Review

Public perceptions of biotechnology

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The very term 'Biotechnology' elicits a range of emotions, from wonder and awe to downright fear and hostility. This is especially true among non-scientists, particularly in respect of agricultural and food biotechnology. These emotions indicate just how poorly understood agricultural biotechnology is and the need for accurate, dispassionate information in the public sphere to allow a rational public debate on the actual, as opposed to the perceived, risks and benefits of agricultural biotechnology. This review considers first the current state of public knowledge on agricultural biotechnology, and then explores some of the popular misperceptions and logical inconsistencies in both Europe and North America. I then consider the problem of widespread scientific illiteracy, and the role of the popular media in instilling and perpetuating misperceptions. The impact of inappropriate efforts to provide 'balance' in a news story, and of belief systems and faith also impinges on public scientific illiteracy. Getting away from the abstract, we explore a more concrete example of the contrasting approach to agricultural biotechnology adoption between Europe and North America, in considering divergent approaches to enabling coexistence in farming practices. I then question who benefits from agricultural biotechnology. Is it only the big companies, or is society at large – and the environment – also deriving some benefit? Finally, a crucial aspect in such a technologically complex issue, ordinary and intelligent non-scientifically trained consumers cannot be expected to learn the intricacies of the technology to enable a personal choice to support or reject biotechnology products. The only reasonable and pragmatic alternative is to place trust in someone to provide honest advice. But who, working in the public interest, is best suited to provide informed and accessible, but objective, advice to wary consumers?

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1 Introduction

In the generation prior to biotechnology, food, health and diet appeared fairly straightforward and simple, but today these are much more technical and complex. Earlier, all food was assumed 'natural', with calories coming from food constituents starch, protein and especially fat. A poor diet, typically indicated in western countries by obesity, was corrected by reducing caloric intake, particularly fats and encouraging exercise.

Today, life is not so simple. Food, we know now, consist of proteins, starch and carbohydrates (carbs), oils and fats. In addition, we've learned about cholesterol, lipoproteins, saturated fats, trans fats, polyunsaturated vegetable oils, monounsaturated fat, good carbs, bad carbs, good cholesterol (HDL), bad cholesterol (LDL) and it is difficult to keep them all straight. This is particularly true when components identified as being good or bad change status, such as fats or cholesterol, which at one time were invariably 'bad' and now may be good or bad, depending on other factors.

We have also changed lifestyles, with leisure time shifting from a reasonably active recreational allocation to a more sedentary TV-watching 'couch potato' or internet web-surfing pastime. Changes in farm production, food processing, storage and long distance transport capabilities increased food variety, availability and choice, all at decreasing cost. The dramatic growth of fast food outlets since the 1960s allowed ever more choice and more 'free time' for consumers in a hurry to get back to the rapidly expanding, but sedentary, TV and internet universe.

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Today, obesity is increasing, especially among children. Concerned parents, themselves often fighting an expanding waistband, seeking answers and remedies are confused by the abundance of information and advice, much of it coming from unqualified sources, or from those seeking to sell a magic solution. Miracle diets, prescription drugs, herbal weight loss nostrums and radical interventions such as liposuction and stomach stapling surgery are among the choices now. Government regulations ensure prescription drugs are safe and efficacious, but so-called natural drugs and herbal remedies are exempt from FDA oversight in the USA, due to DSHEA (Dietary Supplement Health and Education Act of 1994). This means that formulations with little or no true benefit can be sold to confused consumers; the best hope is that these products work as placebos. Under DSHEA, only the clearly dangerous such products, such as ephedra, can be captured for regulatory authority by the FDA, and even then, only after mislead consumers have suffered and perhaps died.

This sets the stage for biotechnology, a powerful technology when applied to providing drugs, and an even more powerful, even scary, technology when applied to food. Borne from the cutting edge high technology of molecular genetics and recombinant DNA (rDNA), how can ordinary consumers make informed choices regarding biotechnology when they cannot comprehend the fundamentals of molecular genetics?

2 Current status of public knowledge of food, agriculture and biotechnology

A number of public opinion surveys on public attitudes to various aspects of biotechnology and GM foods are available. Some of these are professionally designed and conducted, yielding a large amount of useful and illuminating information. Others are poorly designed and often intended, evidently, to garner support for a particular viewpoint. Finally, anecdotal evidence from direct contact with ordinary consumers, although scientifically weak as it is due to the tiny samples and non-random selections, can provide some illumination of popular opinions and concerns, as well as demonstrate, on a marginal basis, the extent of popular understanding of complex issues such as food production and biotechnology.

Among the professional surveys is the FP+I survey from 2004 [1], in which American consumers were asked a slate of questions on food, including some relevant to biotechnology. Among the questions were these gems (wording edited for space):

– Are GM foods in US supermarkets?
– Do ordinary tomatoes contain genes?
– Would a tomato with a fish gene taste “fishy”?
– If you ate a GM fruit, might it alter your genes?
– Can animal genes be inserted into a plant?

The results, expressed as a percentage of respondents answering correctly, were unimpressive:

– 48% Are GM foods in US supermarkets?
– 40% Do ordinary tomatoes contain genes?
– 42% Would a tomato with a fish gene taste “fishy”?
– 45% If you ate a GM fruit, might it alter your genes?
– 30% Can animal genes be inserted into a plant?

Clearly, even before asking about biotechnological approaches to food production, consumers need to learn something about basic biology and agriculture. The status of ordinary consumer’s knowledge of food and agriculture is frightening to those of us involved in public education. It indicates a serious need for greatly expanded educational services when most people do not recognize DNA as a natural component of ordinary tomatoes. Perhaps worse, respondents are not even aware of the degree of their own ignorance. These few questions, although a small and not random sample, all provide for binary answers (Yes or No). If people who didn’t know the answer simply guessed, the proportion should have come out to 50% correct. Optimistically, any reasonable proportion of knowledgeable respondents knowing the true correct answer would pull the mean well into the 50 – 60% range. Unfortunately, the data indicate the results were not skewed upward but actually down, indicating that respondents were not simply guessing, but actively thought they knew the correct answer. The problem is, what they ‘knew’ to be correct was actually wrong! Therefore, the public educator trying to teach ordinary consumers about food and food production is not starting from a level field of ignorance, they start well behind ignorance, and must unlearn the incorrect information consumers have come to believe is true but isn’t.

Americans are not alone in their deep ignorance of food and agriculture, so before blaming the appalling result on the US educational system, consider the similar results from the European survey on public attitudes, called the Eurobarometer {INRA (EUROPE) – ECOSA, 2000 [2]}. Across the European Union, when asked if ordinary tomatoes contained genes, one-third of respondents said ‘No’, and another third said “Don’t know”. The question asking if eating a GM fruit might alter one’s own genes resulted in one third saying “Don’t know”, and one quarter said “Yes’.

One other Eurobarometer question was very similar to that of the FPI survey. Respondents were asked if they agreed with the statement “It is impossible to transfer animal genes to plants”. Almost half said “Don’t know” and a quarter each said “Yes’ and “No”. Clearly, citizens on both sides of the Atlantic cannot make informed decisions and choices about biotechnology when they lack even the underlying knowledge necessary for making rational comparisons.

With this dismal level of basic knowledge among non-scientists setting the stage, the next issue is how to help consumers make better informed decisions. Fortunately, the International Food Information Council (IFIC) 2006 [3] survey shows that while almost 2/3 of respondents say they've heard little or nothing about biotechnology, they often express a desire to learn. This provides some encouragement to those of us in public education.

Less encouraging is where non-specialists seek information. Most people now get their information from the internet, with zero quality control and plenty of organizations with an agenda to sell. Television and radio remain major sources, but few programs can provide in depth analysis of technical issues. There are some excellent science programs available, but they tend to be underrepresented. Popular media remains a major source of information, but also a major source of misinformation and therefore confusion. Accessible technical journals do exist and help inform a small cadre of non-scientists interested enough to actually subscribe and read the articles. But this group is a very small segment of society, and not the group needing help.

3 Some examples of inconsistencies and misunderstandings based on poorly informed populace

3.1 Red *vs.* Green

A curious paradox relates to the apparent contradiction in public opinion contrasting "red" or medical and health applications of biotechnology and "green" or agricultural and food applications. rDNA has been used to transfer genes from one species to another to create useful products both in the medical and health field (*e.g.*, insulin) and in the agriculture and food field (*e.g.*, cooking oil from GM soybeans). The major controversy in the public debate is clearly over the agricultural applications, where concerns over 'unexpected results' or 'long-term health consequences' restrain agricultural and food development. The same technology, with the same kind and degree of risks, when used to create medical products attracts minimal such concerns. That is, if GM soybeans, due exclusively to the process of rDNA in their development, were eventually found to cause some unexpected medical disorder, then GM insulin should also cause the disorder and warrants the same current concern. But it does not; the public seems not only to tolerate medical applications of biotechnology, but also to embrace them [4].

A second, more ironic curious paradox on this same issue is the widespread public opinion that if any agricultural applications would be acceptable, it would be a GM crop developed for better environmental sustainability – say reduced pesticide use. On the other hand, the suggestion to transfer human genetic material to a lesser species (and they are all lesser species) is often met with horrified dismay. Humans – including their genes – are 'sacred', and the thought of creating a new organism with human genetic material is ethically unacceptable. The irony, of course, is that the majority of GM crops – the ones attracting the most concern – are indeed grown with reduced environmental pesticidal load, and the most common and popular supported GM medical application is insulin, produced from bacteria into which a human gene had been inserted.

3.2 Terminator confusion

The ETC group coined "Terminator" for the patent awarded to USDA and Delta and Pine Land on a mechanism to produce sterile seeds. What the patented mechanism does – at least in theory – is ensure seeds produced on the transgenic plant expressing the 'terminator' genes cannot germinate. In practice, it does not work well enough to justify commercialization (too 'leaky', producing too many fertile, viable seeds), and, with public opinion dead set against it, Monsanto shelved plans to develop it for their commercialized GM crops. There are two major concerns driving public opposition: (1) Farmers, contrary to ancient practice, would not be able to keep a portion of the harvested seed of one season to use in planting the next crop. Instead, farmers of crops with the terminator gene would be forced to buy new seeds each year. According to opponents, this would impose an unfair hardship, particularly on resource-poor farmers, and deprive them of an ancient right. (2) There is the fear that the terminator gene would escape from the farm, infect nearby crops and native plants, and render those recipient plants sterile also. Both of these scenarios incite great emotional fear in the public mind; as well they should, if they were truly founded on fact. In the first case, terminator technology would indeed require farmers to acquire fresh seed every year. But this is true of current hybrid technology, adopted and accepted by farmers for half a century. Even many farmers in developing countries grow hybrid corn and do buy seed each year. In this respect, terminator is not forcing unwary farmers into buying fresh seed each year, as they are already familiar with the practice, and can choose whether they wish to grow hybrids or not. Terminator technology will not deprive farmers of anything they enjoy now. But it would give them an option to choose a new technology that may be beneficial for them, just as many farmers choose hybrids and buy fresh seed year after year. Apart from this, agronomists recommend that farmers buy fresh seed as often as possible, even with those crops and cultivars where seed may be saved for subsequent replanting. Fresh pedigreed seed is cleaner and of higher quality than saved seed, so the upfront financial outlay is usually compensated by better quality and higher yields at harvest time, translating into better financial returns for the farmer.

The second issue can be readily dismissed. The great fear of having life on Earth eradicated by a rampant steril-

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ity gene is palpable, but a moment of rational consideration can calm these waters. If the point of the terminator gene is to cause sterility, how can it spread? The original, intended GM crop plant produces seeds that do not germinate, and if pollen containing the gene is transferred to a distant host, the one seed resulting from the fertilization by the one GM pollen grain similarly doesn't germinate. If a seed with terminator cannot even germinate, it would be difficult to even invade, let alone conquer, the countryside. Since the whole point of the terminator gene was to contain the GM plants and keep them from spreading, the fear of widespread and untimely demise of life on Earth is greatly exaggerated.

Fear often keeps us from thinking clearly. Instead of inciting derision, terminator (or a similar gene containment system) may be applied to maintain control over GM crops, to keep them from consorting with non-GM crops growing nearby, thus mitigating the concerns from organic farmers and others fearful of GM spread. Indeed, in international negotiations Canada has officially suggested using a GM sterility system for exactly this purpose, but the suggestions was dismissed by anti-GM activists worldwide, even though such a system would advance their desired agenda.

4 How do we deal with the problem of science illiteracy among the public?

4.1 Media issues

In an effort to provide balance, most media try to present 'both sides' of a story, particularly in controversial issues such as biotech in food. But this is a mistake. In controversial issues of, say politics, it is appropriate to interview and give reasonably equal coverage to politicians on either side of an issue. Such coverage is said to be balanced and fair with both sides having a chance to explain their positions. Both sides should present cogent arguments by articulate and credible spokespeople. But in scientific issues, the media provides equal opportunity to those with unequal credibility and authority. Interviews almost invariably "balance" a person with high credibility, such as Nobel laureate Norman Borlaug, speaking in favor of deploying biotechnology to assist poorer and malnourished peoples, against a charismatic opponent with little or no scientific expertise. A recent example comes from CBS national news in the US. The clip, entitled "Are organic foods really any safer?" (CBS-TV news, 2007 [5]) asks a common and legitimate question to which many consumers would seek an informed answer. But the clip – necessarily brief in a news program – interviews an expert academic nutritionist who says there is no scientific data to support the notion that organic food is any safer than regular food. Then, the interview shifts to a young couple of non-scientist organic consumers, who say they buy organic food because they believe organic is safer, and to them, their faith that something is true makes it factual, in spite of a lack of evidence to support the belief. The journalist does not challenge the organic consumers with the scientific evidence undermining their beliefs, either directly to the young couple or to us, the viewers, who may come away with the impression that both sides are equally credible and legitimate. To those with expertise or who apply critical analysis, the interview is ludicrously lopsided, but to the ordinary consumer, it may seem like both sides gave compelling arguments. The journalists, in their own defense, will claim they are merely providing both sides of the story, as is their professional obligation. But this is easily countered: When the same journalists interview an astrophysicist on the latest estimates of the age of the universe, they do not also interview a biblical literalist to challenge the scientist and present the 'other side'. Similarly, when talking to a genetic engineer about advances in medical applications of rDNA, they usually tap a technical competitor to offer alternative approaches, and rarely interview the anti-biotech activists invariably interviewed in agbiotech stories. In these situations, the media is complicit in misleading the populace by presenting the inexpert as an expert.

Popular opinions on GM crops and foods vary widely. A UK television story presented a relatively positive viewpoint of a GM crop – a GM safflower modified to produce pharmaceutical grade insulin (BBC-2, 2007 [6]). The webpage includes a blog service, allowing viewers to respond to the story. Of the 46 coherent (a small number were not) responses to date, the range of opinions (clearly not a scientifically valid study, as these are self-selected respondents) is reasonably representative of my own anecdotal experience. Seventeen responses (34%) were negative, arguing agricultural biotech is primarily driven by corporate greed; 9 (18%) were negative, saying we do not have enough confidence in managing the risks to food or environmental safety, 4 (8%) were opposed to humans "messing" with nature, 16 (32%) were more positive, saying let's take a closer look and allow it if the benefits outweigh the risks. Interestingly, those worried about agbiotech being dominated by big multinational corporations rarely offer to support public institutions in their development of agbiotech crops for the public good. Public institutions such as USDA and many agricultural universities have been actively pursuing agbiotech crop breeding programs since the early 1980s, at the very beginning of the technology, and were instrumental in forging the enabling technologies. Unfortunately, critics of the big companies perhaps unwittingly condemn small companies and public institutions at the same time, effectively throwing the baby out with the bathwater.

Also noteworthy is that those critical of big company involvement in biotech are curiously silent concerning big company involvement in non-biotech seed, food and other agricultural products, including the domination of the organic industry by big companies.

Those critics of biotech driven by concern over possible risks have, at least, some legitimacy in expressing their concerns. What they may not be aware of is the extent of regulatory oversight investigating those same concerns for substantiated threats to the environment and food supply. Independent experts have studied those threats since the early days of the technology, and invariably come to the same conclusion, that products of biotechnology pose the same risks as products of conventional breeding. Such professional and independent organizations as the Organization for Economic Cooperation and Development (OECD) and US National Research Council of the National Academies of Science (NRC) have been conducting comprehensive scientific analyses of risks associated with various aspects of biotechnology since 1986 (see, for example, OECD, 1986 [7], NRC, 1987 [8]). For more recent scientific studies on environmental risks, see NRC, 2002 [9] and, for health risks, see NRC 2004 [10].

The critics opposed to human intervention in natural processes, or in "God's domain" (to use HRH Prince Charles' argument) are expressing a religious or spiritual belief. And it is their right to hold such beliefs. But their beliefs do not relate to scientific safety issues, they are instead a legitimate personal conviction. While they can choose to reject biotechnology for any reason, they cannot legitimately force others to adhere to the same beliefs. Finally, their beliefs seem hypocritical when they fail to condemn the same 'meddling' when used to make pharmaceuticals, or fail to condemn equally intrusive breeding technologies such as induced mutagenesis, embryo rescue, somaclonal variation or other 'conventional' breeding technologies used to develop new crop varieties.

5 Coexistence: Contrasts between US and European approaches

5.1 Coexistence in the USA

San Luis Obispo County, California, conducted a democratic vote in 2004 to ban GMOs. Local farmers campaigned against the ballot measure, and they were supported by the populace when the votes were finally tallied, much to the dismay of anti-biotech community there. Nevertheless, the County, seeking to heal tensions, sought to negotiate a coexistence mechanism to allow farmers the right to grow GMO crops if they so chose, and also to allow organic and other farmers who wish to avoid GMOs the opportunity to take appropriate measures. The success of the compromise is based on the traditional farmer's community ideal neighborliness and good communication. The proposed mechanism is based on a pinmap of the locale, maintained by a non-governmental neutral third party, in which farmers growing GM crops place a pin in the map to mark the location. The neutral third party then notifies interested farmers nearby that a GM crop is being grown, and the interested farmer can take whatever measures appropriate to minimize contamination. Critics of this system argue that the plan, being voluntary, is entirely dependent upon the good will of the GM farmer to place the pin in the map. This is a legitimate concern, but it was the goodwill of regular farmers who voluntarily came to the table with organic farmers in the first place, even though the vote of the ballot initiative gave them the public mandate to ignore their organic neighbors altogether. If and when this coexistence measure is implemented, many jurisdictions will be watching closely to see how well it operates.

5.2 Coexistence in European Union

The EU decided the tolerance for commingling, admixtures or other forms of GM 'contamination' are to be limited to 0.9%, and any exceeding that threshold should be so labeled. In 2003, the European Commission published guidelines for policies to ensure the coexistence of GM, conventional and organic crops (2003/556/EC) [11]. In contrast to the California coexistence proposal, the EU coexistence policy imposes the burden of costs on the party introducing an innovation, saying "*those farmers bringing in the innovation into a region should be the ones taking measures and changing practices if needed to ensure coexistence.*" (Gómez-Barbero and Rodríguez-Cerezo, 2007 [12]). In theory, this policy will allow farmers to choose their crops in peaceful coexistence with those who choose others. But the pragmatic question is how many farmers will accept the seemingly unlimited liability. The policy also fails to define 'innovation', so farmers (and crop breeders) may unnecessarily eschew all manner of new innovations in agriculture, fearing that such innovative products as seedless fruit, broccoflower, dwarf wheat or other non-GM developments may run into similar liability issues.

6 Who benefits?

One of the common complaints about biotech crops is that they are designed to benefit primarily, if not exclusively, the big companies who developed them. To many people suspicious of private enterprise, this seems to make sense, because the GM crops on the market are almost all modified for input traits like herbicide tolerance or insect resistance, and little or nothing to offer end consumers. Various studies have shown, however, that while private companies are in business to compete and report a profit, GM crops do generate benefits to ordinary people, from the farmers who grow them to the consumers who (ultimately) eat them. For example, GM insect-resistant Bt corn is demonstrably safer than regular corn, due to the diminution of mycotoxins. In developed countries, that is not a major issue because regulatory inspections ensure corn with higher than allowed mycotoxins are kept off the market. But in poorer countries with lax or no such regulations, consumers directly benefit from the safer GM Bt corn. In more general terms, consumers also benefit from lower grain prices resulting from the higher yields generated by GM crops. Again, this is particularly evident in poorer countries, where the yield potential of regular corn is rarely achieved because the poorer farmers cannot afford the input costs of crop protection chemicals taken for granted in richer countries [13].

An indication that the value that the GM crops accrue benefits more than the companies is evident in the worldwide adoption of GM crops among farmers (who by nature are no more inclined to support private industry than their neighbors). Last year, according to James [14], 10 million farmers (10.3 million) in 22 countries planted 102 million hectares of biotech crops, making GM the fastest adopted technology in the history of agriculture. In doing so, they substantially increased their income, achieved a 15.3% reduction in environmental impact (due mainly to reduced pesticide use), and substantially reduced greenhouse gas emissions (Brookes and Barfoot [15]). Farmers may try a new product once, but if the product disappoints and fails to provide tangible benefit, the farmer will reject it and go back to what he or she had been growing previously. But that has not happened with GM crops. If anything, the demand is only increasing. This is occurring even in Europe, arguably the most GM-hostile area on the planet, and even in France, where farmers are very traditional and any innovation, including biotechnology, is looked upon with great skepticism. In 2005, a handful of tentative French farmers were allowed to grow a mere 500 hectares of GM corn under government supervision. In 2006, the area increased 10-fold, and intentions for 2007 estimate another 6- to 10-fold increase, for a total of 60–100-fold increase over just 2 years (USDA-FAS, 2007 [16]). Clearly, the previously skeptical French farmers are seeing some benefit from GM corn; the benefits are not going entirely to the private companies. According to the same report, the benefits enjoyed by the French farmers included a 9 – 12% yield increase and a dramatic drop in toxic fumonisin content.

A recent study in the EU investigated benefits from the only member country growing substantial acreage of a GM crop: Bt corn in Spain. Zika *et al.* [12] said "*The largest share of welfare* (value) *created by the introduction of Bt maize* (i.e., corn) *(74.4 % on average) went to Bt maize farmers and the rest went to the seed companies (25.6% on average), taken to include seed developers, seed producers and seed distributors*".

7 Whom do you trust?

Ultimately, it comes down to a question of trust. Ordinary consumers do not have the time or inclination to learn the various intricacies or technicalities of molecular genetics and of agriculture generally. They may be interested, even anxious, about agriculture and food safety and security, but most ordinary consumers would rather find someone they trust to champion the public interest and provide advice on esoteric scientific issues.

In the USA, public trust is usually afforded to government agencies to investigate environmental and health hazards, to set and enforce appropriate regulations, and to advise the public in an accessible manner on these issues. Biotechnology is not new in this regard, everything from automobiles to barbeques warrants appropriate experts working in the public interest to assure safety, and typically these experts are employed by government agencies.

But where do we find such experts? Industry certainly employs scientists with appropriate expertise. But industry scientists are usually prohibited from public outreach – that's the job of the sales force. And when they do engage in public education, their presentation must conform to the company line. In addition, activists are sure to point out that industry people cannot be trusted, as their loyalty is to the shareholders, not the public. Similarly, government employs many capable scientists and their loyalty should be to the taxpayers. But, again, activists quickly criticize and challenge the loyalty of government scientists, as public service experts exchange jobs with industry on a regular basis, the "revolving door policy with big industry", thus undermining their allegiance and credibility. The other major source of scientists with appropriate expertise is academia, as both public and private universities engage in broad research into the issues. But here again, the credibility and loyalty of even public academics is challenged by some activists who point out that many academic research programs are funded by industry, and question whether the academic scientist can be truly objective if their research program is tied to the industry in question.

Fortunately, most people do place trust in legitimate experts [17]. Usually, the most trusted sources for scientific/medical information are academic scientists. Family physicians are a powerful and influential source of information, but typically that is restricted to the patient's own health concerns. And physicians typically are not the most knowledgeable when it comes to agriculture and food issues, and in any case are usually too busy to learn and disseminate such information. Academic scientists working on agriculture and food are knowledgeable and credible sources of meaningful information for ordinary consumers. Unfortunately, typical academic scientists suffer two major deficiencies: One, most academic scientists have honed their communication skills to interact with other scientists, and are not adept at communicating technical information in an accessible manner required by non-scientists. Two, most academic scientists are penalized by their university employer if they do attempt to communicate with the general public, because their career progression depends on technical research and teaching within the academy. Those academics with accessible communication skills and who are conscientious enough to take time away from their 'real work' to help inform the public are penalized because the efforts are not recognized by their employers – even those in public universities – and because every hour they spend on outreach or public education is an hour they did not spend conducting research. Both of these deficiencies are major obstacles to a scientifically literate populace, and must be overcome if we wish a better informed public.

8 Concluding remarks

Clearly, most ordinary consumers lack the ability to voice an informed opinion on agricultural biotechnology, whether that is to support or reject it. As a public scientist, particularly disturbing is encountering an interested citizen supporting or rejecting biotechnology against their own values, because of simple misunderstandings. It is a sad reflection on the state of modern society – and especially of education – when people vote against their own best interest. Such people probably are not interested in being taught the intricacies of molecular genetics to enable the better informed debate and decision. But they may be willing to learn critical thinking skills to enable better analysis of all controversial issues facing them in our increasingly complex modern world.

Those best suited to mentor these skills are academic scientists. Few such scientists are employed to engage in public outreach efforts, so the first step to a better informed populace is to remove the professional obstacles deterring more academics from engagement. Unfortunately and paradoxically, few universities – including public universities – see public education and social empowerment as their responsibility.

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