disease, the human version of BSE, not only created a crisis of trust in risk-management agencies and political institutions, but also in science itself. Science was no longer viewed as independent, but as having taken part in a political decision to conceal the dangers of BSE.

This increasing interlinking of science and society puts greater pressure on science to produce applicable results, to come up with solutions in times of crisis and to support economic growth. "The public is more commanding today, as a consumer of science," said Fuller. Science cannot be isolated in its ivory tower, but it would be equally wrong to turn science into a service industry that is driven by politics, business and society, given that applied and problem-orientated research must rest on the knowledge that comes from independent open-ended basic research. As Fuller noted, a way out of this dilemma—how to maintain the autonomy of science while using it to find solutions to social problems—would be to strengthen the traditional role of universities as independent institutions of knowledge production and dissemination, as originally advocated by Wilhelm von Humboldt around the turn of the nineteenth century. "Research today is becoming more privatized and teaching is becoming much more instrumentalized and vocational," said Fuller. "The Humboldtian ideal has to be reinvented in an era where the main centre of research has shifted from the humanities to the natural sciences." At the same time, the shift towards more society-driven research is irreversible and scientists must adapt to this expanded role. As Rose emphasized, "…we [need to] go for greater transparency and recognize that the scientist is just one player in a much more complex world" (Rose, 2004).

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GM plants for your health

The acceptance of GM crops in Europe might grow as soon as the first products to offer direct benefits for consumer health become available

When will agricultural biotechnologies, such as genetically modified (GM) crops, reach Europe? This was the main question at the Agricultural Biotechnology International Conference (ABIC)—the largest of its kind—that took place in September this year in Cologne, Germany. Given that the ABIC was accompanied by a parallel conference organized by critics of GM crops and foods, this is an appropriate question. Most of the European Union (EU) member states have not yet approved the GM crops that are used widely and safely elsewhere in the world. Moreover, although the EU has finally lifted its moratorium on GM crops, and has passed new regulations for growing and marketing GM foods, national politics, legislation and ideological views about consumer and environmental protection have further hampered their use. European consumers remain wary of agricultural biotechnology and its products, as they do not see any direct benefits from GM crops and are, therefore, understandably reluctant to accept them. But it is only a matter of time before GM foods arrive on supermarket shelves across Europe, predicts Ashley O'Sullivan, President and CEO of Ag-West Bio Inc. (Saskatoon, Saskatchewan, Canada). "The reality for legislation to regulate agricultural biotechnology is that the train has left the station and there is no way of going back," he added.

> …to convince the cautious European public, agricultural biotechnology still has to […] offer products that directly benefit consumers

But to convince the cautious European public, agricultural biotechnology still has to show that it can do more than increase the returns to farmers, and offer products that directly benefit consumers. The next wave of GM plants, which are currently being developed and tested in academic and industry laboratories around the world, including Europe, may soon do this. A range of new GM crops in the research pipeline will offer direct benefits to consumers and environmental health, and could therefore change the public perception of this technology and, accordingly, the political and legal situation in Europe.

A look at the global picture shows that the EU is still standing at the sidelines when it comes to the commercial use of GM crops, although its academic and industrial plant scientists remain at the forefront of this research. Worldwide, farmers in 18 countries grow GM crops on a total of 67.7 million hectares (Figs 1,2). In Europe, only farmers in Spain and Germany grow pest-resistant GM maize. The UK recently approved a herbicide-tolerant maize after extensive risk assessment showed that it benefits the environment and wildlife, but its manufacturer, Bayer CropScience (Monheim, Germany), later withdrew the crop, claiming that the conditions imposed by the British Government on its growth had left it economically unviable. This reluctance to grow GM crops is surely due to ideological views, political and public reactions to various food scandals in Europe—such as bovine spongiform encephalopathy (BSE), foot and mouth disease, and acrylamide in fried foods—and pressure from non-governmental organizations. But it is also a result of limited options. "Six countries, four crops, two traits. That's what it is at the moment," said Bernward Garthoff of Bayer CropScience. So far, only GM maize, canola, soy and cotton have been approved worldwide, and only two traits are subject to genetic modification: herbicide tolerance and pest resistance through the introduction of the *Bacillus thuringiensis* toxin gene. Moreover, just six countries—the USA, Canada, Argentina, Brazil, China and South Africa—account for more than 99% of the global market in GM crops, which was estimated to be worth between US$4.5 and 4.75 billion in 2003. "We have here a case of 'invented in Europe' and 'exploited in the rest of the world'," said Manuel Hallen from

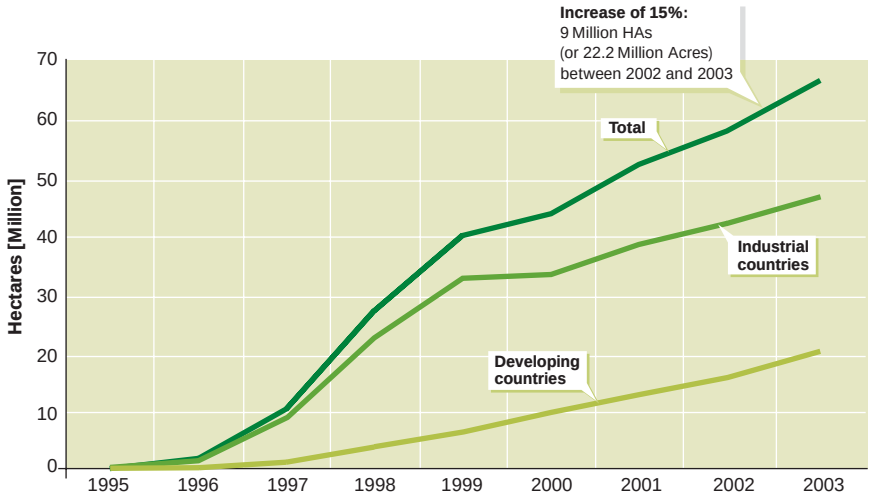

Fig 1 | Global area of transgenic crops. Source: James, 2003.

the European Commission (EC) Directorate General of Research (Brussels, Belgium).

GM crops have already shown benefits for farmers and the environment, as O'Sullivan illustrated by citing data from Canada on the growth of herbicide-resistant canola. The switch from conventionally bred to GM herbicide-tolerant canola increased the yield by 10%, reduced herbicide use by 40% (approximately 6,000 tonnes) and reduced fuel use because the farmers needed to spray less often. Canadian agriculture saved a total of C$464 million by growing GM canola, according to O'Sullivan. Elsewhere, Argentina reaped massive benefits from GM soybeans, as well as insect-resistant and herbicide-tolerant maize, cotton and canola, as Esteban Hopp from the National Institute of Agricultural Technology in Buenos Aires, Argentina, pointed out. The use of GM crops allows farmers to significantly reduce their costs, which has made the country one of the leading exporters of soy and soy products. During the financial crisis in Argentina in 2002, the agricultural sector continued to expand and to employ more people. Furthermore, food donations from Argentinian farmers helped to ease food shortages in major cities.

Similarly, Florence Wambugu, founder and CEO of Africa Harvest Biotech Foundation International (based in Nairobi, Kenya), and Jocelyn Webster, Executive Director of AfricaBio (a biotechnology stakeholder association in Cape Town, South Africa), have described how modern seed technologies, including GM crops, have helped small-scale African farmers to make a living. "The seed became the delivery of technology for farmers that cannot be reached by Western aid," Wambugu said about programmes to supply African villages with pest-resistant high-yield plants. For these farmers, it does not matter whether the seed comes from conventional breeding or GM. "We can talk about GM technology, hybrid or tissue culture and all that, [but] we must do more to actually reach out to the poor," she said. "The technology has potential but there is a need to move beyond the current four crops."

These arguments will do little, however, to convince farmers, food marketers and consumers in Europe. Without tangible benefits, consumers will not buy GM foods and food marketers will not put them on supermarket shelves. Moreover, European farmers, who are pampered by heavy subsidies, do not have to grow GM crops to stay competitive. To achieve acceptance, products that offer direct health and nutritional benefits for European consumers are needed. This has not escaped the attention of agricultural businesses. Companies such as Monsanto (St. Louis, MO, USA), DuPont Agriculture & Nutrition (Wilmington, DE, USA) and Bayer CropScience are investing heavily in what Hans Kast, President and CEO of BASF Plant Science GmbH (Limbergerhof, Germany), has called the second revolution in agricultural biotechnology: GM foods with health benefits. These products would gracefully merge agricultural biotechnology with the rapidly growing market for functional foods (with additives such as vitamins or micronutrients) and nutraceuticals (compounds isolated from foods or plants with claimed health benefits). Given that many consumers who are wary of GM foods nevertheless eat nutraceuticals or functional foods, despite the often unfounded or unproven health claims, functional GM foods might overcome the widespread rejection of agricultural biotechnology by offering proven health benefits—unlike functional foods and nutraceuticals that are sold over the counter, GM plants are subject to rigorous safety and efficacy tests.

Obvious candidates for incorporation into GM foods are omega-3 polyunsaturated fatty acids, which are particularly important for prenatal and early childhood neuronal development. These compounds are primarily found in cold-water fish, such as salmon, tuna, halibut and herring. Given the declining state of marine fisheries and concerns over mercury contamination, GM plants that supply omega-3 polyunsaturated fatty acids would not only be beneficial for consumers, but could also ease the pressure on fish stocks. Bayer CropScience is collaborating with the research group of Ernst Heinz at the University of Hamburg, Germany, to develop flax plants that produce omega-3 polyunsaturated fatty acids. At the ABIC, Petra Cirpus from Bayer CropScience presented preliminary results from transgenic flax equipped with algal genes, which can produce omega-3, omega-4 and other polyunsaturated fatty acids. Once this GM flax is tested and approved, oils from this plant will probably do more to convince consumers of the benefits of biotechnology than any public-education campaign.

> …unlike functional foods and nutraceuticals that are sold over the counter, GM plants are subject to rigorous safety and efficacy tests

Similarly, Steve Padgette, Vice President of Biotechnology at Monsanto, and Ganesh Kishore, Vice President of Technology at DuPont Agriculture & Nutrition, presented information on the efforts of their respective companies to develop foods with health benefits for consumers. Both companies are focusing on GM soy and canola to produce omega-3 fatty acids, although other fatty

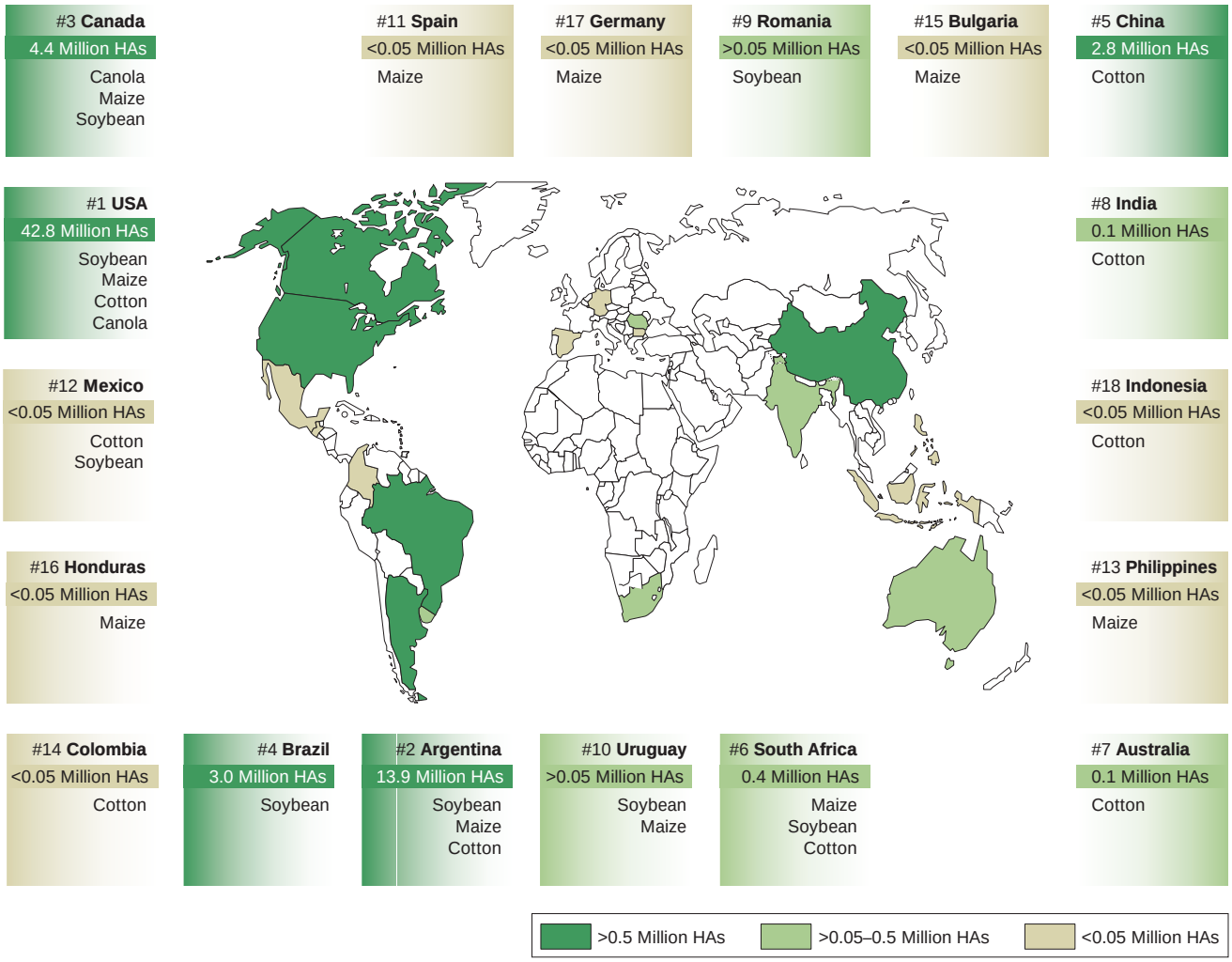

Fig 2 | Countries growing GM crops in 2003. Source: James, 2003.

acids and proteins are also equally pursued. One goal is to create soy and canola with longer-chain unsaturated fatty acids, which would lower the levels of low-density lipids and cholesterol in the blood, thereby reducing the risk of heart disease. Other efforts aim to create vegetables that contain larger amounts of compounds that protect against cancer, such as lycopene in tomatoes, or to engineer basic staple crops, such as rice, wheat and maize, that can produce larger amounts of vitamins and micronutrients. For example, academic researchers at the Danish Institute of Agricultural Sciences in Tjele, Denmark, have already developed such plant varieties for developing countries, where many people rely on only one food staple and can rarely afford vegetables, meat or fish. This research is not just focused on GM plants, but, as Padgette pointed out, "We can deliver new traits for the customer through conventional breeding and we certainly do that, but there are certain traits where you can't do that."

This change in the marketing of GM crops might serve to sway public opinion. Marcus Girnau from the German Federation of Food Law and Food Science, an umbrella organization for the German food industry, cited an online survey from Dialego, a market research company based in Aachen, Germany, along with an article from the German financial newspaper *Handelsblatt* from July this year, which found that Germans might, in time, accept GM foods if they believe them to have health advantages. Although 38.5% of the respondents would not buy foods with GM content at present and more than 80% said they wanted GM food to be labelled as such, more than 30% would choose GM fruits if they tasted better than normal ones and more than 65% would be willing to buy a yoghurt with GM content if it protected them from colon cancer. Girnau concluded that even in Germany, which is one of the strongholds of the anti-GM movement, opposition might eventually fade. Another survey in the UK showed that 37.8% of respondents would have no preference between non-GM and GM breakfast cereals (Moon & Balasubramanian, 2003). As Jocelyn Webster put it, "If we had an apple that contained Viagra® or an apple that [suppressed] appetite, we wouldn't have these problems."

GM plants may not only help to maintain or improve health, but there is also an as yet untapped potential for producing pharmaceuticals of all kinds, as Julian Ma from St. George's Hospital Medical School at the University of London, UK, has

shown. So far, the production of pharmaceutical compounds, most notably proteins and peptides, has been largely done in GM bacteria or mammalian cell cultures, which the public seem to support fully. However, plants have several advantages over bacterial systems; in particular, they have a full complement of organelles that can produce even the most complex mammalian proteins. Ma and colleagues used plant cells to produce correctly folded active immunoglobulins that were biologically active in mice, and it would take only a small step to apply this same procedure to human proteins. Plants also have another important advantage over other production methods: "Production on a globally relevant scale might only be achievable with plants," said Ma, citing a vaccine against the human immunodeficiency virus (HIV) as an example. If it were available, the global need for such a vaccine would be so overwhelming that the only option to meet the demand would be to produce it in fields of GM plants. Public resistance against GM plants would probably fade rapidly in the light of such an enormous benefit for public health.

The EC wants to move past the debate about GM crops to reap the economic and scientific benefits of plant research. That was the rationale behind lifting the moratorium on GM plants and issuing the Directive on GM labelling (EC, 2003), which requires that all foods that contain more than trace amounts of GM content must be labelled as such. This would not only help to overcome the suspicions of consumers, but would also finally give food producers and marketers in Europe clear regulations and a legal framework under which they could market GM foods, as Girnau pointed out. "We have to have a freedom of choice not only on the consumers' side but also on the producers' side," he said. However, the translation of the EC Directive into national law has been disappointing, with many countries dragging their feet or passing additional legislation with the aim of preventing the growth of GM crops. The German Federal Ministry of Consumer Protection, Food and Agriculture, for instance, has drafted an addendum to the law on genetic engineering that would allow the deliberate release of GM crops in Germany but would impose such strict regulations that it would be almost impossible to grow them. This would have serious consequences not only for agriculture but also for field trials of experimental crops that were developed by German researchers, as the Deutsche Forschungsgemeinschaft (DFG), the main scientific funding agency in Germany, commented in a harsh rebuke of the draft (DFG, 2004).

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Whether GM crops are grown in Europe as part of the normal diet, as functional foods or to produce therapeutics, the lessons to be learned from the accompanying debates are clear to regulators and business alike. "Public concerns and perceptions cannot be ignored in a democratic Europe," Hallen said. Girnau also warned of repeating some of the early errors that were made in the debate over GM crops: "Consumer trust is indispensable in the marketing of GM food, and basically of all food." This message also seems to have been heard by industry. Harvey Glick, Director of Scientific Affairs at Monsanto, explained that his company now considers stakeholder concerns to be as important as shareholder expectations, and supports outreach programmes with stakeholders in the GM crop debate.

Others are also willing to move ahead, while meeting public concerns along the way and adhering to EU regulations. "The EU has passed the most strict legal framework in the world," Kast said about the requirements on labelling, GM content thresholds and traceability, and "we in industry need to accept this." But he also warned the governments of EU member states not to squander the potential opportunities by further postponing the introduction of GM crops. "If we fail to implement these EU rules and regulations, there will be consequences," he said. "No innovation, no new products and EU farmers and EU industry will lose global competitiveness."

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