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Biofortification of Edible Plants

Set the Stage for Better Nutrition

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1.1 Introduction

The human organism requires a large number of organic and mineral nutrients that are crucial for the growth, development, and the prevention of diseases and disorders. These nutrients, required at relatively high levels – macronutrients – or low to very low levels – micronutrients – are supplied either by our plant or animal food intakes. However, often the daily diet is balanced in calories and quantity, but does not provide the required amount of these nutrients, leading to malnutrition. Consequently, this malnutrition – or nutrients deficiency – can lead to a variety of metabolic and health problems such as digestive problems (Brodeur et al. 1993), skin disorders (Prendiville and Manfredi 1992), stunted or defective bone growth (Branca and Ferrari 2002) … etc.

To compensate these low levels of nutrients in plants, biofortification of edible plants is becoming one the most efficient strategies to overcome malnutrition, and many foods such as cereals, fruits, and vegetables are being fortified with nutrients that are needed to prevent minerals and vitamins deficiencies (Nestel et al. 2006).

From ancient times, agriculture has been the primary source of food and all nutrients for human, and the production systems have been subject to numerous changes to ensure quantitative and qualitative food supplies. With human development, the Industrial Revolution, and then the Green Revolution, food and nutrition turned to agriculture and agro-processing as a primary mean to mitigate, if not eradicating, nutrients deficiencies and malnutrition (Welch 2005). On another hand, the development of novel life science technologies and biofortification of edible plants is regarded as a powerful tool to reduce malnutrition and improve dietary intake of essential minerals and vitamins in staple foods (Figure 1.1). New discoveries in biochemistry and molecular biology have led to incredible development of advanced biotechnology and great promises for improving the output of bioavailable micronutrients from agricultural systems (Welch 2005). However, we need to pragmatically assess whether the biofortification is compatible with the diet diversification

Vitamins and Minerals Biofortification of Edible Plants, First Edition. Edited by Noureddine Benkeblia.

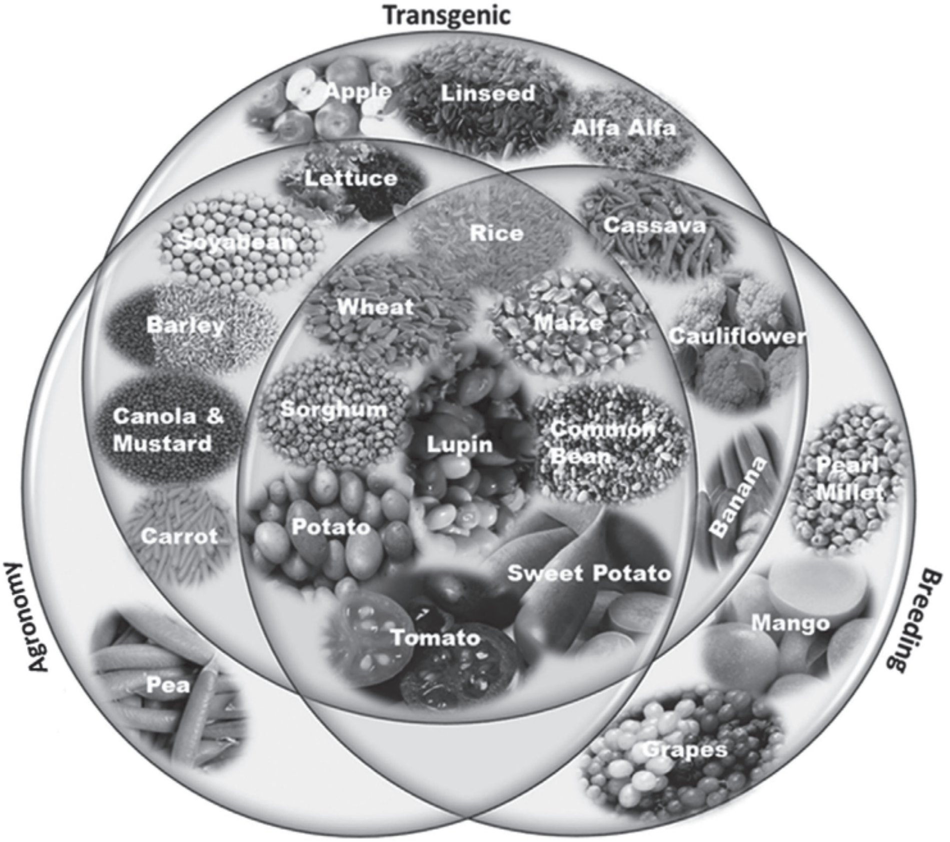

Figure 1.1 Biofortified crops generated by different approaches: transgenic, agronomic, and breeding. Staple cereals, most common vegetables, beans, and fruits have been targeted by all three approaches. Some crops have been targeted by only one or two approaches depending on its significance and prevalence in the daily human diet. (From Garg et al. 2018. Open access publication under Creative Commons Attribution License [CC BY] terms with free permission).

and how it might impact agricultural biodiversity for long-term sustainability (Bouis and Welch 2010; Johns and Eyzaguirre 2007).

This chapter provides a general overview of the different approaches and opportunities for the biofortification of edible plants to achieve the goal of improving human diet and setting the stage for the eradication or alleviation of malnutrition through sustainable agriculture.

1.2 Biofortification and Nutrition

To alleviate nutritional issues and nutrient deficiencies, biofortification of edible plants is considered the most appropriate approach. Modifying dietary customs of the population runs into likely resistance from communities. By contrast, biofortification focuses on improving the nutritional content of region's current agricultural biodiversity, preserving its habits and customs (Johns and Eyzaguirre 2007).

Biofortification of food crops thus has the potential of reaching all the population and communities, particularly rural poor and vulnerable ones with no or limited access to industrially biofortified foods, or where conventional biofortification is difficult or cannot be implemented for technical, economic, or social reasons, and where large quantities of staple rather than nutrition foods crops is consumed.

In recent decades, action has been taken to address malnutrition and micronutrient intakes issues in developing countries. Biofortification technology has been identified as a priority initiative; however, it became evident that this technology might also benefit developed countries consumers as well. Therefore, biofortification became more common in developing countries and evidence of malnutrition mitigation nutrient, bioavailability enhancement and biofortified crops acceptability, are raising more interests. Recent data are showing that 150 different varieties of biofortified crops belonging to 10 different crop species have been released in 30 different countries, of which 27 are developing countries, while 12 other crop species are under evaluation for release in 21 other different countries (Bouis and Saltzman 2017; Bouis et al. 2006; Global Panel 2015). In this regard, many examples can be cited, and some of the studies have confirmed the nutritional value and cost-effectiveness of high-iron bean, orange-flesh sweet potato, cassava, maize, rice, and pearl millet (Global Panel 2015).

Vitamin A deficiency (VAD) is the most prevalent nutrient deficiency in young children in the developing countries, with more than 200 million children under the age five worldwide (WHO 2009). VAD has been rated as the first public health problem in more than 70 countries, and this deficiency affects about 33% of children aged between six months and five years in 2013, with 48% found in sub-Saharan Africa and 44% in South Asia (WHO 2009). In this regard, different studies showed the role of biofortified crops in alleviating VAD deficiency and improving the nutritional status of the population. In developing countries, a study carried out in sub-Saharan Africa showed that the daily vitamin A needs of young children can be covered by the intake of 100 g of orange-fleshed sweet potato (OFSP), a carotenoid-biofortified tuber (Low et al. 2017). Similar observation was noted in Zambia, where inadequate vitamin A intake prevalence was reduced by 3% (Lividini and Fiedler 2015), and diarrhea was reduced by biofortified crops as well (Jones and de Brauw 2015).

Mineral deficiencies are also a major concern, and studies have shown that biofortification might be one of the most cost-effective approaches in alleviating this public health issue (Broadley et al. 2008, 2009). Using Zn-biofortified wheat, valuable increases in Zn absorption have been achieved (Rosado et al. 2009). Feeding two-year-olds with zinc and iron biofortified pearl millet more than adequately enhanced the absorption of both minerals to meet the dietary requirement (Kodkany et al. 2013), and the iron status of schoolchildren (12 to 16 years old) and women fed iron-biofortified beans and pearl millet was significantly improved (Finkelstein et al. 2015; Haas et al. 2016).

Nevertheless, assessment of the efficacy of biofortified foods for enhancing human nutritional status and alleviating malnutrition requires further research in the laboratory, as well as community-based trials. Research should consider the impacts of biofortified crops for larger groups of different gender and age and for long-term consumption (Bouis and Saltzman 2017). Furthermore, additional research is required to assess the nutrients bioavailability of various genotypes of biofortified crops, in particular genetic engineered crops, using different in-vitro and/or in-vivo tests. Additionally, trials need to be carried out to evaluate the agricultural, environmental, and socioeconomic impacts, and these trials must include the communities, the stakeholders, and the policy makers as well (King 2002).

Biofortification of food plants also causes potential alterations of the plants metabolism, and these alterations should be thoroughly assessed beyond the few studies that have already analyzed these alterations. The alteration of these different metabolic pathways might affect growth, development, and productivity of these plants, and it is imperative to determine to what extent these alterations can be minimized or even avoided. However, recent development in omics, particularly metabolomics and related techniques, is significantly contributing to deciphering the potential alterations in plants caused by biofortification (Hall et al. 2008).

1.3 Cultural Practices and Plants Biofortification

Agricultural practices are more likely the simplest and readily most accessible to farmers to overcome the problem of nutrients deficiency of edible plants, and these agronomic-based strategies might be interesting alternative solutions. Indeed, agronomic-based strategies have shown be efficient in improving nutrient contents by many folds. Although the application methods differ, soil fertilization and/or foliar application of fertilizers at different stages of plant growth have shown to increase the nutrients levels of many crops, and fertilization as agronomic strategy for plants biofortification is considered to be a good and effective way (Mao et al. 2014; Zhao and Shewry 2011) (Figure 1.2) (Table 1.1). Another strategy consisting of intercropping between dicots and gramineous species to increase mineral contents of crops (Zuo and Zhang 2009).

Worldwide, iron (Fe) is the most prevalent deficient nutrient. Different attempts to increase iron contents of food crops have been conducted, and the results have been encouraging. The application of iron fertilizers, either inorganic or chelated forms, did not show any Fe increase in cereal. However, improved nitrogen nutrition of plants increased Fe content (Aciksoz et al. 2011; Cakmak 2012; Cakmak et al. 2010), and this might be due to the contrasting abilities of cereals to acquire Fe because the phyto-siderophores chemistry is species-specific and determines iron absorption by plants (Bashir et al. 2006). Similarly, foliar application of Fe-fertilizers had shown no or little positive effect on grain-Fe content (Aciksoz et al. 2011); however, when urea (Aciksoz et al. 2011) or boron (Jin et al. 2008) were incorporated to foliar fertilizers, grain Fe concentration was increased by threefold. Hence, nitrogen plant status deserves special attention in Fe-crops biofortification (for further details, see Chapter 6).

Zinc, which is often associated to iron, is the most ubiquitous micronutrient deficiency issue in plants, and this deficiency is to a large extent caused by soils factors

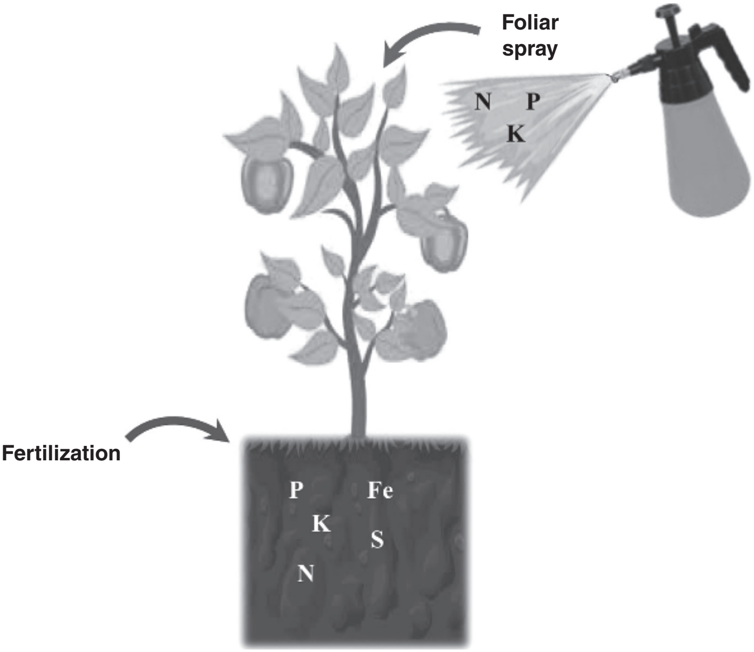

Figure 1.2 Foliar application of mineral solution for corps biofortification.

including Zn deficiency (Alloway 2009; Cakmak 2008). Many plants, particularly cereals, might be fortified with Zn using agronomic approaches. Trials showed that foliar application of $ZnSO_4$ to wheat crop increased grain Zn concentration by threefold (Cakmak 2008). However, trials on Zn fertilization did not increase the concentration of Zn in rice grain (Wissuwa et al. 2008). Other studies showed that the application of inorganic Zn salts ameliorates crops Zn deficiency (Takkar and Walker 1993), while when high Zn concentrations in grains are desired, studies showed that soil fertilization combined with foliar application is the most effective method of Zn application (Yilmaz et al. 1997).

These discrepancies between the different studies on Zn fertilization and Zn biofortification of plants might be explained by the zinc chemistry and its behaviour in soils, its concentration, soil pH, calcite and inorganic matter, and the concentration of other minerals such as Na, Ca, Mg (Alloway 2009) (for details, see Chapter 10).

By adding a small amount of selenium (Se) to fertilizers, its concentration was increased in many plants in Finland, which was the first country to adopt this agronomic approach (Hartikainen 2005), and a similar strategy was adopted in the UK, where Se concentration in crops was increased by about tenfold (Broadley et al. 2010). Addition to iodine (I) to fertilizers also showed that plant can be fortified with higher concentration of iodine. Trials iodine fertigation (iodination of irrigation water) increased significantly iodine intake through foods intake (Cao et al. 1994; DeLong et al. 1997).

Table 1.1 Studies of crops biofortification using agronomic approaches.

Class	Crops	Nutrients	References
Cereals	Rice	Iron	Fang et al. (2008), He et al. (2013), Wei et al. (2012a), Yuan et al. (2013)
		Zinc	Boonchuay et al. (2013), Fang et al. (2008), Guo et al. (2016). Jiang et al. (2008), Mabesa et al. (2013), Ram et al. (2016), Shivay et al. (2008, 2015), Wei et al. (2012b)
		Selenium	Chen et al. (2002), Fang et al. (2008), Giacosa et al. (2014), Liu and Gu (2009), Premarathna et al. (2012), Ros et al. (2016), Xu and Hu (2004)
	Wheat	Iron	Aciksoz et al. (2011)
		Zinc	Cakmak and Kutman (2018), Cakmak et al. (2010), Yang et al. (2011)
		Selenium	Aro et al. (1995)
	Maize	Zinc	Alvarez and Rico (2003), Fahad et al. (2015), Lopez-Valdivia et al. (2002), Wang et al. (2012), Zhang et al. (2013)
Legumes	Soybean	Selenium	Yang et al. (2003)
	Chickpea	Zinc	Shivay et al. (2015)
		Selenium	Poblaciones et al. (2014)
	Pea	Iron	Poblaciones and Rengel (2016)
	Common Bean	Zinc	Ibrahim and Ramadan (2015), Ram et al. (2016)
	Cow pea	Iron	Márquez-Quiroz et al. (2015)
Vegetables	Potato	Zinc	White et al. (2012b)
		Selenium	Cuderman et al. (2008), Poggi et al. (2000)
	Sweet Potato	β-carotene	Laurie et al. (2012)
	Carrot	Iodine	Smolen et al. (2016)
		Selenium	Smolen et al. (2014)
	Lettuce	Iodine	Smolen et al. (2014)
		Selenium	Carvalho et al. (2003), Smolen et al. (2014)
Fruits	Tomato	Iodine	Landini et al. (2011)

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1.4 Conventional Breeding and Crops Biofortification

For a long time, plant breeding was limited in crossing individuals of interesting and targeted traits and thereafter selecting the interesting varieties. This approach changed with the discovery of the genetic and the sexual propagation of plants. The twentieth century has seen the introduction of hybrid technology and boosted breeding of many crops (Poletti and Sautter 2005). Vitamins and micronutrients biofortification of crops through breeding has been considered for decades (Graham et al. 1998, 1999). This strategy is based on two different approaches:

1) Explore the genetic diversity of the existing species by identifying the parental genotypes potentially interesting for crosses.
2) Identify the existing varieties or germplasms (Welch and Graham 2004).

However, and before contemplating this strategy, some criteria should be considered. Among these breeding criteria, the first to consider is the productivity or the yield of the bred crop (Bouis 1996; Graham et al. 1998), the biofortification level, the stability of the enriched mineral or vitamin across cropping, the varying cropping and environmental conditions, and the nutritional bioavailability of the nutrient (Ortiz-Monasterio et al. 2007; Welch and Graham 2004).

Many attempts have been successful in increasing vitamins and minerals by conventional breeding, including increasing the concentration of β-carotene and carotenoids (Champagne et al. 2013; Pixley et al. 2013; Suwarno et al. 2014), iron and zinc (Pixley et al. 2011; Velu et al. 2007), as well as other minerals such as selenium (Graham et al. 1999, 2005). However, crops biofortification through breeding has shown some limits and constraints. One example is the inverse correlation noted between the increase of iron and zinc content of crops and the yield due to a dilution effect caused by enhanced starch content (Table 1.2) (Bänzinger and Long 2000).

Indeed, crop breeding for biofortification has targeted widely used staple food like maize, cassava, sweet potato, banana, and some legumes. Vitamin A–rich orange sweet potato is likely the most successful development in biofortification resulting from crop breeding. Although many food crops bred, especially fruits, are providing sufficient levels of nutrients to targeted populations, a greater emphasis is being laid on transgenic research. However, breeding is much accepted by the greater consumers compared to transgenic crops.

Unfortunately, crops biofortification through conventional breeding have known limited success in general, because this approach requires years to achieve significant enhancement in adapted varieties. The absence of key vitamins and minerals in many crops reflects the fact that the corresponding metabolic pathways are absent, truncated, or inhibited in the targeted species. Therefore, it is obvious that in order to enhance the biosynthesis vitamins pathways and minerals accumulation, genes encoding key enzymes of vitamins biosynthesis and minerals accumulation should be introduced using transgenic methods (Christou and Twyman 2004; Khan et al. 2013; Zhu et al. 2007).

1.5 Molecular Engineering and Crops Biofortification

During the last few decades, molecular engineering has entered an exciting phase of rapid development and discovery. More generally, genomics tools have been and are still being developed and applied to improve plant crops for human benefit. Most of the edible crops are now subject of in-depth molecular engineering investigations driven by a need for support of biofortification programmes to enhance nutritional quality of food-plants. Indeed, biofortification of crops using genetic techniques focuses on genes with

Table 1.2 Studies of crops biofortification using conventional breeding approaches.

Class	Crops	Nutrients	References
Cereals	Rice	Iron	Sperotto et al. (2012)
		Zinc	Gregorio et al. (2000)
	Wheat	Iron	Cakmak et al. (1999, 2004), Monasterio and Graham (2000), Welch et al. (2005)
		Zinc	Velu et al. (2014)
	Orange Maize	Vitamin A, Provitamin A and Carotenoids	Maqbool et al. (2018), Palmer et al. (2016), Pixley et al. (2013)
		Vitamin E	Goffman and Böhme (2001), Muzhingi et al. (2016)
	Sorghum	Iron	Reddy et al. (2005)
		Zinc	Reddy et al. (2005)
		β-carotene	Reddy et al. (2005)
	Millet	Iron	Rai et al. (2012), Velu et al. (2007)
		Zinc	Rai et al. (2012), Velu et al. (2007)
Legumes	Lentils	Iron	Kumar et al. (2016)
		Zinc	Kumar et al. (2016)
	Cow pea	Iron	Santos and Boiteux (2013)
		Zinc	Santos and Boiteux (2013)
	Bean	Iron	Beebe et al. (2000), Gelin et al. (2007), Hoppler et al. (2014)
		Zinc	Beebe et al. (2000), Blair et al. (2009), Gelin et al. (2007)
Vegetables	Potato	Iron	Brown et al. (2010), Burgos et al. (2007), Haynes et al. (2012)
		Zinc	Brown et al. (2010), Burgos et al. (2007), Haynes et al. (2012)
		Copper	Haynes et al. (2012)
		Manganese	Haynes et al. (2012)
	Sweet Potato	See Chapter 4	
	Cauliflower	β-carotene	Muthukumar (2016)
	Cassava	β-carotene Carotene	Chavez et al. (2005), Maziya-Dixon et al. (2000), Peninah et al. (2014)
		Iron	Chavez et al. (2005), Maziya-Dixon et al. (2000)

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different expression patterns targeting for development into breeding new varieties of crops with greatest levels of nutrients. Moreover, the efficiency in genetic techniques has been enhanced through the use of diagnostic DNA-based markers to develop biofortified crops and the approach of using modern technologies might be viewed as one of the key decisions that breeders make concerning the objectives of biofortification programmes to achieve this goal. The genetic transformation of food-plants is considered a faster method to achieve the nutritional improvement of crops, and the transgenic approaches might be a good and more realistic alternative, particularly where breeding approaches have not been successful or to overcome its limitation (Brinch-Pedersen et al. 2006; Kumari et al. 2014; Zhu et al. 2007). Consequently, the number and genetically modified and biofortified crops with different vitamins and minerals is much larger compared to the number of biofortified crops using agronomic or conventional breeding. Furthermore, spectacular advances in genes and genotyping had led at dissecting in depth the architecture of important traits providing the most advanced genomic platforms and analysis methods available for food-plants. These techniques combined to new advances in genomic research have led to unprecedented access into the structure and function of crop genomes.

From a genetic engineering perspective, different transgenic crops have been developed because of the identification of the respective genes encoding the biosynthesis of vitamins and minerals accumulation in plants (Table 1.3) (White et al. 2012a,b; Zhang et al. 2009). For example, many cereals have been successfully biofortified, such as β-carotene, vitamin B_9 (folate), iron and zinc biofortified rice, high provitamin A and iron content wheat, provitamin A, vitamin E, ascorbic acid and iron biofortified maize, high zinc content barley, and β-carotene biofortified sorghum. Furthermore, many other legumes, fruits, and vegetables have been biofortified with minerals and vitamins using transgenic approaches (Table 1.4).

Nevertheless, crops biofortification using transgenic approaches is constrained by two limitations. The first limitation is the knowledge gap in the genes' functions and their interaction with the environment, and without this knowledge the transgenic transformation of plants remains still limited to some nutrients or vitamins and to some species as well. The second and perhaps more constraining limitation is the regulatory issues restricting the development and commercialization of transgenic biofortified crops (Johnson et al. 2007; Powell 2007; Ramessar et al. 2009). Moreover, in order to select appropriate crops for minerals and vitamins biofortification using transgenic transformation, two criteria are essential. First, the selected crop for transformation should be of large consumption and economically interesting. Second, the accumulation of the targeted nutrient should not limit the accumulation of another nutrient nor the physiology and development of the crop.

1.6 Conclusions and Future Perspective

Conclusively, biofortification of edible crops for food is considered the most useful and efficient approach to supplement diets and alleviate malnutrition. Agricultural research, both fundamental and applied, is aimed at developing biofortified crops. The relationship between diet and health has long been demonstrated and numerous scientific studies indicate that food components affect our body and health by influencing the physiological

Table 1.3 Studies in which chromosomal loci (QTL) have been identified in crop plants that affect the concentrations of vitamins and essential mineral elements most commonly lacking in human diets.

Crop species	Tissue	Elements	References
Rice (*Oryza sativa*)	Grain	Fe, Zn	Garcia-Oliveira et al. (2009), Gregorio et al. (2000), Lu et al. (2008), Norton et al. (2010), Stangoulis et al. (2007), Zhang et al. (2011)
		Provitamin A	Paine et al. (2005)
Oilseed rape (*Brassica napus*)	Seed	Fe, Zn	Ding et al. (2010)
Potato (*Solanum tuberosum*)	Tuber	Fe, Zn	Subramanian (2012)
		Carotenoids	Ducreux et al. (2005), Diretto et al. (2007)
Sweetpotato	Tuber	β-carotene	Cervantes-Flores (2006)
Cassava	Root	Carotenoids	Welch et al. (2010)
Cauliflower (*Brassica oleracea*)	Leaf	Zn	Broadley et al. (2010)
		Carotenoids	Crisp et al. (1975), Dickson et al. (1988), Li et al. (2001)
Canola (*Brassica napus*)	Seed	Carotenoids	Fujisawa et al. (2009), Ravanello et al. (2003)
Brassica rapa	Leaf	Fe, Zn	Wu et al. (2008)
Wheat (*Triticum* spp.)	Grain	Fe, Zn	Distelfeld et al. (2007), Genc et al. (2009), Peleg et al. (2009), Shi et al. (2008)
Barley (*Hordeum vulgare*)	Grain	Zn	Lonergan et al. (2009), Sadeghzadeh et al. (2009), Zeng et al. (2016)
Maize (*Zea mays*)	Grain	Fe, Zn	Jin et al. (2013), Lung'aho et al. (2011), Simić et al. (2012)
		Carotenoid Provitamin A	Burt et al. (2011), Chandler et al. (2013), Harjes et al. (2008)
Bean (*Phaseolus vulgaris*)	Seed	Fe, Zn	Beebe et al. (2000), Blair et al. (2009, 2010), 2011), Cichy et al. (2005, 2009), Gelin et al. (2007), Guzman-Maldonado et al. (2003)

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processes. Thus, biofortified crops are of increasing interest in the prevention of malnutrition and its related diseases.

For years, it was thought that plant-based foods simply provide energy and essential nutrients, but medical and nutrition sciences have demonstrated that many other micronutrients are required although some are at low levels. Food crops are known to have different nutritional profiles and the dietary insufficiency of one or more micronutrients, and the deficiency of one or more nutrient remains a major concern in populations that have an unbalanced diet, leading to nutritional deficiencies and metabolic diseases and disorders. Furthermore, most of the plant-based and staple crops consumed in many regions do not contain many essential nutrients or their levels are not sufficient to meet minimum daily intake.

Table 1.4 Studies of crops biofortification using molecular engineering approaches.

Class	Crops	Nutrients	References
Cereals	Rice	β-carotene	Beyer et al. (2002), Burkhardt et al. (1997), Datta et al. (2003), Paine et al. (2005), Ye et al. (2000)
		Vitamin B9	Blancquaert et al. (2015), Storozhenko et al. (2007)
		Iron	Goto et al. (1999), Lee and An (2009), Lee et al. (2012), Lucca et al. (2002), Masuda et al. (2012, 2013), Paul et al. (2012), Takahashi et al. (2001, 2016), Vasconcelos et al. (2003), Wirth et al. (2009), Zheng et al. (2010)
		Zinc	Lee and An (2009), Masuda et al. (2008)
	Wheat	Iron	Borg et al. (2012), Sui et al. (2012)
		Provitamin A Carotenenoids	Cong et al. (2009), Wang et al. (2014)
	Barley	Zinc	Ramesh et al. (2004)
	Maize	Provitamin A Carotenoids	Aluru et al. (2008), Decourcelle et al. (2015), Zhu et al. (2007)
		Vitamin E	Cahoon et al. (2003)
		Vitamin C	Chen et al. (2003), Levine et al. (1995)
	Sorghum	Provitamin A	Lipkie et al. (2013)
Legumes	Soybean	β-carotene	Kim et al. (2012), Pierce et al. (2015), Schmidt et al. (2015)
		Vitamin E	Van Eenennaam et al. (2003)
	Lentils	Manganese	Ates et al. (2018)
Vegetables	Potato	β-carotene Zeaxanthin	Diretto et al. (2006), Ducreux et al. (2005), Lopez et al. (2008), Romer et al. (2002), Song et al. (2016), Van Eck et al. (2007)
		Zinc	Burgos et al. (2007), Brown et al. (2010), Haynes et al. (2012)
		Copper	Haynes et al. (2012)
		Manganese	Haynes et al. (2012)
	Sweet Potato	See Chapter 4	
	Cauliflower	β-carotene	Lu et al. (2006)
	Lettuce	Iron	Goto et al. (2000)
	Carrot	Calcium	Morris et al. (2008), Park et al. (2004)
	Cassava	β-carotene Provitamin A	Telengech et al. (2015), Welch et al. (2010)
Fruits	Banana	β-carotene	Waltz (2014)
		Vitamin A	Davey et al. (2008)
		Provitamin A	Paul et al. (2017)
	Tomato	Folate, β-carotene Lycopene Provitamin A Carotenoid	Apel and Bock (2009), Davuluri et al. (2005), Dharmapuri et al. (2002), Enfissi et al. (2005), Fraser et al. (2007), Huang et al. (2013), Rosati et al. (2000), Wurbs et al. (2007)
Oilseeds	Linseed	Carotenoids	Fujisawa et al. (2008)
	Canola	β-carotene	Fujisawa et al. (2009), Ravanello et al. (2003), Shewmaker et al. (1999), Wei et al. (2009), Yu et al. (2008)

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Malnutrition and deficiencies or hidden hunger have been significantly alleviated in many regions of the world, particularly in the developing and poor countries as results of programs that aim to fortify food crops. Nevertheless, much remains to be done regarding biofortification of staple food crops in the poor countries because these approaches have not always been successful due of the limited agricultural resources.

Demand for biofortified food will likely increase in the future due to numerous issues faced by the growing population, including the possible effects of climate change on food production and food quality. Therefore, it will be even more important to educate consumers on the benefits of biofortified foods.

Nowadays, the real challenge is no longer the science of biofortification. We know it works and have showed its efficiency in dealing with nutritional deficiencies; but the real challenge is to make biofortified crops common plant-foods for populations at risk, and to do this, rather than modifying their diet, it is more efficient to provide biofortified staple crops. Farmers, stakeholders and policy-makers should thus scale up biofortified crops to reach millions of households through institutional, regulatory, and financial policies.

Summary

Large number of nutrients are not only required and crucial for the growth and development of our organisms, but they also help in preventing many diseases and disorders. However, often the daily diet is not balanced and does not provide the required amount of these nutrients. To supply adequate nutrients, biofortification of edible plants is becoming one the most efficient strategies to improve daily diet and overcome malnutrition. For the last few decades, crops biofortification technology using different approaches has been identified as a priority initiative and has shown great potential for mitigating malnutrition and enhancing nutrient bioavailability. To improve the nutritional quality of food crops, agronomic, conventional breeding, and molecular engineering approaches have been used. Technically, each approach has its benefits, disadvantages, and constraints. However, to be viable, each approach should be economically feasible, less time consuming, and readily apparent to the consumers.

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