Can a growing world feed itself without genetically modified crops?

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Global agriculture produces enough to feed everyone if we take 2,720 kilocalories (kcal) per person per day as the intake that would satisfy most people who lead a moderately active lifestyle. Yet there are still 925 million who are undernourished, or about 13 per cent of today's world population, and nearly all live in less developed countries.[1,2] The Global Hunger Index[3] has fallen from 19.7 in 1990 to 14.7 in 2012 (less than 4.9 is low hunger; 5–9.9 moderate; 10–19.9 serious; 20–29.9 alarming; and more than 30 is considered extremely alarming), but some 19 countries are in the alarming or extremely alarming categories, and urgent action is called for in Burundi, Eritrea and Haiti.

Population pressure is an underlying factor because it can lead to the collapse... of individual societies

The long-term effects of malnutrition cause one in three children to have stunted growth with risks of learning disabilities, mental retardation, poor health and chronic diseases in later life. Hunger can lead to even greater hunger because of an inability to work and learn.[2] Population pressure is an underlying factor because it can lead to the collapse, or nearly so, of individual societies.[4,5] Capability-deprivation is another because it is not only a question of how people actually function that matters but their capability of functioning in important ways, if they so wish.[6] Food price volatility is a further concern due to market uncertainties, whether driven by speculative future trading of agricultural commodities or the demands of renewable fuels for land.

How can we feed more people?

Moving large supplies of food around the world would be one possibility, but it is expensive, is often the wrong type to meet the dietary needs of those in greatest need, and adds to the burden of greenhouse gases. So if we fail to feed everyone today, what are the chances we can feed an extra 2 billion people by the middle of this century, many of whom will live in the urban areas of less developed countries? Can food be produced with new technologies? Can global trade be improved through better policies? Can we reduce waste so that over 30 per cent of food is saved from being discarded and instead used to feed hungry people?[7]

Global food productivity has been a success story over the past 200 years. Science and technology have given humans power over nature through a mix of technological advances and social change.[8] Per capita food production has been raised in many parts of the world by between 1.5 and nearly 3-fold through the application of a wide range of conventional practices.[9,10] The relative global production of main grains has increased 2.5-fold over the past 50 years (wheat, barley, maize, rice, oats) and coarse grains and root crops nearly 1.5-fold (millet, sorghum, cassava and potato). Chicken numbers are up nearly

4.5-fold and pigs 2.5-fold, though cattle, buffalo, sheep and goats have increased less than 1.5-fold.[10]

In Africa, however, growth of cereal production per capita has been almost stagnant because of limitations in technology availability, investment, transportation, access to markets and security of land rights.[11] In India, by comparison, M.S. Swaminathan has described how within a half century innovative steps were taken to maximise rice and wheat yields in districts where irrigation was available, building the Green Revolution. His appeal for an "evergreen" revolution through ecologically sound and sustainable policies went largely unheeded,[2] and poverty still presents a substantial problem in many parts. Nonetheless, a persuasive case has been strongly argued by Gordon Conway for a "doubly-green revolution" as the basis of a theory of change for developing countries.[8]

High-input agriculture is criticised for its intensive practices that result in environmental costs, including the loss of 20 per cent of topsoil due to erosion, desertification and salinity; 20 per cent of agricultural land degraded by overgrazing and the generation of marginal land; and 33 per cent of forests denuded by overexploitation. Climate change, decreased water availability, loss of biodiversity, urbanisation and dietary upgrading (greater numbers of people obese than suffering malnutrition and starvation) are all recognized as a drain on food productivity. However, encouraging scenarios paint a picture of 100–180 per cent more food becoming available for consumption, provided food production is achieved through sustainable systems[13] which do not have to mean a reduction in yields or profits.[14]

Sustainable intensification – growing more from less – has become the new rallying cry

Sustainable intensification – growing more from less – has become the new rallying cry.[10,14,15] Each hectare of land will need to feed five people by 2050 compared to just two in 1960, and with less available water. Whereas in the past the primary solution was to bring more land into production and to take a greater quantity of fish, such options are no longer straightforward, as little additional land suitable for agriculture remains and many fisheries have been diminished.

Bright spots, as they are called, will be noted, for example integrated management schemes for pest control, livestock, forestry and aquaculture, along with conservation of soil nutrients and water supplies by reduced tillage and harvesting, respectively[14].

Currently, the best yields that can be obtained from cereal crops are significantly greater than those typically obtained by farmers.[10] Wheat yields in the UK were 2.8 tonnes per hectare in 1948 and have increased to 8 tonnes per hectare now. The best wheat growers can achieve 10–12 tonnes per hectare, limited only by water availability. This yield gap, as it is called, reflects the influence of plant breeding on yields over the last 25 years, as well as agronomic improvements, but there is little prospect of a comparable increase in the future unless the performance of crops can be radically advanced.

Will new advances in genetics help?

Closure of the yield gap has to be one of the major opportunities for the future since the gap can be as great as 50–60 per cent in countries in Asia and South America. Accelerated breeding has become a reality through new knowledge of plant genomes, the discovery and cloning of key genes, and the use of marker genes to aid selection. Breeders have improved their understanding of the genetics of crop yield and the capacity to manipulate determining complex characters.

Enhanced productivity has provided a major boost to farmer income ... with significantly reduced environmental impacts

First-generation biotechnological techniques consist of non-transgenic (biochemical and genomic screening, marker-assisted selection) and transgenic procedures (genetic modification by exogenous DNA sequences). They have successfully modified a few simple input traits in a small number of commercial commodity crops leading to a reduction of chemical usage in the control of destructive pests and diseases. GM cotton as a cash crop has had qualified success, but has increased overall the incomes of farmers and processors. Where lessons have been learned, plant biotechnology programmes sustained by substantial investments show significant progress.[16]

As an agricultural innovation, the adoption of GM crops worldwide has expanded rapidly. In 2012, 17.3 million farmers (out of the 525 million estimated by Global Agriculture to be farming around the world) cultivated 170.3 million hectares in 28 different countries. For the first time, developing countries grew more (52 per cent) biotech crops globally in 2012 than industrial countries (48 per cent). Enhanced productivity has provided a major boost to farmer income and to the economic value of the four major crops – soybeans, corn, cotton and canola – with significantly reduced environmental impacts through both lower pesticide use and lower carbon emissions.[17] Second-generation GM technologies are waiting in the wings with the aim of enhancing consumer benefit through increased food availability and improved nutritional quality.

Genetics can be used to overcome deficiencies in dietary micronutrients such as iron, zinc and vitamin A (biofortification).[18] The best known transgenic approach is Golden Rice fortified with provitamin A. After a prolonged period in the regulatory process it is expected to be available in the Philippines within the next two years.[19] The HarvestPlus consortium has breeding programmes using available biotechnologies for six of the most important staple foods crops. The Vitamin A partnership for Africa (VITAA) works on enhancing provitamin A in the sweet potato. Industry's portfolio includes over 20 future novel traits with potential benefits for human health including omega-3 stearidonic acid (for cardiovascular disease) and low Raff-starch (for diabetes).

Encouraging signs are also emerging in Africa,[1,16] where the need is greatest. The regulatory pipelines include over 20 applications for plants with traits that provide resistance to drought, salinity, fungi and viruses, as well as enhanced nutritive value. Net economic benefits have been demonstrated but the results are variable depending on crop, trait, location and producer. They are a reminder that the science is not simple, and that time is in short supply in view of the alarming effects of global climate change. These modern planting materials have the potential to increase yields and reduce labour costs, and therefore offer the prospect of greater economic independence and social development for farmers otherwise locked into subsistence agriculture.

As with many new technologies, people are keen to identify and embrace the benefits, but continue to have concerns about the potential risks. Multiple reviews by independent councils and academies[21,22,23] and long-term studies in animals[24,25] have found no evidence of human health hazards. A new study from France initially raised concerns,[26] until, after close scrutiny, it was seen to be flawed because it "appeared to sweep aside all known benchmarks of scientific good practice and, more importantly, to ignore the minimal standards of

It would be foolhardy to dismiss a genetic toolbox that has a unique role to play in feeding a growing population scientific and ethical conduct in particular concerning the humane treatment of experimental animals".[27,28,29] Ethical concerns also continue[30] regarding governance of the technology, the influence of the corporate sector, the significance of a precautionary approach, and the provision of consumer choice. In the European Union, but not in California, if a food contains or consists of GM organisms, or contains ingredients produced from GM organisms, this must be indicated. One outcome has been that retailers withdraw such products from the shelves, thereby removing consumer choice.[31]

In Europe it is the manner of introduction of these new technologies and the associated regulatory regime coupled to a lack of coherent political policy that has led to polarisation and a loss of consumer confidence. This has also had negative effects in developing countries, particularly in Africa.[32] But, as Richard Flavell has commented, "crops did not evolve to serve humankind and many crops are not well designed for agriculture.... Man must continue to seek to make the crops he needs".[33]

Conclusion

We urgently require the best of options and the engagement of the natural, social and political sciences. After all, food security should be for everyone and embraces production, environment, social justice and cultures.

The Malthusian polemic of the 19th century has been replaced today by a different metaphor, the Perfect Storm.[10,34] Godfray *et al.* point out that not only is this an apt descriptor of the challenge of feeding a growing population, it also encompasses the urgent battle to mitigate rising greenhouse gas emissions and global warming, to preserve the Earth's resources, and to provide for intergenerational needs. "There is no simple solution to sustainably feeding 9 billion people, especially as many become increasingly better off and converge on rich-country consumption patterns."[10] So while the Millennium Development Goal of halving hunger by 2015[35] and efforts to restrict global warming to only a 2ºC rise look to be beyond our reach, it would be foolhardy to dismiss a genetic toolbox that has a unique role to play in feeding a growing population and reducing chronic malnutrition, particularly in less developed countries.[36,37] It is no longer a Pandora's box. It has become part of the essential kit for those whom Nobel Laureate Sydney Brenner calls "natural engineers".

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