

Public Attitudes Toward Molecular Farming in the UK

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Plant-made pharmaceuticals represent the third generation of genetically modified crops as well as a potentially significant development in pharmaceutical and vaccine manufacturing. Successful development is contingent on a number of factors, one of which is social acceptance. This article outlines the results of a focus group study conducted in the UK on public attitudes toward molecular farming. It finds that attitudes are predominantly positive. Judgments about molecular farming are made in terms of perceived need and benefits, not limited to the participants themselves. Concerns do exist about whether molecular farming represents the best approach to pharmaceutical production, which diseases are targeted, and whether it can be controlled and contained. While participants are unfamiliar with molecular farming, they draw on a range of existing knowledge and examples to anchor their understandings of it.

Key words: molecular farming, plant-made pharmaceuticals, qualitative research, public attitudes, UK.

Introduction

Plant-made pharmaceutical (PMP) production involves the use of plants as a production platform for valuable biological molecules, including industrial enzymes and pharmaceutical proteins. It represents a convergence of research into the genetic modification of plants and the production of biological pharmaceuticals. An increasing demand for biopharmaceutical production (Walsh, 2003) may lead to the adoption of plant-based pharmaceutical production on a large scale (Ma, Chikwamba, et al., 2005).

Technologies increasingly develop in a context of implication, in which the social and ethical consequences of research are co-produced with the form of new technologies (Jasanoff, 2005). The public is an important part of this process, as demonstrated by the reception of first generation GM crops in Europe. Engaging with public views at an early stage is crucial, not only for reducing the likelihood of clashes between scientists and the public, but also in the development of more socially robust science (Wilsdon & Willis, 2004).

Frewer, Howard, Hedderley, and Shepherd (1997) showed that attitudes toward biotechnology are application-specific and that applications involving plants and microorganisms are more positively regarded than those involving animals or human genetic material. A division of attitudes by application is supported by evidence from Eurobarometer studies. However, here this specificity is generalized to a divide between positive attitudes toward medical ('red') biotechnology and negative perceptions of agricultural ('green') applica-

tions (Gaskell et al., 2006). This representation of public attitudes toward biotechnology has become a key stakeholder belief about public attitudes (Marris, Wynne, Simmons, & Weldon, 2001) and is obviously pertinent to discussion of public attitudes to molecular farming, which sits at the intersection of red and green.

Comparatively few studies exist exploring the social, political, and economic context of molecular farming, especially in the European Union. As molecular farming involves a complex intersection of agricultural and medical biotechnologies, it is difficult to draw inferences from studies of other applications (Einsiedel & Medlock, 2005; Spök, 2007).

Most research into public attitudes toward molecular farming has focussed on the North American context (Einsiedel & Medlock, 2005; Kirk & McIntosh, 2005; Knight, 2006; Nevitt et al., 2003; Nevitt, Mills, Reaves, & Norton, 2006; Pew Initiative on Food and Biotechnology Polls, 2004). The support identified in these studies echoes that of US publics for first generation genetically modified crops (Hoban, 2004). The European context for agricultural biotechnology has been significantly different. The divergent reception of technologies from first-generation GM crops to stem cells between the United States and Europe suggests that the results from studies of public attitudes in North America may be of limited relevance to the European context.

The availability of studies in Europe is much more limited. The Public Perceptions of Agricultural Biotechnology in Europe (PABE) study (Marris et al., 2001) considered medical applications of GMOs as a foil to

agricultural GM crops, using the examples of tobacco engineered to produce haemoglobin and beta-carotene-enriched “Golden Rice.” The study identified a number of factors, including access to information, risk assessment procedures, and regulation, that are felt to be more satisfactory in the medical field, as well as appreciation of personal benefit. However, it cautions against the simple red/green division and points out that these characteristics are an “ideal type,” which may vary.

In the UK, a study of non-food uses of agriculture considered two medical applications, a vaccine for dental caries in tobacco and an HIV microbicide produced in maize or tobacco (Corr-Willbourn Research and Development, 2005). The first of these was not well regarded by participants, while the latter was viewed less positively when participants realized they were discussing a preventative measure rather than a vaccine or cure. An interesting distinction is made here between the potential applications of molecular farming, and attitudes to both were related to the perceived benefit and the risks of contamination.

This article builds on these findings by examining in more detail the construction of public attitudes to molecular farming in the UK. It explores the medical representation of the technology and examines how it is distinguished from the techniques of agricultural biotechnology used in the production of pharmaceutical crops.

The Focus Group Process

This study was undertaken using repeated focus groups. Focus groups are used to explore how people use knowledge and experience in order to make sense of novel issues in a social setting. They provide insight into *how*, *why*, and *what* people think about various subjects. While surveys are valuable for tracing patterns of public opinion, focus groups open up the processes that generate these patterns for analysis. As such, they are an excellent method for investigating subjects to which participants have little prior exposure, as people form attitudes during the group process (Gaskell et al., 2006; Kitzinger, 1995; Morgan, 1997).

Qualitative research approaches such as the use of focus groups regard language and discourse as a social practice in which norms, institutions, and social practices are actively constituted. It is through attention to the discussion that the ways in which public attitudes are expounded, developed, and become concrete can be understood. In contrast, quantification of the findings of qualitative research removes the nuance of discussion

Table 1. Focus group constitution

Group	Age	Gender	Location	Type of Group
A	Young	Male	Urban	Sports club
B	Young	Female	Urban	Colleagues
C	Older	Mixed	Urban	Church group
D	Older	Female	Rural	Support group
E	Older	Mixed	Rural	Shared interest group
F	Young	Mixed	Rural	Colleagues

that the use of these methods is intended to capture. As Asbury comments, “focus groups are not oral surveys; that is, participants comments should not be tallied, counted, or otherwise taken out of the context in which the comments originated” (Kitzinger & Barbour, 1999, p. 17).

Six groups were constituted from 35 individuals with between four and nine participants in each and were formed from established groups, including a sports team, a church group, two groups of co-workers, a hobby group, and a support group. Using existing groups facilitates recruitment and can lead to the production of data more closely, approximating ‘natural’ interaction (Khan & Manderson, 1992; Kitzinger, 1994). In focus group research, the aim is to draw on a heterogeneous array of comparatively homogenous groups. Homogeneity within groups allows people to draw on shared experiences (Kitzinger & Barbour, 1999), while heterogeneity between groups allows a range of views to be captured, providing a better understanding of responses to molecular farming across disparate publics.

The groups contained 20 women and 15 men. Three groups were mixed, one group contained only men, and two groups contained only women. Fourteen participants were young (less than 40 years old) while 21 participants were older than 40. Three groups (16 people) were conducted in rural England, and three groups were conducted in London (19 people), in order to capture the geographical diversity of the population. The groups were made up as presented in Table 1.

Each group met twice, a week apart, with each meeting lasting 1.5 hours. The two meetings were designed to stand alone. The first meeting focused on attitudes toward food, medicine, and biotechnology in general. This meeting generated data about participants’ eating practices, relations to medicines, and previous encounters with (and understandings of) biotechnology. At the end of the first session, participants were provided with an information booklet about molecular farming based on reviews in the scientific literature (particularly Ma, Barros, et al., 2005). The booklet contained a definition,

proposed advantages and disadvantages, information on which plants are used, types of containment, institutions involved in research and development, and extant regulatory frameworks. Further details were provided on three examples: HIV microbicides produced in maize, rabies antibodies produced in tobacco, and gastric lipase produced in maize. These examples were chosen for two main reasons. First, all three are at an advanced stage of development in the EU, the first two by the EU-funded PharmaPlanta Consortium, the third by French company Meristem. Second, the three examples cover a range of applications and types of disease, from the very large-scale production of antibodies for transmissible disease to the production of enzymes for sufferers of genetically-inherited cystic fibrosis.

The examples of an HIV microbicide and gastric lipase had previously been used in studies of molecular farming (Corr-Willbourn, 2005; Einsiedel & Medlock, 2005). This has a number of advantages for the research. First, using the same examples enhances comparability between qualitative research studies, both within and between national contexts. The use of the example of an HIV microbicide allowed the conclusions of the 2005 Corr-Willbourn study to be expanded, given the interesting distinctions they introduce between cures, vaccines, and treatments as the goals of medical research.

All group discussions followed a loosely structured format. The same topics were considered in every group, although not in the same order, as group discussion was allowed to follow its own direction with minimal intervention. The facilitator opened discussion by asking participants for their initial responses to reading the booklet, before asking about the specific examples. After this initial opening of discussion, each group went in a slightly different direction. In all groups the question of where and how to grow plant-made pharmaceuticals and of whether food crops should be used for molecular farming were introduced by the facilitator if it did not arise spontaneously. However, these topics were introduced by participants in all but one group; this group, Group C, was the only one in which a strongly negative discussion of molecular farming was found. As such, the facilitator's role was to encourage and develop these discussions. Following a short break after an hour of discussion, the facilitator introduced a series of statements about molecular farming to gauge group response. These described the potential of the technology from the perspective of patients, researchers, and an environmental NGO in order to ascertain the preferred source of information about molecular farming.

The group discussions were recorded and transcribed verbatim. The analysis of qualitative data is often undertaken through reading transcripts and identifying and 'coding' relevant and recurring themes. Instances of these themes from different groups are then combined and compared, and common or distinguishing features are identified and coded in a second iteration. In this study, initial coding of the data was done by hand, and ATLAS.ti qualitative data analysis software was used for further coding and analysis of the group transcripts.

This article concentrates on the dominant themes of discussion on the topic of molecular farming. It examines how participants categorize molecular farming by drawing on interpretive repertoires, which allow them to fit it into existing understandings of their world. Participants bring a range of related concerns and contextual knowledge to the group, which serves to frame discussion of molecular farming in distinctive and significant ways, as is discussed below. The discussion presented here shows how groups draw on their knowledge of the past behavior of actors involved in molecular farming, questions such as crop choice and containment, and participants' experience of research in both agriculture and medicine.

Findings and Discussion

The topics presented here do not exhaust the range of public attitudes to molecular farming but provide the foundations for a typology of responses and concerns. Those themes presented are those which were emphasized in the focus group sessions and were often repeated in a number of groups. The key findings of this research are summarized in Table 2.

The Promise and Intentions of Molecular Farming

Throughout discussion of molecular farming, people draw on their understandings of past behavior by individuals and institutions in examining the choices made by these actors. This often coincided in group discussion with discussion of the motives behind PMP development. Here, the link with pharmaceutical production is evident, as the perceived motives of the pharmaceutical industry are important in ascribing characteristics and putative motives to the unfamiliar molecular farming industry. Molecular farming is thus drawn into the tension between a prominent discourse of profit and money-making, most vividly expressed in the description of making "so much money out of people's misery"

Table 2. Summary of findings.

Findings	Main findings	Other conclusions
The promise of molecular farming	There is a positive view that molecular farming has the potential to be a useful development in medical response to diseases.	Assessment of the potential of molecular farming is prospective and is tempered by an understanding of the need for social and political responses to disease. Discussion was dominated by HIV, while the example of gastric lipase was ignored.
Food or non-food	The choice of crop for molecular farming is important, but drawing the line between food and non-food is not simple.	Tobacco is viewed with suspicion due to its addictiveness and the need for purification. Neither tobacco or maize are widely encountered in the UK.
Containment	Containment is crucial for the introduction of plant-made pharmaceuticals, preferably in greenhouses.	Although all forms of containment are viewed as potentially fallible, greenhouses are better than the rest.
Regulation	Specific regulation addressing molecular farming is necessary. The preference of growing location for pharmaceutical crops is influenced by the perceived strength of regulation.	There is greater faith in regulatory regimes in Europe and the UK than in the US and developing world.
Testing	Plant-made pharmaceuticals must be thoroughly tested before introduction.	The testing regime described by participants involves trialling of both pharmaceutical crops and products, in a combination of biopharmaceutical and agricultural biotechnology regimes.

(Woman, Group C), and a more trusting discourse which sees pharmaceutical production as necessary and well-intentioned.

Overall, good intentions and the perceived scale of disease problems are a powerful motivating factor for support for molecular farming. The PABE study, discussed earlier, highlighted that personal benefits were not the sole concern in attitudes toward agricultural biotechnology (Marris et al., 2001), and the same can be seen to be true of molecular farming. The potential for the technology to be of benefit to a more general 'humanity' is of importance. This humanitarian discourse was particularly evident in discussions of an HIV microbicidal cream produced in tobacco, as HIV is seen as a problem worthy of any possible response.

However, positive assessment of the humanitarian promise of the technology exists in tension with a more sceptical outlook on HIV prevention. In particular, this draws upon knowledge about past approaches to both HIV prevention and international development and concern. It is seen as important that the development of PMPs should not lead to less emphasis on alternative social and cultural approaches to preventing the spread of HIV. In the case of HIV, technological intervention is seen as limited by social and cultural factors, in particular, reluctance to use condoms. In two groups the difficulties encountered in restricting the spread of HIV were compared with the success with which rabies has been controlled in the UK using quarantine regulations. This latter example served to reinforce the importance of technology only as part of a broader solution.

Food or Non-Food Crops

The choice of crop for pharmaceutical production is also an important consideration. Tobacco has a number of positive characteristics, including that it is a non-food crop, and that it is already in wide-scale production. There is thus an existing knowledge of farming techniques and capacity for production. In light of an increasing number of public smoking bans in the developed world, not least in the UK where the introduction of the ban was imminent at the time of the research, participants in the groups saw a need to find a use for tobacco and simultaneously provide an alternative source of income for tobacco farmers.

However, the perceived benefits of tobacco-based production are accompanied by a number of concerns. Four groups pointed out that tobacco is addictive, and wondered whether this represented a potential problem for their use in pharmaceutical production. Consequently, groups were concerned about the need for processing involved in tobacco production, also described in the information booklet. For tobacco-based production, this would appear to suggest that the negative public image of tobacco remains a concern, and consequently people may be unwilling to trust tobacco-based production.

In group discussion, people draw on their existing knowledge of plant characteristics and wildlife behavior. As such there is skepticism about whether tobacco can truly be considered a non-food or feed crop. In particular, Group E focussed on the potential for pests to eat

tobacco and then be eaten themselves. In addition, maize farming is rare in the UK, and participants are generally unfamiliar with it, so it was discussed in much less detail by the groups in this research. This highlights the difficulties that may be encountered by both regulators and researchers in establishing firm delineations between food and non-food crops. As recognized by participants in this research, there is a large amount of slippage between these categories.

The importance of distinguishing between food and non-food production derives from concerns about the contamination of foodstuffs with pharmaceutical products. Unease about the production of pharmaceuticals in food crops specifically was expressed in some groups. However, perhaps surprisingly, the risk of contamination of the human food chain was not a dominant theme in the group discussions, and indeed was no more emphasized than the risk to wildlife and the environment posed by contamination. Despite this, it cannot be concluded that no such concerns exist. Instead, this equality of concern is most likely due to the way in which discussion of molecular farming frames it as a question of effective containment. Containment, particularly in greenhouses, and the separation of agricultural and pharmaceutical production is regarded as an inescapable condition of molecular farming, as is discussed below. Consequently, field production is not considered as a particularly viable option.

Containing Plant-made Pharmaceuticals

The containment of pharmaceutical crops is a major concern across all discussions. There is a strong preference for containment, at least for an initial period and, in some cases, indefinitely. Greenhouses are seen as the preferred containment approach, as they provide physical, tangible, separation from the environment. However, the preference for greenhouses is not only expressed in terms of protecting the outside. The potential for greenhouses to speed production and prevent stealing of valuable crops was also discussed.

Although they are seen as the most reliable containment method, greenhouses are not without their problems. Greenhouses were initially considered infeasible by all groups due to the perceived scale of production required, although the examples of large-scale greenhouse production of daffodils and tomatoes were introduced by participants in three groups to exemplify its possibility. However, when presented with a quote from Arntzen (in Ma, Barros, et al., 2005) stating that hepatitis B vaccine production for south-east Asia would

require 250 acres, participants were surprised and more positive about the potential for commercial greenhouse production. As with large-scale greenhouse production of food, concerns still exist with some participants about the effects on the visible landscape.

A number of other potential methods of separating pharmaceutical crops from food farming were considered in group discussions. Although isolated growing, on an island for example, met with some initial support, it is not seen as a feasible option. The possibility of birds carrying seeds or being affected by the plant is seen as a risk, and even in extreme isolation, greenhouse containment would still be preferable. Two groups went on to describe their preferred level of isolation as growing in space.

In a reflection of the awareness of social and political context introduced in discussion of HIV treatment, difficulties are foreseen in selecting an appropriate location. Discussion of the technology thus addresses not only its technical feasibility and narrow development path, but the sociopolitical challenges faced during development. These are couched both in terms of public acceptability, not least in relation to first generation genetically modified crops, and in terms of protecting the crops. As in the discussion of greenhouses described above, there is concern about crops being stolen from isolation, as seen in what one participant strikingly described as “Pirates of the Caribbean with genetically modified maize.”

There is significant skepticism as to whether successful containment is achievable. Two arguments are prominent here, which represent both the technical and social challenges of containment. The first considers any attempt to modify and control nature as doomed to failure, drawing on previous examples of nature ‘biting back’ and the examples of BSE and antibiotic resistance in particular. As well as these more catastrophic examples, other groups are concerned about the uncertainty and unpredictability involved in biological containment methods. The second argument focuses on the likelihood of human error, drawing on examples such as Chernobyl or skepticism about the competency of British people. At the time the groups met, an outbreak of H5N1 bird flu at a turkey farm in eastern England was leading the national news. This was used to exemplify the infeasibility of containing biological matter, be it viruses or seeds.

Regulatory Control of Molecular Farming

Discussion about human ability to control and contain plant-made pharmaceuticals extends to regulatory, as well as physical, restraint. Specific regulation for molecular farming is needed. However, perhaps surprisingly, three groups expressed a significant amount of confidence in the competency of governments to regulate. This feeling is not universal, and other groups expressed mistrust and uncertainty as to who could, or would be responsible. However, the UK, and to an extent European regulatory regimes, are seen favorably in comparison with other jurisdictions, particularly in the developing world, but also the United States. Both the will and ability of regulators to effectively characterize and implement a balanced approach to risks are seen as better in these countries than in those where government was seen to be weaker.

The perceived standard of regulation is important in considering site locations for PMP production. Five of the six groups felt that pharmaceutical crops should be grown where they would be best regulated: in Europe, and in the UK in particular. Personal understandings of national and international regulatory regimes, particularly in the context of food production, and the belief that it was better to keep growing under close supervision are important in this decision. However, the desire for effective regulation exists in tension with a preference for growing PMPs close to where they would be required, and to avoid the perceived personal risks of growing in the UK. For regulatory control, as well as physical control, consumers recognize that regulatory authorities are not infallible, and several examples are drawn upon to exemplify this, from both medical and agricultural contexts, including BSE and thalidomide.

This discussion of regulatory regimes is particularly interesting in terms of the development of molecular farming. Previous studies (for example, Miller & Conko, 2004) have commented that the regulatory regimes imposed for genetically modified crops in Europe have served to stifle research and innovation in biotechnology. However, what this discussion suggests is that at the same time, the imposition of stricter regulation may have bolstered consumer confidence in the regulatory system. There are two caveats to this conclusion, however. First, the concern about containment described above contributes to a preference for molecular farming production to occur where containment can be well supervised. The preference for the UK and EU can be seen as a 'better the devil you know' conclusion about the relative strength of these regulatory environ-

ments, compared particularly to the developing world context in which the products discussed here are most likely to be applied. Second, the medical nature of much of the discussion of molecular farming may allow it to draw on a comparatively greater level of trust in the regulation of pharmaceuticals than agricultural products, distancing it from the major examples of regulatory failure in the latter field such as BSE.

There is a strong feeling, exhibited in all groups in this study, that PMPs should be comprehensively tested before introduction. This was an issue often strongly promoted by one or two members of each group and was accepted by all participants as a key facet of the discussion. The verification of both product and production method links plant-made pharmaceuticals to existing biopharmaceutical production, but also equally to first generation genetically modified crops. The examples of testing used in discussion highlight these links, including the UK GM field trials, thalidomide, rofecoxib/Vioxx,[®] and the failed Northwick Park clinical trials. Not only is the final pharmaceutical product to be established as safe in the same way as other pharmaceuticals, but the environmental risks of crop production also must be assessed in the same way as for other genetically modified varieties. Discussion of field trials of crops genetically modified for pharmaceutical production again focus on containment and the conflict between the need for field testing of crops and the environmental risks of open air growing, even for the purpose of testing. This was described by one participant as "crossing the Rubicon." Other groups consider the risk to the crops to be equally significant as first generation GM crops, where the intervention of protesters is seen to have prevented trials being completed.

Discussion and Conclusions

There is significant support for molecular farming, which if not unconditional, does not represent the same type of response as that afforded first generation genetically modified crops. This support is not related to personal benefit and is freighted with skepticism drawn from past experiences of efforts at disease prevention and of the institutions involved. Secondly, there is significant concern about the control and confinement of PMPs, both physically and through effective regulation. However, there is no expectation of zero risk. Although no method of containment is expected to be perfect, all methods are not seen as equal, and there is a strong preference for greenhouse containment. Finally, extensive testing of PMPs is required, both pharmacological and

environmental. This dual metric of testing distinguishes molecular farming from either agricultural biotechnology or existing biopharmaceutical production, and highlights that it would be insufficient to treat the technology in regulation and research as uniquely medical.

Molecular farming represents the convergence of medical and agricultural research traditions and techniques. Public discussion of the technology involves an interplay between features of these traditions. A key finding of this research is that discussion of molecular farming is framed by medical characteristics, notably the promise of treatments and cures. This was reflected in group discussion, in which participants argued that the medical applications of molecular farming made it a medical biotechnology. However in the discussions described here, the technology can be seen to be more than its applications, representing as it does the third generation of genetically modified crops. Considerations of molecular farming as an agricultural technology are important, as displayed both in discussion of containment and in efforts to delineate between food and non-food crops. In the future development of molecular farming, this medical framing may result in its appropriateness as an *agricultural* biotechnology being considered in less depth by publics and regulators. Importantly though, these agricultural characteristics may become more prominent if the strict containment measures described by the groups are not present.

Attention to public attitudes and clear communication with the public are increasingly becoming crucial in the development of new technologies, and particularly biotechnologies. A study of stakeholder assessments of molecular farming in Canada found that all groups rated public acceptance and education as the most significant challenge (Mistry, Einsiedel, Medlock, & Perraton, 2005), while Ma et al. argued that “social rejection alone is sufficient to derail the endeavour” (Ma, Barros, et al., 2005, p. 597). There is a belief among molecular farming researchers that attitudes to molecular farming will be more positive than for current agricultural biotechnologies (Daniell, Streatfield, & Wycoff, 2001; Ma, Drake, & Christou, 2003; Mascia & Flavell, 2004; Peterson & Arntzen, 2004). However, there is little existing evidence for this belief, particularly in Europe. Instead, existing research indicates that it is unlikely that PMPs will fall neatly into the medical side of a red/green division in public attitudes to biotechnology in the UK, and that envisaging such a divide is perhaps not heuristically useful in the introduction of new biotechnologies.

Although five out of six groups in this study were broadly supportive of molecular farming, both social and technical concerns do exist. It is important that these are not addressed *post hoc*, once the technology has been introduced. In discussion of regulation and in participants’ assessments of the trustworthiness of information sources, there is significant faith in regulators and researchers. In order to maintain this confidence, concerns must be engaged with ‘upstream’ at an early stage of development to ensure successful, safe, and socially acceptable technology.

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