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PLANT BIOTECHNOLOGY: FACTS AND PUBLIC PERCEPTION

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Key Word Index—Plant biotechnology; public perception; genetic engineering; risk; outrage; ethics.

Abstract—The facts, importance and public perception of plant biotechnology are described and discussed. The bases for public concerns are examined and the scientists' role in increasing public understanding of this key technology emphasized.

INTRODUCTION

Recent surveys [1] indicate a large measure of support for plant biotechnology by the public, but also some concerns. It is important, therefore, that scientists engaged in plant biotechnology should be aware of the public's perception of their work. The development of biotechnology is driven by the ideas bubbling up from scientists, the chosen targets of commercial companies and government regulations, which are influenced by the viewpoints of scientists, industry, concerned special interest groups and the general public. In a modern democracy, this regulatory infrastructure should reflect the public's wishes so that biotechnology develops at an optimal rate but with socially and ethically acceptable targets. Scientists need to communicate with the public, and especially regulators and consumer groups, in order to present the facts and likely developments accurately and understandably, since they are best placed to explain the science involved. Otherwise, the worth of their work could be disparaged and acceptable progress inhibited by unreasonable regulations and views (see for example, [2]). This paper, addressed to scientists, examines these issues and suggests how and what they might do.

FACTS

What is plant biotechnology and why is it important?

The broadest definition of plant biotechnology is the use of living plants, microorganisms and biological processes for our needs. In this sense, plant biotechnology has been around for a long time. Old biotechnology includes agriculture, beer and bread making. Modern biotechnology spawned the industries producing vaccines and antibiotics and now, just starting, is the new biotechnology, for example, genetic engineering. The public usually does not appreciate the long, safe history

of biotechnology in producing goods and the food crops and drinks we consume.

Plant biotechnology is, and will continue to be, of great benefit for the progress of mankind. Politicians, industrialists and scientists all identify the new plant biotechnology, and particularly genetic engineering (GE) as a key, new area of technology for the public good and wealth creation [3-6], comparable in significance with information technology. GE can provide, among other benefits, more nutritious and safer foods, pharmaceuticals, increased agricultural productivity in poor environments, agricultural sustainability and help in protecting the environment. As with many new technologies the time-scale for reaping the benefits of plant biotechnology, for example, has been underestimated [7], but this fact should not be allowed to undermine the importance of biotechnology in the immediate future or to affect adversely the debate on public perception.

How is plant biotechnology regulated and what risks are involved in its use?

With the advent of genetic engineering in the early 1970s, scientists appreciated the power of gene transformation and called for a moratorium until their safety concerns could be investigated under strictly contained conditions. Ironically, this public-spirited approach was interpreted by many as proof that there must be something wrong, otherwise why would leading scientists act in this way? In the event, the worst scenarios were not realized and genetic engineering proceeded worldwide under a set of guidelines and legislation. For example, the report 'Recombinant DNA safety' [8] was an early scientific framework for the safe use of GE in industry, agriculture and the environment; the regulations were called for by scientists that had the force of law [9].

By the mid-1980s it became clear that the risks of GE were similar to those posed by other novel organisms,

whatever their origin. The original regulations were for contained conditions (in laboratory, fermenter or greenhouse), but in 1992 a report was published by the Organisation for Economic Co-operation and Development (OECD) covering small-scale field trials of genetically modified plants and microorganisms [10], and in 1993 this was followed by 'Safety Considerations for Biotechnology: Scale-up of Crop Plants' [11]. The scientific principles set out in the reports are embodied in the regulations, whereby plant biotechnology is regulated by law in many countries in Europe. (Similar regulations exist in the U.S.A., Japan and many other countries [12].) Safety is achieved by the application of risk/safety analysis and risk management. Risk/safety analysis is based on the characteristics of the organism, the introduced trait, the environment, the interactions between the organism and the environment and the application (see, for example, [13]). Information about any of these factors provides 'familiarity' which is an important part of the assessment. Familiarity is defined as having enough information to judge the safety of the use, or to indicate ways of managing the risk; low levels of familiarity may be compensated for by appropriate management. Sufficient may be known of the science, and/or from previous experience of the organism/trait/environment, that a risk assessment suggests little risk. On the other hand, this may not be the case and monitoring of specific possible effects is called for, and in other applications more data are required before proceeding with large-scale trials.

A large body of scientific information, data from performance trials of conventional agriculture and the results of specifically designed small-scale field trials with safety considerations in mind, have identified the following safety concerns in the use of plant biotechnology, particularly GE: the process itself leading to unintended genetic and phenotypic variability, the possibility of engineered crops becoming weeds, the escape of transgenes by cross-pollination with wild and weedy relatives giving rise to super weeds that cause damage to the environment and costs to agriculture, loss of biodiversity, changed agricultural practice and the inadvertent production of toxins/allergens in new plants used as food.

GE is a different method of gene transfer compared with conventional plant breeding and Table 1 sets out the key elements of the two methods.

The main differences between the two methods are the greater technological input, wider gene pool and random chromosome location of the transferred gene(s) in GE compared with conventional breeding. A transferred gene incorporated into a chromosome in an indirect way may inactivate or activate other genes, giving an effect other than that expected from the products of the gene alone; this is therefore more likely with a gene inserted by GE. In this connection it is important to make a distinction between coding and regulatory sequences, the former producing a specific gene product (protein of known function) and the latter determining the activity of the gene. Normally a hybrid gene is transferred with its own regulatory sequence replaced by one of a few well-charac-

terized regulatory sequences designed for expression in the particular host. However, if the transferred gene encodes, or affects, a regulatory molecule (transcription factor, hormone), the activity of other genes could be affected (pleiotrophic effects). The inactivation, or enhanced activation, of individual genes can and does occur on crossing in natural populations and so these processes occurring from GE are, *per se*, not expected to produce phenotypes novel to the species. The products of genes can interact with one another (epistasis) but there is no biological reason to suppose that epistatic effects would be greater with engineered plants. However, DNA sequences foreign to the history of the species are being introduced into the chromosomes and novel fusion genes and gene products could be created by random insertion with novel, unpredicted properties. Such unpredicted events are amongst the reasons for the heterogeneity frequently seen in populations of newly regenerated engineered plants. Another source of increased variation are the technological operations (e.g. a tissue culture step) of GE. On a statistical basis, the variation due to both these causes is not great compared with the variation frequently encountered by crossing non-identical parent plants. Also, there is no reason to presume that unpredictable variation from GE is any more likely to pose a hazard than variation emerging from sexual crosses. On most occasions, the known identity of the genes inserted by GE and the ability to analyse their structure, activity and stability, makes predictions of new variation introduced by a transgene an easier and more accurate process, leading to a shortening in the length of the associated breeding programme to generate a new variety compared with conventional breeding. The process of gene transfer, therefore, whilst different, would appear to pose no unforeseen additional risks and it is being generally accepted that genetically engineered organisms should be evaluated and regulated on their phenotype (product not process) [14].

Just as genetically engineered modification of crops results in the production of 'novel' individuals genetically modified organisms (gmos), so does sexual crossing through recombination of genetic variation. In both processes unwanted novel plants can be identified and eliminated in early (small-scale) field trials, but not necessarily all unwanted genotypes. The consequences of releasing any novel organism, generated through recombinant or non-recombinant approaches, in all environments is not predictably precise and monitoring of any undesirable side effects would need to be considered.

The evolution of virulent weeds has been suggested by many as potentially the greatest threat from engineered plants, either through the plants themselves spreading or by transfer of genes from cultivated plants to wild and weedy relatives, by hybridization [13]. The history of the establishment of conventional agriculture is rife with examples of both these ways of generating virulent weeds [15]. There are also many examples where the introduction of alien, non-cultivated species has led to damage to the environment [16]. However, for the foreseeable future GE will be of crops already growing in a country so

Table 1. Gene transfer

	Recombinant technology	Conventional technology
Gene source:	Unlimited. Usually, one or a few known genes. Gene flow can be followed during subsequent breeding programme.	Usually limited to relatives within species but crossing between genera possible with embryo rescue. Usually many blocks of genes whose identity is unknown. All individual genes changed cannot be monitored.
Location of genes:	More or less random into recipient genome.	Normally genes remain in sites in which they evolved—but not always.

that situations where the destruction of ecosystems followed the introduction of alien species, either cultivated or non-cultivated, are not strictly relevant. Nevertheless, the establishment of conventional agriculture has generated weeds, and lead to the whole-scale destruction of existing ecosystems, (forest clearance, monocultures, etc.) and it must be asked, therefore, will GE exacerbate the situation?

Although a considerable body of work exists on weeds, there is still no agreement on what and how many qualities a plant needs to be weedy [17, 18]. Similarly, experts cannot agree on the extent of the risks involved. Some, such as Keeler [19, 20] claim the risk is small, others (Williamson [21]) are more cautious.

Most of the genes presently being used to produce transgenic plants are of plant, virus or microbial origin, although animal genes are being used to produce pharmaceuticals. Many of these genes are already in plants and have been involved previously in conventional breeding programmes.

Genes from both conventional and engineered crops may be transferred by pollen to other cultivars or to wild and weedy relatives that grow in the agricultural environment, depending on a series of specific events, e.g. sexually compatible plants within the range of pollen movement. For the major crop plants much is known about these events from the many performance trials of conventional agriculture and from the specially designed small-scale field trials of transgenic crops [11, 22]. Although the latter may not detect the rare event [11], which may only be apparent after a crop has been grown commercially for several years, nevertheless, existing data allow the prediction, testing and planning for most events that may be of concern, prior to transgenic crop use in agriculture generally. Performance trials observe and evaluate many different attributes including those of safety concerns, e.g. outcrossing, site carry over to become a weed, increased toxicity (compounds responsible being known for the major crops). In cases where no compatible wild or weedy relatives exist locally, safety is not at issue. In other cases, where pollen transfer to sexually compatible plants would occur, or the nature of the trait to be transferred was of concern, e.g. insect resistance or

herbicide resistance, then it would be necessary to ensure that management practices were employed so as to reduce the risk to acceptable levels. A wide range of appropriate practices for this purpose already exist as a result of performance trials of conventional agriculture. In some cases, further work is required before proceeding to large-scale field trials, e.g. use of some virus nucleotide sequences for resistance to viruses.

Thus, there is some risk to the large-scale use of engineered crops and this cannot be precisely quantified. Existing data (although incomplete), experience and biological considerations suggest that we can proceed reasonably safely with large-scale field trials in most cases under the latest regulatory systems, as exemplified by the U.S.A. and U.K., especially considering the risk (loss of benefit) of not proceeding. Monitoring, where appropriate, should be mandatory.

This contrasts with the attitude of some environmental groups, e.g. Greenpeace, who say GE should be stopped as risky, without quoting specific data to prove (or even suggest) the level of the risk. This is because they consider any risk unacceptable as they claim GE is unnecessary since alternative practices (multi/inter-cropping for example) could also feed the growing world population, but where is the evidence for this assertion?

The public expects biological scientists to have performed sufficient pro-active, precautionary research to avoid problems of the type subsequently found in the chemical and nuclear industries, which were not foreseen at the time of technology introduction.

The ecologists have done sterling service by highlighting the crucial importance of biodiversity and how greatly undervalued the world's biological wealth is [23]. A further charge levied by some ecologists, is that plant biotechnology will reduce biodiversity, aggravating what has already been a serious affect of conventional, especially high-tech, agriculture. However, the methods of biotechnology are some of the most powerful for investigating plant life and we know so little about how plants and ecosystems work. At the very least, therefore, ecologists and plant biotechnologists should collaborate in a consensus, holistic approach to the problems of conserving biodiversity.

PUBLIC PERCEPTION—WHAT ARE THE CONCERNS/FEARS ABOUT PLANT BIOTECHNOLOGY*

The public's concerns about plant biotechnology fall into two categories: (i) it is risky, and (ii) it is morally wrong. The new plant biotechnology, as its name implies, dates only from the early 1970s. The public now view new technologies with caution and with good reason. The benefits that the technology may deliver are not yet apparent, there is a lack of knowledge about the scientific facts, but, more importantly, the public are aware that new technologies often bring hazards not fully realized at the time of their introduction. Although the public perception of new risks is not irrational, there are cultural (outrage) factors involved and it is important to expose these to scrutiny.

Plant biotechnology is risky

Actual risk v. perceived risk. With every technology there is a level of associated risk. Actual risk is the magnitude of the hazard multiplied by the probability of it happening. Perceived risk is actual risk modified by a so-called 'outrage reaction' [24]. The components of this outrage reaction are many, but the main ones are familiar v. unfamiliar, more knowable or less knowable, diffuse or concentrated, non-dreaded or dreaded, voluntary or involuntary, non-memorable or memorable, natural or artificial, fair or unfair, controlled or uncontrolled, morally irrelevant or relevant (see [24] for definitions and explanation of these terms). In general, due to an outrage reaction, the public underestimates the risk if the first of the pair of opposites apply and overestimates it if the second of the pair apply. For example, most members of the public underestimate the risks associated with car travel and overestimate the risks associated with air travel, similarly they underestimate the risk of sunbathing and overestimate the risk of food irradiation.

Public perception of plant biotechnology exaggerates the actual risks involved [24]. *Familiar v. unfamiliar.* Familiarity in the present context is having lived with a risk without anything going wrong. Since new biotechnological products are only now becoming available to a limited public, the perception of risk is presently overestimated simply because of newness. As the flow of products increases, this component of overestimation should diminish.

Knowable v. unknowable. Knowability is determined by the level of understanding of the science, the extent to which experts agree about the risk and the degree of trust in the sources of the information by the public.

At present, GE is relatively unknowable for the following reasons: (1) As is the case with science generally, the level of understanding by the public is low (due to the complexity of the subject matter and its specialist position in education); (2) There is considerable disagree-

ment among experts as to the extent of the risks involved in specific aspects of GE. For example, experts disagree about the risks involved in releasing engineered plants into the environment. This disagreement arises because not enough useful data exist and experts therefore project from their differing concept bases (see later). Thus, although more than a thousand field-release experiments have been carried out worldwide, most of these have been conducted in situations where the possibility of damage to the environment has been minimized [25].

The public obtain their knowledge about biotechnology mainly from the media, which in turn obtains it from the scientific community and from special interest groups, e.g. customer and environmental groups. All these sources have their own agendas and constituencies, e.g. the media to supply information that they think their customers want, scientists who have a job to do and the pressure groups who have been known to be selective with regard to their comments on research findings. The public have a relatively high degree of trust in the information supplied by customer and environmental groups and by scientists in universities and institutes, but less in that supplied by commercial companies or the media [26, 27].

The level of public understanding could be raised by increased and improved teaching in schools (now part of the U.K. National Curriculum), scientists producing short accounts of their work suitable for media use, scientists replying to fact distortion in the media whenever possible and scientists communicating their own work and its implications to the public in local or national forums.

It is clear from the results of conferences such as the recent U.K. National Consensus Conference on Plant Biotechnology [28] that ordinary people can get to grips with the complexities of technology and produce a clear and rational report [29].

Attempts should also be made to acquaint the public with the methods and results of very elementary statistics (i.e. calculating the probability of a risk) since without this knowledge the public is easily confused. For example, the statistical concept of alternative risks is not appreciated, so the public will accept the argument that, since it is not possible to eliminate all risk, GE should be stopped, i.e. the public concentrates on theoretical risks of GE and ignores the disadvantages (risks) if it is not used.

GE could also be made more knowable if it were possible to reduce the disagreement between experts in the field. Meetings that bring together scientific disciplines where members have differing viewpoints, e.g. plant molecular biologists and ecologists, such as those organized by the Dutch government, at which a consensus is sought, are very useful in this context [30].

It is important, when presenting the topic to the public, to quote a full range of estimates of the risk, both high and low, so as to convert expert disagreement into known uncertainty. Although uncertainty decreases knowability, it still generates less 'outrage' than when experts disagree [24].

*GE is the aspect of plant biotechnology that causes most concern.

Everything should be done to ensure that scientists retain public trust and confidence; this is particularly important with the launch of new products. Scientists should bear in mind that part of the assessment of the public trust of experts is based on experience of earlier introductions of new technologies, e.g. atomic energy for peaceful purposes where some industrial scientists, industrialists and politicians either misunderstood or distorted the risk; now the public appreciate that new technologies may carry risks not foreseen at the time of their introduction. A classic example of the role of the public is the curtailing of the indiscriminate use of chemical pesticides following the publication of Rachel Carson's book *The Silent Spring*.

Levels of trust and confidence in scientists are related to some extent to the public perception of the effectiveness of the regulation of the technology, and the public should be made aware that GE is properly regulated in Europe, the U.S. and in most of the rest of the world and that it is scientists themselves and industry that have encouraged this regulation [31].

Non-memorable v. memorable. Memorability is how easy is it to envisage something going wrong. For GE, memorability is a key factor and affected by perceptions strongly rooted in our culture, as reflected in literature (e.g. Frankenstein myth) and films (e.g. Jurassic Park). As pointed out by Warner [32] "*Frankenstein* has become the contemporary parable of perverted science", but this misses the main point of Mary Shelley's novel *Frankenstein*, which sets out not to vanquish her man-made monster, but to plead on the monster's behalf; he is capable of goodness if his creator, Victor Frankenstein, does not abandon him. Victor Frankenstein's hostility to his creation and his desire to be victorious over his monster has its mainspring in his own self loathing. The monster is not alien, but a part of us and the quenching of Frankenstein's hubris does not lie in destroying the monster.

Genes, the materials of biotechnology, are also associated with the eugenic pronouncements of some early geneticists and with the Nazi regime and its eugenic programme and are, therefore, memorable. There is a need to discuss these matters openly, separating fact from fiction wherever possible in order to reduce outrage. Questions such as, to what extent is it morally justified to alter human characteristics by biotechnology, need urgent consideration.

Non-dreaded v. dreaded. Certain risks are associated with the phenomenon known as 'dread'. For example, radiation which cannot be visualized is dreaded and it is largely for this reason, rather than the actual risk, that radiation of food is prohibited in the U.K. Perception of dread can be derived from personal and non-personal sources, both of which distort rational perception. An example of a personal source would be when polluting waste has associations with childhood experiences. Non-personal sources include, for example, recall of images in the memory due to media coverage of past events; these images may not be directly connected with the risk itself because dread is often associated with certain words. As

pointed out by Gell-Man [33], the impact of scientific discovery on the literary world and popular culture often gives rise to words or phrases, interpreted vaguely or incorrectly, so that important qualifications and distinctions and even sometimes the ideas themselves get lost; in these circumstances, the public may pay more attention to outrage (dread) than they do to the actual risk. Consequently, the perceived risk is high. Biotechnology has a large dread component, e.g. possible contamination of air and water by 'escaped' genes which cannot be visualized or recalled. In order to reduce dread an open discussion of the reasons for the dread (so far as they are understood) is needed.

Voluntary v. non-voluntary. Voluntary risks are much more acceptable than non-voluntary risks. An example of this is a pastime such as hang-gliding which carries a high risk of fatal accident relative to walking, but those participating in hang-gliding accept the risk voluntarily and underestimate it. Current estimations predict that voluntary risk has a level of acceptability approximately 1000-fold higher than non-voluntary, or imposed, risk [34]. The introduction of GE has an element of perceived, non-voluntary, risk, since, although regulated, the public have yet to be consulted over its introduction: although a moratorium on some GE activities is in place, e.g. germ-line gene therapy of humans.

Accordingly, whether or not to label food produced by GE is a major debate. Labelling would make any risk involved voluntary and many believe that this would boost public confidence and in the case of those sections of the community, e.g. Muslims who should not eat food containing genes from some sources, ethically correct to do so [35]. However, not every component of a food can be labelled and respondents to a recent survey in the U.S. about labelling and methods of food production ranked biotechnology fifth out of seven factors when compared with other types of information; more interest was shown in fat content, levels of pesticides and food additives [27]. Whether or not to label is a decision of government after receiving advice from appropriate committees, but it is important that these committees include a wide representation of the public.

Natural v. technological risk. There is a distinction to be made between natural and technological risk, as the public exaggerate the latter. Some 'genetic engineering' modification processes do take place in nature, mainly among microorganisms, but it is misleading to claim on this evidence that GE is natural, since most of the operations of GE are laboratory based. Although GE is artificial and as such attracts outrage, this can be reduced by understanding that most scientists, for example, view GE as conceptually no different to conventional breeding (see Facts). Furthermore, GE is subject to step-by-step regulations which many consider err on the side of caution [36].

Diffuse v. concentrated. Risks concentrated in time/space are perceived as greater than diffuse risks; there is the distinction between chronic and catastrophic risks. For example, the car is perceived as less risky than the aeroplane, since aeroplane disasters, when they occur, are

highly concentrated in the sense that many may die at once. Concentration also refers to the severity of the risk and whether future generations will be affected. For example, if a chemical spill were to occur it would be a single event for which attempts can then be made to minimize its consequences, whereas mistakes with genetically engineered changes are inherited and perpetuated. Much debate takes place as to whether or not biotechnology is a concentrated risk. Some ecologists, on little data, claim that although the chance of GE causing serious ecological damage is small, if it occurred, the consequences could be disastrous. This aspect of an outrage reaction can be reduced by not only having publicly acceptable regulations in place, but also contingency plans ready if anything did go wrong.

Control v. uncontrolled. Whereas voluntariness refers to who decides if it will happen, control refers to who regulates its implementation. Most biotechnological projects have been initiated without prior discussion with the public, i.e. involuntarily, but proper representation of the public on regulatory bodies would nevertheless mean control of its implementation.

GE is morally wrong

There are four facets to this view: biotechnology is blasphemous or unnatural or disrespectful or unfair [37]. These four facets of concern invoke arguments against the development and use of the new biotechnology based on ethical considerations rather than concerns about risk. Recently, the discussion has been complicated by assertions that science is anti-religious and undermines man as a transcendental being, thereby destroying life's meaning. The following discussion is based on the treatment of Straughan [37].

GE is blasphemous? This view is based on the Christian religious belief that God created a perfect, natural order and to manipulate DNA and to cross species boundaries, as is done in GE, is to 'play God' and therefore wrong. However, not all religious believers have this view of creation; many accept that species have changed in evolution and recognize continued interference is reasonable. Others claim that man, in acting out God's purpose, should be a steward of nature and as such, should not interfere with nature via GE, whereas others feel man is part of nature and in carrying out GE is using gifts given to him by God to adapt to his environment. This specific moral concern also applies equally forcibly to traditional animal and plant breeding and other human activities which interfere with 'created order'.

GE is unnatural? Some individuals take the view that since biotechnology is artificial it is wrong. The basis for this view is that all that is natural is good and all that is unnatural is bad [37]. But not everyone sees everything natural as good, e.g. ('nature red in tooth and claw'). Furthermore, in nature's world the question of individual responsibility does not apply, i.e. it is amoral.

In any case, the lack of a clear cut definition of or distinction between natural and unnatural activities pla-

ces the unnatural viewpoint of biotechnology on a very unsound base [37]. How unnatural is it to cure cancer with drugs? Changes to humans by genetic engineering are especially contentious whether these are by manipulation of eggs or by adding new traits, especially if they do not aim simply to restore the body to 'what nature intended'. Although not part of plant biotechnology, they are mentioned here since some claim GE of plants is the thin edge of the wedge. Normal medicine is defined by these protagonists as maintenance and restoral of what nature has given, anything in addition to that is unnatural. As, undoubtedly, many individuals could benefit from these so-called unnatural activities a balance may have to be struck. Various committees, e.g. the Human Fertilisation and Embryo Authority already advise the U.K. government and it will be for parliament, after taking advice, to make the balanced judgement as to what will be allowed.

It is interesting how our view of nature changes. Not so long ago the prevalent view was to distance ourselves from nature, which was seen as dirty and germ laden, and it is true that public hygiene has contributed more to health care than even medicine, but now the pendulum has swung, at least for the opinion formers, in the opposite direction.

Naturalness is also often confused with nostalgia for a past golden era, but it is very doubtful whether such an era ever existed. The Rousseauism myth that man lived as a noble savage in tune with nature before technology destroyed this symbiosis has been discredited. Man has always interfered with and drastically altered his natural environment; the difference is that nowadays his sheer numbers and power aggravate the consequences. World population will grow and if science is to keep public support it is essential that it demonstrates that it can protect the world for life and preserve, not damage, life's support systems.

GE is disrespectful? The basis of this view is that biotechnology is reductionist and sees life as merely a collection of genes and chemicals available for manipulation without regard for the 'ends' of others, i.e. invokes the charge of disrespect. However, there are difficulties with this viewpoint; for example, are we disrespectful when we kill a mosquito? Does the view apply equally to sentient and non-sentient organisms such as plants? Are we disrespectful to the grass when we cut it and disregard its end to grow tall? (see [37]). Some compare the biological changes to the changes brought about by the physical scientific 'revolutions' to the physical environment. Will they, therefore, not lead to an engineered biological world run like a machine with no free will and compassion, only efficiency? This latter view rests on a misunderstanding of the role of genes in heredity, which only predispose organisms to have complex character traits but which are also strongly dependent on environmental influences and the particular genetic background.

Related to the above concern is that the public often see scientists as arrogant and cut-off, pursuing their own curiosity without regard to other values. This is partly the fault of the scientists themselves who have, in the past,

represented scientific information as different in kind, true, infallible and untouched by social or moral considerations. It is important therefore for scientists not only to present their science in an understandable way, but also to counter this earlier view and point out that science advances by aiming to disprove its current theories [38] and by its nature is the very opposite of infallible. Science is a body of probabilities, quantum uncertainties and chaos. Its difference from other intellectual endeavours has been exaggerated, and the division is not between science and arts, but between those who do or do not recognize that the search for knowledge is central to our humanity. Science is not qualitatively different to arts disciplines, which also seek to be in a form of falsifiable propositions and build on a body of previous answers.

In considering moral outrage it should be appreciated that the moral view of biotechnology can exercise a powerful influence over its acceptance [27, 37]. To reduce outrage it is important to bring into the open the basis for the moral view and to understand that it cannot be proven right or wrong by logic. Belief in God is a matter of faith which is very important to give meaning to many peoples' lives. Nevertheless, science is required to provide the wealth to allow free exercise of the mind.

GE is unfair. If the distribution of the risks from GE does not correlate with who will benefit, the 'not in my backyard' syndrome will occur, e.g. if the only perceived benefit is high profits for industry; GE is viewed in this way by some sections of the public.

Plant biotechnology is also seen as being unfair in other respects, e.g. its possible adverse effect on the economies of the Third World, leading to loss of jobs, and by patenting living organisms. Each of these concerns are complex issues which need to be addressed much more fully than is possible here; possibly, careful examination could allay all these fears but wide-ranging open debate is essential in order to do so.

To reduce outrage, effort should be made to make the public more aware of the past benefits of biotechnology as they affect the individual, along with realistic time estimates of the introduction of future benefits. The presentation should include not only the material benefits but other benefits such as increased jobs [39], and would include all social and ethical considerations.

THE SCIENTISTS' ROLE IN INCREASING THE PUBLIC UNDERSTANDING OF SCIENCE

As far as the public at large is concerned, science is complicated, difficult to understand and for the most part not very exciting. Apart from what was learnt at school, the public's perception of science is obtained from the media. This means that the number of outlets for communicating high quality science to the public is limited to a few popular magazines, e.g. *New Scientist*, articles in the broadsheet newspapers and limited coverage on radio and TV. The relatively poor coverage of science on radio and TV has been the subject of a recent review [40] which argued for increased coverage of scientific issues.

The media often obtain much of their copy from highly vocal groups with specialized interests. Studies by anthropologists and others are identifying the formative influences which lead individuals to become members of specialist groups as part of attempts to explain irrational behaviour [2]. Although to what extent such clarifications would change attitudes is unclear.

Scientists themselves have an important responsibility therefore. In the past, scientists have had a very poor record in communication with the public and have relied on a few enthusiastic individuals rather than involving the majority of the scientific community. It is the responsibility of scientists to ensure that the proper communication of their results are made public in a well-balanced, understandable, interesting and relevant way. This will require some training, as specialist skills are involved, especially understanding and presentation of outrage. Scientists must also collaborate with writers to produce copy that overcomes the existing conflict between 'hard science' and entertainment. However, scientists cannot be solely responsible for the presentation of the wider context of scientific results as discussed in this article. There are so many special interest groups, each with their own constituencies and agendas, as to make the situation too complex and time-consuming to place the burden on scientists alone and it is the responsibility of their employers, whether government or industry, to provide funds to pay specialists also [see 41, 42].

Clearly, a key group of the public where much could be done are the school children and it is encouraging to see the increasing number of joint ventures between universities, research institutes and schools to promote the general understanding and appreciation of science.

How should scientists communicate with the public?

When communicating with the public it is important to be aware of what is to be achieved. The objective of communication should be to encourage the public to understand the beneficial role that plant biotechnology can play in their lives, to provide an opportunity to influence the direction the research takes and to share the benefits and risks of this new technology. It is important that the public appreciate the great benefits of science and technology as well as being aware of the effects of 'outrage'. Simply engaging in communication with the public, especially if past mistakes are not acknowledged, can be perceived as an imposition of a particular view and is likely to encourage only passive tolerance. A better approach would involve asking the public what they would like to know about the risks and benefits of GE, entering a more interactive discussion, see, for example, the recent BBSRC sponsored Plant Biotechnology Consensus Conference held in London [28, 29]. Such an approach requires much more effort and financial commitment than a public relations exercise such as issuing an information booklet or producing a television programme. In general, the approach should be non-technical, stress a concern with possible risks and contingency plans, be aware of the outrage reaction as de-

scribed in this article and how to minimize it. It is important to realize that the public weigh evidence rather like a jury when listening to expert testimony, which is different to the way used in the scientific method.

Scientists would gain by talking to the public in a way they can understand since by doing so they gain their trust and also their understanding of the importance of science in wealth creation, hence improving status, bypassing any unfair distortion due to media and increasing the likelihood of working under reasonable regulations.

CONCLUSIONS

Biotechnology will deliver important benefits to the individual and its development should be at as fast a rate as is compatible with social and ethical concerns. Rightly, the public are becoming more involved in setting the related science agenda, but there is therefore an urgent need for an increased public understanding of both the science itself and the issues, including the cultural bases of so-called subjective irrationality, which generally in the past, has been in dynamic equilibrium with rationality. Scientists, sociologists, professional bodies, industry and the Government all have important roles to play in this education process.

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