Up to the challenge?

Rising prices for food and oil could herald a renaissance of plant science

For many years, plant science has resembled the neglected stepchild of molecular biology. New and promising research fields—such as the various ‘omics’—and a strong interest in biomedical research and its applications, have drawn public attention and funding away from plant research. Moreover, academic plant science has been suffering collateral damage from militant opposition to genetically modified (GM) crops and food, particularly in Europe. This might be about to change. The past months have seen drastically rising oil prices and an increasing obsession with biofuels; famines and riots in developing countries triggered by the sudden explosion of prices for staple foods; protests by milk producers in Germany; protests by fishermen in Ireland; and increasing concerns about the ability of agriculture to feed the growing human population. Added to the concerns about global climate change, these developments have brought plant science and agricultural research back to the attention of politicians, the public and the media; it seems that plant scientists might be facing interesting times.

This challenge was well reflected at the fourth meeting of the European Plant Science Organisation (Brussels, Belgium) in Hyères, France, this June: the meeting programme had a strong focus on sustainable development, increasing food production and the development and efficient use of ‘energy’ plants to reduce the world’s addiction to fossil fuels. The meeting also provided a good indication of the current sentiment among European plant researchers, many of whom feel that the political currents and public debate are finally swinging in their favour. Yet, in Europe in particular, public opposition to GM coupled with politics that influence the regulatory system are still the main hurdles to harvesting the fruits of plant research.

In any case, plant scientists are facing serious challenges. Although global food production is increasing, it is not yet sufficient to keep pace with the increasing human population. For example, the average amount of cereals available per person has been dropping since the 1980s to its current level, which is now less than in the 1960s, as Mike Gale from the John Innes Centre in Norwich, UK, pointed out. The demand for ‘energy crops’ to produce bio-fuels, and fickle weather in the USA and Australia, have further contributed to a current shortage of important staple crops. The annual wheat production of 605 million tons is obviously not enough to meet the current demand for more than 620 million tons, according to Catherine Feuillet, from the French National Institute for Agricultural Research (INRA) at Clermont-Ferrand, France, and co-chair of the International Wheat Sequencing Consortium.

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“It is a scary time and a disturbing time, but it is also a very interesting time,” commented Richard Flavell, Chief Scientific Officer of Ceres (Thousand Oaks, CA, USA). “And it is agriculture that has come to the rescue.”

The main challenge for plant research is therefore to use fewer resources in terms of water and arable land while simultaneously working to increase the yield of important crops, increase their uptake of nutrients from the soil—to reduce the use of fertilizers—increase drought tolerance, and improve resistance to pests and pathogens. The main focus so far has been on breeding to produce new varieties that meet these

demands, rather than on using genetic modification. Yet, breeders increasingly use the tools provided by basic research: genetic markers for certain traits and knowledge about plant physiology, genetics, metabolism, genomics and systems biology. Feuillet, for instance, demonstrated how the ongoing wheat sequencing project provides new genetic markers that can be used directly by breeders. In fact, scientists are increasingly cooperating with breeders to quickly translate their research into applications. “There is a huge urgency to match anything that the politicians are expecting,” Flavell commented in regard to the need to speed up the translation of knowledge into products. “Many of the people who set the goals don’t understand how much time it takes to produce a [new variety].”

Ultimately, further improvements can only come from a better understanding of plant physiology, genetics and metabolism, and how plants react to and interact with their environment. This was obvious during the presentations on research aimed at improving yield under drought conditions. As Peter Langridge, from the Australian Centre for Plant Functional Genomics at the University of Adelaide (Glen Osmond, SA, Australia), pointed out, this involves dealing with more environmental factors than just the availability of water; the availability of nutrients, tolerance to salinity and frost, or resistance to toxic boron and aluminium ions in the soil also need to be considered. The complex interplay of these factors means that, “[f]or intensively bred species—and that applies to most of our crops—significant improvements in yield under drought will require complex and novel breeding solutions,” Langridge said.

Similarly, François Tardieu from the INRA at Montpellier, France, emphasized that there is no such thing as the “drought-tolerance gene”. To improve crop yield under drought conditions will therefore require considerable research to understand the role of many genes, and modelling the interactions among them and with the environment. “The question is not whether a gene conveys drought tolerance, but ‘how often’ and ‘under what conditions,’” Tardieu said. Consequently, “[w]e should associate drought tolerance with exact conditions, otherwise it is meaningless.”

Research into drought tolerance demonstrates once again that a ‘one-size-fits-all’ solution is not the best one, as Ian Bancroft from the John Innes Centre commented: “The UK cannot export [varieties] to China and expect that they grow the same.” Instead, breeders and scientists need to create different varieties that are adapted to specific environmental conditions. According to Bancroft, this will require a systems biology approach to inform breeding strategies instead of focusing on a few select traits. It also highlights the danger of the current practice of using just a few elite lines of the most important food crops.

One obvious solution is to exploit the natural variety among wild relatives in order to breed varieties that are tailor-made to the conditions in which they are about

to be grown (Feuillet *et al*, 2008). Yet, the wild varieties of crop plants are dwindling rapidly, thus spurring efforts to preserve the biodiversity of wild and local varieties in gene banks, seed collections and botanical gardens. In this vein, Stephen Hopper from the Royal Botanical Gardens in Kew, UK, presented some projects that are intended to encourage the use of existing biodiversity and locally grown plants, which are better adapted to local conditions. Yet, preserving plant biodiversity will mean even bolder steps in his view, such as growing crops in cities and giving back marginal lands with little productivity to nature. Certainly, this will be a “fundamental challenge to humans as an expansive species,” Hopper noted.

A better use of existing biodiversity also requires understanding evolutionary processes, and the factors that create new varieties and eventually new species. In this light, ‘pure’ basic research, such as the work of Simon Hiscock from the University of Bristol, UK, on hybridization and speciation events in flowering plants, gains practical importance. A better understanding of how natural evolutionary processes take place not only informs conservation strategies and policies to preserve biodiversity, but also ultimately feeds back into applied research and breeding programmes.

As though the challenge of feeding the world’s population were not enough, agriculture has come under additional stress from increasing oil prices, which have fuelled the demand for ethanol and biodiesel. The increasing production of biofuels from staple crops has already become an important driver of their increasing prices and current food shortages, according to a recent report by the World Bank (Washington, DC, USA; Chakraborty, 2008). In addition, US President George W. Bush is pursuing an ambitious initiative to produce 35 billion gallons of bio-based fuels by 2017, which is simply impossible to achieve through the current practice of fermenting corn (Ruth, 2008). In fact, this target could only be met through massive advances in agricultural production and scientific and technological progress in producing biofuels.

The solution, if any, will come from so-called second-generation biofuels that are based on celluloses and hemicelluloses. The challenge for agriculture and plant science is to identify and improve plants that grow quickly and produce large quantities of biomass even under suboptimal conditions. “Biomass is, of course, getting renewed interest”, commented Lothar Willmitzer from the Max Planck Institute for Molecular Plant Physiology in Golm, Germany. He and other speakers presented research on

how to increase biomass production, both in model organisms such as *Arabidopsis thaliana* and in potential energy crops such as switchgrass, poplar or miscanthus.

Yet, even if agriculture produces such energy crops, the technological problems of converting cellulose into ethanol remain. Birgitte Ahring from the University of Aalborg in Ballerup, Denmark, presented results from a pilot industrial plant that converts lignocellulose into ethanol. As a first step, lignin is removed from the raw material—straw—and is then enzymatically fermented to convert cellulose into glucose. Further high-temperature fermentation by thermophilic bacteria produces ethanol, whereas solid leftovers can be anaerobically fermented to methane or used as solid fuel. Overall, the system is 69% efficient at turning straw into fuels and could, if scaled up, produce ethanol for about €0.35 per litre.

Yet, the picture is not particularly rosy as the first enzymatic fermentation process is still a considerable bottleneck. “Enzymes are right now the absolute showstopper,” Ahring commented. Nonetheless, in the long run, this issue will have to be solved, simply because, according to Ahring, “biomass is the only renewable source of energy to meet our transportation needs.” In addition, this type of solution will require changes in agricultural practices to use fertile productive soils for growing food crops and less productive lands to grow energy crops such as perennial grasses, which grow quickly with less water and fertilizers. “It is not going to be one thing, we will have a mixture of different things,” Ahring said.

Once there is a sound supply of biomass, however, there is little to stop human ingenuity from taking things further. Jay Keasling from the University of California (Berkeley, CA, USA), for example, presented ongoing work in his research group that is using bacteria to produce biodiesel. His team have already developed GM bacteria to produce a precursor for the anti-malaria drug artemisinin and are now modifying it to produce fatty acids and isoprenoids as a basis for biodiesel and biokerosene (Hale *et al*, 2007; Keasling & Chou, 2008).

The greatest hurdles to meeting our future needs in terms of food and energy might not be scientific or technological, however, but rather, political. The recent decision by the European Commission to reject the application for a GM maize variety against the explicit advice of the European

Food Safety Agency (EFSA; Parma, Italy) was just the latest example that GM crops still suffer from the whims of public opposition and the politicizing of regulatory processes (Morris & Spillane, 2008).

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Unfortunately, this attitude prevents the use of a technology that can lead to massive improvements—not just in agriculture, but even more so in tackling human health problems. Matin Qaim, an agricultural economist from the University of Göttingen in Germany, calculated the economic benefits of Golden Rice, a GM variety of rice that produces the vitamin A precursor β -carotene (Stein *et al*, 2006). It was developed in 2000 by Ingo Potrykus, then at the Swiss Federal Institute of Technology in Zurich, Switzerland, and Peter Beyer, at the University of Freiburg in Germany, to address the problem of vitamin A deficiency—which can lead to early death or blindness during childhood—in developing countries. On the basis of field research in India, Qaim and his co-workers calculated that Golden Rice could save up to 1.37 million disability-adjusted life years (DALYs) per year by reducing childhood mortality and blindness in India. Even a far more pessimistic scenario would reduce the burden by 200,000 DALYs per year. Furthermore, Golden Rice could be an enormously cost-effective economic solution to the problem, costing only US\$3.06 per DALY. As Qaim commented, the World Bank considers anything that costs less than US\$150 per DALY as effective. Unfortunately, the massive opposition to Golden Rice from environmental groups has delayed its testing and use since 2000; it is only now that the first field trials are about to begin.

Moreover, while the USA and other countries are massively increasing their public funding for agricultural research and plant science, the European Union's Seventh Framework Programme for research includes only meagre funding for both basic and applied plant research. This neglect of funding for plant science at a European level, the prohibitive regulatory system and public opposition to GM crops have had consequences that reach beyond

the continent—they are also affecting agricultural practices and public opinion in developing countries.

Consequently, plant scientists are not able to bring new products to the marketplace alone. “The products of public research are not coming through the pipeline,” Gale commented. “The only players who can push their products through are a few major corporations.” Europe needs to see major changes in policy and public perception in regard to both GM crops and agricultural science in general if the continent wants to prepare for the agricultural challenges ahead. “The real tragedy is that the GM debate is reflecting and affecting the public's general attitude to plant science,” commented Joachim Schiemann, from the German Federal Research Centre for Cultivated Plants and Institute for Biosafety of Genetically Modified Plants in Brunswick, Germany.

Plant scientists in Europe therefore need not only to improve crops, but also public opinion by actively engaging with the public to convince them of the benefits of their work. “It's the wrong way to become cynical,” Schiemann said. “We have to take the [public's] concerns seriously, we have to start where the people are.” Given the rapidly increasing prices for food and oil, and the worries about global climate change, it seems like a good time to convince consumers and politicians alike that plant science—including the genetic modification of crops—is an integral tool to meet the challenges of the twenty-first century.

REFERENCES

- Chakraborty A (2008) Secret report: biofuel caused food crisis. *The Guardian*, 4 July
- Feuillet C, Langridge P, Waugh R (2008) Cereal breeding takes a walk on the wild side. *Trends Genet* **24**: 24–32
- Hale V, Keasling JD, Renninger N, Diagana TT (2007) Microbially derived artemisinin: a biotechnology solution to the global problem of access to affordable antimalarial drugs. *Am J Trop Med Hyg* **77** (Suppl): 198–202
- Keasling JD, Chou H (2008) Metabolic engineering delivers next-generation biofuels. *Nat Biotechnol* **26**: 298–299
- Morris SH, Spillane C (2008) GM directive deficiencies in the European Union. The current framework for regulating GM crops in the EU weakens the precautionary principle as a policy tool. *EMBO Rep* **9**: 500–504
- Ruth L (2008) Bio or bust. *EMBO Rep* **9**: 130–133
- Stein AJ, Sachdev HP, Qaim M (2006) Potential impact and cost-effectiveness of Golden Rice. *Nat Biotechnol* **24**: 1200–1201

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