LITTLE THINGS MEAN A LOT
Enhancing nutrition through biofortification

12

The micronutrient opportunity

Since the 1940s, farming has drawn on many new techniques and practices – some conventional, some cutting-edge – which have helped to achieve higher yields of the major staple crops and, thereby, keep pace with rapid population growth. But not all regions or countries have enjoyed equal success, particularly in Africa.

Until recently, improvements have focused on food production as measured in the carbohydrate content of grain crops such as wheat, maize and rice, and many other staples including cassava and plantain, though the latter two are produced in much smaller quantities (Figure 12.1). Carbohydrate content is a good measure of the nutritional calorific content of food. It is, after all, a critical source of energy needed to sustain life. But it is not the whole story.

Humans – like the plants they consume – need more than carbohydrates. We need protein and fat, the other macronutrients that are needed in large amounts. But we also require micronutrients – the vitamins and minerals that are essential to our diet, albeit in far smaller quantities. Often, staple crops contain few or no micronutrients, with sometimes devastating consequences.

Micronutrient malnutrition

Plants themselves synthesise vitamins and their precursors, whereas minerals such as iron, zinc and iodine are absorbed from the environment in which the plants grow. Of course, plants produce or absorb chemicals to suit their own biological needs, but humans and other animals have evolved to take advantage of a broader chemical diversity. So much so that, without it, a number of health problems can arise.

Throughout history, micronutrient insufficiencies have taken a heavy toll. Too little iodine impairs both physical and mental well-being. Until sea salt containing traces of iodine entered our diet, enlarged thyroid glands, producing a swelling of the neck known as goitre, were commonplace.

Other longstanding problems include the nervous system and cardiac disorder beriberi (deficiency in thiamine and vitamin B1), scurvy (vitamin C), the childhood

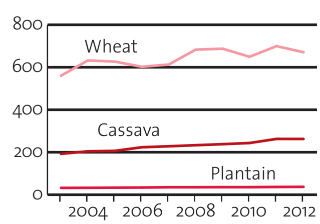
KEY THEMES

- Micronutrient deficiency and malnutrition.
- The role of biotechnology in biofortification.
- Arguments in favour.
- Resistance and underfunding.

Figure 12.1 Wheat, cassava and plantain production worldwide, 2002–2012

Million tonnes

Cassava and plantain are produced in much smaller quantities than other staples such as wheat, so are still considered orphan crops.



Source: FAOSTAT

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Enlarged thyroid glands associated with iodine deficiency were once so common that depictions found their way into medieval manuscripts. The condition is still a feature of a diet poor in micronutrients.

bone deformation condition rickets (vitamin D) and pellagra, which affects both the skin and mental functioning (vitamin B3).

Lack of vitamins and minerals in the diet is not simply of historical interest. Today, the Copenhagen Consensus meetings of top-level economists consistently list micronutrient provision as a high priority in solving mankind's most pressing problems. Rickets is still a scourge in some societies as a result of too little exposure to sunlight, which helps synthesise vitamin D in the body. Insufficient folic acid (vitamin B9) in the diet of pregnant women is another common deficiency that can cause deformities in babies. Ample green vegetables would overcome this, but are often inaccessible among impoverished populations.

The most prevalent micronutrient deficiency of all is that of iron, estimated to affect half the world's entire population. The debilitating physical and mental effects of iron deficiency are often irreversible. Equally worrying is the lack of vitamin A in the diets of people in developing countries. A recent World Health Organization estimate suggests that perhaps 250 million people are vitamin A deficient, predominantly children under five years old, due to lack of fruit, vegetables and animal products in their diet. This is having a massive impact on health. Vitamin A deficiency is the single biggest cause of preventable blindness as well as a widespread cause of many common diseases resulting from impaired immune function.

These nutritional insufficiencies would be overcome if more people enjoyed greater diversity in their diets, from both plant and animal sources. Unfortunately, however, an estimated 2 billion people worldwide, usually the educationally or financially disadvantaged, are simply unable to access the desired level of dietary diversity. Non-staple foods that contain the most micronutrients have the major disadvantage of being the most expensive. Even those living in the countryside often lack the resources to access a wide variety of foods, and remain dependent on staples that contain few or none of the essential micronutrients. So the poor in developing countries are clearly very vulnerable. They are the ones most likely to suffer malnutrition – of both the macronutrient and micronutrient variety.

Alleviating the problem

There are several ways to address the issue of micronutrient insufficiency. One is to fortify foods and other products during manufacturing. Iodine has been added to salt; vitamins A and D to margarine; folic acid to flour; and fluoride to toothpaste – all with some success in both industrialised and developing countries. In the Lao

People's Democratic Republic, for example, the incidence of goitre in children dropped from 40 per cent to 9 per cent in around 10 years after iodine was added to salt. This kind of fortification, though, does depend on foods undergoing industrial processing and being widely distributed by means of an adequate infrastructure: someone has to pay for this.

Another approach is supplementation – the use of tablets or capsules containing the required micronutrients. Supplements, again, have to be paid for, but they can be highly effective. Since the early 1990s, 500 million vitamin A capsules have been given to at-risk populations every year in order to cut child and maternal mortality and vision problems. The annual cost is US$ 0.5–1 billion, largely met by US and Canadian government aid funding.

Despite this initiative, however, the number of preventable deaths remains high. Conventional supplementation and fortification programmes run the risk of missing the most needy, most inaccessible and marginalised people.

A third strategy is to modify the make-up of food crops so that they generate the desired micronutrients while they grow: biofortification.

Back to source: the attraction of biofortification

Plants are sophisticated biochemical factories producing or storing all the compounds and chemicals humans and animals need for life. But the distribution of chemicals synthesised or absorbed within the tissues of crops may not be available in those parts of the plants that humans usually eat.

Take, for example, rice. The part of the rice grain that is eaten – the endosperm – is almost totally carbohydrate, along with small amounts of fats and protein, and it is the thin sheath of tissue surrounding the endosperm that contains most of the micronutrient vitamins and minerals. But before rice can be stored as food, it has to be polished to remove the outer layer, otherwise fats there would turn the rice rancid and bad-tasting. In other words, to keep the rice edible means automatically removing the source of valuable micronutrients – an apparent dilemma that a study carried out with a community of nuns in the Philippines helped to resolve (see Case study).

The Nuns Study led to the establishment of the Harvest Plus programme, which is using largely traditional breeding techniques to increase the levels of nutrition

Pearl millet, which remains an orphan crop even though it has been grown in Africa and India since prehistoric times, is a good candidate for biofortification with iron.

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The wild relatives of bananas and plantains grow plentiful seeds. In today's cultivated crops, however, the seeds have diminished to virtual non-existence, making further improvement feasible only through genetic modification.

already present in low amounts in the edible parts of staple crops. Harvest Plus is breeding biofortified (through increased iron, zinc and vitamin A) sweet potato, bean, pearl millet, cassava, maize, rice and wheat. Growers in Bangladesh, Democratic Republic of the Congo, India, Mozambique, Nigeria, Pakistan, Rwanda, Uganda and Zambia are benefiting – or will soon benefit – from the new varieties.

Role of biotechnology

Conventional breeding for biofortification can have limited results. Plants that produce few, if any, seeds – like plantain, cassava and banana – are reproduced vegetatively, so are ill-suited for selective or cross-breeding. And sometimes none of the desired micronutrient can be conventionally bred into the part of the plant that we eat – as in the case of rice. Another way of building in micronutrients is required.

Much proof-of-concept research on the new biotechnologies achieved to date has yet to be applied in practice in developing countries; nonetheless, new varieties are set to help address these problems of micronutrient deficiency. Rice has been engineered to produce folic acid to overcome a lack of it in pregnant women and to combat deformities in children. Zinc is another micronutrient currently receiving attention in rice, involving modifying the action of a key gene. Low iron content has also been studied: the genetic control of iron uptake and storage within plants is a complicated process involving perhaps 12 different genes, but two research groups in Switzerland and Australia have used genetic modification (GM) to raise iron levels in rice endosperm. High-iron bananas have also been developed using this technology.

CASE STUDY *Lessons from nuns in the Philippines*

Removing the outer layer of rice during polishing takes away the crop's iron content. So researchers decided to try differential polishing which allowed them to retain more of the iron-rich sheath. They gave this rice to one group of nuns and to the others – the control group – they gave low-iron rice in which the whole of the outer layer had been polished off.

The results were striking. Even modest increases in daily iron consumption caused by eating the high-iron rice improved the health status of the nuns compared to the control group. This important finding demonstrated not only that the more outer layer is retained, the better the micronutrient content of rice. It also showed that, if rice has to be polished in order to be stored, then breeders would need to concentrate their attention on the endosperm – the part that is eaten. How can this be fortified with more iron?

Best-known of all are efforts to combat vitamin A deficiency through so-called Golden Rice, in which the plant's endosperm has been engineered with two genes for generating the carotenoid, beta-carotene – the necessary biochemical precursor to vitamin A. The carotenoids are also the pigments that give Golden Rice its distinctive yellow colour.

Golden Rice has shown that it can significantly reduce vitamin A deficiency in societies that eat rice, and is as effective as taking capsules or milk and eggs in providing the vitamin. Just a cooked handful can save lives and sight.

Acceptability of biofortification

For all the potential of Golden Rice – and other promising crops with enhanced micronutrient content based on genetic engineering – the path to acceptability of these innovations has not run smoothly.

Suspicion about GM, anti-globalisation feelings, distrust of the motives of the private sector in supporting these technologies, as well as fear of activist attacks have all, primarily in affluent Europe, slowed things down. Golden Rice, as the first generation of genetically engineered biofortified crops, has perhaps been on the receiving end of more hostility than subsequent GM crops might expect.

The Golden Rice story began nearly 30 years ago, shortly after the dawn of genetic engineering of crops, but is still, in 2014, only at the stage of field trials, and those taking place in the Philippines have been wrecked by activists.

Research with resource-poor growers and consumers tells a different story. Poor farmers would like to grow the new rice crop and believe that it would benefit their families. They welcome the fact that the new rice costs them the same as the old one and are not concerned about the way it was developed. They also care more about its nutritional and health advantages than its unusual colour.

There are powerful economic arguments too in favour of Golden Rice and other GM crops:

- the technology lies in the seed so no factory is needed to access its nutritional value;
- no new road infrastructure is necessary;
- no more money needs to be spent on cultivation than with any other rice;
- no special packaging or processing is required;

The successful introduction in Mozambique of orange-fleshed sweet potato, which is naturally higher in beta-carotene than the white or yellow varieties traditionally grown in Africa, could serve as a model for the acceptance of other biofortified food crops.

USGov/PD

- resource-poor farmers in developing countries are free to sow, harvest, save seed, replant and sell locally without having to pay licence fees.

Taking the Asian countries as a whole, the total impact on wealth is estimated to be huge. Even moderate Golden Rice consumption could add up to US$ 18 billion annually to Asian gross domestic product (GDP). There are massive savings to be made too in health-care expenditure. Each case of iron deficiency averted is estimated to save US$ 45; every vitamin A deficiency US$ 96.

Once biofortified varieties of staple food crops have been widely distributed among subsistence communities, there is no further need to supply food supplements – often at considerable expense and with limited uptake.

Cost-effective but underfunded

Biofortified crops – whether conventionally bred or engineered – offer so many practical and economic advantages that they seem to have enormous potential for the long-term sustainable prevention of micronutrient deficiencies. They also fit well with the 1992 United Nations recommendations for locally available food-based strategies to alleviate these deficiencies, relatively cheaply and with excellent coverage of the population.

The extraordinary advances in mapping plant genomes and using sophisticated molecular techniques contribute to rapid progress in biofortification which could well be applicable across a broad range of plants in the future.

Yet for all this promise, biofortification programmes are dramatically underfunded. Although micronutrient-enhanced crops have the potential to save many millions of dollars in health-care costs, investment lags far behind that of pure health-related research. It is surely time for the balance to be redressed.