The future of food

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Currently, about a billion people live on less than a dollar a day. This is such a simple sentence that those of us who live in affluence find it easy to ignore the magnitude of the problem it describes. However, due to many factors this problem is set to get worse. The simplest to explain is that by 2050 there will be about 50 per cent more of us on the planet, but current crop breeding programmes are not generating equivalent increases in yield. In addition, developed countries aim to grow more crops for biofuels and, combined with global urbanization, less land is available for agriculture. Population growth and loss of agricultural land can be seen in real time at http://irri.org (a panel on the left-hand side of the webpage shows the change in population and loss of agricultural land). Because of the high population density in Asia, the crop that will have the largest impact on future food security for most people on the planet is rice.

The International Rice Research Institute (IRRI) is based just south of Manila and was founded in 1960 by the Ford and Rockefeller Foundations in cooperation with the Philippine Government. Agronomists at IRRI have, over nearly 50 years, been responsible for almost all the improvements in production of rice. In the 1960s and 1970s, scientists at IRRI developed the semi-dwarf varieties of rice that led to the massive increases in yield that are now described as the Green Revolution. This breeding programme was extraordinary, and is estimated to have saved millions of Asians from famine and provided a platform for the region's subsequent economic growth, which lifted more people out of poverty than at any other time in recorded history. Since 1965, research at IRRI has led to rice production increasing 2.5 per cent each year, cumulatively boosting rice production by an impressive 170 per cent (from 199 million tons in 1961 to 540 million tons in 2000). Until last year, this increased production resulted in a spectacular drop in the real price of rice and this provided the poor with vital additional income.

So IRRI has been incredibly successful in breeding higher yielding varieties of rice. However, over the last ten or so years the maximum yields recorded at IRRI in their annual growth trials have not altered. Maximum yield and actual yield are distinct, and all the time that actual yield increases but maximum yields are static, the potential we have to improve production further declines. In other words, the current breeding strategies at IRRI are not producing varieties of rice that will generate significant increases in yield in the future. Given that the best attempts of breeders at IRRI over the last decade have led to almost no increase in maximum yield, suggesting that by 2050 we need to develop varieties of rice that produce 50 per cent more grain to feed ourselves seems ambitious (many people would say ridiculous). The issue is that if we don't find some way of increasing yields by this order of magnitude we seem to be heading for a Malthusian humanitarian disaster.

As an optimist and a biologist I am hopeful that we can evade Malthus's predictions. There are a good number of crops that do yield about 50 per cent more than rice, and these crops all use a particular form of photosynthesis called the C4 pathway. The name is derived from the fact that the biochemical product of the photosynthetic process is a compound containing four carbon atoms (in most plants, including rice, the first product of photosynthesis is made up of a three carbon molecule). 'C4 plants', as they are known, use a more efficient photosynthetic cycle, which allows them to grow more quickly and to produce more grain. They are at a particular advantage in tropical and semi-tropical regions, exactly the regions where rice is grown. The C4 pathway is fascinatingly complex, with the leaves of these plants possessing alterations in their structure, the organisation within cells, and the enzymes used during photosynthesis. In other words, attempting to reconfigure rice so that it uses C4 photosynthesis is extremely ambitious. But this is what IRRI have decided to attempt, and to do this they have formed an international consortium of scientists, including myself, to start to modify photosynthesis in rice. There are a number of reasons to be optimistic, despite this project undoubtedly being extremely challenging. Perhaps the most important is that there is significant biological precedent for it: we estimate that C4 photosynthesis has evolved at least 50 times independently in plants. This implies that there are a relatively small number of alterations that occur in the genome of lineages of plants that evolve the C4 pathway, and that these changes induce a larger-scale remodelling of the leaf.

The work we are doing in Cambridge is focussed on increasing our understanding of how the C4 pathway works, identifying the genes, understanding how they are regulated in C4 plants, and starting to build up a functional C4 pathway in rice. And yes, some of the work we do involves genetic engineering. I suspect we will never generate a variety of rice that produces 50 per cent more grain without 'GM' technology. For the record, I am not completely pro 'GM': I think that each new crop needs to be assessed on its merits, but I strongly believe that GM crops will have massive impact on food security in economically developing nations. I am also convinced that the anti-GM lobby in parts of the economically developed world has already had negative impact on crop improvement programmes for less advantaged parts of the globe.

An interesting thing about C4 rice is that because of the way the C4 pathway works, in addition to faster growth and higher yields, less water and fewer nitrogen applications would be required for the same yield. This reduces the costs of inputs, but should also mean lower environmental impact because irrigation and fertilizer run-off are reduced. One common reaction to the problem of how we feed ourselves in the future is 'Why don't we control population growth, rather than supply more food?'. An interesting point is that so far, in all major societies in which population size has stabilized, the driver seems to have been increased agricultural productivity. This encourages small farmers in allowing their children to become educated, and, once educated, family-planning is realistic.

We estimate that it will take at least 15 years to generate rice that uses C4 photosynthesis. It is possible that we will fail, but the increase in knowledge that we gain is likely to feed into other crop breeding programmes. If we succeed, it will be immensely satisfying to think that we have been able to convert knowledge generated from pure, basic science, into something that helps feed people and pulls millions of people out of poverty. More information about the C4 pathway is available on various websites (including wikipedia, IRRI's and my University website, http://www.plantsci.cam.ac.uk/research/julianhibberd.html).

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This is rice (Oryza sativa) growing in the North of the Philippines, on terraces constructed using wooden tools by the Ifugao people about 2000 years ago. The terraces have been used for growing rice ever since