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REVIEW ARTICLE

Durum Wheat (*Triticum durum*) biofortification in iron and definition of quality parameters for the industrial production of pasta – A review

Inês Maria Pataco[1], Mara Palma Mourinho[1], Karliana Oliveira[1,2], Cátia Santos[1], João Pelica[1], Isabel P. Pais[4], José Cochicho Ramalho[3], António Eduardo Leitão[3], Paula Scotti Campos[4], Fernando Cebola Lidon[1], Fernando Henrique Reboredo[1] and Maria Fernanda Pessoa[1]

[1]*Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal*
[2]*Bolsista da CAPES – Processo 153113-1 – CAPES Fundação, Ministério da Educação do Brasil, Brasilia-DF 70040-020, Brasil*
[3]*Grupo Interações Planta-Ambiente & Biodiversidade (PlantStress&Biodiversity), Centro de Ambiente, Agricultura e Desenvolvimento (BioTrop), Instituto de Investigação Científica Tropical, I.P. (IICT), Av. República, Quinta do Marquês, 2784-505 Oeiras, Portugal*
[4]*Unidade Estratégica de Investigação e Serviços de Biotecnologia e Recursos Genéticos, Instituto Nacional de Investigação Agrária e Veterinária, I.P. (INIAV), Av. República, Quinta do Marquês 2784-505 Oeiras, Portugal*

Abstract

The biofortification, process of nutrients creation for food crops, provides a sustainable strategy for rural populations in developing countries. Crops are created for greater levels of micronutrients, by using conventional and transgenic breeding methods. Recent studies provide evidence that biofortification is a promising strategy to combat nutritional deficits. Being a basic and common food of the population of developing countries, the flour got a significant attention as appropriate matrix for biofortification.

Key words: Biofortification, Durum wheat, Iron, Pasta, Wheat flour

Introduction

The Food and Agriculture Organization estimates that until the year 2050 the world’s population reaches 9.1 billion. In order to feed this more urban population, food production must increase by 70% (FAO, 2009). However, basic cultures contain reduced levels of micronutrients, making them insufficient to meet the minimum daily requirements (Carvalho and Vasconcelos, 2013).

Nutritional deficits are serious problems of public health and affect more than half of the world’s population, particularly in developing countries due to growing population, unavailability of resources and lack of legislation. Deficits of minerals such as iron, zinc, iodine, selenium, vitamin A and folic acid affect about 30% of the world population. These deficits lead to low weight that accounts for 3.7 million deaths per year and also anemia by iron deficit associated with approximately 861,000 deaths (Akhtar et al., 2011). In the specific case of anemia has been reported a number of consequences, including reduced psychomotor and mental development in children, premature birth and reduced immune function (Welch and Graham, 2005; Bouis and Welch, 2010; Akhtar et al., 2011). A recent study (Haidar, 2010) performed in Ethiopian women indicates that folic acid and iron are the main nutritional deficits which suggests deficits of multiple micronutrients.

The reduced consumption of meat and meat products seem to be one of the causes that contribute to the incidence of these nutritional deficits in the developing countries. Children and women in childbearing age are the most vulnerable group (Martínez-Navarrete et al., 2002; Akhtar et al., 2011).

Among the various strategies to control micronutrient deficits, biofortification of staple crops seems to be the most feasible method. This is a process related to the development of crops rich in micronutrients, which may constitute a strategy

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*Corresponding Author

Inês Maria Pataco
Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal

Email: inespataco89@gmail.com

of intervention to correct nutritional deficits, using breeding and culture management techniques. Some advantages of this strategy, compared with systems of food supplements are: low production costs; greater population coverage; better long-term prophylactic approach. However, it is not expected that biofortification reduce micronutrient deficits in all population groups.

This strategy aims to complement existing interventions, providing micronutrients in a sustainable way for the most vulnerable groups (Akhtar et al., 2011; Saltzman et al., 2013).

The cereals are considered as the best vehicle for biofortification in developing countries, since 95% of the population consumes cereals as staple food. They are relatively inexpensive, grown and consumed worldwide by all economic classes generally. Wheat flour is a staple food of the population and provides more than 50% of energy total consumption. Several countries in Middle East and North Africa implemented flour biofortification programs for wheat with iron and other micronutrients. These developments led to the increase of worldwide percentage of wheat-flour biofortification from 18% in 2004 to 27% in 2007. Despite this progress, more than two-thirds of the world's population still lacks access to biofortified wheat flour, including millions of women in childbearing age (Akhtar et al., 2011).

This study intends to provide a review of some aspects of production and industrial processing of durum wheat, following a technological perspective.

Production and consumption in the world

It is estimated that the first cereal grains were domesticated about 10.000-12.000 years ago in the Fertile Crescent of the Near East, in the Central America and in the southern China by ancient farming communities (Lev-Yadun et al., 2000). The earliest cultivated forms of wheat were essentially landraces selected by farmers from wild populations (Shewry, 2009).

Wheat cultivation spread in all directions, however the Mediterranean basin played a fundamental contribution in their differentiation, particularly in durum wheat (Nuñez, 2003; Marti and Slafer, 2014). With respect to the Iberian Peninsula, the cultivation of wheat was dated 4.000 years ago (López Bellido, 1991).

Durum wheat production reaches approximately 30 million tons in about 16 million hectares. Durum wheat production areas are concentrated in the Middle East, North Africa, India and Mediterranean Europe. The Mediterranean region produces about 60% of the world production of durum wheat, being the European Union the leading global producer (Morancho, 2000). However, this production of durum wheat represents only 8% of the world production of wheat (Manzano, 2007; Pinheiro et al., 2013). In spite of its reduced area of production, durum wheat is an economically important crop because of its unique characteristics and final products. Its protein and gluten content enable the manufacture of diverse food products, namely pasta that is the most common durum wheat final product consumed in Europe and North America (Roncallo et al., 2009; Pinheiro et al., 2013).

Italy is the first position of consumption of dry pasta per capita/year with a value of 28 kg/inhabitant/year, followed by USA, Chile, Greece, Venezuela, Tunisia, Switzerland, Peru and, finally, France, Russia and Argentina with an average consumption of 9 kg per inhabitant/year (Roncallo et al., 2009).

Characterization

Wheat grain contains about 12-18% bran, 80-85% endosperm and 2-3% germ. Wheat flour is obtained from the endosperm after being separated from other components during the milling process. Wheat bran contains several components, such as phenolic compounds, starches, soluble and insoluble dietary fiber, proteins and mineral content (Table 1) (Xie et al., 2008).

Table 1. Concentration of iron in grain of durum wheat.

Iron concentration (mg kg^{-1})	References
39.9-42.5	Narwal et al. (2012)
46.6	Ficco et al. (2009)
30-73	Cakmak et al. (2004)
23-52	Velu et al. (2011)
25.6-34.5	Zhang et al. (2010)
37.7-47.8	Gao et al. (2012)

Figure 1. Bread wheat (left) and durum wheat (right) spikes.

In wheat are two distinct classes of grain hardness, according to the cultivated species: bread wheat (*Triticum aestivum*) and durum wheat (*Triticum durum*) (Figure 1). The designations of soft and hard are related with the texture of the seed. The durum wheat requires more strength to disintegrate compared with bread wheat, creating products with larger particles. Thanks to its high texture the technique used in the milling of durum wheat has enough influence on the damaged starch and rheological properties. In general, bread wheat contains less crude protein than durum wheat but has higher starch content (Rosenfelder et al., 2013).

Durum wheat is the main cereal crop in the Mediterranean regions and it is mainly used in pasta production. The colour of pasta products is the result of the natural carotenoid pigments present in the semolina, of their residual content after storage and milling (Simone et al., 2010; Meziani et al., 2012). The quality of durum wheat is dependent on factors such as soil fertility, fertilization and water availability (Pinheiro et al., 2013). Several studies (Rharrabti et al., 2003; Kilic et al., 2005; Mohammadi et al., 2011) have shown that environmental conditions have a significant influence on the quality of wheat, particularly the protein content and gluten index.

Biofortification strategies

Concerning the accumulation of micronutrients in plants there are still many barriers to overcome. The mineral concentrations on edible parts of plants require several actions in the vegetative organism, which begins with mineral absorption by roots, its translocation to the shoots, thus its mobilization to vegetative tissues and accumulation in grains, in available forms to the human body (Bouis and Welch, 2010).

Root-soil interface determines the rate of nutrients uptake. In this context, increasing micronutrient uptake by the roots might require increased levels of micronutrients. Micronutrient uptake can be improved by changing the morphology of roots, or by altering the solubility and circulation of metallic elements. Furthermore, transport of minerals to the rhizosphere occurs primarily by diffusion, playing the soil moisture an important role (Welch and Graham, 2005; Velu et al., 2014).

Consequently, the uptake mechanisms must be active enough, since those metallic elements enter the root cells of the apoplasm. Micronutrients are more phytoavailable to be absorbed by roots in the form of cations. Micronutrients should also be actively translocated and accumulated in plant organs, turning them bioavailable to the metabolism of the human body (Welch and Graham, 2005; Sperotto et al., 2012; White, 2012).

Testing the rate of nutrients' assimilation through the use of caco cells in order to simulate the absorption in the human intestinal mucosa is currently a test model. However it is possible to assume that the obtained data for iron bioavailability will reflect bioavailable zinc levels in promising genotypes, since most of the plant food factors that inhibit or promote the bioavailability of iron also inhibit or promote the bioavailability of zinc (Welch and Graham, 2005; DellaValle et al., 2013). A test performed (Rosado et al., 2009) in adult Mexican women in order to determine the bioavailability of iron in biofortified wheat showed that iron absorption was greater from biofortified wheat compared to control wheat. An important consideration relates to the negative correlation between phosphorus and iron. About 75% of the total phosphorus in the wheat grain is stored in the form of phytic acid, particularly in the germ and aleurone. In this context, improving the bioavailability of iron should be much easier than increasing the concentration of this mineral in grains (Bohn et al., 2008; Velu et al., 2014).

Some of biofortification strategies can be acquired through by fertilization, conventional breeding and/or genetic engineering. The mineral fertilizer can be a problem not only because of the cost but also because of environmental issues. The fertilization in iron becomes a complex process, since iron has a strong trend to insolubility. Another strategy is the foliar application, process that improves the productivity of plants grown in soils with iron deficit and increases the final concentrations in cultures (Sperotto et al., 2012; Carvalho and Vasconcelos, 2013). Some studies show that foliar applications of iron constitute a fundamental role in the growth of this mineral in the grain (Narwal et al., 2012).

Some studies (Cakmak, 2010; Yadav et al., 2011; Khoshgoftarmanesh et al., 2012) show that the iron fertilizers applied in the inorganic form ($FeSO_4$) or in the chelates form (Fe-EDTA, Fe-EDDHA) into soil and through foliar application were not efficient in improving grain iron concentrations of wheat grain. These authors showed that between applied iron fertilizers, Fe-EDTA appeared to be the best iron source for increasing grain iron concentrations.

Recent publications (Kutman et al., 2010; Aciksoz et al., 2011; Erenoglu et al., 2011) indicate that nitrogen can influence directly or indirectly the root uptake and translocation of micronutrients. The strategy of foliar application of nitrogen was highly effective in improving root uptake and shoots as well as iron accumulation in the grain. Negative correlations have been observed between glutenin content and iron concentrations and strong negative correlations between iron and plant height and glutenin content. These results indicate that shorter plants with lower glutenin content allow a higher concentration of iron in the grain (Velu et al., 2014).

According to Graham et al. (2007), the concentration of iron in the grain will be increased to 25 mg kg^{-1} in order to get a measurable biological effect on human health. Thus, the goals of iron biofortification in wheat grain are 60 mg kg-1, assuming current average iron concentrations of 35 mg kg-1. Studies in field tests demonstrated that iron concentration in seeds ranged between 15 and 109 mg kg-1, with an average of 46 mg kg-1 (Cakmak et al., 2004).

Rosado et al. (2005) demonstrated that iron biofortified flour shows an excellent stability when stored at room temperature. The authors mention the retention of 95% iron, after 90 days of storage. They suggested elemental iron as the most suitable for grain and flour biofortification, because of their low reactivity and insolubility in water (Akhtar et al., 2011).

Develop plants that efficiently mobilize iron and enrich in soils with limited availability of this element, accumulating in the edible parts, translates into an interesting process. Wheat is a particularly important cereal in biofortification process, because it is a staple food and the wheat grains contain reduced available levels of relevant micronutrients, such as iron. In this context, even a small increase in bioavailable micronutrients in wheat grains would have a significant impact on human health, particularly in developing countries (Sperotto et al., 2012).

Iron metabolism

Iron is an essential element in the function of all cells, but the amount of iron required for each particular tissue varies during development. At the same time, the body must protect itself from free iron, highly toxic because of its participation in chemical reactions that generate free radicals. Thus, were developed in living beings complex mechanisms that allow the availability of iron for physiological functions, but which simultaneously retain this element and process it in order to avoid toxicity (Gurzau et al., 2003; Longo et al., 2011). The main role of iron in mammals is to carry oxygen as part of hemoglobin. In the absence of iron, the cells lose their ability to transport electrons and energy metabolism (Longo et al., 2011; Sperotto et al., 2012). Any excess iron needed for daily production of erythrocytes derived from the diet. Typically, an adult man needs to absorb at least 1.0 mg of elemental iron per day to meet the needs, and women in childbearing age need to absorb an average of 1.4 mg/day (Longo et al., 2011).

Industrial processing of durum wheat

In order to obtain a quality pasta product is required from a quality raw material (Toussaint-Samat, 1992). In this context, the process used by industries in milling wheat is composed by four main steps. In the cleaning of the grain, foreign materials are removed through equipment that separate by size, specific gravity and shape. Then follows the conditioning so that the grains reach the optimum moisture content for maximum extraction of flour, followed by milling and, finally, the classification, process performed by screens allowing to obtain the desired flours (Amorim, 2007).

The milling process to obtain the white wheat flour consists of the endosperm flour reduction, preceded by the separation of germ and pericarp, with the purpose of creating higher quality products. The germ is separated to reduce the lipid content, thus reducing the flour rancidity and preserving their characteristics during storage. The outer layer of the grain (pericarp) is also removed in order to make a lighter meal, reducing the fiber content and improving the technological characteristics (Castelo et al., 1998; Feillet et al., 2000). The shape and texture of the grain as well as technical conditions of milling, including the extraction rate, are important to determine the extent of mineral loss (Cubadda et al., 2009).

From the milling of durum wheat we obtain mainly semolina used in the manufacture of high-quality pasta, thanks to its unique color, low lipoxygenase activity, taste, high protein content, cooking quality and because it preserves their qualities and nutritional value for a long time (Aalami et al., 2007).

The processing parameters used to make the pasta, in particular drying and extrusion conditions, can modify their structure and hence its digestion rate (Aravind et al., 2011).

Drying process is a key to the final pasta characteristics, particularly in terms of modification of its main components. The traditional drying methods are carried out at reduced temperatures between 29 and 40°C and long time treatments between 24 and 60 h. As regards the application of high temperatures between 75 and 100°C or very high, > 100°C and short time treatments (5-12 h or 1-2 h) have been widely adopted in the industrial production. Through the application of quickly treatments and high temperatures is possible to obtain an improvement in pasta cooking properties, an increase of the productivity and a reduction of the microbial contamination (Giannetti et al., 2014).

The quality attributes of pasta are influenced mainly by the properties of the protein and starch fraction and by factors such as the origin of the semolina and processing conditions (Maache-Rezzoug and Allaf, 2005). The quality of this product is usually evaluated by technological parameters, such as colorimetric indices, protein content, ash content, vitreousity, gluten content, moisture content, SDS Sedimentation Test, hectoliter mass or properties that affect the consumer preferences, such as the degree of firmness and rigidity (Migliori et al., 2005; Giannetti et al., 2014). In the case of quality products, the protein content level should be between 12% and 16%. Vitreousity is an important quality trait for pasta industry, since it is associated to commercial value, being responsible for high semolina yield, good granulation and purity. The acceptable minimum value of vitreousity is 80%. Ash content should be less than 1.8% and gluten content should be higher than 40%. For the SDS Sedimentation Test ideal value for durum wheat is exceeding 50 mm and the moisture content a value below 12% (Pinheiro et al., 2013).

Conclusions

The consequences of micronutrient deficit are adverse and they still exist in an apprehensive way in developing countries. The correct estimate of the prevalence of micronutrient deficit in the region, the selection of mineral fortification, fortification levels and the selection of feasibility studies are some of the main issues for a fortification program. Biofortification becomes a source of research for application of several technologies that can allow the production of different types of biofortified foods. The main gaps regarding biofortification should be tackled from more studies to confirm and increase the promising evidence obtained until this moment.

Author contributions

All authors contributed to the writing of the paper. I. M. P. was mostly involved in the overall planning and writing. F. C. L. was mostly involved in the supervision of the work. M. P. M., K. O., C. S., J. P., I. P., J. C. R., A. E. L., P. S. C., F. H. R. and M. F. P. were mostly involved in the revision of the paper.

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