Biofortification: Creating a Healthier Food Supply

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Introduction

The human body requires a broad range of nutrients. Carbohydrates, proteins, fats, water, vitamins, and minerals are all necessary for the body to function. Specific macronutrient (required in large amounts) and micronutrient (required in smaller amounts) compositions are needed as well. Certain amino acids (the building blocks of proteins) are essential, and plant-based nutrients like flavonoids and carotenoids have proven health benefits.

Similarly, livestock need certain nutrients to maintain their health; nutrient requirements and digestive abilities differ by species. For example, a cow's four-chambered stomach allows it to use different food sources than those used by the single-chambered stomach of poultry or swine. The nutrients that livestock and crops receive during production also affect human health. If the plant or livestock lacks nutrients, the food produced will also lack those nutrients. Naturally, different food sources have different levels of nutrients, so it is important to understand whether human and livestock diets meet all requirements.

Diverse human and animal diets can accommodate nutrient requirements. However, maintaining food and feed diversity can be difficult because of price, geography, and availability. In humans, taste preferences also play a large role. To compensate for diets lacking diversity, fortification (i.e., nutritional supplements) is widely used for both livestock and humans.

Biofortification is another method to improve nutrient levels. Instead of supplementing food nutrient levels, it targets the source of the food: the crops and the livestock that consume the crops. Biofortification is the process of improving the nutritional quality of food and feed through management practices, breeding, and genetic modification of crops.

History

Biofortification originated in the 1990s. It has progressed alongside biotechnology to become an incredibly powerful tool for developing a healthier food supply (Nuti 2018). Many high-yielding staple crops lack wholesome nutrition for humans and livestock. For this reason, biofortification efforts started by focusing on staple crops like rice, wheat, and corn. Perhaps the most famous example of biofortification is Golden Rice (International Rice Research Institute 2019). Golden Rice attempted to address the issue of vitamin A deficiency in developing countries. By altering the grain's genetics, more beta-carotene — a precursor to vitamin A — is produced and potentially available to humans, resulting in the grain's golden color. Currently, there are many crop biofortification efforts. Table 1 outlines many biofortified crops and the type of biofortification efforts. However, not all biofortification efforts have advanced to the food supply for human consumption.

Table 1. A variety of crops have undergone biofortification efforts, though not all efforts make it to market. Some have multiple types of biofortification methods (Garg et al. 2018).

Crop	Management	Plant Breeding	Genetic Engineering
Alfalfa			✓
Apple			✓
Banana		✓	✓
Barley	✓		✓
Canola	✓		✓
Carrot	✓		✓
Cassava		✓	✓
Caulflower		✓	✓
Corn	✓	✓	✓
Grape		✓	
Lettuce	✓		✓
Linseed			✓
Lupin	✓	✓	✓
Mango		✓	
Pea	✓		
Pearl Millet		✓	
Potato	✓	✓	✓
Rice	✓	✓	✓
Sorghum	✓	✓	✓
Soybean	✓	✓	✓
Sweet potato	✓	✓	✓
Tomato	✓	✓	✓

Types of Biofortification

Management

Agronomic management strategies can improve the nutritional value of crops. The most common method is through foliar and soil application of nutrients (fig. 1). If plants have access to larger nutrient quantities, they can incorporate more nutrients into their fruits, grains, or vegetative parts. Nutrient application has been very successful with minerals like zinc and selenium, especially in cereal crops (Garg et al. 2018). For example, large portions of global land used to grow wheat are deficient in zinc, which prevents wheat food products from containing sufficient dietary zinc (Cakmak and Kutman 2017). By applying zinc fertilizer, the crop has more zinc available to incorporate into its grain. In contrast, selenium is usually provided by foliar application, in which the plant absorbs selenium through its leaves (Garg et al. 2018).

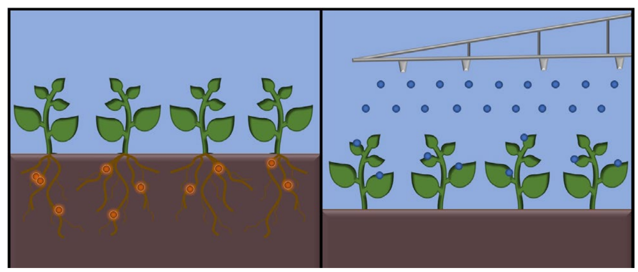

Figure 1. Nutrients can be applied through (A), soil, or (B), foliar applications. The plant will reallocate these nutrients to harvestable areas (de Valenca et al. 2017).

Other management methods can also be used to biofortify feed for livestock, which can in turn biofortify food products from livestock. Biosorption is a method for improving nutrient levels in food products such as goat milk and cheese. This method uses the natural qualities of feeds to absorb minerals. These minerals then progress through the food supply. For example, soymeal feed was shown to absorb copper, manganese, iron, and zinc, which then made their way through the food supply into human diets (Witkowska et al. 2015). Similar to plants, when livestock have higher quantities of nutrients available, nutrient levels in their food products also increase.

Plant Breeding

Plant breeding is the process of developing plant varieties with desired traits by controlling pollination and then selecting for those traits in offspring. To improve crop value, plant breeding historically focused on traits like yield and disease resistance for staple crops. Unfortunately, this focus negatively impacted nutritional diversity in foods (Martin and Li 2017).

With biofortification, the trait selection process focuses on increasing nutrient quantities in food and feed products. A complex set of mechanisms controls how nutrients are incorporated into food. In addition, the environment (e.g.,soils and weather) is constantly interacting with these mechanisms. Figure 2 is a simple outline of the movement of a nutrient through a grain crop and shows how environment can affect this movement. In poorer growing conditions, nutrient relocation within the plant becomes more important than overall nutrient uptake.

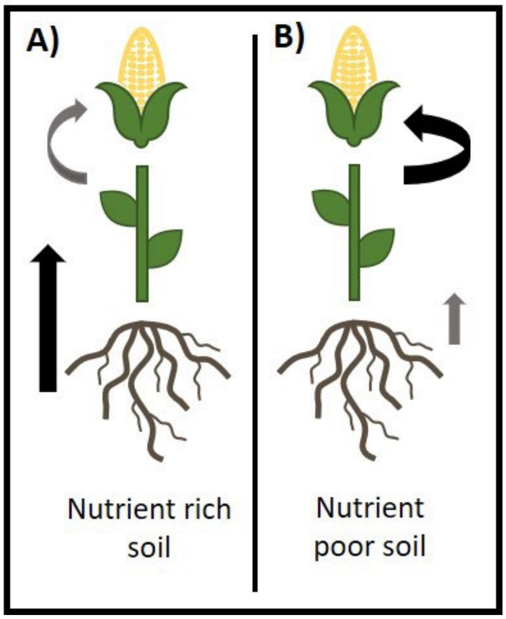

Figure 2. Different mechanisms such as uptake and relocation play a role in the final nutrient level of grains (Cakmak and Kutman 2017). (A), Nutrient-rich soil allows uptake mechanisms to continually transport nutrients to the grain, whereas (B), deficient soil will activate relocation mechanisms to move more nutrients from vegetative parts to the grain.

The variety of nutritional traits and their interactions can make it even more difficult for biofortification by breeding. Therefore, plant breeders must outline specific steps to successfully improve nutrient levels (fig. 3). By understanding how the traits interact to create nutrient levels within plants, breeders can make informed crosses and selections. It is very important for breeders to also understand where the crop will be grown, the corresponding environment, and the consumer's preference, which is especially critical in developing countries. A breeder must take cultural opinions into consideration and be patient with new consumer bases.

For example, the orange-flesh sweet potato in sub-Saharan Africa is considered the most successful plant breeding biofortification project (Laurie, Faber, and Claasen 2018). However, even with its health benefits, consumers were not initially receptive. It takes time and understanding for people to accept changes to traditional diets.

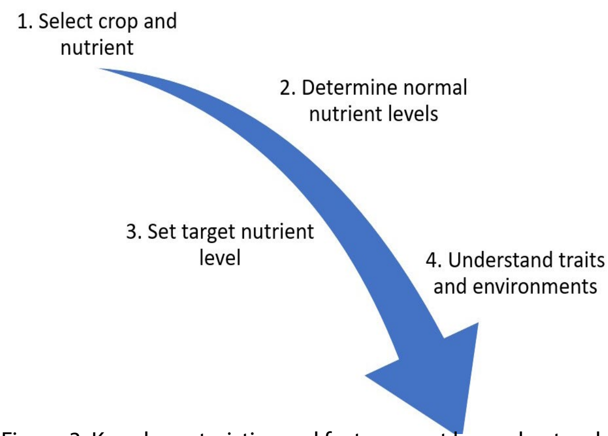

Figure 3. Key characteristics and factors must be understood before making breeding decisions.

Genetic Engineering

Biofortification using genetic engineering can include genetically modified organisms and gene editing technology used to improve nutrient levels. Genetic engineering and plant breeding work similarly to change traits by adjusting the genotype (genetic makeup): Breeding uses natural variations between varieties, while genetic engineering directly manipulates the genes that control traits. Genetic engineering, though, is a quicker, more specific technique that can introduce higher nutrient levels into plants with limited natural nutrient variations (Mulualem 2015). Future advances could potentially add nutrients to food sources that lack them originally.

Genetic engineering usually employs two methods when targeting nutrients in food: pull or protect (Martin and Li 2017). Pull methods target genes to increase overall nutrient biosynthesis — the production of nutrients by the plant. For example, this method was used in Golden Rice production. Protect methods target genes to prevent the degradation of nutrients over time. This is important for crops like sorghum in Africa, where the crop is the crop is stored over a long period of time before consumption (Che et al. 2016). High nutrient levels in crops are irrelevant if the nutrients are not present when consumed.

Agricultural Impacts of Biofortification

Producers

The overall impact of biofortification in developed countries is dependent on producers. If farmers do not receive value from biofortified crops, they have no reason to grow them. The biofortified crop must also provide additional revenue to cover any additional expenses from production methods. Yield cannot be harmed by biofortification unless the value increases enough to compensate for the yield loss. However, with well-developed biofortification projects, producers can see higher value for some crops. An interesting example would be purple popcorn, which was bred to have higher levels of anthocyanins, which are antioxidants that help fight chronic disease (Lago et al. 2013). They are abundant in wine and berries and provide the purple color to foods. Similar products with unique traits have high market potential for producers.

Livestock

As previously mentioned, biofortified products must add value to be successful. One of the avenues for increasing value is livestock feed. Many livestock require supplements added to their feed; for example, soymeal is low in methionine, a critical amino acid for poultry production. This requires methionine supplements in poultry feed. Biofortified soymeal would have increased value from higher methionine levels and would prevent poultry farmers from having to supplement diets. Biofortified livestock products such as milk and cheese could also increase value for livestock producers, as opposed to fortified vitamin D milk, which occurs during milk processing.

Human Health

Biofortification could have an enormous impact on global human health, especially in developing countries. In developed countries, it is easier to eat a diverse diet, and nutrient supplements are more affordable. Biofortification is also widely considered part of the solution to hidden hunger. Hidden hunger occurs when populations have enough total food but the food supply lacks overall nutrient levels for people to remain healthy (de Valenca et al. 2017). As the world's population continues to grow, the food supply needs to increase in quantity and quality. Biofortification will be an increasingly important tool for maintaining healthy diets in the future. However, consumer opinions will continue to determine the true efficacy of biofortification. Extension and outreach will be critical for communicating the benefits of a biofortified food source.

Conclusion

Biofortification is used to create healthier, more valuable, and well-rounded food products from crops and livestock. It has progressed from an idea to improve nutrition for a handful of staple crops into an industry sector for a wide range of foods. It can be accomplished by a variety of methods: management, breeding, and genetic engineering. All methods work to increase overall nutrient levels in food by targeting nutrient concentrations at different points in agricultural production. Biofortification will be incredibly important for maintaining healthy global food supplies as the world's population grows.

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Produced by Virginia Cooperative Extension, Virginia Tech, 2020

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VT/1120/SPES-267P