Scientists' Perspectives on the Deliberate Release of GM Crops

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ABSTRACT

In this paper we analyse scientists' perspectives on the release of genetically modified (GM) crops into the environment, and the relationship between their perspectives and the context that they work within, e.g. their place of employment (university or industry), funding of their research (public or industry) and their disciplinary background (ecology, molecular biology or conventional plant breeding). We employed Q-methodology to examine these issues. Two distinct factors were identified by interviewing 62 scientists. These two factors included 92 per cent of the sample. Scientists in factor 1 had a moderately negative attitude to GM crops and emphasised the uncertainty and ignorance involved, while scientists in factor 2 had a positive attitude to GM crops and emphasised that GM crops are useful and do not represent any unique risks

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compared to conventional crops. Funding had a significant effect on the perspective held by the scientists in this study. No ecologists were associated with factor 2, while all the scientists employed in the GM-industry were associated with this factor. The strong effects of training and funding might justify certain institutional changes concerning how we organise science and how we make public decisions when new technologies are to be evaluated. Policy makers should encourage more interdisciplinary training and research and they should make sure that representatives of different disciplines are involved in public decisions on new technologies.

KEYWORDS

GM crops, ignorance, science, context, values

INTRODUCTION

Scientists play an important role in the introduction of new technologies. They are often the ones that develop these technologies and the ones that are called as *experts* to evaluate the safety of new technologies. The public is, on the other hand, often portrayed as ignorant and irrational concerning their ability to evaluate new technologies (Cook et al. 2004; Slovic 2001; Wynne 2001). This central position of scientists in the introduction of new technologies makes it important to pay attention to their perspectives on new technologies and contextual factors that may relate to these perspectives. This paper examines scientists' perspectives on a particular technology – genetically modified (GM) crops – and the relationship between their perspective and the context in which the scientists are trained and work.

GM crops are plants whose genetic material has been altered by the direct introduction of DNA in order to confer particular characteristics on the plant. More than 99 per cent of the GM crops grown are varieties of maize, soybean, cotton and oil seed rape and more than 99 per cent of these GM varieties have been engineered to be herbicide tolerant and/or insect resistant (James 2004).

The introduction of GM crops into agriculture has been subject to considerable debate. Concerns have been raised about the potential irreversible impacts of releasing genetically modified organisms (GMOs) into the natural environment (Wolfenbager and Phifer 2000), while others emphasise their potential benefits in increasing agricultural output and enhancing certain aspects of food quality, as well as potential environmental benefits such as reduced pesticide and herbicide use (Conner et al. 2003; James 2002; McGloughlin 1999). Significant participants in this debate have been scientists, industry representatives, environmental organisations and consumer organisations. The general public has also participated.

A growing number of studies shed light on the public's perspectives on GM crops (see for example Bredahl 1999; Gaskell et al. 2000; Grove-White 2001; Marris et al. 2001). Perspectives among scientists are much less studied (Meyer and Sandøe 2001). However, it seems as if scientists hold opposing viewpoints on the deliberate release of GM crops. Busch et al. (2004) emphasise that the GM crop issue is characterised by low consensus with respect to the parameters of the scientific issues and the analytical methods to be applied. This paper focuses on how scientists evaluate the reasonability of releasing GM crops into the environment and how this evaluation is related to their contextual background. We are particularly interested in:

1. What are the perspectives scientists hold on the release of GM crops into the environment?
2. What characterises scientists with the same perspectives on the release of GM crops into the environment?

We have employed Q-methodology and logistic regression to examine these two questions. Sixty-two Scandinavian scientists from different disciplines (molecular biology and related fields,[1] ecology and conventional plant breeding) were interviewed. These disciplines were chosen because they represent perceived expert knowledge concerning the biological impacts of releasing GM crops. The scientists were employed in the university and the industry sector. The scientists working in universities included scientists with purely public funding and scientists with some industry funding.

The paper is organised as follows. We start with two sections where we first identify four dimensions that might be important for scientists when they evaluate the reasonableness of releasing GM crops. Next we analyse how scientists' responses to these dimensions might relate to their contextual background. These two issues are then analysed empirically in the next sections. First we identify different perspectives on the release of GM crops among the scientists in our study by Q-methodology. Next we examine the relationship between the contextual background – like discipline and funding – of the scientists and the perspective they hold on the release of GM crops. The two final sections summarise the findings and discuss the general lessons of these findings.

IMPORTANT DIMENSIONS FOR SCIENTISTS' EVALUATION OF THE RELEASE OF GM CROPS

Following the debate about GM crops among scientists it seems that there might be four important dimensions for scientists' evaluation: 'the consequences of releasing GM crops', 'our ability to predict the consequences', 'whether GM crops are fundamentally different from conventional crops', as well as 'the moral status of nature'. Diverging responses to these dimensions both in terms of how they are factually evaluated, but also the importance given to them might partly explain why scientists disagree on the reasonableness of releasing GM crops.

Scientists' evaluation of the release of GM crops into the environment might depend on their beliefs about the consequences of releasing GM crops and their evaluation of these consequences.[2] This involves both factual beliefs about nature and society (what will happen) and value commitments (how consequences are evaluated). Divergence on both of these issues is especially evident concerning the environmental effects of the deliberate release of GM crops as well as their role in decreasing poverty and hunger in developing countries (Pretty 2002).

Scientists' responses to the second dimension, 'our ability to predict the consequences' of releasing GM crops, might also influence their evaluation of the deliberate release of GM crops. The concepts risk, uncertainty and ignorance represent different degrees of predictability. Risk implies known outcomes with known probabilities, while uncertainty means known outcomes but unknown probabilities (Knight 1921). A situation where even the outcomes are unknown is defined as ignorance (Shackle 1955). Ignorance arises from many sources, including 'incomplete knowledge, contradictory information, conceptual imprecision, divergent frames of reference and the intrinsic complexity or indeterminacy of many natural and social processes' (Stirling 1998: 103). The scientists' evaluation of the reasonability of releasing GM crops into the environment is likely to be influenced by whether s/he believes that we are faced with risk, uncertainty or ignorance. If uncertainty and ignorance are recognised, an important issue is also whether the scientists argue that we should take precautionary measures or not.

A further central issue, if uncertainty and ignorance are recognised, is whether they are assumed to be reducible i.e. if they can be reduced by more scientific knowledge (Faber et al. 1996; Wynne 1992). Uncertainty can be perceived to be irreducible due to measurement problems (Spash 2002) and ignorance can be irreducible due to the incompleteness of scientific methods and complexity or indeterminacy in social-ecological processes. An example of a response to assumed reducible ignorance is to emphasise that we have no previous experience on how to predict the impact of GMOs on ecosystems, and so need to accumulate a large and reassuring body of data (Tait and Levidow 1992). An example of a response to assumed irreducible ignorance is to emphasise that the complexity of an ecosystem implies that we never will be able to predict all the effects of releasing GM crops and therefore will need to remain precautionary for the foreseeable future (Tait and Levidow 1992).

Scientists' evaluation of the release of GM crops might also depend on the third dimension 'whether GM crops are fundamentally different from conventional crops'. It has been claimed both that biotechnology offers better control and predictability over nature and that it offers less control and predictability over nature than conventional plant breeding (Krimsky and Wrubel 1996). The central issue is whether the application of gene technology means that there is a greater chance for surprising adverse effects of GM crops than of conventionally bred crops (National Research Council 2000).

Beliefs about 'the moral status of nature' are likely to influence the evaluation of the release of GM crops since this influences the view on how we can and should interact with nature (Bruce 2003; Carr and Levidow 1997; Nielsen 1997; Regal 1994; Sjöberg 2002; Wagner et al. 2002). One aspect is the differences in perspective that stem from whether the scientist holds an anthropocentric or ecocentric worldview. Given an ecocentric approach, the heart of the debate might be to what extent genetic engineering is perceived to violate the integrity of plants and nature. From an anthropocentric point of view the centre of the discussion might be whether GM crops are seen to benefit mankind or not.

There is a strong relationship between the four dimensions. One example is that assumptions about the predictability of releasing GM crops might influence how scientists evaluate possible consequences. Another example is that views on the moral status of nature might influence whether 'natural' methods or more human-created methods are perceived as most risky (Bruce and Eldrige 2000). A third example is that views on whether GM crops are fundamentally different from conventional crops depend on the moral status of nature as well as assumptions on our ability to predict nature.

CONTEXTUAL INFLUENCE ON SCIENTISTS' PERSPECTIVES ON GM CROPS

Scientists observe and understand the external world via humanly constructed concepts. The locus of knowledge is the social group of scientists and not the individual scientist (Restivo 1995). Products of science are contextually specific constructions, which are influenced by the situational contingency and interest structure of the process by which they are generated (Knorr-Cetina 1981). We are interested in how the contextual factors disciplinary background, place of employment, research funding and type of research relate to scientists' response to the three first dimensions in the previous section. Other contextual factors are likely to be more important for the response to 'the moral status of nature', but these factors are not examined in this paper.

The disciplines ecology, conventional plant breeding, molecular biology and related fields study different aspects of biological systems and they hold different assumptions on our ability to predict nature. Ecology is a holistic discipline that studies large biological systems over long time spans by looking at organisms and their interactions with each other and the environment (Sterelny and Griffiths 1999). These interactions are mainly studied in the environment where they occur and explanation and descriptions rather than prediction predominate (Krimsky 1991). An important focus is nature's complexity. There are different ways to approach this complexity. Two main, opposing positions can be identified within the discipline (Pickett et al. 1992; Worster 1990), though most ecologists place themselves somewhere between these two extreme positions. The first position views the 'ecosystem' as a system directed toward achieving as large and diverse an organic structure as possible within its physical limits. The idea is that all natural systems move toward equilibrium by going through successional stages in a certain order. According to this position, any human interference will disturb nature's strategy of development. The second position gives more emphasis to disturbance, disharmony and chaos when studying ecology. Change is without any determinable direction and goes on forever, without ever reaching a point of stability. There is no such thing as equilibrium within this position, which sees nature as fundamentally discontinuous, unpredictable and chaotic. Some ecologists might therefore emphasise that effects of releasing GM crops are unpredictable, others will focus attention towards the fact that genetic engineering might be a costly interference with nature, possibly disturbing balanced ecosystems.

Molecular biology and related fields such as molecular genetics and biochemistry work at the subcellular level with organelles and molecules. The tools known as biotechnology and/or genetic engineering have emerged from these disciplines. The primary concern is the construction and improvement of the theoretical understanding of the molecular mechanisms involved, as well as of experimental and technological laboratory methods, products and practical solutions (Strand 2001). Confidence in human control over biological systems and our predictive capacities as well as reductionism and genetic determinism dominates (Busch et al. 1991; Krimsky 1991; Nielsen 2002; Strohman 1997; Verhoog 1993). The concern is not merely to understand nature, but to control it. The idea is that if we can understand and control the way genes work, we might increase our ability to control and understand nature. Scientists that belong to these disciplines might be expected to emphasise that the application of biotechnology in plant breeding is likely to increase control and predictability and therefore that the application of this technology can benefit mankind and nature.

Today conventional plant breeding is seen as the 'unfashionable older cousin' of genetic engineering (Knight 2003). In many ways this discipline has more in common with molecular biology and related fields than with ecology. The two fields share an emphasis on the control of nature and crop improvement for human needs (Busch et al. 1991). Still, conventional plant breeding differs considerably from molecular biology and related fields, both because conventional plant breeders work largely with whole plants, either as individuals or as large but uniform populations (Krimsky 1982), and because they apply other techniques than genetic engineering. This last property of conventional plant breeding makes it especially interesting to study their perspective on GM crops. Conventional plant breeders may hold a different perspective from molecular biologists on whether GM crops are fundamentally different from conventional crops.

An interesting question is whether place of employment, i.e. whether the scientists are employed in the university or the industry sector, might be related to their perspective on GM crops. Scientists employed by industry have a duty to serve the interests of its shareholders (Stone 2002). Industry research is therefore directed by an obligation to make profit. This implies incentives for producing knowledge that can result in valuable products. Topics and issues that are external to the market place become less important under industry research. The incentives under public employment are less clear. The idealised account of public science is that it should be based on a dialectic approach between intellectual inquiry and public need (Caldart 1983). However, this idealised account is found not to be an adequate description of science (Mulkay 1979).

It is increasingly being argued that the research culture within universities has become more similar to that of industry and that this development has gone particularly far within areas such as plant biotechnology (Gibbons 1999). University research has become more market oriented, partly through increased industry funding (Newberg and Dunn 2002). Hence, it becomes useful to distinguish not only between scientists employed within industry and universities, but also between university scientists that have industry funding and those who do not. Industry funded scientists are likely to hold a perspective that serves the interests of the shareholders. This implies that they are likely to emphasise the positive aspects of GM crops to create a positive public opinion on GM crops, but at the same time they have to secure that no products that could harm the reputation of their company enter the market. Publicly funded scientists are unlikely to have any homogenous perspective on the deliberate release of GM crops.

Type of research in terms of whether the scientists undertake risk research, basic or product research might also relate to their perspective on GM crops. Scientists that undertake risk research are likely to pay attention to the risks, while scientists that are involved in product research are likely to pay more attention to the useful attributes of GM crops when they evaluate the reasonability of GM crops.

METHODOLOGY

Perspectives on the deliberate release of GM crops among scientists were assessed through Q methodology. Q methodology is a type of discourse analysis that enables the identification of common patterns of opinion held by a certain group of people (Addams and Proops 2000; Barry and Proops 1999; Brown 1980). Respondents are asked to sort a given number of statements, in relation to each other, according to an evaluative profile ranging from agree to disagree. This data is then factor analysed to identify patterns of communality and divergence in expressed viewpoints, i.e. typical discourses or perspectives among the respondents. The basic distinctiveness of Q methodology is that, unlike standard survey analysis, it is interested in establishing patterns within and across individuals rather than patterns across individual traits, such as gender, age etc.

Q-methodology includes the following stages: 1) Selection of statements which 2) participants are asked to rank. This set of ranked statements constitutes the 'Q sort' for each participant. 3) From these Q sorts factor analysis allows the extraction of a few factors and 4) the generation of a single typical or ideal Q sorts for each factor. 5) A qualitative analysis is conducted of these ideal Q-sorts.

In our study a series of 245 statements were obtained from interviews with scientists, and from reports, books, webpages and peer-reviewed articles. The goal was to achieve a rich diversity of statement types which existed in the scientific discourses on GM crops. A final number of 36 statements were chosen based on the result of pilot-testing with scientists. The 36 statements are included in table 2.

The second step – the ranking of the 36 statements by each participant – was administered through personal interviews with 62 Scandinavian scientists. As a starting point a group of nearly 70 scientists was identified by contacting different universities, public research institutes and firms. Some of these scientists did not participate because they did not respond to e-mails or phone calls or because it was not practically feasible to interview them. Respondents were asked to rank the 36 statements in a forced normal distribution along the scale of strongly agree (5) to strongly disagree (-5) as shown in table 1.

TABLE 1. Distribution of 36 statements in a Q sort on a scale from strongly disagree (-5) to strongly agree (5)

Strongly disagree	-5	-4	-3	-2	-1	0	1	2	3	4	5	Strongly agree
	-5	-4	-3	-2	-1	0	1	2	3	4	5	
		-4	-3	-2	-1	0	1	2	3	4		
			-3	-2	-1	0	1	2	3			
				-2	-1	0	1	2				
					-1	0	1					
						0						

The third step – the factor analysis of the 62 individual rankings (Q sorts) – was undertaken by principal components factor analysis with varimax rotation. This procedure resulted in the extraction of a few factors. The number of factors extracted was based on three criteria: 1) the factor should have an eigenvalue greater than one, 2) the number of factors extracted should depend on the point where the eigenvalues begin to level off in a scree plot, which graphs the eigenvalue against the factor number, and 3) the factors should be theoretically important and reveal distinct and coherent views. Factor loadings (correlation coefficients) that indicate the degree to which each Q sort correlates with each extracted factor were generated. A significant[3] factor loading is one which is sufficiently high to assume that a relation exists between the respondent and the factor.

The fourth step was to generate a single 'ideal' Q sort and thereby also factor rankings[4] for each factor by merging, according to a procedure of weighted averaging, the rankings of the scientists that loaded significantly on the respective factor (Brown 1980). More weight was given to the rankings of participants who had higher factor loadings, since they were more representative of the factor type. Hence, emergent ideal Q sorts do not represent the viewpoint of any given individual, but the shared patterns within the pooled data. The 'ideal' Q sorts are termed 'perspectives' in this paper.

The final step was the process of factor interpretation by developing a plausible explanation of the factor rankings of each factor. The statement had to be interpreted in relation to the other statements since the Q-sorts represents relative ranking of statements.

The personal interviews involved other elements than ranking the statements. The participants were asked to explain the positioning of the three most agreed/disagreed statements and to comment on the selection of statements as well as how well their Q sorts expressed their perspective on the deliberate release of GM crops. Participants also completed a questionnaire about their age, gender, discipline, place of employment, external funding of their research, whether they were doing basic, applied or risk research, as well as their general attitude to GM crops.

SCIENTISTS' PERSPECTIVES ON GM CROPS

This section presents the results from employing Q methodology to assess the perspectives held by scientists on GM crops. First we present the results of the factor analysis. Next we present the factor rankings of the extracted factors. Finally we interpret the factor rankings.

Factor analysis

The factor analysis yielded 13 factors with eigenvalues greater than 1. However, only three factors were extracted as the use of a scree plot indicated a natural break in the sizes of eigenvalues when three factors were extracted. The three factors accounted for 55 percent of the variance of the rotated correlation matrix. 32 participants loaded significantly on factor 1, 25 participants loaded significantly on factor 2 and one participant loaded significantly on factor 3. The last factor[5] was not accepted since there were less than two Q sorts loading significantly on it.[6] Both remaining factors were theoretically important and revealed distinct and coherent views. We also ran two separate Q sort factor analyses to explore the diversity of viewpoints among the participants that loaded significantly on each of the two factors. These two factor analyses did not add much new information to the information already gained from the first factor analysis and are therefore not included in this paper.

Factor rankings

Table 2 presents the factor rankings of the 36 statements for factor 1 and 2.

TABLE 2. Q-sort statements and their factor rankings

Statement	Factor rankings 1[1]	Factor rankings 2[2]
1. The use of GM-crops in agricultural production is unnecessary.	0	-4
2. Gene technology will contribute to the achievement of a sustainable agriculture.	-1	4
3. It is unethical to deny the exploration of gene technology since it may play an important role in future food security for the world's population.	0	4
4. The ability to break species' boundaries is a strongly negative feature of gene technology independent of whether GM-crops represent unique risks.	0	-5
5. Genetic modification is a natural process since horizontal gene flow between sexually incompatible species occurs regularly in nature.	-1	0
6. The environmental issues raised by growing currently available GM-crops do not differ qualitatively from conventional crops, therefore the characteristics of each crop variety must be evaluated, not the specific plant breeding method used.	-1	5
7. Potential unanticipated effects from GM-crops might arise from the capability of transferring genes into very different genetic backgrounds.	2	0
8. Genetic engineering increases the degree of control and predictability regarding the traits expressed by the new variety compared to other methods applied in conventional plant breeding.	-2	3
9. An important uncertainty is how farmers apply the GM technology in the field.	1	0
10. I have little confidence in the gene technology research undertaken by industry since it is highly influenced by commercial interests.	3	-4
11. Scientific knowledge is not and never will be sufficient to predict future impacts of GM-crops.	1	-2
12. Our present scientific knowledge is not sufficient to evaluate the environmental safety of GM- crops today.	4	-3
13. GM-crops are safe because no one has shown that significant environmental damage has occurred following cultivation of GM-crops.	-4	-1
14. The lessons of history tell us that new technologies bring new unknowns and that we sometimes have rushed forward to exploit new technologies, only subsequently to discover the environmental costs. It is likely that this will happen with GM-crops, unless we take precautionary measures.	3	-1
15. Standardised quantitative methods need to be the primary basis for assessing the environmental impacts of GM-crops.	1	3

16. It is impossible to quantify the ecological impacts of growing GM-crops.	1	-1
17. It is important to take unforeseen consequences into consideration when evaluating the release of GM-crops into the environment.	4	2
18. The consequences of a GM-based agriculture have to be compared with the consequences of organic agriculture.	0	1
19. Lay people are sceptical to GM-crops because they lack knowledge about the technology.	0	1
20. We live in a risk-society and have to accept that technologies, like genetic engineering, with the risk of unlikely but very negative consequences are part of our life.	-2	0
21. Risk and uncertainty regarding ecological effects in natural habitats should not prevent the use of GM-crops in agriculture if these have documented positive effect on productivity and result in reduced use of pesticides.	-2	1
22. GM- traits that enhance resistance to certain herbicides benefit the environment by decreasing the need for chemicals.	-1	2
23. The use of insect resistant GM-crops, such as the different Bt varieties, will enhance the development of resistance among target pest species.	2	1
24. The instability of the transferred gene is of key concern.	2	-3
25. We cannot take into consideration the theoretically possible, but extremely unlikely event of severe reduction in the population of pollinators into consideration when considering the release of a GM-crop.	-2	-2
26. The unintended spread of herbicide resistance from genetically modified crops to weeds and other plant life is likely to raise concerns for the structure and function of ecosystems.	2	-3
27. The potential effects of Bt-crops on non-target organisms are expected to be less severe than the potential effects of broad-spectrum insecticides on non-target organisms.	-1	3
28. We have the same ability to predict ecological changes from both GM-crops and conventional crops.	-3	2
29. Any negative environmental consequences that may arise from growing GM-crops will be adequately addressed by future developments in genetic engineering or other technologies.	-3	0
30. The possible negative impacts of GM-crops on biodiversity are likely to be reversible.	-3	0
31. The really serious problems with GM-crops may arise only slowly, subtly and through long chains of events.	3	-1
32. I see no danger whatsoever of releasing GM-crops into the environment, because of the stability and resilience of ecosystems.	-5	-2
33. Many ecosystem interactions are so complex that the risk of modern biotechnology is unpredictable.	5	-1
34. Results from laboratory experiments on GM-crops can be, in most cases, directly transferred to natural conditions.	-4	-2
35. Man has an obligation to use the possibilities embedded in nature for the betterment of mankind.	0	2
36. Nature possesses an intrinsic value that is independent of human needs.	1	1

[1]Factor 1, [2]Factor 2

Factor interpretation

Perspective 1: 'The environmental effects are unpredictable'
Factor 1 exemplars[7] strongly emphasise the unpredictability of the environmental effects from GM crops. Ecosystems are complex (33:5)[8] and our present scientific knowledge is insufficient (12:4). Major long-term unanticipated impacts might arise (14:3; 31:3). However, factor 1 exemplars have no strong opinion on whether we are faced with irreducible ignorance (16:1; 11:1). They emphasise that results from laboratory experiments on GM crops can not be directly transferred to natural conditions (34:-4) and they have little confidence in research undertaken by industry (10:3).

Factor 1 exemplars have no strong opinion on the claimed beneficial effects of GM crops (3:0; 2:-1; 27:-1; 22:-1), while they emphasise that the unintended spread of herbicide resistance from GM crops is likely to raise concern for ecosystems (26:2). The possible negative impacts are likely to be irreversible (29:-3; 30:-3).

They appear neutral on whether the ability to break species' boundaries is a negative feature of gene technology (4:0) or whether the environmental issues raised by growing GM crops differ from conventional crops (6:-1). However, they emphasise that potential unanticipated effects might arise from the capability of transferring genes into very different backgrounds (7:2) and that effects from GM crops are more unpredictable than effects from conventional crops (28:-3; 8:-2).

Box 1: Characteristics of perspective 1
Factor 1 exemplars strongly emphasise the unpredictability of the environmental effects from GM crops, while they have no strong opinion on claimed positive consequences of GM crops and whether GM crops are fundamentally different from conventional crops. The presence of negative consequences of growing GM crops is moderately emphasised. This means that less emphasis is put on known possible harmful effects than on unpredictability. They have little confidence in gene technology research undertaken by industry.

Perspective 2: 'GM crops present no unique risks and are useful'
Factor 2 exemplars strongly emphasise that the ability to break species' boundaries is not a negative feature of gene technology (4:-5)[9] and that the environmental issues raised by growing GM crops do not differ from conventional crops (6: 5). We have the same ability to predict ecological changes from GM crops and conventional corps (28:2) and genetic engineering increases the control and predictability of the expressed traits compared to conventional plant breeding (8:3).

The use of GM crops in agriculture is considered necessary (1:-4). This is partly explained by the role that GM crops might play for increased food security (3:4), sustainable agriculture (2:4), and reduced pesticide use (27:3; 22:2). The unintended spread of herbicide resistance from GM crops is not likely to raise concern for the structure and function of ecosystems (26;-3). Scientists in factor 2 appear neutral on whether the use of Bt-crops will enhance resistance among target species (23:1) and whether the negative impacts of GM crops will be reversible (30:0; 29:0).

In general, scientists in factor 2 appear neutral on aspects regarding the predictability of GM crops (33:-1; 7:0; 31:-1; 14:-1; 16:-1; 13:-1) However, they emphasise that it is important to take unforeseen consequences into consideration when evaluating the release of GM crops (17:2). They disagree that scientific knowledge is not (12:-3), and never will be, sufficient to predict impacts of GM crops (11:-2). Further aspects of factor 2 exemplars are their confidence in gene technology research undertaken by industry (10:-4) and that they emphasise that man has an obligation to use the possibilities embedded in nature for the betterment of mankind (35:2).

Box 2: Characteristics of perspective 2
Factor 2 exemplars strongly emphasise that GM crops are not fundamentally different from conventional crops and that these crops are likely to have major positive consequences. They have no strong opinion on the predictability of the environmental effects from GM crops or on potential negative impacts from growing GM crops. They have confidence in gene technology research undertaken by industry.

Areas of agreement and disagreement among perspective 1 and 2

One of the main tendencies in our findings is that factor 1 and 2 exemplars rarely have opposing views on the same issues; rather, they feel strongly about different issues.[10] Examples are positive consequences of GM crops (3:0,4; 2:-1,4; 27:-1,3; 1:0,-4),[11] whether potential negative impacts are likely to be reversible (29:-3,0; 30-3,0), whether ecosystem interactions are so complex that the risk of modern biotechnology is unpredictable (33:5,-1), the possibility for major long-term unanticipated impacts (14:3,-1; 31:3,-1), whether the ability to break species' boundaries is a negative feature of gene technology (4:0,-5), whether the environmental issues raised by growing GM crops differs from conventional crops (6:-1,5), and whether GM crops are safe because no one has shown any significant environmental damages (13:-4,-1).

The major areas of disagreement among the two factor groups are whether present scientific knowledge is insufficient to assess the environmental safety of GM crops (12:4,-3), whether the spread of herbicide resistance from GM crops is likely to raise concern for ecosystems (26:2,-3), whether genetic engineering increases control and predictability (8:-2,3; 28:-3,2), and whether industry funded gene technology research is influenced by commercial interests (10: 3,-4).

The scientists have no strong opinion on most of the issues that they agree on. Neither of the groups have strong opinions on whether nature possesses an intrinsic value (36:1,1), whether lay people are sceptical to GM crops because they lack knowledge about the technology (19:0,1), whether how farmers apply the GM-technology is an important uncertainty (9:1,0), and whether it is impossible to quantify the ecological impacts of growing GM crops (16:1,-1). They also agree that the use of Bt-crops will enhance the development of resistance among target species (23:2,1).

CHARACTERISTICS OF SCIENTISTS WITH THE SAME PERSPECTIVE ON GM CROPS

Having identified different perspectives on GM crops, an important question is what characterises scientists that hold the same perspective. We have addressed this issue by analysing whether the scientists' general attitude to GM crops and their contextual background (discipline, funding, type of research, place of employment) is linked to significant loading on factor 1 and 2, i.e. whether they hold perspective 1 or 2. These two perspectives cannot be considered to be the only two ways scientists think about GM crops. However, the two perspectives point out basic differences among the participating scientists' perspectives on GM crops. Examining the characteristics of the scientists in each factor group can suggest reasons why they hold different perspectives on GM crops.

The scientists were asked to indicate their general attitude to GM crops on a scale ranging from 1 to 5, where 1 is negative and 5 is positive. A logistic regression model was then developed to analyse the relationship between the scientists' general attitude to GM crops and the perspective they hold. Table 3 presents the attitudes of the scientists that loaded significantly on the two factors and the results from the logistic regression model.

TABLE 3. Descriptive statistics for attitude[1] to GM crops, and parameter estimates and Wald statistics of a logistic regression model predicting perspective on GM crops by attitude to GM crops (n=56[2])

	Factor		Logistic regression model[3]	
	1	2	β	Z^2
Mean attitude	2,7	4,7	-2,8	15,7*
Std	1,0	0,5		

[1]Measured on a five point Lickert scale (1:negative, 5: positive)

[2]One of the respondents that loaded significantly on factor 1 is excluded from the sample because of negative correlation coefficient.

[3]y=1 if perspective 1, and 0 if perspective 2

*p<0,0001

All of the factor 2 exemplars are very positive to GM crops, while factor 1 exemplars are moderately negative. There is a substantial variation in attitude among the factor 1 exemplars, while this is not the case for factor 2 exemplars. Logistic regression predicting significant loading on factor 1 by attitude to GM crops indicates that general attitude to GM crops has a significant effect on the perspective they hold on GM crops. The more negative the scientists are, the more likely is it that they hold perspective 1.

To analyse whether the scientists' contextual background is related to significant loading on factor 1 and 2, we wanted to develop a logistic regression model that included the explanatory dummy variables funding, discipline, type of research and place of employment, as well as interaction effects between these variables to predict perspectives on GM crops. However, for several of the intended explanatory variables some categories were missing. Ecologists and industry-employed scientists were for example only present in one of the perspectives. It is not possible to include explanatory dummy variables in a logistic regression model if some categories are missing and it was therefore not possible to develop one logistic regression model with all the intended variables. We have therefore analysed the relationship between the contextual background of the scientists and significant loading on factor 1 and 2 by three steps. First we present the background characteristics of the scientists in each of the two perspectives and analyse the association between these background characteristics and perspective on GM crops by chi-square tests (see table 4). Then we present the results from three different logistic regression models that include different explanatory variables and different groups of the scientists (see table 5). Finally we present the interaction effects (see table 6). The control variables age and gender had no significant effect and are therefore not included in the analysis.

Table 4 shows a very clear pattern; no ecologists, and no scientists employed in the foundation (a non-commercial foundation that is located in a research environment) or the conventional plant breeding company are associated with perspective 2, while all the scientists employed in the GM-industry are associated with perspective 2. Most of the scientists that belong to other disciplines (agrobiology, plant physiology, evolutionary genetics and bio-ethics) hold perspective 1. Chi-square tests suggest that perspective on GM crops depends on discipline, place of employment, funding and type of research.

Table 5 presents the parameter estimates and their Wald statistics for three logistic regression models that include different explanatory variables and different groups of the scientists that loaded significantly on factor 1 or 2. The three models were developed since these were the models that satisfied the requirement that no categories in an explanatory dummy variable should be missing, i.e. funding was included since industry funded scientists and publicly funded scientists hold both perspectives, while place of employment was not included as no industry employed scientists hold perspective 1.

TABLE 4. Characteristics of scientists that hold the same perspectives on GM crops, and chi-square tests for independence between perspective on GM crops and discipline, place of employment, funding and type of research

	No. of factor 1 exemplars	No. of factor 2 exemplars	χ^2
Number of scientists	31	25	
Discipline			19,5***[1]
Conventional plant breeding	4	2	
Molecular biology & related fields[2]	8	22	
Ecology	13	0	
Other[3]	6	1	
Place of employment			12,1**[4]
Foundation[5]	6	0	
University	21	14	
Conventional plant breeding company[6]	4	0	
GM-Industry	0	11	
Funding			24,2***
Public[7]	30	9	
Some/all from GM-industry	1	16	
Type of research			10,8*
Risk research	7	1	
Basic research	18	9	
Product research	6	15	

[1]'other' and 'conventional plant breeding' are excluded from the tests to ensure expected cell count greater or equal to 5.

[2] Related fields are molecular genetics and biochemistry

[3]'Other' refers to three agrobiologists (one of them loaded significantly on factor 2), two plant physiologists, one evolutionary geneticist, and one scientists who had a background in molecular biology, but is currently working within the field of bio-ethics.

[4]'foundation', and 'conventional plant breeding company' are excluded from the tests to ensure expected cell count greater or equal to 5.

[5]'Foundation' refers to a non-commercial foundation that is located in a research environment.

[6]The conventional plant breeding company is owned by the state, agricultural cooperatives and private companies.

[7] The scientists that work in the conventional plant breeding company are classified as receiving public funding since the majority of their funding is public and since their private funding comes from other sources than the GM-industry. These private funding sources are not likely to relate to their perspective on GM crops in any particular direction since they are not involved in gene technology.

*p<0,005, **p<0,001, ***p<0,0001

TABLE 5. Parameter estimates and Wald statistics of logistic regression models predicting perspective on GM crops (y=1 if perspective 1, and 0 if perspective 2)

Explanatory variables	Model 1. n=56		Model 2. n=43 (no ecologists)		Model 3. n=30 (only mol. biologists)	
	β	Z^2	β	Z^2	β	Z^2
Discipline[1]: Ot	–	–	2,9	4,3*	–	–
Discipline[1]: Co	–	–	0,7	0,4	–	–
Funding[2]	3,9	10,2**	4,1	7,0**	2,7	5,4*
Type of research: Ri[3]	2,3	2,2	1,2	0,6	–	–
Type of research: Ba[3]	0,3	0,1	-1,5	1,8	–	–

[1] Measured as two dummy variables 'Ot' and 'Co' where in the case of Ot 1 denotes other (agrobiology, plant physiology, evolutionary geneticist, and bio-ethics) and 0 denotes otherwise, and where in the case of Co 1 denotes conventional plant breeding and 0 denotes otherwise.

[2] Measured as a dummy variable where 1 denotes purely publicly funded and 0 denotes otherwise (some/purely industry funded).

[3] Measured as two dummy variables 'Ri' and 'Ba' where in the case of Ri 1 denotes risk research and 0 denotes otherwise, and where in the case of Ba 1 denotes basic research and 0 denotes otherwise.

*p<0,05, **p<0,01

Model 1 in table 5 includes all the 56 factor 1 and factor 2 scientists and examines the relationship between perspective on GM crops, funding and type of research. The model predicts that scientists who are publicly funded are more likely to hold perspective 1 than scientists that are partly or purely industry funded. Type of research has no significant effect.

Discipline could not be included in model 1 as no ecologists hold perspective 2. However, by excluding the ecologists from the model, we could include discipline as an explanatory variable as the other disciplinary categories are present in both perspectives. This is what we have done in model 2. The results are similar to those in model 1 in terms that funding has significant effect, while type of research has no significant effect. Whether the discipline is conventional plant breeding or otherwise has no significant effect, while whether the discipline is 'other' (agrobiology, plant physiology, evolutionary geneticist and bio-ethics) or otherwise (molecular biology and conventional plant breeding) has significant effect. Scientists from the disciplinary category 'other' are more likely to hold perspective 1 than conventional plant breeders and molecular biologists.

Model 3 in table 5 only includes the molecular biologists. Funding has significant effect on the perspectives molecular biologists hold on GM crops. Molecular biologists who are partly or purely industry funded are very likely to hold perspective 2, while publicly funded molecular biologists are as likely to hold perspective 1 as perspective 2.

It was not possible to include interaction variables in any of the three models because some of the categories were present in only one of the perspectives. We have therefore presented interaction effects from discipline, funding, place of employment and type of research in table 6.

We see from table 6 that the only category of molecular biologists where the majority hold perspective 1 is molecular biologists that at the same time are employed in the foundation, are doing risk research and are publicly funded. In fact, all the publicly funded scientists that are doing risk research are associated with perspective 1, while the only industry-funded scientist that is doing risk research is associated with perspective 2. Half of the publicly funded molecular biologists are associated with perspective 2, while more than 90 per cent

TABLE 6. Interaction effect from discipline, funding and type of research on perspective on GM crops

Discipline	Funding	Research	Place of employment	No. of factor 1 exemplars	No. of factor 2 exemplars
Ecology	Public	Basic	University	11	0
Ecology	Public	Risk	University	1	0
Ecology	Public	Risk	Foundation	1	0
Molecular biology & related fields	Public	Basic	University	2	4
Molecular biology & related fields	Public	Risk	Foundation	4	0
Molecular biology & related fields	Public	Product	University	1	3
Molecular biology & related fields	Some/all from GM-industry	Basic	University	0	3
Molecular biology & related fields	Some/all from GM-industry	Product	University	1	2
Molecular biology & related fields	Some/all from GM-industry	Product	Industry	0	10
Conventional plant breeding	Public	Basic	University	0	2
Conventional plant breeding	Public	Product	Conv. plant breed. comp.	4	0
Other (bioethics)[1]	Public	Risk	Foundation	1	0
Other (plant physiology, agrobiology, evolutionary genetics)	Public	Basic	University	5	0
Other (agrobiology)	Some/all from GM- industry	Risk	Industry	0	1
Total no. of scientists				31	25

[1] This scientist had a background in molecular biology

of the partly/purely industry funded molecular biologists are associated with the same perspective. No conventional plant breeders that are employed in the conventional plant breeding company are associated with perspective 2, while no conventional plant breeders that are employed in universities are associated with perspective 1.

DISCUSSION

In our discussion of the findings, we will first look at the importance of the four dimensions 'the consequences of releasing GM crops', 'our ability to predict the consequences', 'whether GM crops are fundamentally different from conventional crops', and 'the moral status of nature' for the two perspectives on GM crops identified in this study. Next we discuss the importance of discipline, funding, place of employment and type or research for scientists' perspectives on GM crops. Finally, we situate the study in the broader context of debates about science, innovation and value and we examine the implications of this study for these debates.

As emphasised above, factor 1 and factor 2 exemplars generally do not have opposing responses on the same dimensions. Rather they feel strongly about different aspects. The dimension 'our ability to predict the consequences of releasing GM crops' is the most important dimension for the scientists in factor 1 in the sense that they emphasise that consequences are unpredictable. Factor 2 exemplars, on the other hand, have no strong opinion on this issue. Neither factor 1 nor 2 exemplars have any strong opinion concerning whether we are faced with irreducible ignorance or not. The dimensions that concern consequences of releasing GM crops and whether GM crops are fundamentally different from conventional crops are the most important dimensions for scientists in factor 2, while these two dimensions are not so important for scientists in factor 1. Factor 2 exemplars strongly emphasise that GM crops present no unique risks and that GM crops are useful, while they have no strong opinion on negative consequences. Factor 1 exemplars moderately emphasise the presence of negative consequences and have no strong opinion on positive consequences. The dimension 'moral status of nature' is of little importance for both groups of scientists in terms that they have no strong opinion on whether we should hold an anthropocentric or ecocentric position.

The contextual characteristics of the scientists revealed a very clear pattern concerning the perspective they hold on GM crops. All the scientists that were employed in the foundation and in the conventional plant breeding company hold perspective 1, while all the industry-employed scientists hold perspective 2. This might indicate that perspective on GM crops is an important aspect in the recruitment process in these organisations, and/or that the socialisation that takes place in these organisations shapes the perspective on GM crops.

The foundation was created to secure an independent research milieu being independent both of the industry and university priorities. This might partly explain why scientists in this group are so homogenous in their perspective on GM crops. The conventional plant breeding company is recently privatised and the scientists emphasised that they perceived themselves as publicly employed scientists. University scientists are associated with both perspectives. This might indicate that being employed in universities has in itself little influence on scientists' perspectives on GM crops.

Funding has a significant effect on the perspective the scientists hold. Scientists that have some industry funding or are purely industry funded are very likely to be associated with perspective 2, while publicly funded scientists are somewhat more likely to hold perspective 1 than perspective 2. Scientists that are funded by the industry might feel an obligation to serve the interests of the shareholders, while publicly funded scientists possibly take a more autonomous role. Industry funding imposes a one-sided focus on the profits in the near future. Aspects of biological systems that are external to the market as well as long-term effects become irrelevant for their research. It is interesting that industry funded scientists are likely to hold one particular perspective, and that this perspective emphasises that gene technology research undertaken by industry is not influenced by commercial interests.

The fact that all the industry employed scientists hold perspectives 2 and that scientists that have some industry funding are very likely to hold perspective 2 might justify the concerns that have been raised about the commercialisation of GM crop research from the 1980s (see for example Caldart 1983; Newberg and Dunn 2002; Pistorius and Wijk 1999; Stone 2002; Victor and Runge 2002). When formulating policies for GM crop research, the governmental authorities ought to consider that industry funding of GM crop research might influence the perspectives scientists hold and/or that mainly scientists that hold certain perspectives are recruited to GM crops research that are industry funded. Governments should consider reversing the industrial dominance in GM crop research by changing policies for intellectual property rights and public research budgets.

None of the ecologists hold perspective 2, while about three-fourths of the molecular biologists hold perspective 2 and two-thirds of the conventional plant breeders hold perspective 1. It was expected that the ecologists could hold a perspective similar to perspective 1 and that most of the molecular biologists could hold a perspective similar to perspective 2. However, quite a few of the molecular biologists hold perspective 1. Half of the molecular biologists that hold perspective 1 are publicly funded, employed in the foundation and do risk research. These molecular biologists might hold a diverging perspective from most of the other molecular biologists because they work in a different context and/or because it is mainly molecular biologists that emphasise complexity and uncertainty that are recruited to this kind of research. All the conventional plant breeders that are employed in the conventional plant breeding company hold perspective 1, while all the conventional plant breeders that work in universities hold perspective 2. One of many possible explanations might be that the university employed conventional plant breeders have much contact with molecular biologists, while this is not the case for those working in the company. A reasonable policy response to these results might be to encourage more interdisciplinary training and research. It is also crucial that the policy makers include several disciplines when they ask for scientific advice on policies for GM crops.

The results from this study are of relevance for the wider debate about science, innovation and value that is increasingly taking place in western countries. During the last decades, science has dominantly been valued for its importance for securing economic growth. Wilsdon et al. (2005) emphasise that instead the public value of science, i.e. the total benefits that flow from public science policy, should be the main measure for the value of science and technology. They suggest upstream public engagement as one way to enhance the public value of science. Stakeholders, scientists and the wider public should deliberate on the visions, ends and purposes of science and they should together influence the trajectories of scientific and technological developments. However, the idea about upstream public engagement in science has generated debate. It has been argued that science is not a democratic activity – the accuracy of scientific 'facts' cannot be decided by referenda – and that the public lack the technical insight necessary to contribute.

The results from this study justify upstream public engagement as they illustrate that both factual judgements as well as value judgements are important for scientists' perspectives on GM crops. The existence of uncertainty and ignorance as such implies that value judgments have to be made, as it is not given how one should respond to uncertainty and ignorance. Scientists are not more qualified for making value judgments than others and these judgments should therefore not be left for scientists alone. However, public engagement is not unproblematic. There are several related challenges, like representativeness and accountability, which one needs to be aware of. Decisions on what research might be most valuable will always be based partly on factual assumptions. At least, in some respect, scientists are likely to be more competent on making these assumptions than others.

Wilsdon et al. (2005) also argue that the structures that surround scientists to a greater extent should encourage scientists to be concerned about the public value of science. Our results show that industry funding might impose limits on scientists' possibilities to reflect on the social dimension of their work or at least that the recruitment process is biased and thereby indirectly influences the reflection that will take place.

Dialogue between different types of scientists is important to secure the public value of science, and should be promoted and rewarded according to Wilsdon et al. (2005). The differences in the perspectives held by the scientists in this study justify the fostering of dialogue between scientists. However, an open-minded dialogue might be difficult to facilitate, as there seems to be a lack of trust between the different groups.

CONCLUSION

The GM crop issue is characterised by low consensus among scientists. This study has revealed two distinct and independently coherent perspectives on GM crops. Perspective 1 emphasise that the environmental effects from releasing GM crops are unpredictable, while perspective 2 emphasise that GM crops are useful and present no unique risks. No ecologists are associated with perspective 2, while all the scientists employed in the GM-industry are associated with perspective 2. Publicly funded scientists are likely to hold perspective 1, while scientists that are funded by the GM-industry are very likely to hold perspective 2.

An immediate response might be that this study undermines the authority of science. This is not our conclusion. Rather the results might justify certain institutional changes concerning how we organise science and how we make public decisions on new technologies, in order to increase the public value of science. Policy makers should encourage more interdisciplinary training and research, and they should consider to reverse the commercialisation of GM crop research to secure that a substantial part of this research is independent from the priorities of the industry and to a greater extent could serve public needs. The results stress the need for involving scientists from several disciplines in public decisions on new technologies. Information about the contextual background of the scientists is relevant in these decisions as we observe that scientists from different contexts interpret the same information differently. The fact that several value judgments are involved in these decisions might justify public engagement. However, it is also important to emphasise that public participation does not automatically solve the problem of fairness and legitimacy in decision-making. Finally, openness and acceptance to the fact that scientists are also human beings with values could provide the basis for new forms of dialogue between the scientific world and the wider public.

NOTES

[1] By related fields we mean molecular genetics and biochemistry.

[2] Ajzen and Fishbein (1980) emphasise that attitudes are influenced by the beliefs about the consequences of the behaviour weighted against the evaluation of these consequences.

[3] We have used three criteria for determining significance: 1) the factor loading should exceed 2,58 divided by the square root of the number of statements, 2) squared factor loading on a factor should exceed $h^2/2$, where h (communalities) is the sum of the

squared factor loadings for all the significant factors, 3) criteria 1) and 2) should only show significance for one factor.

[4] The factor rankings related to a factor constitutes the ideal Q sort of that factor.

[5] This factor is characterised by emphasis on the existence of positive and negative consequences of growing GM crops and that GM crops are not fundamentally different from conventional crops. Low confidence in research undertaken by the industry is also emphasised.

[6] It is normal procedure to ignore factors for this reason.

[7] Q sorts which load significantly upon one factor alone are called 'factor exemplars'.

[8] The numbers in parentheses refer to the statement number followed by the factor ranking associated with factor 1.

[9] The numbers in parentheses refer to the statement number followed by the factor ranking associated with factor 2.

[10] Wilkins et al. (2001) present similar findings.

[11] The numbers in parentheses refer to the statement number followed by the factor rankings for that statement in the order of factors (1,2).

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