Chapter 3

Current and potential uses of GM crops in developing countries

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3.1 In the following section we provide a brief introduction to the concept of genetic modification in the context of contemporary plant breeding.[1] We then describe the traits which researchers are hoping to achieve by means of genetic modification and give an overview of the types of GM crops that are currently grown in commercial agriculture worldwide. Finally, we present eight case studies, which describe in more detail current and potential uses of GM crops in commercial and subsistence agriculture in developing countries.

Research on GM crops in the context of conventional plant breeding

3.2 Following the rediscovery of Mendel's Laws in 1900, selective plant breeding has made dramatic progress. Together with new agricultural methods, the application of this knowledge has contributed to a doubling of global food production over the past 50 years. In parallel, plant breeders have assimilated a variety of new technologies which have been used in both developed and developing countries. Many of these are aided by applications of biotechnology. Examples include:

- *double haploids*, where pure breeding lines can be made in a single step;
- *mutation breeding*, where new variations can be generated by irradiation or by chemical treatments;
- *F1 hybrids*, where farmers can benefit from the expression of *hybrid vigour* (plants grow faster, have higher yields and are more resistant to environmental stresses as a result of selecting parental varieties with specific genetic differences); and
- *tissue culture*, a process which has been particularly beneficial to tens of thousands of small-scale farmers in developing countries (it allows whole, often virus free, plants to grow from a single cell in an artificial medium).[2]

3.3 *Marker-aided selection* (MAS) enables plant breeders to select a piece of DNA that is associated with a particular trait, thereby avoiding time-consuming and expensive tests to select the ideal parent or offspring. MAS can significantly speed up the plant breeding process and a new variety can be produced in approximately four to six generations, rather than in ten. MAS is particularly useful for breeding crops with resistance to moisture-stress for environments with an irregular supply of water. To achieve this characteristic, a variety of different traits would have to be selected and MAS allows plants that express these different traits to be rapidly identified. The technique is also useful in research which aims to interbreed maize varieties that are already resistant to moisture-stress with African varieties of the crop, which are otherwise well adapted.[3]

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1 Further information can be found in Chapter 2 of the 1999 Report.

2 Successful applications of this technique include, for example, the production of improved and disease-free banana seedlings which have been made available to small-scale farmers in Kenya, see Wambugu FM and Kiome RM (2001) *The Benefits of Biotechnology for Small-Scale Banana Producers in Kenya* International Service for the Acquisition of Agri-biotech Applications (ISAAA) Brief No. 22 (Ithaca, NY: ISAAA). Another major application of tissue culture is the *embryo rescue* technique which allowed researchers to cross the particularly high-yielding Asian rice *Oryza sativa* with an African rice variety that was exceptionally competitive with weeds, resistant to moisture-stress and disease resistant, see Jones MP (1999) Basic breeding strategies for high yield rice varieties at WARDA, *Jpn J Crop Sci* **67**: 133–6.

3 Ribaut J-M *et al*. (2002) Use of molecular markers in plant breeding: drought tolerance improvement in tropical maize, in *Quantitative Genetics, Genomics and Plant Breeding*, Kang MS, Editor (Wallingford, UK: CABI Publishing), pp85–99.

Genetic modification

3.4 Genetic modification allows selected individual genes discovered in one organism to be inserted directly into another. This can be a related or unrelated species. Since the way particular genes function is similar in most organisms, genes or part of genes from one organism can generally be transferred to any other organism. The transferred gene is called the *transgene*. Genetic modification can be used to promote a desirable crop character or to suppress an undesirable trait. The technology is also sometimes called gene technology, recombinant DNA technology or genetic engineering. Practical and functional methods have now been developed to modify most of our major crops.

3.5 Regulatory provisions require that the actual transfer of genes into the selected organism must always take place in a laboratory under carefully controlled conditions. GM plants will later be grown in a special glasshouse, and then in fields under regulated conditions, before being grown commercially. Once transferred, transgenes behave like other genes and can be managed further in a conventional cross breeding programme.

3.6 However, the technology has given rise to several concerns. Some perceive the act of genetic modification as more 'unnatural' than processes applied in conventional plant breeding (see paragraphs 3.7-3.17).[4] Critics also fear that genes introduced into GM plants grown in fields, whether for experimental or commercial purposes, might 'escape' into wild relatives of the plant, or to other organisms. There is concern that such events may be irreversible and uncontrollable.[5] There are also questions about the effect of GM crops on human health (see paragraphs 4.43-4.47).[6]

Naturalness

3.7 Some people think intuitively that it cannot be right to change the 'essence' of natural objects like plants. Arguments about naturalness are complex, and raise many difficult issues. We addressed some of these in our 1999 Report, where we examined concerns which were based on commonly held views, or on philosophical, cultural or theological grounds (see paragraphs 1.32-1.40 of the 1999 Report). However, we wish to reconsider two areas in more detail. The first concerns the question of the relationship between conventional plant breeding and plant breeding that uses genetic modification: can it be said that the use of genetic modification is 'unnatural'? The second concerns the question of what it means to transfer genes between species: are such procedures unacceptable because they violate natural boundaries?

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4 For a more abstract discussion of the issue of naturalness, see Alan Holland's submission to the New Zealand Royal Commission on Genetic Modification. Available: http://www.gmcommission.govt.nz/pronto_pdf/save_animals_from_exploitation_safe/(WB%20IP%200085-Al%20Holland).pdf. Accessed on: 14 Oct 2003. See also Food Standards Agency (2002) *Public Attitudes to GM: Debrief notes on qualitative research* (London: FSA). Available: http://www.foodstandards.gov.uk/multimedia/pdfs/gmfocusgroupreport.pdf. Accessed on: 14 Oct 2003.

5 FAO Electronic Forum on Biotechnology in Food and Agriculture (2002) Background Document to Conference 7, 31 May – 6 July 2002. *Gene flow from GM to non-GM populations in the crop, forestry, animal and fishery sectors* (FAO UN). Available: http://www.fao.org/biotech/C7doc.htm. Accessed on: 14 Oct 2003; Independent Science Panel (2003) *The Case for a GM-Free Sustainable World* (London: ISP). See also paragraphs 4.28-4.42.

6 British Medical Association (1999) *The Impact of Genetic Modification on Agriculture, Food and Health: An Interim Statement* (London: BMA).

Conventional plant breeding and plant breeding using genetic modification

3.8 Conventional plant breeding is often understood as the selection of particular individuals from a great variety of naturally occurring types of plants. This activity tends to be seen as natural. Many would also view the systematic interbreeding of naturally occurring types of plants in the same vein. However, plant breeders also create plants which would not be achievable by judicious interbreeding, using techniques such as wide-crossing. This has led to completely new varieties such as Triticale (a hybrid between wheat and rye). Another technique, mutation breeding, involves the exposure of plants and seeds to radiation or chemical substances. These procedures have been, and still are being used to produce many important staple crops around the world (see paragraph 4.44).[7] Thus, it is important to note that the deliberate alteration of plants as they occur in nature has been practised and accepted for several decades. In this context, genetic modification can be seen as a new means to achieve the same end; it is certainly used in that way. It differs from conventional plant breeding in that it can allow for much faster and more precise ways of producing improved crops. For this reason, we concluded in our 1999 Report that it was not helpful to classify a crop that has been arrived at by means of conventional plant breeding as 'natural', and to classify a crop with the same genetic complement as 'unnatural' if it has been produced through genetic modification.

3.9 However, there is some concern that the technique of genetic modification poses risks that differ from those implied by other forms of plant breeding. It may be the case that the intended effect of conferring a particular trait by insertion of specific gene sequences brings with it unintended effects, for example, disruptions in existing genes in the modified material.[8] However, unintended effects are not specific to the use of genetic modification. They are often encountered in conventional breeding, particularly in the case of mutation breeding.[9]

3.10 Other concerns relate to the fact that some forms of genetic modification involve foreign genetic material. Often, viral sequences are used to facilitate the expression of a specific gene sequence in a modified organism (this function is also known as 'switching on' the gene). For example, a short sequence of the genetic material of the cauliflower mosaic plant virus is often used for this purpose.[10] Some people regard this step as crossing a threshold which should not be breached. In their view, an organism has been created which has not previously existed in nature. We now consider the transfer of genes between species in more detail.

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7 For example, radiation in the form of gamma rays was used to alter the genes of a successful rice variety known as Calrose 76. The radiation reduced the height of the plants which resulted in increased yields of grain. The same technique was also used to develop 'Golden Barley', the main variety grown in Scotland until the 1980s. Chemical substances such as sodium azide and ethyl methane sulphonate are still being used, particularly in developing countries, to alter plant genes.

8 See FAO and World Health Organization (2000) *Safety Aspects of Genetically Modified Foods of Plant Origin*, Report of a Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology 29 May – 2 June 2000 (Geneva: WHO), Section 4.3 for a more extensive discussion of this issue. See also Royal Society (2002) *Genetically Modified Plants for Food Use and Human Health – an update* (London: Royal Society), p6.

9 The Royal Society notes two examples: celery and potatoes, see Royal Society (2002) *Genetically Modified Plants for Food Use and Human Health – an update* (London: Royal Society), p6.

10 Such sequences are used as 'promoters', see Royal Society (2002) *Genetically Modified Plants for Food Use and Human Health – an update* (London: Royal Society), p8; Independent Science Panel (2003) *The Case for a GM-Free Sustainable World* (London: ISP). We discuss health issues raised by these and other techniques in paragraphs 4.43-4.47.

The transfer of genes between species

3.11 Genetic modification enables researchers to insert genes from unrelated species into crop plants. This is the case with *Bt* crops (see paragraphs 3.28-3.38) where bacterial gene sequences have been transferred into many crop species. Transgenic varieties of rice are also being produced using genes from bacteria, daffodils and *Arabidopsis* (paragraphs 3.42-3.50). For many people, such possibilities raise the ethical question of whether it is acceptable to mix the genes of different species in this way. The notion underlying this often intuitive response is that there is a meaningful order in nature that needs to be respected (see paragraph 1.43 of the 1999 Report).

3.12 There are several aspects to this view. First, it can entail a claim about the status of species and their role in nature. The diversity of wild species of plants can be seen as a reflection of the process of natural selection and other evolutionary mechanisms. These are frequently interpreted as intrinsically valuable and 'off-limits'. Genetic modification is sometimes viewed critically because it is thought to interfere with these processes. The possibility that GM crops might interbreed with wild relatives is also seen by some as changing natural selection (see paragraphs 4.28-4.42). However, the same objection can be made with respect to many other forms of plant breeding. In fact, crop varieties which are used in agriculture already frequently interbreed with their wild relatives. Given that the systematic cultivation of plants had begun by 6,000 BC, humans have been influencing natural selection for a long time.[11]

3.13 Secondly, the claim that the natural world order should be respected can also be understood as a reluctance to transgress boundaries between species. On this view it could be argued that they are established by nature ensuring a specific balance between different living organisms. However, it does not follow that because something exists in nature, it should exist, or that it is good in and of itself.[12] Furthermore, even within nature, boundaries between species are not irreversibly fixed. There is, for example, increasing evidence that throughout evolution, gene transfer has occurred between lower and higher organisms, including humans.[13] *Horizontal gene transfer*, as this phenomenon is called, appears to occur naturally.

3.14 It is therefore difficult to maintain that nature as such should never be altered. However, a third line of argument may be to say that the order of nature needs to be respected because biological and ecological systems are relatively robust and predictable, and pose few risks for humans. However, interferences may result in irreversible adverse consequences for biological systems, which in turn might eventually endanger the natural world and our relationship to it. While it may be the case that horizontal gene transfer has occurred in nature, this has happened over a very long timescale. But with genetic modification, the transfer of genes between species introduces a sudden change. If GM crops are released into the environment, biological and ecological systems might not be sufficiently adapted to integrate the plants, possibly resulting in unforeseeable and potentially irreversible changes in biodiversity. It could be argued that 'nature knows best' how to integrate genetic changes, and that it would be irresponsible to interfere with this highly complex system that evolves slowly over time.

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[11] Of course it does not follow that all the ways in which humans have influenced natural selection are unproblematic, see Chapter 3, footnote 14. It does mean however that attention should be given primarily to the consequences rather than to the act of interfering with nature.

[12] There is a substantial philosophical discussion on the question of how to derive values from facts. Seminal contributions have been made by David Hume in *A Treatise of Human Nature* (1739-40) and G.E. Moore's *Principia Ethica* (1903).

[13] Syvanen M (2002) Recent emergence of the modern genetic code: a proposal, *Trends Genet* **18**: 245–8; Capy P, Anxolabehere D and Langin T (1994) The strange phylogenies of transposable elements: are horizontal transfers the only explanation?, *Trends Genet* **10**: 7–12.

3.15 Some conclude from this line of argument that all forms of genetic modification which introduce foreign DNA into another organism should be rejected, regardless of the possible benefits. Others conclude that changes in nature should only be undertaken if there can be absolute certainty that no risks are implied. However, while the latter position seems to differ from the former, it needs to be noted that the requirement of absolute certainty is unattainable (see paragraphs 4.35-4.42). Neither do we apply such criteria consistently in other cases where human intervention affects biological and ecological systems.[14]

3.16 A third conclusion is to challenge the assumption that 'nature knows best' with its corollary that altering nature requires proof of the exclusion of all conceivable risks. Proponents of this position would argue that it is more important to assess and balance risks in individual cases. In some instances, it may be clear that risks outweigh benefits. In others, it may be the case that the risks are not severe and that a step by step approach can allow for a responsible use of new technologies (see paragraphs 4.35-4.42).

3.17 For now, we conclude that the arguments about 'naturalness' are insufficient to rule out the responsible exploration of the potential of genetic modification. All forms of plant breeding have directly and indirectly changed biodiversity. It is undesirable to forgo likely benefits because of the possibility of hypothetical adverse events. This is particularly pertinent to the use of GM crops in developing countries. GM crops may prove to be effective tools for addressing specific agricultural problems, while any associated risks for human health and the environment might be contained. To examine this question further, we now consider possible benefits and risks that may arise as a result of the use of GM crops in developing countries. The issue of how best to make decisions about the use of GM crops in conditions of uncertainty is considered in more detail in paragraphs 4.35-4.42.

GM crops relevant to developing countries

3.18 Most commonly, the improvement of plants aims to increase the yield or quality of crops. Yield is influenced by many factors including pests, diseases, soil conditions, or abiotic stresses[15] which stem from unfavourable climatic conditions. Significant improvements can often be achieved by means of irrigation, the application of insecticides or pesticides and the addition of fertiliser. However, most of these interventions are expensive, particularly for small-scale farmers in developing countries.[16] The use of genetic modification provides plant breeders with new opportunities to produce crops that are protected from environmental stresses and attacks from pathogens and insects. The following list gives examples of traits that researchers aim to develop by means of genetic modification. Some of these are still in early stages of development, while others have been achieved more recently in the laboratory setting. A few are in field trials, or can already be found in crops used by farmers.

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14 For example, we may question whether the rhododendron, which originated in Spain and Portugal, should ever have been introduced into the UK; it has been highly invasive and adversely affected the environment, but it seems that this did not prevent its cultivation. Similar effects have resulted from the introduction of other garden plants such as Japanese knotweed (*Fallopia japonica*) which has resulted in a significant loss of biodiversity in some areas of the UK, particularly along waterways. See Royal Horticultural Society (2002) *Invasive Non-Native Species* (Surrey, UK: The Science Departments, The Royal Horticultural Society's Garden). Available: http://www.rhs.org.uk/research/c_and_e_nonnative.pdf. Accessed on: 14 Oct 2003. These examples illustrate the inconsistency in decision making about risks to the natural environment. We take the view that a thorough assessment of the likely benefits and risks is required in all cases.

15 Stresses upon a crop may be either biotic or abiotic. Biotic stresses refer to the influence or impact which other living organisms have on a crop. Abiotic stresses usually refer to physical and chemical components of a crop's environment.

16 For example, the price of urea, a commonly used fertiliser, is US$400 per metric tonne in Western Kenya, US$770 in Malawi and only US$90 in Europe. See Sanchez PA (2002) Soil fertility and hunger in Africa, *Science* **295**: 2019–20. See also Conway G (2003) *From the Green Revolution to the Biotechnology Revolution: Food for Poor People in the 21st Century*. Speech at the Woodrow Wilson International Center for Scholars Director's Forum. 12 March 2003. Available: http://www.rockfound.org/documents/566/Conway.pdf, p8. Accessed on: 10 Oct 2003.

In some cases the traits can be arrived at by conventional breeding, while others are achievable only by genetic modification (see also Appendix 3).

- **Herbicide tolerance** A transgene confers tolerance to a specific herbicide. This trait allows farmers to apply a herbicide which acts on a wide range of weeds while not affecting the modified crop. Herbicide tolerance is currently the most commonly used GM trait worldwide, for example in soybean, maize, cotton and oil seed rape (see case study 7). Herbicide tolerant crops are mainly grown in developed countries with the primary aim of reducing applications of herbicides. The trait has also been achieved using other methods, particularly mutation breeding and gene transfer from wild relatives.
- **Insect/pest resistance** A transgene produces toxins to specific insects that feed on the crop. Such genes have been widely used and are already leading to substantial reductions in the use of pesticides and insecticides. Insect-resistant cotton, maize and potato varieties are being grown in both developed and developing countries (see case study 1 on *Bt* cotton).
- **Bacterial, fungal and viral resistance** Here a transgene makes crops resistant to biotic stresses such as plant pathogens which often reduce yields substantially. Examples of crops in which these traits are being introduced include coffee, bananas, cassava, potato, sweet potato, beans, wheat, papaya, squash and melon (see case Studies 5 and 6 on sweet potatoes and bananas). In some cases the transgenes used are genes which occur naturally in the same species.
- **Abiotic stress resistance** The ability of some plants to survive in harsh climatic or soil conditions is sometimes associated with specific groups of genes. These genes can be isolated and introduced into crops. Such applications promise to be particularly valuable for developing countries, where abiotic stresses such as drought, heat, frost and acidic or salty soils are common. Research on crops such as cotton, coffee, rice, wheat, potato, *Brassica*, tomato and barley varieties is currently in different stages of completion (see case study 2 on rice that is resistant to moisture-stress).
- **Micronutrient enrichment** In aiming to prevent malnutrition, transgenes could play a vital role in the provision of vitamins or minerals. GM crops could help to provide people with essential micronutrients through consumption of their main staple crop. Research in this area is currently being undertaken in rice, cassava, millet and potato (see case study 4 on Golden Rice).

3.19 Another application of genetic modification includes the controversial gene use restriction technology (GURT), also known as ‘terminator technology’, which leads to seed sterility (see paragraph 4.18 of this Discussion Paper and paragraphs 2.26 and 4.75 of the 1999 Report).[17] Other applications which are either in advanced stages of development or already used in agricultural practice include improved shelf-life of fruit and vegetables, and the use of plants for the production of biopharmaceuticals, such as vaccines (see case study 8).[18] There is also a range of traits which are still in relatively early stages of development, but which are nonetheless promising and potentially important. This includes research to enable the transfer of genes conferring *apomixis*, which is the capacity to produce seeds in the absence

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17 Companies developing this technology emphasise that its purpose is to allow the control of gene flow, whereas critics claim that the purpose is the control of seed markets, by making the saving of harvested seed for re-sowing in the next season unfeasible.

18 Agriculture and Environment Biotechnology Commission (AEBC) (2002) *Looking Ahead - An AEBC Horizon Scan* (London: Department of Trade and Industry); GeneWatch (2003) Briefing No. 21 *Genetic Modification: The Need for Special Regulation* (Derbyshire, UK: GeneWatch).

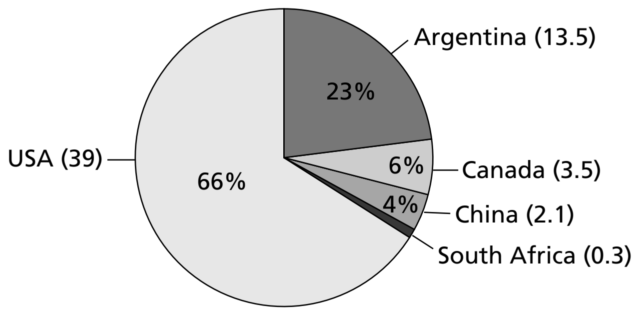
of normal sexual reproduction, to crops.[19] This application could enable outstanding traits to be perpetuated over generations without farmers needing to buy new seed (see paragraphs 2.23, 2.39 and 3.39 of our 1999 Report). Other research aims to produce GM crops that can be used for the production of bioplastics or biofuels, as substitutes for fossil fuels and their products. It may also be possible to develop nitrogen-fixing cereals; gluten-producing sorghum for bread-making in Africa (currently dependent on imported wheat); and crops with such high tolerance to salinity that salty marsh water can be used for irrigation.[20]

3.20 We provide in the next section a brief survey on the kinds of GM crops that were grown worldwide in 2002. This is followed by eight case studies which illustrate current and potential benefits and risks associated with the use of GM crops in developing countries.

Global commercial use of GM crops

3.21 Three-quarters of GM crops which are grown worldwide are cultivated in developed countries, predominantly on large-scale industrial farms in the US, Argentina and Canada. Traits which have been successfully introduced by means of genetic modification relate primarily to the needs of these farmers. However, of the approximately six million farmers who grew GM crops legally in 2002 worldwide, more than three-quarters were resource-poor, small-scale cotton farmers in developing countries, mainly in China and South Africa.[21] While the number of farmers using GM crops is the highest in developing countries, they only account for 27% of the total area. The five countries which grew 99% of the global GM crop are shown in Figure 3.1.

Figure 3.1: **Global area of legally planted GM crops in 2002 by country (million hectares)**



James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA).

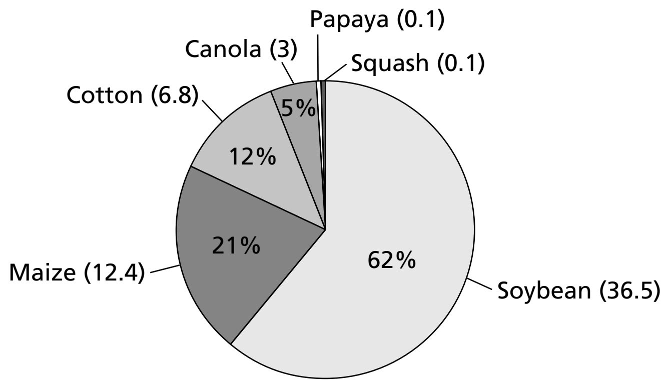
19 For a review see Chaudhury AM *et al*. (2001) Control of early seed development, *Annu Rev Cell Dev Biol* **17**: 677–99.

20 See, for example, Mazur B, Krebbers E and Tingey S (1999) Gene discovery and product development for grain quality traits, *Science* **285**: 372–5; AEBC (2002) *Looking Ahead - An AEBC Horizon Scan* (London: Department of Trade and Industry); Fitzgerald P (2003) Salt-Tolerant GM Wheat, *Ground Cover* **44** (Grains Research & Development Corporation). Available: http://www.grdc.com.au/growers/gc/gc44/gene_scene.htm. Accessed on: 14 Oct 2003; James C (1999) *Global Review of Commercialized Transgenic Crops:* 1999 ISAAA Brief No. 12 (Ithaca, NY: ISAAA).

21 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA). This figure excludes those farmers who grew GM crops illegally, for which there is anecdotal evidence in Brazil, Pakistan and India during 2002.

3.22 Between 1999-2002, the principal GM crops grown have been non-staple crops, grown by commercial farmers in developed countries. The most commonly used traits were herbicide tolerance (75%) and pest resistance (15%). Varieties carrying two or more transgenes which conferred both pest resistance and herbicide tolerance accounted for 8% of all crops. Herbicide tolerant soybean was the most widely grown GM crop in 2002 (see Figure 3.2).

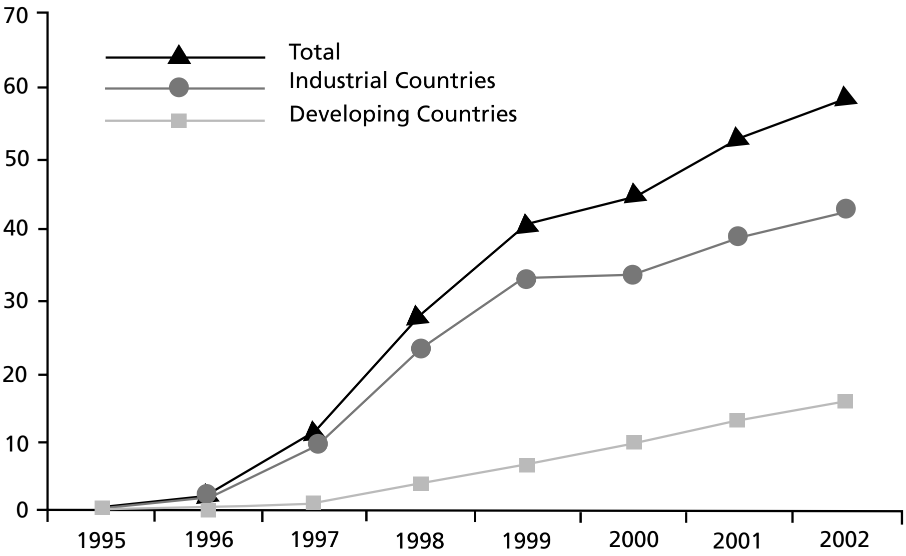
Figure 3.2: **Global area of legally planted GM crops in 2002 by crop (million hectares)**



James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA).

3.23 In 2002, nearly one-quarter of the total area of GM crops worldwide was grown in Argentina. Soybean and maize for export as animal feed were planted predominantly on large-scale farms. Since our 1999 Report was published, the area of GM crops in developing countries has doubled. The growth in cultivation of GM non-staple crops in developing countries is expected to continue over the coming years (see Figure 3.3).

Figure 3.3: **Global area of legally planted GM crops, 1996-2002 (million hectares)**



James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA)

3.24 In China, GM varieties were grown on 51%, or two million hectares, of the land used for growing cotton. In India, GM cotton received regulatory approval in April 2002 and 45,000 hectares were subsequently planted. Indonesia has also recently introduced GM crops, which means that the three most populous countries in Asia have adopted the technology.[22]

3.25 While the rapidly increasing spread of GM crops is noteworthy, most GM food and feed crops, such as soybean or rice, have not yet been approved for commercial planting in Africa, Asia, or the Middle East. The exceptions are South Africa and the Philippines, where GM maize has been approved, and Argentina, where GM maize and soybean are grown. One of the main reasons for this pattern is that regulators in developing countries often opt for a highly conservative precautionary approach when deciding about the use of a new GM crop. Unresolved concerns about the safety of GM crops for human consumption and for the environment (see paragraphs 4.28-4.47), together with possible restrictions arising from international trade policies (see paragraphs 5.43-5.50) have been influential in this respect.

Current and possible uses of GM crops in developing countries

3.26 As we have said, concern has been expressed about the speed with which GM crops have been, or are intended to be, introduced in some developing countries (see paragraphs 1.10-1.13).[23] With regard to food crops, critics point out that despite increasing populations, over the past 35 years, growth in global food production has outstripped growth in population by 16%. They argue that current global food production is sufficient to provide food for the world's population, if only inequalities in access to food were eliminated.[24] GM crops are frequently perceived as a 'technological fix', proposed by those who fail to address the underlying causes of hunger and poverty, which really require economic, political and social change.

3.27 We are aware of these and further general objections and address them in more detail in Chapter 4. Here, we consider what kind of GM crops could offer benefits to farmers in developing countries, and what the likely risks might be. We also aim to assess the claim that GM technology may only benefit agrochemical companies and large-scale commercial farmers in developed countries, and may be of no use or even harmful for small-scale, resource-poor farmers in developing countries.[25] We first consider in more detail the use of GM cotton in China and Africa. We then discuss five examples of research where genetic modification is used to improve traits of rice, sweet potatoes and bananas. These crops are important to many people in developing countries, but have been largely neglected by plant breeders elsewhere. We also examine issues arising from the use of GM soybean in South America and the implications of modifying crops for the production of biopharmaceuticals.

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22 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA).

23 Oxfam (1999) *Genetically Modified Crops, World Trade and Food Security* (Oxford: Oxfam); Five Year Freeze (2002) *Feeding or Fooling the World?* (London: Five Year Freeze).

24 Five Year Freeze (2002) *Feeding or Fooling the World?* (London: Five Year Freeze).

25 See, for example the study on possible benefits and disadvantages of GM coffee in Hawaii, Action Aid (2001) *Robbing Coffee's Cradle - GM coffee and its threat to poor farmers* (London: Action Aid).

Case study 1: Non-food crops – Bt cotton in China and South Africa

3.28 Cotton attracts a variety of serious pests which farmers seek to control by the use of chemicals. One example of these pesticides is based on the naturally-occurring soil bacterium *Bacillus thuringiensis (Bt)*. There are a number of strains of *Bt*, each of which produces a slightly different protein. All cause a toxic reaction in the guts of certain insects or pests when they digest the protein. While such a reaction does not occur in humans, it strongly affects cotton bollworm, maize borers or potato beetles, which devastate many crops worldwide. The toxic effect of *Bt*-derived compounds has been widely used by conventional and organic farmers for several decades.[26] Usually, farmers apply the toxin by spraying the crops. However, this method of application is relatively imprecise and repeated sprayings over an extended period of time are required to control pests effectively.

3.29 The attraction of using the *Bt* toxin is that it is generally not harmful to beneficial insects that are closely related to pest species. These insects, which would otherwise have been killed by the application of conventional chemical pesticides, are left unaffected due to the selectivity of *Bt*. To preserve this useful quality, and to control pests more effectively, researchers have produced genetically modified crop varieties which can express the relevant proteins that are toxic to selected insect pests. While the protein is usually produced throughout the crop, more recent developments also allow it to be expressed in specific parts of the plants, such as the roots.[27]

3.30 The major advantage of *Bt* crops is the reduction in the levels of pesticides used by farmers. This can have considerable ecological benefits, as excessive use of pesticides can be harmful to the environment. There are also potential economic benefits: in 2001, 20% of pesticides applied globally were used on cotton, at a total cost of US$1.7 billion.[28] Significant reductions can also have health-related benefits for farm workers who apply pesticides or insecticides, or who work in fields in which these have been applied (see also paragraph 3.55). Whether or not the use of *Bt* crops leads to overall savings for farmers will depend on a variety of factors, such as the price of seed, licensing agreements with the producer of the seed, costs of insecticides and global cotton prices.

3.31 In China, researchers at the public sector Chinese Academy of Agricultural Sciences (CAAS), in cooperation with regional academies, have successfully developed several *Bt* cotton varieties for domestic use. These varieties have initially been sold by the national seed network. However, due to a reform of the national seed law in 2000, private seed companies now operate in many provinces, enabling farmers to choose from a wider variety of GM and non-GM seed.[29] By 2002, half the cotton grown in China was in the form of *Bt* varieties. Reports have highlighted three main advantages:

- The average application of pesticides fell by as much as 50 kilograms per hectare, a reduction of between 60-80% in comparison to 2001.[30] This implied considerable

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26 James C (2002) *Global Review of Commercialized Transgenic Crops: 2001, Feature Bt cotton* ISAAA Brief No. 26 (Ithaca, NY: ISAAA).

27 Kota M *et al.* (1999) The Next Generation of *Bt* Plants? Auburn University. Available: http://www.ag.auburn.edu/aaes/communications/highlights/spring99/btplants.html. Accessed on: 14 Oct 2003.

28 James C (2002) *Global Review of Commercialized Transgenic Crops: 2001, Feature Bt cotton* ISAAA Brief No. 26 (Ithaca, NY: ISAAA).

29 Huang *et al.* (2002) *Bt* cotton benefits, costs, and impacts in China, *AgBioForum* **5**: 153–66; James C (2001) *Global Review of Commercialized Transgenic Crops: 2001* ISAAA Brief No. 24 (Ithaca, NY: ISAAA).

30 Huang J *et al.* (2002) Plant biotechnology in China, *Science* **295**: 674–6.

financial savings for approximately 3.5 million farmers who managed small farms of an average size of between 0.5-2 hectares (see Table 3.1).[31]

- Yields of *Bt* cotton were estimated to have increased by 10% in 2001, in comparison to farmers who grew non-*Bt* cotton.[32]
- As in many other developing countries, pesticides in China are often applied in the absence of protective clothing. The use of *Bt* cotton seems to have led to reductions of instances in which farmers suffered toxic effects related to exposure to pesticides. Such events were reported to be reduced by 60%, compared with farmers who grew non-*Bt* cotton.[33]

Table 3.1: **Average costs and returns (US$) per hectare for farmers surveyed in China, 2001**

Cost	***Bt***	**Non-*Bt***
Output revenue	1277	1154
Non-labour costs		
Seed	78	18
Pesticides	78	186
Chemical fertiliser	162	211
Organic fertiliser	44	53
Other costs	82	65
Labour	557	846
Total costs	1000	1379
Net revenue	277	-225

Source: Pray CE *et al.* (2002) Five years of *Bt* cotton in China - the benefits continue, *Plant J* **31**: 423–30.

3.32 Similar improvements in yield were achieved in the Makhathini Flats area of KwaZulu-Natal, South Africa, where a well developed extension system is in place.[34] The private company VUNISA Cotton is the sole supplier of seed, agrochemicals and support services. Through its extension officers, it offers several GM as well as non-GM varieties. VUNISA also provides

31 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA). There is evidence that many Chinese farmers growing non-*Bt* cotton apply excessive amounts of pesticides, see Shankar B and Thirtle C (2003) Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case, Working Paper, Dept. of Agricultural & Food Economics, University of Reading. It would therefore be wrong to attribute the total reduction to the use of *Bt* cotton alone. Some reduction could also have been achieved by means of promoting a better understanding of the appropriate amounts of pesticides for use in cotton. This highlights the importance of training and provision of information about pesticide use for both *Bt* and non-*Bt* crops.

32 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA); Pray CE *et al.* (2002) Five years of *Bt* cotton in China - the benefits continue, *Plant J* **31**: 423–30.

33 Conway G (2003) *From the Green Revolution to the Biotechnology Revolution: Food for Poor People in the 21st Century.* Speech at the Woodrow Wilson International Center for Scholars Director's Forum. 12 March 2003. Available: http://www.rockfound.org/documents/566/Conway.pdf. Accessed on: 10 Oct 2003; Pray CE *et al.* (2002) Five years of *Bt* cotton in China – the benefits continue, *Plant J* **31**: 423–30; Huang *et al.* (2002) *Bt* cotton benefits, costs, and impacts in China, *AgBioForum* **5**: 153–66.

34 Thirtle C, Piesse J and Jenkins L (2003) Can GM-technologies help the poor? The Impact of *Bt* Cotton in Makhathini Flats, KwaZulu-Natal, *World Dev* **31**: 717–32.

credit for farmers and buys their harvest, competing with the company NSK. Farmers are members of farming associations, which hold regular meetings to provide support and to discuss mutual concerns.[35] In 1999/2000, 12% of 1376 cotton farmers who mostly managed small farms of an average size of 1.7 hectares adopted *Bt* cotton. This rose to 60% the following year. Ninety five per cent are expected to have grown *Bt* cotton in 2001/2002. Due to increased yields, and reduced costs of pesticides and labour, farmers were able to augment their gross margin by 11% in the first season, and 77% in the second, compared to farmers growing non-*Bt* cotton. These increases were achieved despite the fact that the *Bt* cotton seeds were twice the cost of conventional seeds.[36] The use of *Bt* cotton is also said to have led to savings of approximately 1,500 litres of water per farm.[37]

3.33 Despite these benefits, the use of *Bt* cotton carries a number of risks. Concern has been expressed with regard to a perceived undue influence of multinational agrochemical and seed companies. Companies can decide to levy 'technology fees' from users of newly developed GM crops such as *Bt* cotton. Such fees may be acceptable to large-scale farmers in developed countries, but they could exclude small-scale farmers in developing countries from using GM crops.[38] There are fears that some farmers might try to avoid these costs by reusing seed saved from previous seasons, or by purchasing seeds illegally, both options usually resulting in significantly reduced yields. Such incidents have recently been reported in India.[39] Thus, corporate control of seed markets and ownership of technologies are important issues. For example, the company Monsanto has made 90% of the patent applications for genes relating to the improvement of cotton.[40] In the case of agrochemicals, 10 companies control approximately 85% of the global market.[41] We consider issues relating to intellectual property rights in more detail in Chapter 6.

3.34 Reductions in the use of pesticides arising from the cultivation of *Bt* cotton might lead to less employment for farm workers. However, recent data from the Makhathini Flats have shown that, overall, this can be compensated for by increased demand for farm workers during the harvest, because of increased yields.[42] While this issue of labour is not relevant for small-scale farmers who do not employ labourers, it may require consideration in the case of larger farms. Problems could arise if farm workers are not able to obtain employment on other farms during the growing period of the crop.

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35 Thirtle C, Piesse J and Jenkins L (2003) Can GM-technologies help the poor? The Impact of *Bt* Cotton in Makhathini Flats, KwaZulu-Natal, *World Dev* **31**: 717–32.

36 Ismael Y, Bennett R and Morse S (2002) Benefits of *Bt* cotton use by smallholder farmers in South Africa, *AgBioForum* **5**: 1–5. The disproportionate increase in the second season is a result of exceptionally heavy rainfalls. The rain washed off the pesticides applied to non-*Bt* cotton, which allowed for less effective control of the bollworm. *Bt* cotton, on the other hand, was not affected in the same way.

37 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA).

38 However, as the example of China showed, higher prices for seed can be offset by overall savings in other areas (see Table 3.1).

39 India approved the growing of *Bt* cotton in April 2002. However there are reports that illegal plantings of *Bt* cotton has already taken place over the past three years. Unlicensed seeds have been produced by crossing Monsanto's varieties with other previously used conventional varieties. In Gujarat about one half of the *Bt* cotton seeds sold are estimated to be illegal 'pirate' seeds, which are considerably less expensive than commercial seeds. Several thousand acres had been sown illegally with second and third generation seeds, which had very low yields. Jayaraman KS (2002) Poor crop management plagues *Bt* cotton experiment in India, *Nat Biotechnol* **20**: 1069. While some favour this practice as a democratisation of plant breeding, others point to losses in quality. Monsanto is concerned that its technology is being used without payment of royalties and the company is said to have lodged an official complaint to the Indian Government, requesting an end to the illegal use of its cotton variety. Ghosh P (2003) India's GM seed piracy. http://news.bbc.co.uk/1/hi/sci/tech/2998150.stm. Accessed on: 14 Oct 2003.

40 GeneWatch (2001) Briefing No. 13 *Genetic Engineering: A Review of Developments in 2000* (Derbyshire, UK: GeneWatch).

41 AEBC (2002) *Looking Ahead - An AEBC Horizon Scan* (London: Department of Trade and Industry).

42 Shankar B and Thirtle C (2003) Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case, Working Paper, Dept. of Agricultural & Food Economics, University of Reading.

3.35 It is uncertain whether the concept behind *Bt* crops will prove to be robust over the medium to long term. It is known that pests may eventually acquire resistance to toxins.[43] However, the cotton bollworm has been monitored for *Bt* resistance in China since 1997, and resistant mutants have not yet been reported.[44] Nonetheless, resistance is likely to develop if the first generation of plants remains in cultivation for long enough. The use of *refuges* is one way of addressing this issue. To slow down the emergence of resistance, many regulatory schemes require that sufficient acreage of non-*Bt* crops are grown close to the *Bt* crops, to allow refuges for insects which can mate with potentially *Bt*-resistant insects. There is disagreement about the theoretical and practical effectiveness of refuges. Their success depends on factors such as size, spatial proximity relative to GM crops, the inheritance patterns of the trait that confers resistance to the toxin in pests, and the synchronous emergence of resistant and non-resistant pests.[45] The efficacy of refuges is well documented for *Bt* cotton farms in Australia, where regulatory requirements have been successfully implemented.[46] However, while the monitoring of refuges seems feasible for large-scale commercial farms, it may be much more difficult to achieve for numerous small-scale farms in developing countries.[47] Other approaches to avoid resistance might be to use two or more *Bt* genes,[48] or to carry out research into new insecticidal genes that could eventually take the place of *Bt*.[49] However, at present *Bt* varieties have remained resistant to pest infestation for considerably longer than had initially been anticipated.

3.36 In evaluating the risks and benefits of *Bt* crops it is not sufficient to examine effects solely on the target species. Effective control of, for example, the cotton bollworm may lead to an increase in the numbers of other pests unaffected by *Bt*. These pests may then require control, which in turn might lead to increased use of pesticides. Such changes in the

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43 We note that this is a problem that is not unique to GM crops. It is equally applicable to conventionally applied pesticides.

44 Wu K (2002) *Agricultural and biological factors impacting on the long term effectiveness of Bt Cotton*, Conference on Resistance Management for Bt crops in China: Economic and Biological Considerations, 28 April 2002, North Carolina State University, Raleigh.

45 Liu Y-B, Tabashnik BE, Dennehy TJ, Patin AL and Bartlett AC (1999) Development time and resistance to *Bt* crops, *Nature* **400**: 519; Gould F (1998) Sustainability of transgenic insecticidal cultivars: Integrating Pest Genetics and Ecology, *Annu Rev Entomol* **43**: 701–26; Tabashnik BE (1994) Delaying Insect Adaptation to Transgenic Plants: Seed mixtures and refugia reconsidered, *Proc R Soc Lond B Bio* **255**: 7–12.

46 Peacock J (2003) Presentation at conference *Towards Sustainable Agriculture for Developing Countries: options from life sciences and biotechnologies,* 30-31 Jan 2003, Brussels. For a critical account on the effectiveness of refuges see Liu Y-B, Tabashnik BE, Dennehy TJ, Patin AL and Bartlett AC (1999) Development time and resistance to *Bt* crops, *Nature* **400**: 519.

47 It has also been reported that poor crop management frequently occurred in India when *Bt* varieties were planted legally. Farmers were said to have failed to provide refuges of non-*Bt* cotton. It has been suggested that the crops were introduced too hastily and that farmers had not been made aware that more intense irrigation would be required. Farmers had also paid four times the price of traditional varieties for *Bt* crops Qaim M (2002) *Bt* Cotton in India: Field-Trial Results and Economic Projections, Dept of Agriculture and Resource Economics, University of California. However, there is also anecdotal evidence that professionally managed *Bt* cotton has led to reductions of 70% in the amount of pesticides used in and yield gains of up to 80% comparison to conventionally planted cotton. These developments suggest that is too soon to draw conclusions as to whether the use of *Bt* cotton in India is likely to be beneficial. Jayaraman KS (2002) Poor crop management plagues *Bt* cotton experiment in India, *Nat Biotechnol* **20**: 1069.

48 Peacock J (2003) presentation at conference *Towards Sustainable Agriculture for Developing Countries: options from life sciences and biotechnologies,* 30-31 Jan 2003, Brussels; Gould F (1998) Sustainability of transgenic insecticidal cultivars: Integrating Pest Genetics and Ecology, *Annu Rev Entomol* **43**: 701–26.

49 Bowen D *et al*. (1998) Insecticidal toxins from the bacterium *Photorhabdus luminescens, Science* **280**: 2129–32.

spectrum of pests have recently been reported in the US, South Africa and China, and require close monitoring.[50]

3.37 Additional problems might arise from the possibility of gene flow from *Bt* crops to wild relatives.[51] Some fear that the introduced *Bt* gene may 'escape' from the modified plant and change the genetic composition of other plants. It is argued that this may be particularly relevant in the case of countries such as India, which is a centre of diversity for cotton. Centres of diversity often contain landraces, other cultivated crop varieties, as well as wild relatives, and possible outcrossing of *Bt* crops could irreversibly affect the local gene pool.[52] While some argue that these and related issues simply require stringent monitoring and assessment in field trials, others doubt whether such risks should be taken. We consider questions relating to the management of gene flow in paragraphs 4.28-4.34.

3.38 Further concerns have been expressed with respect to the possibility that the use of *Bt* crops may lead to a decrease in biodiversity. For example, in 1999, researchers undertaking laboratory studies claimed that the pollen of *Bt* maize negatively affected non-target species, such as monarch butterflies. When these insects were fed milkweed leaves dusted with large amounts of *Bt* pollen, increased larval mortality, slower development and smaller sizes of monarch butterflies were recorded.[53] However, subsequent studies have shown that the risk of acute toxicity to monarch butterflies in the wild is negligible.[54] Evidence from *Bt* cotton field trials in KwaZulu-Natal even seems to suggest that the use of *Bt* can contribute to enhanced biodiversity, as increased numbers and varieties of insects and insectivorous birds were recorded in *Bt* fields.[55]

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50 Bacheler JS (2003) Managing insects on cotton, in 2003 *North Carolina Cotton Production Guide* (North Carolina State University), Chptr 11. Available: http://ipm.ncsu.edu/Production_Guides/Cotton/chptr11.pdf. Accessed on: 20 Oct 2003; Joubert GD *et al*. (2001) *South African Experience with Bt Cotton,* International Cotton Advisory Committee Technical Seminar of the 60th Plenary Meeting 16-21 Sept 2001 (Victoria Falls, Zimbabwe). Available: http://www.icac.org/icac/cotton_info/tis/biotech/documents/techsem/SAexperience_tis01.pdf. Accessed on: 20 Oct 2003; Glover D (2003) *Bt Cotton: Benefits for Poor Farmers?* Genetically Modified Crops in Developing Countries Briefing Series Briefing 9 (Brighton, UK: Institute of Development Studies). Available: http://www.ids.ac.uk/ids/env/PDFs/Briefing9.pdf. Accessed on: 20 Oct 2003; Wu K, Peng Y and Jia S (2003) What we have learnt on impacts of *Bt* cotton on non-target organisms in China, *AgBiotechNet* **112**.

51 The transfer of genes via pollen to or from a cultivated crop to other crop plants, wild relatives, other plant species or other organisms.

52 Nester E *et al*. (2002) 100 years of *Bacillus thuringiensis:* a critical scientific assessment, at *100 Years of Bacillus thuringiensis, a Paradigm for Producing Transgenic Organisms: A Critical Scientific Assessment,* 16-18 Nov 2002 (Ithaca, NY: American Academy of Microbiology Colloquium); Shiva V (2002) speech at the Soil Association's International Sir Albert Howard Memorial Lecture 27 March 2002. Available at: http://www.soilassociation.org/web/sa/saweb.nsf/librarytitles/vandanashiva.html. Accessed on: 20 Oct 2003.

53 Losey JE, Rayor LS and Carter ME (1999) Transgenic pollen harms monarch larvae, *Nature* **399**: 214.

54 Sears MK *et al*. (2001) Impact of *Bt* corn pollen on monarch butterfly populations: a risk assessment, *Proc Natl Acad Sci USA* **98**: 11937–42; Hellmich RL *et al*. (2001) Monarch larvae sensitivity to *Bacillus thuringiensis* – purified proteins and pollen, *Proc Natl Acad Sci USA* **98**: 11925–30; Pleasants JM *et al.* (2001) Corn pollen deposition on milkweeds in and near cornfields, *Proc Natl Acad Sci USA* **98**: 11919–24; Stanley-Horn DE *et al*. (2001) Assessing the impact of Cry1Ab– expressing corn pollen on monarch butterfly larvae in field studies, *Proc Natl Acad Sci USA* **98**: 11931–6; Oberhauser KS *et al*. (2001) Temporal and spatial overlap between monarch larvae and corn pollen, *Proc Natl Acad Sci USA* **98**: 11913–8; Zangerl AR *et al*. (2001) Effects of exposure to event 176 *Bacillus thuringiensis* corn pollen on monarch and black swallowtail caterpillars under field conditions, *Proc Natl Acad Sci USA* **98**: 11908–12; Committee on Environmental Impacts Associated with Commercialisation of Transgenic Plants (2002) *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation* (Washington, DC: National Academy Press).

55 Thomson J (2002) *Genes for Africa: Genetically Modified Crops in the Developing World* (Cape Town: University of Cape Town Press), p169; Head G, Freeman B, Moar W, Ruberson J and Turnipseed S (2001) Natural enemy abundance in commercial Bollguard® and conventional cotton fields, Proceedings of the *Beltwide Cotton Conferences*, Anaheim, California, National Cotton Council, Memphis, Tennessee.

Examples of improved traits in staple crops

3.39 Cotton is a non-food crop that is grown predominantly for international trade. We now consider examples of food crops that are relevant to both subsistence and commercial farming. In many tropical areas of developing countries, two or three crops a year can be harvested. Temperatures and daylength are often more favourable to the growth of crops than conditions in temperate developed countries and best-case yields are therefore, often higher in the tropics than in highly productive areas of temperate zones.[56] However, the average yield of almost all crops grown in tropical regions is significantly lower than in developed countries. This is so because poor farmers and government departments in developing countries are generally not well placed to deal with problems such as poor quality seed, salty or otherwise recalcitrant soil, environmental stresses such as drought and heat, pests and diseases, lack of fertilisers, short-term management of farm land, and inadequate control of water.

3.40 Often, substantial improvements can be achieved cost-effectively in one or more of these areas by means of better irrigation, integrated pest management, or agricultural extension services. However, these approaches have limitations. Furthermore, with regard to improved seeds, there are a number of cases where conventional, non-GM approaches have achieved little progress. For example, sorghum and maize in Africa have shown scant improvement in yield. Maize hybrids, which are high-yielding with adequate water and nutrient conditions, have proved very vulnerable to even short delays in the rains during flowering. Hence, it may be worth exploring the potential contribution of GM crops for raising 'yield potential' (that is, the maximum attainable crop yield from a given soil-water regime), and yield stability of crops (see paragraphs 4.20-4.27 of the 1999 Report).

3.41 We now discuss several examples of research on food crops relevant to the developing world which may contribute to increasing yield in terms of quantity and quality. The first three concern research on genetically improved traits in rice, a staple food for over three billion people, in other words, half the world's population.[57]

Case study 2: Abiotic stress resistant rice

3.42 In 2002, researchers at Cornell University successfully tested under greenhouse conditions a variety of GM rice that maintained yields under abiotic stresses such as cold, drought and salty soil. Such research is crucial since one third of the 1.5 billion hectares of the world's arable land is affected by drought.[58] The researchers transferred a set of genes which control the expression of a sugar called trehalose into a variety of *Indica* rice, which represents 80% of rice grown worldwide. Trehalose occurs naturally in many so-called 'resurrection' plants, which can survive prolonged droughts in desert conditions. Under extreme stress, these plants appear dead; however, the sugar helps stabilise biological molecules and protects tissue damage during dehydration. It is estimated that the modified variety has the potential to increase yields under poor conditions by as much as 20%, although field trials will not take place for several years.[59] The researchers plan to seek

56 For example, best-case yields for wheat have been obtained in Amritsar and Ludhiana in the Indian Punjab, and in Sonora and Sinaloa, Mexico; similarly ideal conditions prevail for rice in parts of Taiwan.

57 Lantin R. Compendium on Post-Harvest Operations. FAO. Available: http://www.fao.org/inpho/compend/text/ch10.htm. Accessed on: 20 Oct 2003.

58 James C (2002) *Preview, Global Status of Commercialized Transgenic Crops: 2002* ISAAA Brief No. 27 (Ithaca, NY: ISAAA), p19.

59 Garg AK *et al.* (2002) Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses, *Proc Natl Acad Sci USA* **99**: 15898–903.

patent protection for the modification and will ensure public availability of the modified crop, particularly for farmers in developing countries. They also hope to introduce the trait in other crops, such as maize, wheat or millet.[60]

Case study 3: Increasing yield in rice by dwarfing

3.43 Another method of increasing crop yields is by the production of dwarf varieties. Shorter plants can make more nutrients available for grain production. The introduction of semi-dwarfing genes into wheat was one of the primary technical achievements of the Green Revolution in the 1960s and 1970s, contributing to the doubling of wheat yields worldwide. The development of the dwarf rice variety IR-8 in 1963 was equally important.[61] However, the genes used to reduce height in the two crops were very different. In both cases the farmer could use the improved strength of straw to gain yield because he was able to apply more fertiliser (where he could afford to do so). The wheat variety also had the advantage of increasing yield directly through a greater number of grains in the ear.

3.44 In 1999, a team at the John Innes Centre (JIC) isolated a gene from a common weed (*Arabidopsis thaliana*) which codes for the same type of dwarfism found in the semi-dwarf wheat varieties used in the Green Revolution. When the gene was introduced into rice, dwarf plants were obtained.[62]

3.45 Together with their Indian collaborator, researchers at the JIC have introduced the *Arabidopsis* gene into basmati rice to produce the first dwarf variety. Basmati is commonly grown on the Indian subcontinent, but the plants are usually tall, have weak stems and are highly susceptible to damage by wind and rain. These features frequently lead to considerable yield losses. Previous attempts to reduce the height of the basmati variety while retaining its desirable qualities using conventional breeding methods have resulted in the loss of the very characteristics for which it is valued. Field trials will eventually reveal whether the dwarfed basmati rice varieties have higher yields, as is the case with semi-dwarf wheat varieties. An important feature of this application of genetic modification is that it contributes both to the improvement of traits and the conservation of biodiversity. The single gene can be inserted with minimal disturbance to the rest of the genetic complement and a multitude of locally well-adapted varieties can simultaneously be conserved and improved.[63]

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60 At the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico, trials on moisture-stress resistant wheat plants are currently taking place in experimental greenhouses. See Pellegrineschi A (2003) Drought-resistant GM crops: a promising future, *SciDev.Net* 30 Jan 2003. Available: http://www.scidev.net/dossiers/index.cfm?fuseaction=dossierReadItem&type=3&itemid=5&language=1&dossier=6. Accessed on: 20 Oct 2003. Other crops resistant to abiotic stress, which are currently at the stage of field trials include frost tolerant potatoes in Bolivia, cold tolerant tomatoes in China, salt tolerant wheat in Egypt, moisture-stress resistant *Brassica* in India, and salt and moisture-stress resistant rice in Thailand. See FAO Electronic Forum on Biotechnology in Food and Agriculture (2002) Background Document to the Conference 8, 13 Nov - 11 Dec 2002 *What should be the role and focus of biotechnology in the agricultural research agendas of developing countries?* (FAO UN). Available: http://www.fao.org/biotech/C8doc.htm. Accessed on: 20 Oct 2003.

61 Dalrymple D (1976) *Development and Spread of High Yielding Wheat and Rice in the Less Developed Nations* US Dept of Agriculture, Foreign Development Division, Economic Research Service: Foreign Economic Agricultural Report No. 95, p120.

62 Peng J *et al.* (1999) 'Green revolution' genes encode mutant gibberellin response modulators, *Nature* **400**: 256–61.

63 Peng J *et al*. (1999) 'Green revolution' genes encode mutant gibberellin response modulators, *Nature* **400**: 256–61.

Case study 4: Improved micronutrients in rice

3.46 There are several research projects which aim to produce enhanced levels of ß-carotene in food crops.[64] ß-carotene is an important micronutrient which is converted to vitamin A in the body. In rice, ß-carotene is present in the leaves, but not in the rice endosperm (the edible part). However, ß-carotene can be produced in the endosperm of the grain by means of genetic modification. This development was achieved by Professor Ingo Potrykus and Dr Peter Beyer at the Swiss Federal Institute of Technology in 2000. They transferred one bacterial gene and two daffodil genes into a variety of rice to develop a ß-carotene enriched strain which they called *Golden Rice*.[65] The primary aim of the researchers was to help prevent vitamin A deficiency (VAD) which is a common phenomenon in developing countries. In 1995, clinical VAD affected some 14 million children under five, of whom some three million suffered xerophthalmia, the primary cause of childhood blindness. 250 million children had sub-clinical deficiency, greatly increasing their risk of contracting ordinary infectious diseases such as measles. In many developing countries such diseases contribute significantly to high mortality rates.[66] At least one third of the sufferers are found among poor people in Asia who rely on rice as their staple crop and for whom alternative sources of vitamin A are usually unaffordable.

3.47 There have been reports that the development of Golden Rice was significantly complicated by issues relating to intellectual property rights (IPRs), see Chapter 6. However, these issues were resolved after a public-private partnership with the company Syngenta was established, which provided assistance in the negotiation of access to protected materials and processes. The terms of the partnership are such that the company retains the rights for the commercialisation of Golden Rice, but allows seed to be made available free of charge to farmers and traders whose profit is below US$10,000 per year. Research on Golden Rice is currently being undertaken at 14 public research institutes which form the Golden Rice Network. This is an international research cooperative, bringing together researchers from India, China, Indonesia, Vietnam, Bangladesh, the Philippines and South Africa.

3.48 A successful laboratory strain of Golden Rice has been available since 2000. However, field trials, required before the crop can be made available to farmers, have been delayed. In particular, gaining regulatory approval for trials in the countries participating in the Golden Rice Network has proved to be onerous. Influenced by European debates about the risks associated with the use of GM crops, regulatory agencies in developing countries have been hesitant to grant licences for field trials.

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64 Research is currently being undertaken in India, where researchers aim to produce mustard seeds containing ß-carotene. The seeds are used for the production of oil and preliminary findings suggest that fairly high levels of ß-carotene can be provided. The project is a joint enterprise between the Tata Energy Research Institute (TERI) and Monsanto, with support of the US Agency for International Development (US AID). Monsanto (2002) *Growing Partnerships for Food and Health* (St. Louis: Monsanto). Researchers at the International Crops Research Institute for Semi Arid Tropics (ICRISAT) have produced a variety of millet that contains high levels of ß-carotene, similar to those found in Golden Rice. However, unlike Golden Rice, the Golden Millet strain was produced by conventional breeding techniques. Genetic marker techniques will be used to transfer the trait to other millet varieties. See Jayaraman K (2002) Natural 'golden millet' rivals 'golden rice', *SciDev.Net* 25 June 2002. Available: http://www.scidev.net/News/index.cfm?fuseaction=readnews&itemid=182&language=1. Accessed on: 20 Oct 2003. Further research relating to micronutrient enriched crops involves potatoes. Researchers at the Jawaharlal Nehru University in New Delhi are currently working on the 'Protato'. Adding the *AmA1* gene to conventional potatoes produced three times more protein, including significant amounts of the essential amino acids lysine and methionine. Deficiencies of these nutrients in the diets of children are common. Lack of lysine, for example, affects brain development. See Coghlan A (2003) 'Protato' to feed India's poor, *New Scientist* **177** (2376): 7.

65 In part, the name is derived from the fact that the rice is more yellow in colour than conventional rice. Golden Rice technology was developed with funding from the Rockefeller Foundation (1991-2002), the Swiss Federal Institute of Technology (1993-1996), the European Union under a European Biotech Programme (1996-2000) and the Swiss Federal Office for Education and Science (1996-2000).

66 ACC/SCN in collaboration with IFPRI (2000) *Fourth Report on the World Nutrition Situation: Nutrition throughout the Life Cycle* (Geneva: ACC/SCN with IFPRI); Personal communication, Professor Potrykus, 21 March 2003.

3.49 Proponents of Golden Rice point out that the delays are a particularly undesirable consequence of the EU regulatory framework. They emphasise that the genome of Golden Rice, like any other GM crop, is modified in a much more precise way than is the case for non-GM varieties, where unpredictable and major rearrangements of parental genomes occur frequently. They argue that the regulatory requirements for Golden Rice are therefore unreasonably high. Under the current regulatory regime, the first approved varieties of Golden Rice are not expected to be released before 2007/8.[67] Proponents of the technology, frustrated by these setbacks, point out that Golden Rice could shortly be tested in field trials in many developing countries, if the regulatory procedures were not so burdensome.[68]

3.50 Opponents, on the other hand, have questioned whether the amount of ß-carotene in Golden Rice would actually be sufficient to make a significant contribution to improved vitamin uptake.[69] In addition, the bio-availability of ß-carotene from Golden Rice is unknown, and it is therefore not yet clear to what extent the human body can make use of ß-carotene in this form. Some point out that an adequate intake of fat is needed to make use of the vitamin. Others claim that the yellow colour of the rice may not be compatible with cultural preferences, and that Golden Rice will be rejected accordingly.[70] We consider these questions in more detail in paragraphs 4.21-4.26.

Case study 5: Improved resistance to viruses in sweet potato

3.51 In Kenya, as in many other African developing countries, sweet potato is an important subsistence crop grown typically by small-scale farmers. About 40% of the harvest is usually kept for household consumption. Sweet potatoes can adapt to a wide range of environmental conditions and grow in both fertile and marginal areas. It is the second most important subsistence crop after maize. However, yields are low. The usual African yield of six tons per hectare is less than half of the global average.[71] Viruses and weevils frequently reduce yields by as much as 80%.[72] Effective controls for these pathogens are not available, and the crop has generally been neglected in international agricultural research.[73]

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67 Personal communication, Professor Potrykus, 21 March 2003; Potrykus I (2000) *The Golden Rice Tale*. Available: http://www.mindfully.org/GE/Golden-Rice-Ingo-Potrykus.htm. Accessed on: 20 Oct 2003.

68 Zimmerman and Qaim discuss the usefulness of introducing Golden Rice in the Philippines and estimate that every year of delaying its introduction results in between 1,500 – 9,000 cases of child blindness, see Zimmermann R and Qaim M (2002) *Projecting the Benefits of Golden Rice in the Philippines* Discussion Paper on Development Policy No. 51 (Bonn: Centre for Development Research ZEF). There is also the possibility of producing micronutrient-enriched plants with enhanced levels of iron, vitamin E or protein. Experiments to produce these traits independently and simultaneously in rice have already been completed successfully. However, it has been reported that regulatory authorities might be hesitant to give approval for field trials of crops which involved multiple transgenic events. If that were the case, it would seem unlikely that such crops will be available to people in developed or developing countries in the near future. Personal communication, Professor Potrykus, 21 March 2003; Potrykus I (2000) *The Golden Rice Tale.* Available: http://www.mindfully.org/GE/Golden-Rice-Ingo-Potrykus.htm. Accessed on: 20 Oct 2003.

69 Greenpeace (2001) *Vitamin A: Natural Sources vs 'Golden Rice'*. Available: http://archive.greenpeace.org/~geneng/reports/food/VitaAvs.PDF. Accessed on: 20 Oct 2003.

70 Five Year Freeze (2002) *Feeding or Fooling the World?* (London: Five Year Freeze); Koechlin F (2000) *The 'Golden Rice' – a Big Illusion?* (Third World Network). Available: http://www.twnside.org.sg/title/rice.htm. Accessed on: 20 Oct 2003.

71 Qaim M (1999) *The Economic Effects of Genetically Modified Orphan Commodities: Projections for Sweet Potato in Kenya* ISAAA Brief No. 13 (Ithaca, NY: ISAAA).

72 Monsanto (2003) *Our commitments: Technology Cooperation*. Available: http://www.monsanto.com/monsanto/layout/our_pledge/techcoop.asp. Accessed on: 20 Oct 2003.

73 However, there is a major research programme at the International Potato Centre (CIP), one of the centres of the Consultative Group on International Agricultural Research (CGIAR). CIP's aim is to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweet potato and other root and tuber crops. The research programme comprises 13 projects, several of which involve the use of genetic modification. They include the improvement of sweet potato varieties, virus control, and improving post-harvest quality and nutrition. See CIP Projects. Available: http://www.cipotato.org/projects/ projects.htm. Accessed on: 20 Oct 2003.

3.52 Since 1991 the Kenya Agricultural Research Institute (KARI), in cooperation with Monsanto and universities in the US, has developed GM sweet potato strains that are resistant to the feathery mottle virus. Royalty-free licensing agreements have been signed that allow KARI and research institutes in other African countries to use the technology in the future. The crops are currently being tested in field trials and it is expected that yields will increase by approximately 18-25%. Where farmers sell part of their harvest, it has been predicted that the increased income will be between 28-39%.[74] However, some commentators caution against overly optimistic prognoses for the success of the GM sweet potato. They point out that there are three main viruses, and that resistance to the feathery mottle virus would not ensure protection against the other types.[75]

Case study 6: Improved resistance to diseases in bananas

3.53 Bananas make important contributions to food security in many developing countries. Leaves and fibres are used for a multitude of household and industrial purposes. Bananas also provide income to the farming community through local and international trade. World production of bananas is estimated to be approximately 70 million tons per year, of which around 85% are grown for local consumption by tropical, small-scale farmers.[76] Approximately half a billion people in Asia and Africa depend directly on farming of bananas. In Uganda, the crop is cultivated on one third of the arable land, and per capita consumption is 50 times higher than in the UK.[77]

3.54 Like all plants, bananas attract a range of different and highly adapted pests. However, in bananas these can have a particularly harmful effect. Unlike most plants, bananas only reproduce asexually, because the cultivated form is a sterile triploid. The different varieties grown around the world today have been cultivated from shoots of a small number of naturally occurring mutants. These have been derived from an even smaller number of man-made triploid varieties, some produced over a hundred years ago. Each 'variety' is therefore a clone, and the crop species is characterised by a very low level of genetic diversity. There is little hope that conventional plant breeding will produce crops that are resistant to bacterial or viral infections.[78] However, GM technology offers possibilities of increasing resistance to pests and diseases. It may also help to increase the diversity of banana varieties, which in turn could contribute to slowing down the impact of pests.

3.55 Common infestations of bananas include nematodes, viruses, and fungal diseases. The most harmful fungal disease is black Sigatoka which can reduce fruit yields by as much as 50-70%. It can cut the productive lifetime of a plant from approximately 30 to two or three years. Usually, up to 40 sprayings of fungicide are applied annually to afford protection from the fungus. These sprayings represent up to a quarter of the production costs, are environmentally problematic, and a cause of considerable ill health of farm workers. According to a 1999 study by the National University of Costa Rica, one fifth of the male workers on banana farms in Costa Rica are sterile. It has also been reported that female

74 Qaim M (1999) *The Economic Effects of Genetically Modified Orphan Commodities: Projections for Sweet Potato in Kenya* ISAAA Brief No. 13 (Ithaca, NY: ISAAA); Pew Initiative on Food and Biotechnology (2001) *Harvest on the Horizon: Future Uses of Biotechnology* (Washington, DC: Pew Initiative on Food and Biotechnology).

75 Odame H, Kameri-Mbote P and Wafula D (2002) Innovation and policy process: case of transgenic sweet potato in Kenya, in *Econ Polit Weekly,* **XXXVII** No 27.

76 FAO (2002) FAOSTAT. Available: http://apps.fao.org/. Accessed on: 20 May 2003.

77 Pearce F (2003) Going bananas, *New Scientist* **177** (2378): 26–9.

78 Conway G (2003) *From the Green Revolution to the Biotechnology Revolution: Food for Poor People in the 21st Century.* Speech at the Woodrow Wilson International Center for Scholars Director's Forum. 12 March 2003. Available: http://www.rockfound.org/documents/566/Conway.pdf, p19. Accessed on: 10 Oct 2003.

workers have a 50% increased chance of developing leukaemia and of passing on birth defects to their children.[79]

3.56 One of the goals of a public, global biotechnology consortium led by the International Network for the Improvement of Banana and Plantain (INIBAP) is to sequence the genome of inedible wild bananas from South East Asia, as these are resistant to black Sigatoka.[80] It is hoped that the project will help identify genes which confer resistance. Once identified, the gene(s) could be introduced in leading varieties of edible bananas.[81] Other research is being undertaken to produce bananas that are resistant to nematodes,[82] or to viral diseases such as the banana bunchy top virus or banana bract mosaic virus.[83] There are also other forms of biotechnology-aided plant breeding, such as tissue culture, which have already resulted in improved, disease free crops.[84]

Case study 7: Herbicide resistant soybean

3.57 The genetic trait which confers tolerance to a specific broad spectrum herbicide can allow farmers to control a wide range of weeds while not affecting the modified crop.[85] Herbicide tolerant crops are grown mainly in developed countries. However, more recently, they have also been used in some developing countries. In Argentina, more than 90% of the local soybean harvest in 2002 was produced from GM varieties, making it the world's second largest producer of GM soybeans.[86] The multinational company Nidera provides the majority of commercially traded soybean seeds (70%). The remaining fraction is sold by six other companies, including Monsanto which first developed GM soybeans resistant to the herbicide glyphosate, marketed as Roundup Ready soybeans (RR). It is noteworthy that the RR technology is not patented in Argentina, and that national legislation allows farmers to use farm saved seed, which accounts for 30% of all soybeans planted.[87]

3.58 Proponents of this type of GM crop highlight the fact that its use can lead to more efficient agriculture as the need for herbicides, machinery and labour is significantly reduced. Seeds can be drilled directly into unploughed soil which helps to prevent soil erosion (the so called

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79 Smith J (2002) The truth about the banana trade, *The Ecologist* 22 March 2002. We note that one of the most dangerous chemicals, dibromochloropropane has now been banned. Rates of other types of cancers have been shown to be increased amongst Costa Rican banana plantation workers as compared with the national incidence rate, see Wesseling C, Antich D, Hogstedt C, Rodriguez AC and Ahlbom A (1999) Geographical differences of cancer incidence in Costa Rica in relation to environmental and occupational pesticide exposure, *Int J Epidemiol* **28**: 365–74

80 INIBAP is a programme of the International Plant Genetic Resources Institute (IPGRI).

81 Pearce F (2003) Going bananas, *New Scientist* **177** (2378): 26–9. AstraZeneca is also developing cultivars with resistance to black Sigatoka, see Biotechnology Industry Organization Agricultural Biotech Products on the Market. Available: http://www.bio.org/food&ag/approvedag98.html. Accessed on: 20 Oct 2003.

82 Researchers at the Catholic University of Leuven are developing banana cultivars with resistance to nematodes and to fungal diseases, which can lead to an average 20% loss in banana plantations. KU Leuven Laboratory of Tropical Crop Improvement. Available: http://www.agr.kuleuven.ac.be/dtp/tro/home.htm. Accessed on: 22 Oct 2003.

83 Research at the Catholic University of Leuven and at Queensland University of Technology in Australia has focused on developing bananas which are resistant to these viruses, which are among the major viral diseases relevant for bananas worldwide. KU Leuven Laboratory of Tropical Crop Improvement. Available: http://www.agr.kuleuven.ac.be/dtp/tro/home.htm. Accessed on: 22 Oct 2003; Demegen (2001) International Plant Biotech Groups Collaborate. Available: http://www.demegen.com/prs/pr011213.htm. Accessed on: 22 Oct 2003.

84 Wambugu FM and Kiome RM (2001) *The Benefits of Biotechnology for Small-Scale Banana Producers in Kenya* ISAAA Brief No. 22 (Ithaca, NY: ISAAA).

85 As noted above, paragraph 3.8, this trait has also been achieved through the use of other methods, such as mutation breeding and gene transfer from wild relatives.

86 Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics.*

87 Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics.*

no till practice). Conventional soybeans require regular application of a variety of herbicides, whereas RR soybeans require fewer applications of only one type of herbicide.

3.59 However, the use of RR soybeans in Argentina has raised several issues. Many critics are concerned about the dramatic increase in the use of the herbicide glyphosate.[88] Since the release of RR soybeans, glyphosate sales have increased eleven-fold, amounting to 82.35 million litres in 2001. In part, this is a result of the expiry of Monsanto's patent on the compound: in 2001, 22 companies were able to provide generic versions of the product at competitive prices.[89] The 'no till' practice has also contributed to increased use. However, proponents point out that glyphosate has no residual activity and is rapidly decomposed by soil microorganisms.[90] The increased use of glyphosate also significantly reduced applications of more hazardous herbicides in higher toxicity classes in Argentina.[91]

3.60 Others are concerned about the rapid growth in production of soybeans. In 1995, almost six million hectares of soybeans were harvested, predominantly for export; by 2001, the figure had risen to 10 million hectares.[92] Several commentators claim that the use of RR soybeans is disadvantageous for smaller farms, and leads to deforestation, rural unemployment and food insecurity.[93] The highly complex interplay of technological factors as well as societal, political and regulatory processes means that it is difficult to evaluate these various claims. With regard to the impact on farmers managing smaller farms (less than 100 hectares), recent research shows that they realised greater cost savings and an approximately 5% gain in gross margins than farmers operating larger farms.[94]

3.61 The mean costs in hired labour and custom operation per hectare for RR soybeans and for conventional soybeans were found to be very similar.[95] Because Argentine production of soybeans is fully mechanised, the use of herbicide does not displace hand-weeding labourers. Savings result from fewer tillage operations and more efficient harvesting. Whether herbicide resistant crops will be an appropriate addition to agricultural practice in specific developing countries will depend on the type of agriculture practised as well as on the type of crop. As one respondent to our Consultation observed:

> 'Herbicide tolerance as a trait is harmful, not helpful in our situation …the socio-economic interest of the poor rural community lies in manual weeding which provides wages to agricultural labour, which are usually the land-less farmers. Weeding is mostly done by women, providing them with a direct, and often only, income source. Also,

88 Joensen L and Ho M-W (2003) Argentina's GM woes (Institute of Science in Society). http://www.i-sis.org/AGMW.php. Accessed on: 22 Oct 2003.

89 Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics.*

90 Glyphosate is classified as "Unlikely to present acute hazard in normal use" in *The WHO Recommended Classification of Pesticides by Hazard 2000-2002* (WHO).

91 Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics.*

92 CIARA (2002) Datos Estadísticos, Cámara de la Industria Aceitera de la República Argentina, Buenos Aires.

93 Greenpeace (2002) *Record Harvest – Record Hunger Starving in GE Argentina* (Berlin: Greenpeace); Eduardo Rulli de Jorge (2003) Biotechnology and the origins of the Argentine catastrophe, *Ecopartal* 11 Sept 2002; Backwell B and Stefanoni P (2003) Soya solidarity or food apartheid: The business of hunger in Argentina, *Le Monde Diplomatique* Feb 2003.

94 Savings resulted from reduced use of pesticides and lower seed prices, as saved or uncertified seed is more commonly used by farmers managing smaller farms. See Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics.*

95 The mean cost of hired labour and custom operation per hectare for RR soybeans was US$43.22, compared to US$46.82 for conventional soybeans. See Qaim M and Traxler G (forthcoming) Roundup Ready Soybeans in Argentina: Farm Level and Aggregate Welfare Effects, *Agricultural Economics*.

> some of the plants that are collected as weeds are consumed by the rural household. Many of these are leafy greens like amaranth … a rich source of vitamins and minerals, or serve as fodder for the livestock that is maintained as an additional source of income. These weeds are also medicinal plants which are accessed by rural communities for health and veterinary care.'
> *Suman Sahai, New Delhi, India, Gene Campaign*

As we have said, raising demand for labour is the very essence of reducing poverty. Agricultural innovation should therefore aim to raise labour productivity. However, in poor countries with rapidly growing workforces and severe land and water shortages, productivity of land and water need to rise, so that employment and labour demand can increase. Therefore herbicide resistance which encourages farmers to displace labour is seldom a main priority for GM research in poor countries. But there may be very specific circumstances where less labour intensive crops can be of benefit to small-scale farmers in developing countries, as has been pointed out by the following respondents to our Consultation:

> 'the use of genetically modified crops that reduce labour could significantly address specific social and economic crisis facing rural communities as a result of the AIDS pandemic… In Kenya, for example, the losses in agricultural production from AIDS at household level range from 10-50%. Shortage of farm labourers means that children are increasingly involved in agriculture, impacting their education and quality of life.'
> *International Service for the Acquisition of Agri-biotech Applications (ISAAA) AfriCenter and the African Biotechnology Stakeholder Forum (ABSF)*

Thus, the use of herbicide resistant crops will always have to be considered carefully on a case by case basis, taking into account the specific situation of the developing country concerned.

Case study 8: Biopharmaceuticals

3.62 An application of genetic modification that differs considerably from the previous examples is the possibility of producing biopharmaceuticals, such as vaccines, in crops. Two distinct procedures can be identified. One option is to modify plants so that they produce substances which can be extracted from the harvested plant and then processed into refined compounds. The other option is to modify plants in such a way that they produce vaccines which can be administered by eating the crop. This is achieved by changing the genetic structure of the crop to produce DNA fragments from a specific pathogen. These fragments code for proteins which provoke an immune response in the human body. The advantages of edible vaccines are manifold: injected vaccines are expensive, require trained medical staff for their administration, and usually require constant cooling during transport and storage, which creates difficulties in many developing countries. The use of needles also brings with it the risks of spreading infections.

3.63 Development of GM crops which can produce biopharmaceuticals is at a very early stage. Scientists at Cornell University are currently working on tomatoes modified to be used as a vaccine against the Norwalk virus, which causes severe diarrhoea. Studies on mice have already shown an increased immune response. In another study, bananas have been genetically modified to produce a vaccine against hepatitis, although it has not yet been

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96 AEBC (2002) *Looking Ahead - An AEBC Horizon Scan* (London: Department of Trade and Industry).

97 Wong K (2001) Souped-Up Spuds Show Promise for Edible Vaccines, *Scientific American*. Available: http://www.sciam.com/article.cfm?chanID=sa003&articleID=00019658-ED97-1C5E-B882809EC588ED9F. Accessed on: 20 May 2003.

possible to produce robust levels of antigens in the fruit.[96] There have also been experiments with GM potatoes aiming to develop a vaccine against rotavirus and against the bacterium *E. coli* which causes diarrhoea. Feeding studies involving mice have shown valid responses.[97]

3.64 However, a number of questions remain to be addressed. One of these is how the appropriate dose could be controlled. Another concerns the effect of such crops on insects and other animals which might feed on it. For example, it has been reported that avidin, which has been produced commercially in GM maize for use in research and diagnostics, is toxic for certain insects.[98] There are also environmental issues relating to gene flow from GM crops to non-GM crops. Furthermore, it has been reported that left-over grains from GM maize, modified to express biopharmaceutical compounds, have inadvertently germinated amidst soybeans grown on the same field in the season following the trial.[99] It is clear that this use of GM crops will require the provision of special agronomic facilities that restrict, for example, the spread of seed and pollen. Furthermore, appropriate regulatory oversight would need to be in place to ensure that the required standards are met.

Summary of case studies

3.65 We briefly summarize the possible benefits and risks which have been illustrated by the eight case studies. Current evidence suggests the following advantages of specific GM crops:

- The use of *Bt* cotton has resulted in more efficient and selective pest control, reduced applications of pesticides, reduction of environmental degradation, increased health benefits for farm workers and increased profits for farmers (case study 1).
- Improved resistance to environmental stresses such as cold, moisture-stress and high salt levels in the soil can be achieved in GM rice (case study 2).
- The yield in rice can be increased more efficiently by means of 'dwarfing', (case study 3), while maintaining the benefits of locally well adapted varieties.
- There is potential for the production of micronutrient-enriched rice which could make a significant contribution to prevent health problems such as VAD (case study 4).
- Case study 5 showed that the use of GM virus-resistant sweet potatoes could prevent dramatic and frequent reductions in yield of one of the major food crops of many poor people in Africa.
- Case study 6 on GM bananas illustrated the possibility of achieving protection against serious fungal diseases and reduction in pesticide use, with direct financial and health-related benefits for farmers and farm workers. Since bananas produce sterile pollen and only reproduce asexually, genetic modification could also help to produce a more diverse range of varieties, which would allow for additional protection against pests.
- Case study 7 demonstrated the possibility of reducing the use of environmentally damaging herbicides by the introduction of glyphosate resistant GM soybeans. In the absence of royalty fees being levied, farmers were able to increase their profit margins as a consequence of reduced costs for seeds and herbicides.
- Although somewhat more distant in terms of practical application, GM crops may also offer inexpensive and far-reaching provision of vaccines against diseases such as severe diarrhoea and possibly hepatitis (case study 8).

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98 GeneWatch (2003) Briefing No. 21 *Genetic Modification: The Need for Special Regulation* (Derbyshire, UK: GeneWatch). Avidin is an avian egg white protein, useful due to its high affinity to biotin. The avidin-biotin reaction has now become a tool in molecular biology, with numerous applications.

99 Cohen P (2002) Stray genes spark anger, *New Scientist* **176** (2370): 7.

3.66 We also noted the following possible risks associated with these benefits:

- The occurrence of gene flow, and the potential impact on other plants and organisms needs to be considered in the case of all GM crops which have been discussed, with the exception of bananas (case study 6). Transgenes inserted into crops for the production of biopharmaceuticals (case study 8) will require special consideration. The possibility of gene flow will also need to be considered carefully where a GM crop is planted in an area which serves as a site for *in situ* conservation of plant cultivars.
- Case studies 1 and 7 showed that the effects of genetic modification on insects and animals that may feed on the GM crop need to be evaluated. This aspect may be of particular relevance where crops have been modified to contain substances which wild relatives of the respective crops would not normally contain.
- There were also questions related to the setting of priorities: should developments such as Golden Rice (case study 4) or the production of biopharmaceuticals (case study 8) be pursued, if there could be other ways to achieve the same end? Would investments in these crops distract attention and resources from other approaches?
- Agrochemical companies and others who own IPRs for technologies necessary for the development of GM crops can have considerable influence over the availability of GM crops, as was clear from the case study on Golden Rice (case study 4), *Bt* cotton (case study 1), and on RR soybean (case study 7).
- The case study on *Bt* cotton (case study 1) showed that a multitude of factors determine whether or not the use of such GM crops is preferable to conventional crops. Some relevant factors are: the incidence of pests; the impact of pest control on other pests that might require additional applications of pesticides; the effective management of refuges; resistance of pests to toxins; and the size of any technology fee.
- Case study 7 on RR soybeans illustrated that particular care needs to be given to GM crops which have the potential of reducing labour. This can have negative consequences for those developing countries which have populations of working age unaffected by, for example, HIV/AIDS, and which practise non-mechanised agriculture.

3.67 We next consider arguments in relation to these potential risks and benefits, and possible ways to balance them.