

Ethics and transgenic crops: a review

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This article represents a review of some of the ethical dilemmas that have arisen as a result of the development and deployment of transgenic crop plants. The potential for transgenic crops to alleviate human hunger and the possible effects on human health are discussed. Risks and benefits to the environment resulting from genetic engineering of crops for resistance to biotic and abiotic stresses are considered, in addition to effects on biodiversity. The socio-economic impacts and distribution of benefits from transgenic technologies are reviewed. Fundamental issues of man's relationship with nature and the environment, and theological matters are also addressed. An almost unprecedented amount of discussion has been stimulated on the merits and demerits of genetic engineering of crop plants, and has divided both the public and scientific communities. The arguments for and against transgenics are invariably based on visions of the new technology from widely different ethical perspectives.

The subject of transgenic crops embraces many of the major issues in philosophy; the meaning of words, free will, the concepts of right and wrong and justice, and ultimately the meaning of life itself. It has become a battleground involving scientists, commerce, politicians, journalists, lobby groups and the public. The arguments are about values, which are neither absolute nor universal, and the controversies surrounding transgenic crops have to a large extent polarised society into the proponents and opponents, with once seemingly trustworthy and ethically sound scientists being viewed with suspicion by many. Much of the argument is emotive, with talk of "Cashing in on Hunger", "Demon Seeds", "Terminator Technology" and "Frankenstein Foods", and it is difficult for anyone to appreciate any underlying truths, should they even exist. The polemics have been fierce, questioning the role of god, the sanctity of nature, the motives of big business and the ownership of life forms, and are inevitable consequences of agriculture being at the very origin of human cultures and religions. And yet farmers have been plant breeders for ten thousand years, altering the genetic integrity of most crops without any knowledge of heredity. These farmers were

the first genetic engineers (Jones, 1994), although genetics as such did not come into existence until the work of Mendel was rediscovered by De Vries (1900) and others. Using knowledge of the inheritance of traits, plant breeding assumed scientific status and during the past one hundred years has developed to allow very direct control over crop evolution for man's benefit. Until the advent of genetic engineering (GE) plant breeding was confined to making crosses within and between crop species which could occur naturally, albeit that some crosses were forced (see Forster *et al.*, 1997) for a review of GE of crop plants). Developing transgenic crops has become routine only within the last few years and has changed the nature of plant breeding substantially, raising a whole host of ethical considerations as a consequence. These centre on the associated risks and benefits to man the environment, the balance of the distribution of benefits, and on the technology being good or bad in itself. The moral and ethical concerns are important factors in influencing a risk-averse public (Callahan, 1996), and are a pivotal feature of the debate on transgenic crops and their products (Wadman, 1996; Geary, 1996; Newton *et al.*, 1999).

Risks, benefits and impacts on society and the environment

Concerns about transgenic crops represent important considerations in many instances, especially on the part of the public, although it is the concerns about the consequences of the new technology, the risks, benefits and impacts, referred to as "extrinsic" concerns by Straughan (1995b), that are more usually discussed. Basic questions which require answers are, do transgenic crops represent 1) the solution, albeit possibly partial, to world hunger, 2) unacceptable risks to the environment and human health, 3) a means for improving equitable sharing of the benefits of technological advance? Obviously these issues are inherently linked and any absolute division is artificial.

Science has had an enormous impact on human existence, providing numerous innovations which have improved the lives of many, and scientists have been regarded, in the main, as trustworthy and ethically sound, and agricultural research and its role in food production as being

intrinsically good (Hardon, 1997). This view has been altered somewhat by the advent of GE (Wagner, 1996), although it is generally appreciated that new technologies by their very nature represent a challenge to existing values and systems, and stimulate change in traditional concepts of nature and human identity (Carr and Levidow, 1997). Moreover, the myth that agriculture is practised in a rural Eden needs to be dispelled and replaced with the reality of it being a struggle to produce food for an ever increasing population against natural forces (Borlaug, 1997).

Transgenics and human hunger

It is a commonly held view that transformation of agriculture is a moral imperative for reducing poverty and hunger and promoting equity in many of the world's poorer countries (Serageldin, 1997; Ortiz, 1998). It is Malthusian preoccupations, feeding a human population of ten billion in the foreseeable future, which represent the ethical justification for employing such biotechnology (Jaffe, 1994; Borlaug 1997). This presupposes that food shortage as such is the principal cause of hunger, and ignores to some extent the reasons for poverty, inequitable distribution of food, land tenure inequity, overpopulation, poor health, poor education etc. Carr and Levidow (1997) emphasised the multi-faceted nature of hunger, and criticised the assumption that transgenics have a moral head start on other technologies.

The argument concerning food production should be treated with circumspection given that little is known about how transgenic crops might contribute to sustainable farming practices (Pretty, 1999). Furthermore, transgenic research is mainly conducted by chemical companies and directed towards chemically dependent crop varieties (Hubbell and Welsh, 1998) and value-added products rather than staples (Levidow and Carr, 1997). Rifkin (1998) believes that the current type of agricultural biotechnology is misdirected and promises disaster, while Simmonds (1997) believes it to offer more than it can deliver and Serageldin (1997) stresses that the "opportunities for producing transgenic varieties are endless". Dixon (1998) argues that GE will increase food production in less developed countries and malnutrition could be banished, whereas Shiva (1998) believes GE will displace industries in poorer countries and jeopardise smallholder farming. The range of opinion on the probable impact of transgenic crops is wide.

Where will the required increase in agricultural output take place? There are basically two options: intensification of agriculture in areas currently farmed, or expansion of the area under cultivation to take in new areas, as yet uncultivated. Using current intensive farming methods the first option promises further deterioration of already damaged environments while the second will result in the loss of delicate ecosystems, such as tropical forests and savannahs, and their associated biodiversity. In theory, cultivation of transgenic crops could, through intensification of agriculture, contribute to increased

agricultural production and an alleviation of human hunger, while promoting environmental conservation. The dilemma is that food shortages generally occur in areas characterised by poverty, high population growth rate and political instability, if not war itself. In addition, the environment sets natural limitations. Is it therefore likely that GE can make a positive contribution to relief of hunger where it occurs? Poor farmers cannot purchase sophisticated inputs such as transgenic seed, and would seed companies develop transgenics for such conditions knowing this? It is unlikely that the altruism of big business stretches so far, although poorer countries might represent a good test-bed for new technologies. As a direct and sole solution to human hunger it seems unlikely that transgenics will make the required impact (Pretty, 1999).

Transgenics and the environment

Discussing the science of the environment, Pullin (1996) says it is "not a problem of political or economic theory but a problem of our personal relationship with our environment". Should the environment be protected because of intrinsic moral value or because it is a valuable resource for mankind (Dobson, 1996)? There is an obvious conflict between human requirements and respect for nature (Jameton, 1996) which is a key issue in development and deployment of transgenic crops. Concerns about the natural and agricultural environments differ according to country: there is less concern for agricultural environments in the USA, for example, which has large national parks, than there is in the UK, which does not have such plentiful wild nature (Anon., 1999a). It is known however that modern intensive agriculture adversely affects the environment through its reliance on chemical inputs for optimising soil nutrient conditions, seeds of varieties correspondingly responsive to such conditions, and pesticides for controlling insects, pathogens and weeds (Carson, 1963; Mellanby, 1967; Harvey, 1998). Pimentel (1995), Paoletti and Pimentel (1996) and Harding and Harris (1997), among others, have reviewed risks and benefits of GE in agriculture, and Johnson (1999) presented a case for exercising precaution in releasing transgenic crops into the European landscape until more is known about their effect on natural biodiversity.

Crop plants engineered to suit the environment better through incorporation of genes for tolerance to biotic and abiotic stresses have been suggested to represent an improvement in crop production (Ortiz, 1998), and thereby an ethical advance, while others regard such crops as being just as environmentally unfriendly as the technologies they are supposed to supersede (Rifkin, 1998). The immediate environment, farmland, and the surrounding, non-farmed environments could be affected by introduction of new technologies. GE of crops for reduced fertiliser requirement through *in planta* nitrogen fixation could be beneficial through reducing the negative impact on the soil and the subsequent effects of run-off into rivers and seepage into ground water. Would such a new technology promote

sustainable farming practices? The question is posed by Hubbell and Welsh (1998), who documented three classes of transgenics; those with 1) transitional traits, which reduce environmental damage in the short term through substituting for an input, 2) compatible traits, which reduce use of non-sustainable inputs without polluting the environment, and 3) sustainable traits, which are fully sustainable over time. They concluded that transgenics for the third class have not yet been produced, and will not be produced until there is structural reform of industry, and of public and private sector research.

Objections to development and deployment of transgenic crops rest on several issues relating to the balance of associated risks and benefits. Many crops have been engineered to withstand herbicide application and there is much debate on whether this will lead to more or less herbicide being applied to crops, which types of herbicide (in terms of environmental friendliness) will be applied, the persistence and effects of herbicide residues, the possibility of herbicide resistance developing in target species and their genes being in turn passed on to non-target relatives to create invasive herbicide resistant weeds (Kling, 1996). There is ample evidence that transgenic crops and their genes, through pollen dispersal, can spread (Brookes, 1998) even between species that are mainly inbreeders (Cavan *et al.*, 1998). Regarding transgene and transplastomic containment, there are no standard scenarios (Chamberlain and Stewart, 1999), but it has been established that there is a low probability of chloroplast movement from oilseed rape into wild species (Scott and Wilkinson, 1999). The effects of transgene escape on the environment are uncertain, but modern technology could limit such "genetic pollution" through, in some cases, engineering sterility into the transgenics to ensure vastly reduced gene flow into the farming and natural environments. Crops do not generally survive outside the farming environment and transgenic crops would probably be out-competed should they spread off farm.

Pest and disease resistance is a further area of transgenic technology that has attracted criticism: engineered virus resistance could result in the evolution of new and harmful viruses (Borja *et al.* 1999; Rubio *et al.* 1999), and crops engineered to produce toxins (Bt toxins in the main) might poison non-target hosts (Concar, 1999). There are differences in outcrossing rates between transgenic *Arabidopsis* plants and mutant *Arabidopsis* expressing the same mutant allele (Bergelson *et al.* 1998). There is already evidence that many targeted pest species have developed resistance to engineered genes, much in the same way as they have done to naturally occurring resistance genes (Holmes, 1997). This is a demonstration that nature fights back against the genetic engineer in much the same way as it fights back against the conventional plant breeder and many solutions to pest and disease problems represented by GE are likely to be short-lived. Agrochemical control of crop pests is however inefficient and environmentally and ethically unsound (Pimentel, 1995) and GE could offer a

remedy, allowing more precise targeting of pest management.

Ortiz (1998) suggested that trees would be the next targets on the agenda for GE. This raises new ethical and environmental concerns due to their long-lived and little domesticated nature, and the problems that will ensue through possible pest adaptation, production of environmental toxins, enhanced invasiveness and transfer of transgenes. These specific issues were reviewed by James (1997), who concluded that man has an ethical obligation to the ecosystem which must be considered when balancing the risks and benefits of GE of trees for insect resistance versus application of toxic pesticides. James (1997) highlighted the similarity between biocontrol and GE, the former being concerned with the introduction of entire novel genomes and the latter with the introduction of novel genes. One major consideration of GE and trees is that trees are usually regarded as part of the natural environment, despite forests being commercial to a large extent, rather than the agricultural environment. This may result in fears for preservation of what is perceived to be a natural resource rather than a managed one. In that forests, particularly tropical rainforests, represent massive reservoirs of biodiversity, GE of trees becomes even more controversial. This is especially so given that some tree species become invasive when introduced into new environments. A scenario of transgenic trees produced for commercial forestry requirements escaping into natural forest, where the consequences could be negative and not easily reversed, is disturbing.

Hokkanen and Lynch (1995) dealt with benefits and risks of biological control, including use of genetically modified (GM) organisms. Many of the ethical issues are the same as those associated with GE, but it is interesting that biological control appears to have attracted a lot less attention from the media and the public than transgenic technology and has consequently had a much more positive press. Public perception plays a large role in this; introduction of a pretty and familiar looking ladybird into the environment appears much more acceptable and benign than introduction of bacterial genes into a familiar food crop.

An additional area where ethical considerations are relevant to a discussion of transgenic crops is that of genetic diversity and its possible erosion. Hardon (1997) pointed out that plant breeding relies on genetically diverse germplasm for progress to be made and maintained, which in traditional agriculture is regarded as a common resource of great value and is freely available. He considers it unethical to treat such traditional forms of agriculture as markets to be conquered by private interests (biopiracy). This discussion is directed towards the farming environment, but useful genes will be increasingly sought from the non-farmed environments. While some argue that development of transgenic crops will enhance biodiversity by creating an increased need for exotic genes, others argue that genetic diversity will be diminished through

deployment of a narrow range of germplasm. Biodiversity, both on and off farm, is already in decline due to current farming practices in both the developed and developing world, but whether transgenic crops will accelerate or dampen this remains a debatable issue. The dilemma is that the greatest biodiversity exists in the delicate ecosystems of the as yet uncultivated areas and the cropping systems of some of the world's poorest countries.

Just as it is impossible to prove that an event will not occur, there is likewise no guarantee that not pursuing a line of research will prevent an environmental disaster, but many of the benefits of transgenics have become apparent while the anticipated problems have not materialised. Buccioni (1998), in a review of Reiss and Straughan (1996), pointed out that predicting whether stopping research and development might inhibit production of a desperately needed innovation is mere speculation, and that actually pursuing a course of research could as easily precipitate a problem. Ethically it could be equally unsound to pursue a line of research or not pursue it, but it will only be known retrospectively. Weil (1996) believes that the effects of transgenics on the environment are controversial because of the great difficulty in gauging the associated risks. Although all actions are potentially hazardous, there have been no problems involving transgenics to compare with those that have been encountered previously as a result of classical plant breeding (e.g. T cytoplasm and southern corn leaf blight in the USA in the early 1970's). Moreover, the hazards certainly do not approach the scale of environmental damage wreaked by disasters in traditional industry; the oil spill from the Exxon Valdez and the escape of radioactive fallout from the Chernobyl nuclear power station to name but two. Interestingly, while there is a public preoccupation with the potential hazards arising from GM crops, environmental concerns about conventional crops are few (Anon., 1999a). As pointed out by Concar and Coghlan (1999), an oilseed rape variety has been bred in Canada which carries genes for resistance to two herbicides, but it has been bred using conventional means - is this ethically more acceptable than if the crop had been genetically transformed? Ort (1997) mentioned several crops, including triticale, with its genomes from wheat and rye, which have contained "foreign" genes for a long time without occasioning any public outrage, or indeed causing any environmental damage. Species introductions have not provoked much alarm either, and yet have been problematical in many instances.

Transgenics and human health

Plants are the basis of the human diet. A major worry of the public, aside from fundamental concerns, is that transgenic crops contain ethically sensitive genes, including, for example, antibiotic marker genes and promoter sequences derived from viruses. Rather carelessly presented accounts of GE developments, by journalists and scientists alike, have aroused concern that human health will be adversely affected by consumption of transgenic crops and products

derived from them (Anon., 1999b; Coghlan *et al.*, 1999). This movement has developed to the extent that restaurant chains have removed GM foods from their menus, schools have outlawed GM products (Ward and Hall, 1999), and there has been increasing demand in supermarkets for organic food (Clover, 1999). Is this the start of a biotechnology backlash (Williams, 1998)? In the wake of the BSE scare it is especially apparent that human health is not an area where utilitarianism can be practised; cost-benefit analysis is not useful when human life dominates the discussion. And yet retailers that have opted not to sell GM foods continue to sell tobacco, alcohol, fatty food and candies (Anon., 1999c). This is hardly ethically consistent.

Bengtsson (1997) maintained that as some crop varieties will be transformed many times, antibiotic resistance genes will accumulate, and it is therefore sensible to remove them as plant breeders will soon encounter difficulties in locating new, harmless antibiotic marker genes. The obvious fear is that antibiotic marker genes could be recruited into humans (and domestic animals) rendering antibiotics ineffective in curing bacterial infections. Technologies for targeted gene removal (incorporating site-specific recombinases) have been developed (Kilby *et al.*, 1993), and alternative marker genes to ethically sensitive ones exist. The World Health Organisation (WHO) has judged antibiotic marker genes to be safe (WHO, 1994), but the outcome of their use might be hazardous if they represent a major source of resistance to a wide class of antibiotics. The fear is that these genes could spread from the plants into which they were inserted to wild plant populations and to bacterial populations that would then be advantaged in their natural environment. There is evidence that gene escape can arise as a result of transformation using *Agrobacterium* as the gene vector (Barrett *et al.*, 1997; Mogilner *et al.*, 1993).

Other principal concerns are that transgenic foods will be toxic or allergenic. Franck-Oberaspach and Keller (1997) reviewed the consequences of classical and biotechnological resistance breeding for food toxicology and allergenicity. They reported on many classes of actual and putative toxins and allergens, concluding that several naturally occurring defence substances found in plants are highly toxic to mammals, but also indicating that food safety can be severely influenced by natural pathogens and their products. It is interesting how little we yet know about the toxicity of non-engineered foods. Known toxins and allergens can be screened for in advance however to reduce the chances of releasing potentially dangerous foods. Careful labelling of products would be informative for customers with allergies and for those averse to buying a product derived from a transgenic crop.

It is difficult to maintain good health on a purely vegetarian diet, but what if plants were made healthier through GE, would this be ethically sound from society's and the consumers' points of view? Strict vegetarians might object to gene sequences from animals being introduced into plants. What of the benefits that have accrued for humans

from GE to produce insulin and human growth hormone; are direct medical applications of GE regarded as being different from those which alter plant characteristics for an indirect benefit such as nutritional improvement? Does GE of humans, animals, plants and micro-organisms require different ethical considerations, as described by Reiss and Straughan (1996)? Such questions lie at the heart of the debate on transgenic crops.

Human health already suffers as a consequence of agricultural practices. Commercial banana production, for example, requires application of large amounts of pesticides which pollute the environment, and whose residues accumulate in plantation workers. Would it not be ethically justifiable to produce a transgenic banana variety that would allow for a reduction in pesticide application and a subsequent improvement in human health? Pretty (1999), who proposed that there are more sensitive ways than GE to provide food for the expanding human population, mentions GE nematode resistant bananas as being a potentially useful contribution to sustainable farming.

Transgenics, socio-economic impact and distribution of benefits

Weil (1996) stated that large-scale farmers will be favoured by transgenic technologies, and there could be a loss of third world markets through export substitution. She provided the example of artificial sweeteners and the consequent negative effects on the sugar industry of the tropics; vanilla and various oils is a similar case (Mannion, 1998). It could be argued that development has to begin somewhere, but in the short-term it seems that the poorer section of society is bound to lose out. An additional problem is that of creating dependence in the farming population on companies for complete agricultural packages. Advocates of the technology claim however to be able to revolutionise farming, save the environment and make money (Anon., 1997), and thereby address the humanitarian, environmental and business ethic simultaneously.

A particularly controversial transgenic technology has been described recently and has become known as "Terminator Technology" (Service, 1998; Crouch, 1998). It has raised substantial ethical concerns in that it provides a means of ensuring that seed cannot be saved at the end of one crop cycle for sowing at the following cycle. This would potentially put the farmer very firmly under control of the company providing the seeds and would, if deployed in such areas, preclude using home-produced seed, a common practice in many parts of the world, not just in developing countries. This puts the business ethic and humanitarian ethic in direct conflict, and yet this same technology could be harnessed to limit natural dispersal of transgenes.

Two case studies serve to illustrate the ethical problems concerned with distribution of benefits of transgenic technology.

Case 1) In 1998 Monsanto invested \$550 million in building a Roundup (glyphosate) production plant in Brazil and the Brazilian government made Roundup-resistant soya its first legally approved genetically engineered crop. Soya is grown in Brazil by large landowners that feed it to cattle for export. These farmers are naturally wealthy and can afford to expand areas of soya production. One consequence is that more rainforest is cleared to allow for more cattle pasture and the subsistence farmers, who do not grow soya, and whose crops had been severely affected by drought, are purported to receive no benefits from the transgenic technology (Mack, 1998).

Case 2) The International Maize and Wheat Improvement (CIMMYT) in co-operation with French scientists (ORSTOM) and the Mexican government are working to develop apomictic maize. This involves gene transfer from the wild relative of maize, *Tripsacum*, to the cultivated form. Two routes are being taken, conventional wide crossing and a molecular strategy. Apomictic hybrid maize would allow resource poor farmers to gain from the benefits of hybrid vigour and have the advantage of not having to buy new seed from year to year (Reeves, 1997).

At first inspection it would appear that Case 2), development of apomictic hybrid maize, has the ethical advantage. But, it is not certain that this technology will not be high-jacked and used by rich maize growers of the developed world, just as it is not certain that subsistence farmers will not eventually benefit from the general development which arises from transgenic soya being grown in Brazil. "Trickle-down" development strategies have fallen into disrepute however (GRAIN, 1995).

Ownership of genes and the need for patents is a further area for ethical debate. Luther Burbank, a plant breeder in the 1920s, questioned why years of dedicated research and development work in plant breeding did not result in any material benefit for the breeder. Patents and plant breeders' rights have largely corrected for this unfairness, but what of transgenes? Uncountable numbers of exotic genes have entered crop varieties through conventional crossing programmes, and it would be impossible to trace them back to their origins and compensate the owners. Awareness of the value of biodiversity has increased tremendously such that genetic resources are currently regarded as natural resources like any other, and are no longer free for whosoever wishes to use them and profit from them. Intellectual property rights (IPR) for protecting indigenous resources were discussed by King and Eyzaguirre (1999). They pointed out that biological resources are frequently integral components of cultural systems which, in the face of technological advance, are threatened to an equal extent as the physical and biological resources. Any attempted protection of biodiversity through IPR has to take into account the socio-cultural setting such that value systems and ownership concepts are fully appreciated.

The Convention on Biological Diversity, CBD, resulting

from the Earth Summit held in Rio de Janeiro in 1992, in Article 19, stressed the need for those countries, especially developing countries, providing the genetic resources to participate in biotechnological research activities (CBD, 1999). This is supported by the Food and Agriculture Organisation of the United Nations (FAO) (FAO, 1999) who, following a request from the Commission on Plant Genetic Resources, drafted a code of conduct for biotechnology. The countries of the developing world have principally attempted to safeguard benefits accruing from biotechnology through legislation. FAO (1999) acknowledges that biotechnology is more than just a scientific matter, and indicates that many of the ethics-related issues are being debated in the context of IPR legislation. Moral issues surround patenting of food crops and life forms. The Andean Community (Bolivia, Colombia, Peru, Ecuador and Venezuela) have attempted to legislate jointly under the Cartagena Agreement (Cartagena Agreement, 1996) on access to genetic resources (decision 391) and plant breeders' rights (decision 345) among many other issues. These countries are developing a collective rights system for communities that take account of traditional resources and associated knowledge. Costa Rica made an agreement with Merck and Co., the world's largest pharmaceutical manufacturer, ensuring that it gets a realistic share of royalties from marketable products obtained from bioprospecting. Hulbert (1994) was critical of the CBD however, pointing out that it links two intrinsically different principles impacting on intellectual property: a participant should accept a questionable goal of income redistribution while maintaining biological diversity; an ecological goal. He indicated that for many developing countries intellectual property has not been particularly relevant: Nigeria's patent law from the 1970s excludes biological products and processes. Nor has India protected patents, trademarks and copyrights strongly. As Hulbert (1994) says, "different cultures, conflicting ethics". Genetic Resources Action International (GRAIN, 1995) suggested that there are viable alternatives to western IPRs, especially within the area of biodiversity. It maintains that IPRs, although once used to stimulate innovation and reward invention, are now used for economic expansion and market control, and particularly so following developments in genetic engineering. Moreover, GRAIN (1998) goes further in suggesting that the World Trade Organisation (WTO) is assuming an ever-larger role in intellectual property regimes through its Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs), which will have to be implemented by developing countries. It is suggested that costs will outweigh the benefits and that the outcome will be destruction of the socio-economic fabric promoting innovation in developing countries.

An example of how things can go wrong (biopiracy) with IPR is that of quinoa in Bolivia. Quinoa is a traditional crop of the Andes and the indigenous farmers have been breeding it for the prevailing conditions for centuries. In particular, they have been exploiting cytoplasmic male

sterility (CMS) to produce hybrid cultivars. In 1994 a patent was issued to two agronomists from the USA covering use of CMS in the Bolivian cultivar 'Apelawa'. Granting a patent on a staple food crop from a poor country to outsiders sets a dangerous and disturbing precedent and must be regarded as ethically unsound (RAFI, 1997).

Fundamental ethical concerns

Straughan (1995a) discussed the fundamental ethical concerns under the term "intrinsic", and addressed issues of theology, naturalness and respect for nature. Deeply held beliefs, that clearly separate right from wrong, exist for many and have to some extent been championed by Prince Charles (1998), who claimed that GE takes mankind "into realms that belong to God and God alone". The implication is that the fate of humankind is in god's hands and that our meddling with nature is sinful and goes against his wishes. Being largely built on faith, such beliefs are unlikely to be shaken by statistical or biological evidence that goes contrary to the beliefs. But where do divine responsibilities end and man's begin? The dividing line is not clear, and all human endeavour could be said to interfere with god's will to some extent.

Words and terms are frequently the root of problems associated with GE. "Transgenic" sounds very much like "eugenic" and could therefore be condemned by association, and "engineered" sounds more sinister than "domesticated" (Jones, 1994) though they are virtual synonyms. More reasoned intrinsic opposition to transgenics, however, could conceivably be that crossing species boundaries is wrong. But it should be borne in mind that classification is a manmade concept. Creationist theory views life forms as being fixed and immutable, determined by god, whereas evolutionary theory is based on dynamic concepts and gradualism, whereby small changes (mutations) take place over extended times and the forces of natural selection result in the creation of new species. Brookes (1996) pointed out that hybridisation is in any case more common in nature than is often appreciated, with more than twenty percent of plant species hybridising naturally.

What constitutes being natural, and what is fundamentally good about being natural, are two questions posed by Straughan (1991, 1995a), and Reiss and Straughan (1996). If "natural" excludes anything which man has had a hand in, this would rule out most things being natural; but surely man is as much part of the natural world as any other organism? As to nature being inherently good, natural disasters, including earthquakes, hurricanes, tidal waves and volcanic eruptions, let alone the existence of countless debilitating diseases, are abundant enough to dispel this fallacy.

An additional area of intrinsic ethical concern covered by Straughan (1991, 1995a), and Reiss and Straughan (1996) is that of respect for nature. Reductionism, the diminishing

of life to a series of gene products that can be interspersed between organisms, is regarded by some as being disrespectful, as when applied to humans it is simply dehumanising. The holistic argument contrasts with this and is based on all organisms being integral components of the environment, which are interrelated and interact in delicate balance. Disturbance of this balance is taken to be disrespectful, although it is difficult to see how any technology could escape criticism on these grounds. Weil (1996) discussed fundamental opposition to biotechnology, the commodification of nature and control of evolution by humans - "evolution engineered" (Jones, 1994) - as a risk to world-views and traditional beliefs, and posed the slippery-slope scenario whereby acceptance of one controversial technology inevitably leads to acceptance of more and more, the benefits of which become progressively less certain. She suggested that ethical limits have to be set, and that acceptable and unacceptable activities should be defined.

Fundamental concerns need not though be theologically based and indeed need not necessarily be anti-transgenics. Transgenics could be thought of as being intrinsically good, helping evolution along and providing new knowledge about the natural world; science itself being held to be intrinsically good. Kealey (1996) provides a brief answer to the question "Is science a moral good?" indicating that the outcome of scientific activity may be good, but that does not make scientists' activities intrinsically good, much as scientists' activities are not intrinsically bad even if scientific activities can lead to bad consequences.

It is evident that opinions on transgenic crops are based on value judgements and not on scientifically established facts, and such values and attitudes are likely to change with time and circumstance and with modifications to conceptual systems. Furthermore, as pointed out by Hawtin (1997), the ethical systems of the recipients of any research findings, and consequently their values, may be very different from those of the scientific community carrying out the research. The difficulties involved in making ethical decisions and developing moral technologies were discussed by Sheldon (1996) from a philosopher's viewpoint. He explained how right and wrong are defined by law, religion and custom, and how the deontological (duty), utilitarian and naturalistic moral theories could be used to aid rule and judgement making. He stressed that moral theories should not be confused with the truth and that ethical decision making cannot be made easy.

Carr and Levidow (1997) took issue with Straughan (1995a, 1995b) for drawing a distinction between intrinsic and extrinsic ethical concerns and thereby conceptually separating crop engineering from its consequences, that is, separating ethics from risk. In an additional article, Levidow and Carr (1997) stated that, "official policy downplays ethical judgements by treating risk as if it were an objective technical matter" whereas it depends on opinions and definitions, and is in effect a debate about the

values which drive the research and development of biotechnology. This falls under the heading of "state-sponsored ethics". As pointed out by Levin (1994), the information necessary to assess risk from a scientific perspective is always the same, the ethical implications become apparent when the information has to be weighed in order to make a decision; that is, when responsibility, accountability and justification have to be apportioned (Straughan, 1995b).

Concluding remarks

It is obviously too late to keep the genie in its bottle (Mayer, 1996) - transgenic crops have been produced in abundance and research into GE will continue despite three year moratoria on deployment of transgenic crops as recently announced by the British government (Hibbs, 1999). Whether the European public becomes as accepting of GE and GM foods as the American public will depend on changed perceptions of the risks to human health and the environment. Such changes will hinge on reliable communication of information from scientists, policy makers, industry and the press. It might require that there is more public participation in agricultural research planning in the future (Middendorf and Busch, 1997). It is still being asked moreover whether GE is necessary, and whether it diverts scarce resources away from more appropriate and useful research, including organic food production, exploitation of naturally occurring pest and disease resistance, integrated pest management (Pearce, 1998), and similar technologies. GE is not set to replace plant breeding however; it represents a modern tool for use by the plant breeder.

It may be that there is a moral obligation to supply transgenic technology to areas where human hunger could be lessened, but there will need to be a case-by-case assessment done, and transgenics appear not to represent a panacea. Transgenics are unlikely to become more popular however, if the business ethic is seen to prevail over human welfare and the environmental ethic. Food production will however have to be increased in the future, and increased use of agrochemicals and mechanised agriculture will contribute further to environmental degradation and loss of biodiversity. If transgenic crops in any way reduce these adverse effects, without themselves causing additional problems, they represent a technical and ethical advance.

FAO (1999) suggests that the way forward for biotechnology in the developing world rests on knowledge and information being available and accessible to all partners - (REDBIO) one of the best organised and most useful biotechnology networks in the developing world is that in Latin America, involving more than 700 laboratories (FAO, 1999). This is only possible through establishment of effective partnerships between public and private entities. The organisation suggests that short-term potential benefits of adapting biotechnology applications to enhance food security should be assessed with emphasis placed on

policy matters and “the sensitive area of ethics”. This represents progress, but seems set not to diminish the controversy surrounding the technology by much.

It is too easy to forget the disruptions caused by previous revolutions in agriculture and industry, and how values were challenged as a consequence. In retrospect the “Transgenic Revolution” might not appear to have been particularly special, but until the fears of the public are assuaged it will continue to be ethically contentious. Only by continuing fundamental research on risks and benefits of transgenics will there be a possibility that the public will come to recognise the probable usefulness of genetic engineering in agriculture.

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