Public-good plant breeding: What should be done next?

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Abstract

Plant breeding has played a major role in improving crop production during the past century. From the birth of genetics to the early 1980s plant breeding was driven in the UK mainly by objectives directed primarily to the public good. Since that time most plant breeding has been transferred to the private sector, which must define objectives more narrowly in terms of commercial success. There were significant changes in agriculture over the 20th century, including the use of production subsidies to stimulate increase in crop production. Associated with these changes was a growing public unease about the impact of agriculture on the environment and an increasing dissociation between agriculture and food supply. It is within this context that the UK has recently decided to review whether to proceed with the commercial cultivation of genetically modified (GM) crops. To aid this decision the UK Government has supported a review of the science, economics and public attitudes associated with the decision. As part of this review there has been vigorous campaigning on the topic, which has become polarised and politicised. In considering a future for plant breeding, it is important that we take stock of breeding aims that are directed primarily at meeting public-good and needs-led objectives. Various examples of public-good breeding objectives are discussed. But in meeting future public-good objectives it is important that there is greater honesty and openness in a discussion that values all constructive contributors.

INTRODUCTION

Over the past century scientific plant breeding has made a very significant contribution to satisfying the needs of people for food, feed, fibre and pharmaceuticals. It is estimated that if we had not had innovative scientific plant-breeding programmes in place since the early 1900s, we would now need extra land about the size of India to produce our current world food supply.[1] Over the past 20 years plant-breeding methods have also made astonishing advances in knowledge through molecular genetics, making it possible to modify crops in novel ways. This has provided important opportunities for plant breeding, but has also raised anxieties of a more general nature about agriculture, the environment, world food supply and international trade The recent public debate about the commercialisation of genetically modified (GM) crops in the UK has highlighted the emotive nature of issues related to food production and its impact on the environment around us. GM issues have become a lightning rod for wider concerns in society.

The aim in this paper is to propose a future for plant breeding that is directed primarily at meeting the diverse needs of people and of the environment. Before reflecting on a future for plant breeding that is principally needs-led, it is first necessary to recall its past.

BRIEF HISTORY

Plant breeding relies heavily on the science of genetics, a term that was coined only in 1905. Over the following decades, there were dramatic advances in understanding the principles of inheritance. Crop improvement to that time had been carried forward largely by empirical selection from what were originally wild food plants. Selection and domestication led to the deliberate cultivation of desirable plants in cleared areas. These early crop improvements were achieved with little knowledge of the underlying scientific principles. With increasing knowledge of genetics, people began to appreciate the enormous potential to improve crops by managed hybridisation, along with mass screening and evaluation. During the evolution of breeding methods there have been many advances in methodology.[2] For example, over the past two decades it has become possible to isolate DNA sequences from many different organisms that normally do not cross-hybridise, and to incorporate them into crop plants. The merit of this approach is that it provides a wider source of genes for plant breeders to improve crops.[3,4]

In the early 20th century, plant breeding was seen principally as a public-good activity in the UK

Concurrent with these scientific advances have been major changes in the incentives for plant breeding and in the organisations engaged in it. In the early 20th century plant breeding was seen principally as a public-good activity in the UK. The science of genetics was young, and two world wars emphasised the crucial importance of national self-sufficiency. The need for food security, and cheap food for a population struggling to rebuild and recover, became an important policy objective. Publicly supported plant-breeding institutions, often associated with universities, were established in the UK and across the world.[5] These organisations adopted a wide range of breeding objectives for all the principal crops grown in the UK, and various unfamiliar crops were also evaluated and developed for cultivation. The period from the1950s to the 1980s was the heyday of publicly supported plant breeding in the UK and internationally, with very close ties between basic research, strategic research and practical plant breeding. Cross-communication and collaboration were easy because multidisciplinary groups of scientists were found under the same roof, mixing formally and informally, and mostly with a common primary purpose of improving crops for the public good. Priorities were directed to the crop and plant characters judged at the time to be of value to farming and the public. Objectives were continually evolving, with new programmes adopted and old ones phased out. The UK was also at that time a major training country for plant breeding, attracting students and visiting scientists from across the world, including many from developing countries.

The need for food security and cheap food became an important policy objective

Cross communication and collaboration were easy because multidisciplinary groups of scientists were found under the same roof

In the 1980s it was considered politically desirable to move services from the public to the private sector. As a consequence, most plant breeding was privatised. As part of this exercise the Plant Breeding Institute (PBI) in Cambridge was sold to the private sector at the time when about 80 per cent of the wheat varieties grown in Britain were bred there.[6] The sister plant-breeding institutions in Scotland and Wales were not sold, but the plant-breeding programmes that continued were mostly funded by public–private partnerships or terminated.

Plant breeding left to survive by market forces has undergone a marked change in character

Plant breeding left to survive by market forces has undergone a marked change in character. The principal revenue from breeding is from the royalties paid to breeders from plant variety rights, and from seed sales. As an indication of the revenue available for plant breeding, the total gross income from royalty payments on all crop varieties sold in the UK (from about 18 different crops) is in the region of £34m per annum.[7] For comparison, Tesco, the leading UK supermarket, makes a pre-tax profit of around £2bn per annum. In broad terms, therefore, royalties provide an average gross income of around £2m per crop in the UK. Orphan crops, ones for which there is insufficient income to fund breeding, are those with incomes falling significantly below this threshold. The low income has been further aggravated by loss of revenue for breeders from farmers saving their own seeds, rather than buying new seeds each year. The consequence is that much of private sector breeding is not very profitable, and increasingly is only viable financially by concentrating on breeding crops and crop characters that have global

Crop varieties bred by the private sector are for the public good, but their breeding targets must be commercially viable

importance. Varieties of crops adapted to local environments, regional pests and diseases, minority farming systems and specialised public needs, have largely become uneconomic or at least very difficult to sustain. Crop varieties bred by the private sector are of course used for the public good, otherwise they would not sell, but their breeding targets and production are defined much more narrowly according to national and international commercial constraints.

It was expected that GM varieties would increase the profitability of the seed industry. Income has been obtained from GM varieties in other countries (especially the USA) from one or more of the following sources:

- by patenting genes introduced into crops and by licensing their use to other commercial plant breeders;
- by marketing packages of GM crop varieties and associated herbicides for weed control; and
- by requiring farmers to pay a fee (Technology Transfer Fee) when seeds are purchased, to cover the extra performance derived from the GM crop character.

The drive for abundant cheap food was supported by EU subsidies

Associated with these changes in the science and practice of plant breeding, and its financial support over the last 80 years, there have been deliberately associated and coincidental changes in agriculture in Europe. The drive for abundant cheap food was facilitated by subsidies in agriculture through the EU Common Agricultural Policy in order to provide more efficient agricultural produce from land.[8] Farmers were encouraged to remove trees, hedges and walls, to pipe-up ditches, to fill in ponds and to reap benefits from economies of scale and mechanisation. Farmers were (and still are) given production subsidies to encourage them to grow ever more produce. The consequence is that many crops in the UK and the EU are in surplus, and prices have become so depressed that even with subsidies, farmers are struggling to earn a living. This is adding further pressure on farmers to drive down costs of production by economies of scale and reduction of labour, and to increase yields by chemical inputs.

Farmers were encouraged to remove trees, hedges, etc and reap benefits from the economies of scale and mechanisation

CONCERNS AND EVENTS IN AGRICULTURE

Concurrent with these changes has been an increasing concern among campaigning groups and among interested members of the general public about the impact of agriculture on the environment, the decline in certain farmland birds and wildlife, and the increase in use of chemical sprays and fertilisers. Even though these inputs are overseen and approved by comprehensive regulation, there has been growing public dismay about the course of agriculture and the wider environment. Over 70 per cent of the land area in the UK is farmed in some way, so changes in agriculture inevitably impact on the wider environment. Countries with substantial resources of uncultivated land (eg USA, Canada) can set aside natural parks to help support wildlife. But in the UK, we largely live and farm in our natural parks.[9]

These dramatic changes in agriculture were recognised last year in a report for the UK Government[10] (chaired by Sir Don Curry), which argued that a disconnection has arisen between agriculture and food supply. It recommended that in order to safeguard the future course of agriculture, major review and reform were essential, including significant changes in the financial incentives and subsidies for farmers. A substantial review of the Common Agricultural Policy in the EU has been initiated, and the indications are that measures to favour wildlife and the agricultural environment will be given higher priority in the future.[11]

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Largely coincidental with these events in agriculture was the devastating outbreak of BSE (bovine spongiform encephalopathy) and the associated CJD (Creutzfeldt–Jakob Disease) that causes an untreatable, invariably fatal illness in humans. Over 100 people are confirmed to have died so far from this disease,[12] although the final numbers will certainly be higher and probably spread out over the next 20 years. There was also a major outbreak of foot and mouth disease in the UK in 2001 that devastated many livestock farmers. The consequence of all of these events in agriculture has been to raise social and political awareness of problems in agriculture, food production and the environment within a significant proportion of the UK population.

Within this context, the UK launched a public debate on the commercialisation of GM crops

NATIONAL GM DEBATE

It is within this context that in 2003 the UK held a national public debate on the possible commercialisation of GM crops in the UK.[13] The UK Government sponsored two further strands of enquiry associated with this debate: a review of the economic impact of the commercialisation of GM crops,[14] and a review of the science associated with the assessment and possible impact of GM crops.[15] The public debate strand involved a series of meetings across the country where people discussed the issues and were able to register their views. High-profile campaigns by activist groups, and the press, accompanied the public debate, both groups being largely opposed to commercialisation. Activists have organised vandalism of the scientific trials designed to evaluate the environmental impact of the herbicide treatments applied to the GM crops currently being considered for commercialisation.[16]

High-profile campaigns by activist groups and the press accompanied the public debate

There was no attempt in the report of the national debate[17] to say whether the public were right or wrong about any GM issue, even on matters of fact. The report acknowledges that a significant number of people participating in the public debate were associated with campaigning groups, most of which were against the commercialisation of GM crops in the UK.[18] The report also acknowledges that concerns about GM crop commercialisation have to some extent become a proxy for broader anxieties and perceptions in society,[19] about the environment, influence of big business, mistrust of regulation and authority and about plant breeding being driven by profit rather than for the public good. Some members of the public expressed concern that decisions affecting UK food, agriculture and the environment are being made by powerful organisations abroad. Opposition from some members of the public to the recent war in Iraq[20] has not helped to calm anxieties about the international influence of the USA and the apparent lack of response from the UK Government to public opposition to it.[21] As a result of this background, it is fair to say that modern GM methods of plant breeding have taken on a social and political profile far beyond a rational assessment of their direct impact and significance.

The report on the GM debate acknowledges that concerns about GM crops have to some extent become a proxy for broader anxieties in society

A major ongoing source of disagreement has been that the 'sides' in the GM debate often use a different 'currency' in their reasoning. The scientific community largely uses scientific analysis and reasoning of the kind adopted by the scientific advisory committees to judge the impact of GM crops on human health and the environment. Many of the activists, however, are concerned about who has power over food supply and the environment. The latter often argue that an imbalance has developed, which gives too much power to multinational companies, and decisions are often made on purely commercial grounds. This significant difference in 'currency' makes it difficult to reach a common understanding because neither 'side' places the same value on the other's 'currency'. Calm, rational dialogue is also difficult because, in argument, issues (including the science) are often presented in a manner that has the greatest political and judicial impact.[22]

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WHERE DOES THIS LEAVE THE FUTURE OF PUBLIC-GOOD PLANT BREEDING?

It is fair to say that public-good plant breeding is in crisis

It is fair to say that public-good plant breeding is in crisis. This is not least because farmers, the buyers of plant breeders' seed, are also in crisis from falling incomes. Some radical thinking is called for, beginning with reminding ourselves why most of us first became interested in plant breeding – it was for the public good. Our aim is to provide food, feed, raw materials and specialised products. Novel thinking is needed to review plant-breeding objectives. Either we conclude that all future plant-breeding objectives must depend on the vagaries of market forces, or that a principal driver for plant breeding is the public good, and explore the current means to facilitate this.

It is first important to examine what kind of objectives would qualify for the status of contributing to the public good. Views vary considerably and individual breeders will have their own preferred list. To catalyse the process of thinking, a meeting was held in May 2003 at the Natural History Museum in London to stimulate discussion on plant-breeding objectives.[23] At that meeting I described my personal list of primary public-good objectives, and I will present them again here.

Either we conclude that all future plant breeding objectives must depend on the vagaries of market forces or that the public-good is a principal driver

PROPOSED OBJECTIVES FOR PUBLIC-GOOD BREEDING

I have highlighted five broad areas relevant to both developed and developing countries. The knowledge base needed to address plant-breeding objectives in developed and developing countries is basically the same even though the ways of applying knowledge may be different in the various applications.

Resistance to pests and diseases

This is an important objective. Pests and diseases destroy more than 25 per cent of world crop production annually, while it is not uncommon to see figures in particular crops and regions much higher than this, even up to 100 per cent. Chemical sprays are widely used for control, but the methods used to apply them in developing countries can often be harmful to operators. There are well-documented instances each year of people being poisoned and even killed by the application of these substances.[24] Three examples of breeding for crop pest and disease resistance are highlighted below.

Wheat rust resistance

In recent years, a race of leaf rust developed in durum wheat that virtually wiped out the CIMMYT breeding programme in Mexico. There are new races of rust developing continually in all countries, which have the potential to wipe out substantial areas of crops. Infection is occasionally serious in the UK, but at present we have fungicides to control it. Resistance genes have been cloned, principally to understand how they work, so that breeders can incorporate more robust and resilient genetic resistance. Breeding for fungal resistance will reduce the need to control yellow rust by fungicides in developed countries. In developing countries there is rarely the opportunity to apply fungicides, so genetic resistance would meet an important need.[25]

Rice yellow mottle virus resistance

This is a serious disease in West and East Africa, and sometimes leads to total crop failure. A form of resistance has been introduced in a collaborative research programme involving UK scientists, and the efficiency of resistance is being evaluated. Resistance has been demonstrated against low and high doses of virus inoculum. Research is needed to evaluate the performance of the genetic resistance mechanisms under African agriculture.[26]

Striga *in maize*

Striga is a parasitic weed that attaches to the crop plant and extracts its nutrients.

The weed *Striga* is estimated to affect about 100 million people

The weed makes a significant contribution to poverty in Africa and is estimated to affect about 100 million people. It can cause 20–100 per cent crop yield reduction and is a problem on 20–40 million hectares in sub-Saharan Africa. Breeding lines of maize have been selected that are tolerant to a specific herbicide. Use of the herbicide (Imazapyr) applied to the maize seed coat kills the *Striga* but allows the tolerant maize to survive. Control of *Striga* by this low-cost herbicide is estimated to cost about US$4 per hectare and give a benefit-to-cost ratio of about 25:1.[27] In order to provide robust and sustainable solutions to this very significant *Striga* problem, it is important to develop other control strategies by crop breeding.[28]

Tolerance to stressful environments (salinity, drought, acid soils, high and low temperatures)

Soil salinity

Over 6 per cent of the world's land has saline soil. Salt tolerance genes have been identified in wheat, and tolerant lines are being developed in a collaborative programme involving UK scientists.[29]

It is estimated that a third of the world's arable land is affected by drought

Drought tolerance

Research on this topic is crucial because one-third of the 1.5 billion hectares of the world's arable land is affected by drought[30] and over half of the 40 million hectares of rainfed lowland rice in South-East Asia is affected by drought annually.[31] Genes have been mapped for tolerance and advanced breeding lines are being developed. A set of genes that control the production of trehalose, a drought-protecting sugar, is also being introduced into Indica rice which represents 80 per cent of the rice grown worldwide.

Human nutrition and health

Enhanced vitamins and minerals

Approximately 250 million people (WHO figures) suffer from vitamin A deficiency, which can lead to blindness. An estimated 400 million people suffer from iron deficiency and anaemia. Breeding lines of wheat have been selected at CIMMYT with enhanced micronutrients. It is hoped that the much publicised Golden Rice will provide enhanced levels of dietary vitamin A and iron.[32] These plant-breeding lines are currently being evaluated. Mustard crop plants with enhanced Vitamin A in the extracted cooking oil (Golden Mustard) are also being evaluated. It is important that these enriched crops are soon tested under realistic conditions in developing countries.

Anti-cancer properties

Brassicas naturally contain glucosinolates that protect against a wide range of cancers (lung cancer, stomach cancer, colon cancer and rectal cancer). Genes controlling relevant glucosinolates have been identified in broccoli and breeding lines are being enriched 80 times for anti-cancer properties.[33]

Introducing apomixis into crops

Apomixis is a process by which some plants have evolved to produce seeds without relying on pollination (colloquially called 'seed without sex'). Its introduction into crops would provide a potential way of allowing farmers to save hybrid seeds, where the seeds of a crop would be genetically identical to the hybrid parent. Hybrids can have 30 per cent or so higher yields, so apomixis would be a way of providing farmers, perpetually, with the advantage of hybrid varieties. With conventional hybrid varieties, farmers must buy new seeds from the breeders or seed producers each year. Interestingly, over 400 plant species are naturally apomictic, but this includes very few crop plants, and there are attempts to transfer this character from *Tripsacum* to maize. There are also parallel programmes in wheat, rice and cassava. Apomixis is a complex plant character and various research groups have been working on understanding it for several years.

This plant-breeding objective raises an important issue of financial support for public-good plant breeding. If apomixis is successfully transferred into crops, farmers will be able to save their own high-yielding seeds for many years and, therefore, the revenue from seed sales will be limited. This objective fits well, therefore, into the public-good category but would probably not be attractive to a private company.

Pharmaceuticals from plants

Infectious diseases kill 13 million children and young adults in the Third World annually

About 300 million children born every year are not adequately immunised. Infectious diseases kill 13 million children and young adults in the Third World annually. Cholera, dysentery and typhoid fever kill almost 2 million children under 5. The ideal vaccine should be safe, easy and cheap to produce, temperature-stable and easy to deliver and administer. Fortunately, plants are able to make vaccines correctly and efficiently, and plants are naturally very efficient producers of protein. One hundred hectares of greenhouse could potentially provide enough Hepatitis-B vaccine for South-East Asia every year.[34]

The crop improvement debate has become preoccupied more by plant breeding method than mission

This application raises questions about the practicalities of producing vaccines in plants and whether such plants would need to be grown in contained glasshouses or could be cultivated outdoors. It also raises issues of the plant species used to produce vaccines and whether vaccine-producing crops and food-producing crops can coexist. These issues will need to be examined very carefully. There is also a challenging issue of how the dose of a vaccine might be controlled. If the vaccine is extracted and administered in the conventional way, this should not be difficult. But controlling dose is likely to be more challenging if the plant material (eg fruit) is eaten.

The different sides have become imprisoned by their campaigning positions

In discussions with a range of plant scientists and breeders, many other public-good objectives have been proposed, including plant architecture and yield, nutrient use and nitrogen fixation, bioremediation, biofumigation,[35] removal of allergens from food (eg peanut allergies), plant architecture, dwarfing, water efficiency, production of high-value compounds and so on. The intention is that views will be canvassed from different people and organisations over the coming months to develop and refine ideas on opportunities and constraints.

TECHNOLOGY

This paper has deliberately avoided discussing details of the technology being used to approach these public-good breeding objectives, because it is believed that the crop improvement debate has become preoccupied more by method than mission. For those interested in method, about a third of the examples quoted are derived from conventional breeding, about a third by conventional and GM breeding in parallel, and about a third by GM methods alone. The production of novel pharmaceuticals in plants, for example, can be achieved only by GM breeding.

FUTURE CHALLENGES AND CONCLUSION

To regain interest in public-good plant-breeding objectives that are primarily needs-led will demand radical thinking and challenging decisions by all players. This will require some important ingredients:

- **Greater honesty and openness in discussion**. One of the major casualties in the GM debate, and the events leading to it, has been open and honest discussion. The different sides have become imprisoned by their campaigning positions. This has not been helped by issues that demand careful description and analysis being presented in campaigns and in the media as soundbites, and in ways deliberately aimed to have maximum political and judicial impact. The

A review of the public-good needs of plant breeding and an assessment of how the private sector can meet them are needed

There are few commercial incentives to improve crops for desperately poor and malnourished people

A casualty of the dispersion of plant breeding in the UK is that there are now more limited opportunities for multidisciplinary training in plant breeding

Drawing desperately poor people out of grinding poverty will require attention to many things, including access to seeds to grow productive crops

author suspects if the different sides genuinely recognised their different 'currency' in debate (as discussed earlier), rather than hiding it, there may be a greater measure of agreement. Whether or not the UK commercialises GM crops next year has become the overriding matter of principle and the sole purpose of the campaigns. Measured and rational debate is the casualty.

- **Support for public-good breeding**. There is virtually no plant breeding in the UK that is supported entirely by the public sector. Many plant-breeding programmes that were in the public sector in the early 1980s are now entirely in the private sector, in public–private partnerships or have been closed. In the UK we need to review this balance urgently: first, by reviewing the major public-good needs, and then by assessing how far the private sector can meet those needs. It is important to note that the objectives of plant breeding can be influenced by the kinds of varieties given regulatory recommendation for use in agriculture and by the provision of financial incentives to encourage particular farming practices. Claims that modern private sector breeding will feed the world need to be tempered by commercial and ideological realism. In reality, there are few commercial incentives to improve crops for desperately poor and malnourished people in the world. Only by placing all the issues and realities on the table will we make real progress.
- **Centres of learning**. A significant further casualty of the dispersion of plant breeding in the UK is that there are now limited opportunities for multidisciplinary training in plant breeding. This is to some extent a function of the greater sophistication of methods now used in handling and analysing plants, but a major problem is that there are few centres of learning with a wide diversity of skills and experience, including skills and first-hand experience in plant breeding. There is also a gap in the development from basic and strategic research through to the stage of 'proof of principle', so that it can find application in practical plant breeding.

Above all, there is a need for respect for the different contributors. This is, without doubt, difficult with the highly polarised and sometimes acrimonious exchanges. But the responsibilities are too great to be deterred by this. The current disagreements cannot be allowed to overshadow the needs of humanity. Drawing desperately poor people out of grinding poverty will demand attention to many things, including: providing land, water, markets, credit and also seeds to grow productive crops. All constructive contributions to achieving this goal are important and need to be recognised.

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2. Advances in plant-breeding methods have included embryo culture and the hybridisation of crops with different plant species or genera, induced polyploidy, induced haploidy, chemical and irradiation-induced mutagenesis, plant tissue culture, virus elimination, an array of mass screening tests to identify superior plant types, and marker assisted breeding. Evolution of breeding methods is still ongoing, such as TILLING (Targeting Induced Local Lesions IN Genomes) which involves the directed identification of random mutations controlling a wide range of plant characters (GM Science Review First Report; URL: http://www.gmsciencedebate.org.uk/report/pdf/gmsci-report1-pt1.pdf).
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Principles and Prospects', Chapman & Hall, London.

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5. In the UK the Plant Breeding Institute was established in Cambridge in 1912 initially within the Cambridge University School of Agriculture, but Rowland Biffen began wheat breeding before this following his appointment to Cambridge University in 1896. The Welsh Plant Breeding Station was founded in Aberystwyth in 1919 and the Scottish Plant Breeding Station in Edinburgh in 1921.

6. The PBI was sold to Unilever in 1987. It was then resold to Monsanto in 1998. During the time of private ownership, the range of crops bred has been rationalised several times, some programmes were terminated completely, others sold. At the time of writing only winter wheat and spring barley are bred on the former PBI site. An announcement has recently been made (October 2003, 'Monsanto retreats from Europe'; URL: http://news.bbc.co.uk/1/hi/business/3198312.stm) of the intention of Monsanto to sell the former PBI site and the remaining breeding programmes.

7. Approximately 10 per cent of this gross income is used by plant-breeding organisations to fund the official testing of new varieties (British Society of Plant Breeders: personal communication).

8. Joint Nature Conservation Committee (2002), 'Environmental Effects of the Common Agricultural Policy and Possible Mitigation Measures' (URL: http://www.defra.gov.uk/farm/sustain/envimpacts/envimpacts.pdf).

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10. 'Farming & Food – a sustainable future' (2002) (URL: http://www.cabinet-office.gov.uk/farming/pdf/PC%20Report2.pdf).

11. CAP reform is taking place in the context of other significant developments, including enlargement of the EU from 15 to 25 countries, negotiations on international trade at the World Trade Organization and unprecedented shipment of agricultural produce worldwide.

12. The UK Creutzfeldt–Jakob Disease Surveillance Unit, University of Edinburgh. These figures show the number of suspect cases referred to the CJD surveillance unit in Edinburgh, and the number of deaths of definite and probable cases in the UK, up to 3rd November, 2003 (URL: http://www.cjd.ed.ac.uk/figures.htm).

13. GM Nation Public Debate Website (URL: http://www.gmnation.org).

14. Prime Minister's Strategy Unit Report – 'Field work: Weighing up the costs and benefits of GM crops', July 2003 (URL: http://www.number-10.gov.uk/su/gm/index.htm).

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17. GM Nation Public Debate Report, URN number 03/1292 (URL: http://www.gmpublicdebate.org/ut_09/ut_9_6.htm#download).

18. GM Nation report quotations: Paragraph 91 'Both meeting goers and observers commented on the number of people who went to meetings with established views on GM, and who felt themselves well informed about it, which prompted comments that meetings might be missing the general public. People complained that some local meetings were strongly polarised and dominated by partisans for and against GM (generally against). Pro-GM meeting goers and platform speakers suggested that some meetings had been hijacked by anti-GM campaign organisations, and at others there were complaints of excessive proselytising by individual anti-GM campaigners'. Paragraph 96 'We believe that some organisations, including the National Trust, Friends of the Earth, Greenpeace and the Soil Association encouraged their members to participate in the debate.'

19. GM Nation report. Quotation from Paragraph 45: 'As was noted above, GM is a very broad issue. It is not only an issue in its own right but acts as a proxy for many other current concerns which provoke strong feelings'.

20. GM Nation report. Quotation from paragraph 183: 'Many were puzzled by the national debate. Why had GM produced one (a national debate) when other big issues, including the war in Iraq, had not?'

21. GM Nation – the findings of the public debate (URL: http://www.gmnation.org/docs/GMNation_FinalReport.pdf).

22. Comments for an AEBC discussion on the paper by Grove-White, R. (2001), 'New wine, old bottles? Personal reflections on the new biotechnology commissions', *Political Quarterly,* Vol. 72(4), pp. 466–472 (URL: http://www.aebc.gov.uk/aebc/meetings/papers/aebc0124.htm).

23. Link to website presentation of the 'Public-good plant breeding: What are the international priorities?' meeting held on 22nd May, 2003, in association with the Natural History Museum, the BBSRC and the John Innes Centre (URL: http://www.nhm.ac.uk/

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