4 countries have voluntary fortification, while for rice 7 countries have mandatory fortification and 11 countries have voluntary fortification.

The list of countries that have mandatory or voluntary fortification can be consulted in FFI (2019a) and WHO (2018b).

5. Concluding remarks and future perspectives

Micronutrient deficiency is a serious problem that has adverse consequences and leads to economic and health tragedies for populations that are in risk around the world. Food fortification programs are extremely important to overcome and ensure the correct intake of micronutrients by these groups of population, so fortification of food is seen as an excellent methodology in the correction of nutritional deficiencies.

In general, flours are a potential vehicle for fortification, because of their high consumption worldwide. Nevertheless, the success of flour fortification is based on the correct evaluation of the prevalence of micronutrient deficiency, political opinions and their implementation, selection of fortifiers, levels of fortification, usual level of flour consumption and products derived from that staple food, fortification of other food vehicles, feasibility, cost and acceptability studies. Systems of monitoring and inspection of fortified products are also necessary.

Despite being fortification a mandatory priority for the international corporations to eliminate micronutrient deficiency, it remains a problematic issue in several countries. Thus, food fortification should be included into the national health and nutrition plans of each country, as a strategy to overcome micronutrients deficiency. These fortifications should include the incorporation of different micronutrients in the staple foods, in order to meet different purposes of millions of people around the world, being considered a low-cost, effective strategy with a low toxicity risk.

Moreover, the studies that have been performed until now, clearly show the high potential of fortifying flours as an alternative to combat micronutrient deficiencies, and consequently to control and/or eliminate various diseases, thus bringing nutritional benefits and improving health in general.

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Author contributions

I.C.F.R. Ferreira and A.M.G.P. structured the manuscript; R.V.C.C wrote the manuscript with collaboration of A.F. and L. Barros; I.C.F.R. Ferreira, L.B. and A.M.G.P. reviewed the manuscript.

Conflict of interest

The authors declare that they do not have any conflict of interest.

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