Iron-biofortified cereals to reduce hidden hunger in Africa

Associate Professor Alex Johnson
The University of Melbourne

Abstract

Micronutrient deficiencies are among the most serious health issues facing billions of people in developing countries of Africa, Asia and Latin America. Rice and wheat provide a significant proportion of dietary energy in these countries, yet people who consume large quantities of cereals often suffer from 'hidden hunger' due to low concentrations of iron, zinc and provitamin A in the grain. Human iron deficiency is the most common nutritional disorder in the world, affecting more than two billion people, with symptoms ranging from poor mental development in children and depressed immune function, to iron deficiency anaemia. The development of iron enriched crops – a process commonly referred to as iron biofortification – has emerged as a highly economic and sustainable approach towards increasing iron intakes in developing countries at no additional cost to growers and food manufacturers. We have used genetic engineering to produce rice and wheat plants that are more effective at mining soil for iron and transporting iron to grain. These iron-biofortified plants contain significantly increased iron concentrations in edible grain tissues. They yield normally in multi-location field trials, and have high iron bioavailability as indicated by cell culture assays. Whilst the first release of iron-biofortified rice will likely occur in Bangladesh, subsequent adoption of iron-biofortified rice in West and Central Africa could contribute to major reductions in human iron deficiency. Iron-biofortified wheat is likely to have similar impact if adopted in wheat growing regions of North Africa.

The talks that have preceded this presentation have made it clear that 'hidden hunger', or the lack of vitamins and minerals, affects a huge number of people around the world. Iron deficiency, for instance, affects more than two billion people around the world (WHO Global Health Observatory database). It is the most common nutritional disorder that we have on the planet affecting humans. There are also huge problems with zinc deficiency and vitamin A deficiency. All these deficiencies negatively impact on our health. They can cause anaemia, in the case of iron, and stunting when you lack zinc. Earlier today we heard that over 155 million children are stunted. The effects of hidden hunger are terrible, and definitely need to be corrected.

How did we get to a situation where we have such big problems with hidden hunger, particularly in developing countries around the world? Some of this situation is a legacy of the Green Revolution. During the Green Revolution we worked to produce more calories, mostly focusing on the 'Big 3' crops:

This paper has been prepared from a transcript and the illustrative slides of the presentation.

rice, wheat, and maize. Those crops were bred to provide calories, not micronutrients. Today there are a huge number of people who depend on, say, rice and wheat, for most of their daily calories, yet those grains do not contain significant amounts of micronutrients. Rice, for instance, contains no vitamin A.

This presentation focuses on iron. None of the major cereals is a rich source of iron because those cereals do not accumulate much iron in the grain. The small amount of iron that they do accumulate is in the outer layers of the grain – the bran and germ layers – which are removed by milling. That outer layer is quite oily, and the milling makes a much more stable product that does not go rancid. Milling, however, also removes most of the iron. Further, most iron in cereal grain is bound to phytate, a storage molecule that humans cannot digest. Therefore most iron in wholegrain is not bioavailable to humans.

Lack of micronutrients is likely to get worse in cereal grains, according to a few high profile studies that have been published over the last few years. A wide range of experiments have found that as atmospheric CO_2 increases so the concentrations of iron and zinc are likely to decrease by about 10% in all the C3 grains – including wheat and rice – and also in the C3 legumes, and protein concentrations are likely to fall also (e.g. Myers *et al*. 2014). We shall be dealing with this situation in the very near future, at CO_2 levels that we expect will occur by 2050. The effect is not simply dilution because the plants seem to take up as much iron as at lower CO_2 levels, but more remains in the leaf and less is distributed into the grain.

Biofortification

There are already many tools available to tackle hidden hunger, and we need every one of them. One approach is to supplement and fortify cereal products via food processing, but the costs are recurrent and this approach work best in urban areas or cities, therefore largely not benefiting rural populations. On the other hand, biofortification – the development of micronutrient-enriched cereal plants – benefits consumers in urban *and rural* regions.

Biofortification can be very expensive, but it is a one-time investment that then can have impact around the world. Some crops have been biofortified through conventional plant breeding: for instance, high zinc rice and wheat. Other nutrient concentrations cannot be fortified by conventional breeding, and the enhanced vitamin A in golden rice is a good example. That modification to the rice plant, giving the grain its golden colour, requires genetic engineering.

Fortifying with iron also requires genetic engineering. I have worked with an organisation called HarvestPlus for over ten years on the problem. Decades of conventional breeding have failed to adequately biofortify the three major cereals with iron.

Modifying a single gene can make rice more effective at extracting iron from soil (Johnson 2013), and a similar outcome is possible for wheat. The work entails finding genes that are involved in the chelation of iron, which keeps the iron soluble in the plant. Then the geneticist amplifies that effect with a strong promoter, a ‘constitutive promoter’. Figure 1 shows a conventional rice grain on the left, and a biofortified rice grain on the right, imaged in the Synchrotron

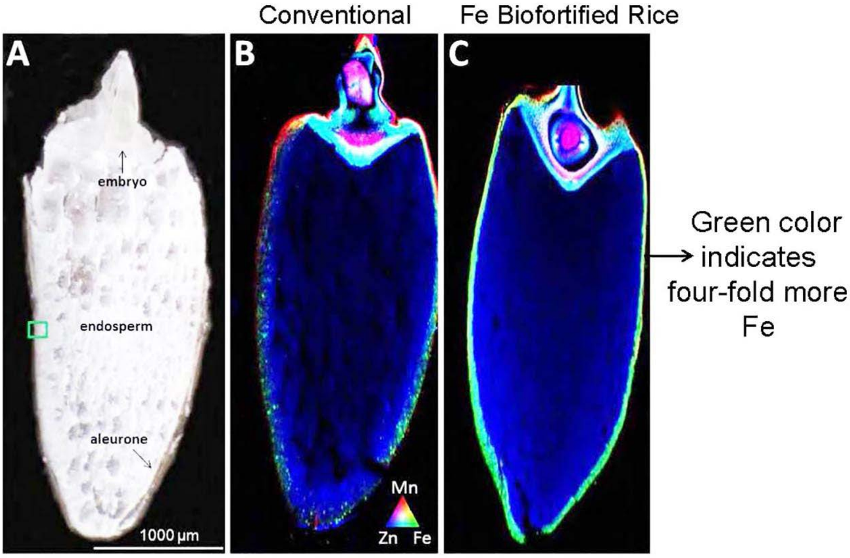

Figure 1. Biofortified rice grain (Johnson *et al.* 2011; Kyriacou *et al.* 2014).

where we are able to colour-code where elements are within a grain. The green colour in the right-hand grain reveals that these biofortified rice plants are putting about four-fold more iron into the grain, which means that the milled grain reaches biofortification targets. To achieve this we 'turned up' a single rice gene so it can chelate iron more effectively and the plant can harvest more iron from the soil. That success in harvesting iron is indicated by the good growth of the biofortified rice plants (see Figure 2) in soil of pH 8.5, pre-alkaline soil, which almost kills the conventional plants.

We can do the exact same thing with wheat, by taking that single rice gene and implanting it into wheat. With this approach we observed big increases in the

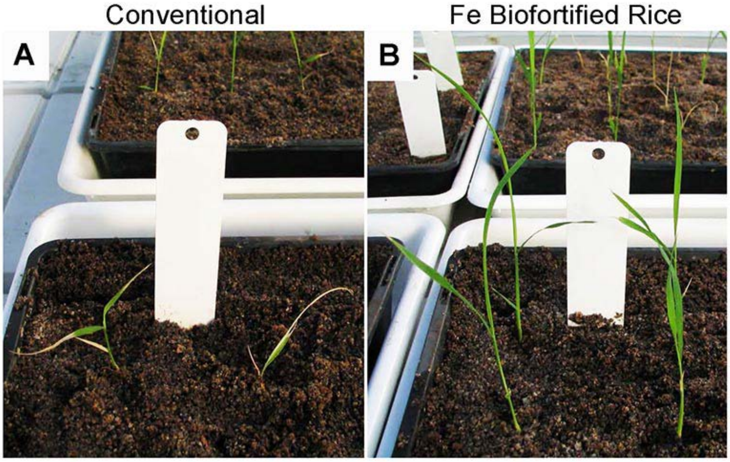

Figure 2. Genetically modified rice seedlings (right) grow well in soil mix with pH 8.5 (UC Davis soil mix), unlike unmodified rice in the same soil mix (left) (Johnson 2013).

amount of iron deep in the endosperm of the wheat grain. Therefore, even after milling, the grain is still iron-biofortified.

The future

The iron-biofortified rice project has now moved into a deregulation phase, with the aim of making this genetically engineered biofortified rice available in Bangladesh.

Why Bangladesh? In 2013 the Bangladesh Government approved genetically engineered eggplant (Bt brinjal) which is resistant to its major pest, and that has been a big success. They are quite open to biotechnology, so we see this as an opportunity to release the iron-biofortified rice and have a big impact in a country where the people eat a lot of rice, and rice is grown on 80% of the cultivated land.

Our next challenge is to see if biofortified grain can be accepted in Africa, because so far we have not found a country in Africa that is as open to biotech as Bangladesh. If iron-biofortified rice and wheat crops could be grown in Africa – say in West Africa for rice, or North Africa for wheat – they could make a big difference.

I think that to tackle hidden hunger via biofortified plants there needs to be a change of attitudes towards agricultural biotechnology, from everyone around the world who is working in this area. Conventional breeding can deliver a range of biofortified crops – provitamin A cassava, iron-biofortified pearl millet and beans, for instance – and that should be applied wherever it achieves the targets. But where that is not the case we need to use crops modified by agricultural biotechnology – for example, golden rice and iron-biofortified rice and wheat.

It is expensive technology: the costs of discovery, development and authorisation (deregulation) of a genetically engineered crop can exceed $100 million. Therefore we need the support and investment of developed countries like Australia, and of governments, to enable genetically engineered biofortified crops to be commercialised for use in developing countries – via public–private partnerships for example – to realise these crops’ full potential.

References

Johnson A.A.T. *et al*. 2011. Constitutive overexpression of the OsNAS gene family reveals single-gene strategies for effective iron- and zinc-biofortification of rice endosperm. *PLOS ONE* **6**(9):e24476. https://doi.org/10.1371/journal.pone.0024476

Johnson A.T. 2013. Enhancing the chelation capacity of rice to maximise iron and zinc concentrations under elevated atmospheric carbon dioxide. *Functional Plant Biology* **40**:101–108. https://doi.org/10.1071/FP12029

Kyriacou B. *et al*. 2014. Localization of iron in rice grain using synchrotron X-ray fluorescence microscopy and high resolution secondary ion mass spectrometry, *Journal of Cereal Science* **59**:173–180. http://dx.doi.org/10.1016/j.jcs.2013.12.006

Myers S.S. *et al*. 2014. Increasing CO_2 threatens human nutrition. *Nature* **510**:139–142. https://www.nature.com/articles/nature13179

WHO Global Health Observatory database. http://apps.who.int/ghodata

Alex Johnson heads a research laboratory focused on plant nutrition and biofortification in the School of BioSciences at The University of Melbourne. His research explores how plants absorb nutrients from soil and the factors affecting nutrient bioavailability in edible parts of plants. He has worked with the non-profit initiative HarvestPlus over the past decade to develop iron-biofortified varieties of rice and wheat to combat human iron deficiency in developing countries. Alex has a Master of Science and PhD from Virginia Tech in the USA. Prior to Melbourne he held postdoctoral positions at the University of Cambridge (Cambridge, UK) and the Australian Centre for Plant Functional Genomics (Adelaide, Australia).