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Why rational argument fails the genetic modification (GM) debate

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Abstract

Genetic modification (GM) of crops provides a methodology for the agricultural improvements needed to deliver global food security. However, public opposition to GM-food is great. The debate has tended to risk communication, but here we show through study of a large nationally representative sample of British adults that public acceptance of GM-food has social, cultural and affective contexts. Regression models showed that metaphysical beliefs about the sanctity of food and an emotional dislike of GM-food were primary negative determinants, while belief in the value of science and favourable evaluation of the benefits-to-risks of GM-food were secondary positive determinants. Although institutional trust, general knowledge of the GM-food debate and belief in the eco-friendliness of GM-food were all associated with acceptance, their influence was minor. While a belief in the sanctity of food had a direct inverse effect on GM acceptance, belief in the value of science was largely mediated through favourable perception of benefits-to-risks. Furthermore, segmentation analysis demonstrated that anxiety about GM-food had social and cultural antecedents, with white men being least anxious and older vegetarian women being most anxious. Rational argument alone about the risks and benefits of GM-food is unlikely to change public perceptions of GM-technology.

Keywords Genetic modification debate · Attitudinal survey · Rationality · Affect · Food

1 Introduction

Debate about consumer acceptability of GM-foods has been rekindled in the wake of contemporary concern about food security, climate change and dwindling natural resources. It is crucial that agriculture produces more food, more sustainably, in order to nourish an escalating world population (European Academies Science Advisory Council 2013). A new generation of transgenic crops offer environmental, economic and nutritional advantages, with evidence of improved yields, lower pesticide and herbicide usage, decreased tillage, reduced fossil fuel use, and commercial benefit at the farm level (Baulcombe et al. 2014; National Academies of Sciences Engineering and Medicine 2016). While GM-agriculture is a powerful tool to address modern agronomic challenges, its true value for agricultural sustainability depends on integration with good husbandry practices such as regular crop rotation (Baulcombe et al. 2014). Nevertheless, there is a scientific consensus that GM technologies can increase efficiency and sustainability of agriculture.

Genetically modified organisms, as defined by the European Union (EU) in Directive 2001/18, are organisms with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural re- combination. There has been a virtual moratorium on commercial production of GM-crops across the EU, although some 60 GM-crops are licensed for import to be used as food or in animal feed. The only crop approved for cultivation is MON810, a pest-resistant maize, with Spanish planting outstripping the rest of Europe, but still

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comprising only 1% of Spanish arable land. While the European Food Safety Authority have deemed MON810 safe on both environmental and health grounds, Directive 2015/42 allows individual EU Member States the opportunity to prohibit cultivation. As of 2017, around 20 countries have opted out; including Wales, Northern Ireland and Scotland, suggesting public anxiety about GM-agriculture has sway over scientific consideration. It has been suggested that such stringent GM regulation in Europe has been founded on the false premise of the novelty of transgenesis in contemporary genetic engineering (Ammann 2014).

Indeed, across Europe, public support for GM-agriculture has declined, and on average opponents outnumbers supporters by three to one (Gaskell et al. 2010). Contrastingly, the same survey showed greater public acceptance of GM-application in medicine. Crucially, European socio-political and media debate about the desirability of GM-agriculture has spilled to developing nations particularly to Sub-Saharan Africa, resulting in uncertainty in policymaking and protracted approval processes for GM-crops (Wesseler et al. 2017). Poignantly, it is in such countries where population growth is greatest, malnutrition is widespread and GM-crops offering enhanced nutrient content could have greatest health potential (Whitty et al. 2013).

Although some 13 public attitudinal surveys have been conducted across Europe between 1990 and 2010 (Frewer et al. 2013; Gaskell et al. 2010), these are fragmented in terms of geography, temporality and focus. Focus has variously covered personal acceptance, benefit and risk perception, knowledge of GM-science, general attitude to science and trust in the governance of GM-crops. While there are indications that GM-food is perceived as dangerous to health, anti-natural and environmentally damaging, these surveys collectively fail to examine the socio-economic and demographic antecedents of opinion, albeit such descriptive data are available (Frewer et al. 2013). Acceptance of GM-agriculture has often been construed as a binary response, which ignores nuance and variation within the population. Furthermore, consumer negativity to GM-food has been primarily appraised through the lens of reason-based decision-making (cognitive evaluation of the risks and benefits of GM-food), while the role of emotion (affect) has been less studied (Connor and Siegrist 2011; Gupta et al. 2012).

As Joffe has pointed out, although studies exploring perceptions of risk have taken a cognitive approach, public and media debate about GM-food is often couched in emotive language (Joffe 2003). Indeed social representation theory posits that individual perception of risk is underpinned by sociocultural and media influences (Joffe 2003). A limited body of research has attended to how broader sociocultural attitudes to food processing and worldviews, such as environmentalism and universalism, may relate to acceptance of GM-food (Dreezens et al. 2005; Loner 2008; Mohr and Golley 2016).

In this research we hypothesise that consumer decision-making about GM-food is not solely a function of conscious awareness about the benefits and risks of GM-food as they relate to health, food security, the environment and general safety. We propose that acceptance of GM-food is influenced by broader sociocultural attitudes embracing attitudes towards science, the environment, food, food technology, food security, health risk-taking behaviour and knowledge of the GM-food debate. We further hypothesise that acceptance of GM-food is determined by emotionally based concerns about GM-food and level of trust in various bodies involved in the GM-debate. Figure 1 depicts our model with personal acceptance of GM-food as our dependent variable.

Our hypotheses acknowledge the theories underpinning dual process psychological models from the risk behaviour literature (Haidt 2001; Joffe 2003; Slovic et al. 2007). Dual process models suggest that people make decisions based on two separate but inter-linked systems, involving analytical or cognitive thinking on the one hand, alongside and orientated by experiential thinking, which is founded on experience and emotion. Slovic et al. (2007) proposed that people employ an affect heuristic, which guides decision-making especially in the realm of judgments of risk and benefit; affect in this specific context signifying a quality of "goodness" or "badness" experienced as a feeling state (with or without consciousness).

We further draw on social representation theory, which posits that risk decision-making goes beyond individual thinking (either cognitively or affectively), suggesting that external messages about risk as disseminated through social networks and the mass media shape individual judgment. Social representation theory contends that anxiety and trust play pivotal roles in how consumers apprehend risk of GM-food.

2 Methods

2.1 Survey design and questionnaire development

We conducted an online questionnaire-based survey to establish public attitudes to and acceptance of genetic modification (GM) among adults aged 18–65 years representing the geographic, age and gender distribution of the population of the United Kingdom. The questionnaire set out to examine the interrelationships among acceptance of GM-food, attitudes to GM-food and a set of theoretical antecedents. These antecedents encompassed demographic measures and broad socio-cultural attitudes.

Ethical approval for the study was obtained through the School of Medicine's ethical review procedure at the University of Sheffield. Respondents were provided with online information about the study prior to their participation and their consent was affirmed before they had access to the online questionnaire.

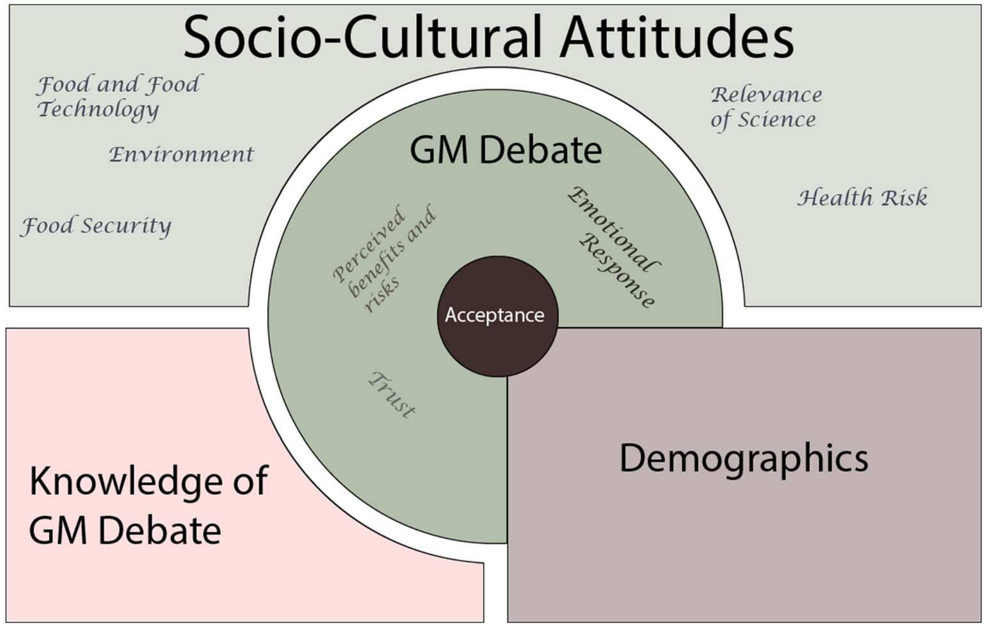

Fig. 1 Proposed model of elements shaping personal acceptance of GM-food

The questionnaire was implemented using a proprietary online survey tool (Qualtrics; Utah, USA). Qualtrics recruited participants through survey partners, which gave access to over 1 Million respondents across the UK. We used Office for National Statistics census data for setting quotas for gender, age and geographic location to ensure a nationally representative sample of at least 3000 participants. The sample size was chosen to be broadly equivalent to that of the British National Diet and Nutrition Survey (which is used to provide nutritional surveillance information at an individual level), and to be large enough to support complex statistical modelling such as regression analysis, following Green's rule-of-thumb for minimum sample size (Green 1991).

Nominal cash-equivalent rewards were given as an incentive to complete the questionnaire. In total 3340 people responded to the survey during the period 12th February to 13th March 2016. A total of 3116 qualifying responses were collected following data cleaning. The 165-item questionnaire comprised four sections (see supplementary material for the full questionnaire). The majority of questions were replicated from previous questionnaires (see Tables A1 and A2 in the supplementary material for the constituent questions and their sources). Section one of the questionnaire related to respondent demographics and contained items that measured educational attainment and dietary identity. Sections two, three and four were developed from a comprehensive literature review of qualitative and quantitative studies, incorporating 53 surveys carried out between 1999 and 2012. Section two comprised socio-cultural attitudinal questions, which evaluated attitudes towards five issues that we hypothesised would influence GM-acceptance: (i) science, (ii) the environment, (iii) food, (iv) food security and (v) health risk-taking behaviour. Answers were measured on a seven-point scale except for health risk-taking behaviour, which was evaluated on a five-point likelihood scale using the health-related section from the Domain-Specific Risk-Taking (DOSPERT) scale (Blais and Weber 2006).

Section three covered general knowledge of the GM-food debate: it comprised questions designed to test knowledge of GM-science, plant genetics, governance of GM-food in the UK and awareness of GM agri-medical applications. Respondents were asked twenty-two questions and were required to answer on a five-point scale whether they thought each statement was 'definitely true', 'probably true', 'probably false', 'definitely false' or to answer 'don't know'.

Section four comprised statements designed to determine attitudes towards GM across five areas: (i) trust (confidence in the veracity of GM-related information as provided by government, multinational companies (MNCs) and other parties), (ii) GM concerns (relating to the various applications of GM-technologies, including an extreme emotionally-based viewpoint), (iii) perception of the risk and benefits of GM, (iv) attitudes towards various GM-applications such as food production, use in animal feed and for pharmaceuticals, and (v) acceptance of GM-food including attitudes to the cultivation and sale of GM-food and willingness to consume GM-food. The main outcome of the study, personal acceptance of GM-food, was constructed from the responses to questions in part (v) of section four. Questions were presented in a random order within subsections of sections two, three and four.

2.2 Statistical analysis

We performed principal component analysis (PCA) using the direct oblimin method of rotation on responses to sections two and four of the questionnaire; factors with an Eigenvalue of greater than one were retained. In the case of the PCA of the food security items, the final factor identified lacked semantic coherence and had a low Cronbach's alpha. This factor was discarded. The analysis produced eight factors from section two and eight factors from section four. The questionnaire items within each factor, the factor loading and internal consistency using Cronbach's alpha coefficients are provided in Table A1 in the supplementary material. The score from each of the questionnaire items was summed across the appropriate factor to obtain summary factor measures, reversing scores where appropriate. Standardised scores for all measures were used for the analysis (standardised scores had a mean of 0 and standard deviation of 1).

Each item in section three, which investigated general knowledge of the GM-food debate, was scored from −2 to +2 and a total score was calculated as the sum of the scores across all items for each participant (see Table A2 in the supplementary material for the questions).

Our data reduction generated 16 factors: eight factors from section two, the socio-cultural attitudinal questions, and eight factors from section four, the GM-attitudinal questions. All factors demonstrated satisfactory internal consistency, Cronbach's alpha coefficient ranged between 0.71 and 0.96 (Table A1 in the supplementary material).

The eight socio-cultural attitudinal measures comprised 'investment in science is important for the future', 'science has benefited the world', 'personal interest in science', 'green behaviour', 'belief in the sanctity of food', 'food neophobia', 'UK food security is important' and 'willingness to take health risks'. The eight GM-attitudinal measures comprised 'trust in the integrity of government and MNCs regarding GM', 'trust in information about GM from universities, medical professionals, non-governmental organisations (NGOs) and campaign groups', 'trust in information about GM from media sources and friends', 'emotional dislike of GM', 'GM agri-food can be eco-friendly', 'benefits-to-risks rating', 'acceptance of GM-agri-medical applications' and 'personal acceptance of GM'. Benefits-to-risks rating was determined from 24 statements, 12 relating to perceived benefits of GM-technology and 12 relating to perceived risks of GM-technology. The answers to the risk statements were reverse coded and the mean score of all 24 statements was taken as the participant's benefits-to-risks rating.

The measure 'knowledge of the GM-debate' was created from the summary score of section three. The highest possible total score for knowledge of the GM-debate is +44 and the lowest −44: the distribution of scores for the sample is shown in Fig. 2.

In total we produced 17 summarising measures: eight socio-cultural measures, eight GM-attitudinal measures including personal acceptance of GM-food (main outcome of the study) and one single measure for knowledge of the GM-debate. Mean scores and standard deviations for each summarising measure are reported in Table 1.

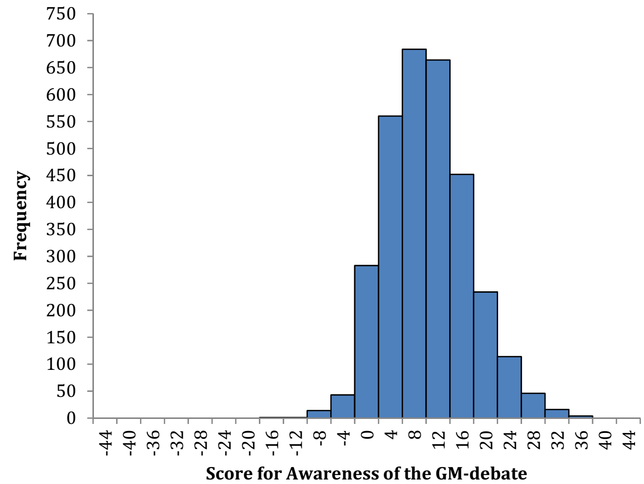

Fig. 2 Distribution of scores for knowledge of the GM-debate

We used regression analysis to produce two models to identify which measures had the most effect on personal acceptance of GM-food. The first model used both demographic variables (gender, age (linear and quadratic terms), geographical location, physical location (urban or rural), household income and diet identity) and the socio-cultural attitudinal measures (including knowledge of the GM-debate). The second model used only the GM-attitudinal measures as predictor variables. Both models had acceptance of GM-food as the outcome variable. Standardised variables were used to negate differences in measurement scales of predictor variables.

In order to determine the model of best fit, all predictor variables were entered into the model simultaneously and again using the backward stepwise selection method; the least useful predictor variable was removed with each iteration. Explanatory power was calculated by entering the predictor variables with the greatest impact individually into the final regression model. No substantive evidence was found for heteroscedasticity after inspection of residuals.

Mediation analysis was used to explore influences on acceptance of GM-food using the results of the regression analysis. The four major socio-cultural variables from the first regression model (belief in the sanctity of food, investment in science is important for the future, food neophobia and science has benefited the world) were used singly as a predictor variable, with the other three socio-cultural variables included as covariates. The mediation variables were the four major GM-attitudinal predictor variables from the second regression model (emotional dislike of GM-food, GM-food can be eco-friendly, benefits-to-risk rating of GM-food, and trust in the integrity of government and MNCs regarding GM). The analysis followed the method for mediation model number four described by Hayes (2013). The models were fitted using the PROCESS macro for SPSS version 2.15.

Table 1 Mean scores for the 17 summarising measures

Summarising Factors:	Mean (SD)
Investment in science is important for the future	5.6 (0.8)
Science has benefited the world	4.7 (1.1)
Personal interest in science	4.7 (1.1)
Green behaviour	4.3 (1.0)
UK food security is important	4.8 (1.3)
Belief in the sanctity of food	4.5 (1.0)
Food neophobia	3.4 (1.0)
Willingness to take health risks[a]	2.0 (0.8)
Trust in the integrity of Government and MNCs regarding information about GM	3.8 (1.4)
Trust in information about GM from universities, medical professionals, NGOs and campaign groups	4.7 (1.1)
Trust in information about GM from media sources and friends	3.6 (1.1)
Emotional dislike of GM-food	4.0 (1.2)
GM agri-food can be eco-friendly	4.8 (1.1)
Benefits-to-risks rating	4.3 (0.8)
Acceptance of GM-agri-medical applications	4.2 (1.4)
Personal acceptance of GM-food	4.2 (1.5)
Knowledge of the GM-debate[b]	8.8 (6.9)

All factors scored between 1 = lowest and 7 = greatest except for [a] Willingness to take health risks 1 = lowest and 5 = greatest; [b] knowledge of the GM-debate - 44 = lowest score and + 44 = highest score

In the final part of our analysis we segmented the data using k-means cluster analysis using the socio-cultural attitudinal measures (including knowledge of the GM-debate). This analysis assigned respondents to clusters that maximised similarities within and differences between each group. Groupings ranging from 2 and 9 clusters were tested and Roy's largest root values were used to select the 7-cluster solution. This procedure is similar to the standard method of 'best cut' where clusters are identified by levels of differentiation between groups (Everitt et al. 2011). The demographic characteristics of the seven clusters and distribution frequencies were compared using the chi-square test. The scores of the seven clusters for the socio-cultural attitudinal measures and the GM-related attitudinal measures were analysed using one-way Analysis of Variance (ANOVA).

The statistical analysis was conducted using SPSS (IBM SPSS 22.0) and a p value of less than 0.05 was the criterion for statistical significance.

3 Results and discussion

3.1 Demographic characteristics and description of acceptance of GM-food

The demographic characteristics of the sample are summarised in Table 2. The sample distribution for ethnicity was close to UK census data with marginal overrepresentation in Northern Ireland of Mixed and Black ethnic groups. Equally, education attainment was similar to UK figures reported by Eurostat, the exception being a 5% excess of participants reporting a basic educational attainment (up to General Certificate of Secondary Education). We took personal acceptance of GM-food as our main outcome; the average score of this measure for the sample was just above neutral. Over half (54.7%) of our survey respondents were open towards GM-food based upon aggregate scores to personal acceptance questions. Although other surveys have reported lower levels of support, acceptance questions across surveys are not comparable (Gaskell et al. 2010); indeed some surveys used a single item to measure acceptance, which may invite a biased response. There were demographic differences in attitudes to GM-food (Table 3). Men were more likely to accept GM-food than women ($p < 0.001$), and young adults (18–24 years) had greater acceptance than their older counterparts. These gender and age differences are broadly congruent with European surveys (Costa-Font et al. 2008; Finucane and Holup 2005). Household income and having a scientific education (AS/A-level or higher) were positively associated with GM-food acceptance ($p = 0.019$ and $p < 0.001$ respectively) as found elsewhere (Costa-Font et al. 2008).

However, general education was not associated with acceptance in line with other research (Lucht 2015). Differences in acceptance were observed for dietary identity, non-vegetarians were more accepting than other groups ($p < 0.001$). Other demographic contrasts, such as regional/national location, urban/rural area and household size were not associated with acceptance.

Table 2 Demographic characteristics of the sample ($n = 3116$)

		n	%
Gender:			
Male		1511	48.5
Female		1605	51.5
Age range (years):			
18–24		418	13.3
25–34		675	21.7
35–44		656	21.1
45–54		702	22.5
55–65		665	21.3
M_{age}: 41.5 years, SD: 13.3 years			
Household size			
1		504	16.2
2		1027	33.0
3		639	20.5
4		595	19.1
5 or more		351	11.3
$M_{Household\ size}$: 2.9, SD:1.5			
Household income			
Up to £9499		292	9.4
£9500 - £13,999		238	7.6
£14,000 - £18,999		246	7.9
£19,000 -£24,999		423	13.6
£25,000 - £31,999		458	14.7
£32,000 - £40,999		489	15.7
£41,000 - £51,999		358	11.5
£52,000 - £64,999		239	7.7
Over £65,000		366	11.7
Prefer not to say		7	0.2
$M_{Household\ income}$: £35,400, SD: £23,300			
Highest level of education attained			
G.C.S.E.		773	24.8
AS/A Level		722	23.2
Further education (diploma etc.)		459	14.7
Degree		810	26.0
Postgraduate		352	11.3
Science-based education (AS/A level or higher)		1018	32.7
Urban or rural			
Urban		2457	78.9
Rural		659	21.1
Regional distribution:			
England:	Overall	2641	84.8
	North East	126	4.0
	North West	358	11.5
	Yorkshire & Humber	280	9.0
	East Midlands	228	7.3
	West Midlands	268	8.6
	East	235	7.5
	London	414	13.3
	South East	463	14.9
	South West	269	8.6
Scotland		252	8.1
Wales		149	4.8
Northern Ireland		74	2.4
Dietary identity			
Vegan		54	1.7
Lacto-vegetarian		127	4.1
Semi-vegetarian		159	5.1
Flexitarian		94	3.0
Non-vegetarian		2682	86.1

Table 3 Personal acceptance of GM-food by demographic factors where 1 = lowest acceptance and 7 = greatest acceptance

	Mean Score (SD)	
Gender		
Male ($n = 1511$)	4.43 (1.53)	$F(1,3114) = 100.90$, $p < 0.001$
Female ($n = 1605$)	3.89 (1.48)	
Age range (years)		
18–24 ($n = 418$)	4.48 (1.44)	$F(4,1474.82) = 6.75$, $p < 0.001$[a]
25–34 ($n = 675$)	4.19 (1.40)	
34–44 ($n = 656$)	4.06 (1.53)	
44–54 ($n = 702$)	4.05 (1.62)	
55–65 ($n = 665$)	4.12 (1.58)	
Household size		
1 ($n = 504$)	4.11 (1.66)	$F(4,1295.63) = 1.49$, $p = 0.203$[a]
2 ($n = 1027$)	4.14 (1.52)	
3 ($n = 639$)	4.09 (1.52)	
4 ($n = 595$)	4.20 (1.47)	
5 or more ($n = 351$)	4.31 (1.46)	
Household income		
Up to £9499 ($n = 292$)	3.89 (1.56)	$F(8,3100) = 2.29$, $p = 0.019$
£9500 - £13,999 ($n = 238$)	4.06 (1.56)	
£14,000 - £18,999 ($n = 246$)	4.03 (1.49)	
£19,000 -£24,999 ($n = 423$)	4.17 (1.44)	
£25,000 - £31,999 ($n = 458$)	4.18 (1.56)	
£32,000 - £40,999 ($n = 489$)	4.17 (1.58)	
£41,000 - £51,999 ($n = 358$)	4.19 (1.54)	
£52,000 - £64,999 ($n = 239$)	4.28 (1.46)	
Over £65,000 ($n = 366$)	4.33 (1.48)	
Highest level of education		
Up to G.C.S.E. or equivalent ($n = 773$)	4.05 (1.48)	$F(4,3111) = 2.38$, $p = 0.050$
AS/A Level or equivalent ($n = 722$)	4.27 (1.50)	
Further Education ($n = 459$)	4.08 (1.52)	
Undergraduate Degree ($n = 810$)	4.20 (1.57)	
Postgraduate Degree ($n = 352$)	4.16 (1.58)	
Science-based education (AS/A level or higher)		
Yes ($n = 1018$)	4.32 (1.54)	$F(1,2340) = 12.60$, $p < 0.001$
No ($n = 1324$)	4.09 (1.54)	
Urban or rural		
Urban ($n = 2457$)	4.18 (1.51)	$F(1,996.88) = 3.54$, $p = 0.060$[a]
Rural ($n = 659$)	4.05 (1.59)	
Region/Nation		
England: North East ($n = 126$)	4.11 (1.54)	$F(11,3104) = 0.758$, $p = 0.682$
England: North West ($n = 358$)	4.17 (1.49)	
England: Yorkshire and Humber ($n = 280$)	4.26 (1.45)	
England: East Midlands ($n = 228$)	4.31 (1.57)	
England: West Midlands ($n = 268$)	4.16 (1.51)	
England: East of England ($n = 235$)	4.20 (1.48)	
England: London ($n = 414$)	4.04 (1.47)	
England: South East ($n = 463$)	4.11 (1.51)	
England: South West ($n = 269$)	4.17 (1.67)	
Scotland ($n = 252$)	4.17 (1.57)	
Wales ($n = 149$)	4.00 (1.66)	
Northern Ireland ($n = 74$)	4.22 (1.53)	
Dietary identity:		
Vegan ($n = 54$)	3.80 (1.63)	$F(4,3111) = 10.06$, $p < 0.001$
Lacto-vegetarian ($n = 127$)	3.74 (1.48)	
Semi-vegetarian ($n = 159$)	3.73 (1.59)	
Flexitarian ($n = 94$)	3.66 (1.44)	
Non-vegetarian ($n = 2682$)	4.22 (1.52)	

[a] Welch F-Ratio used when there was evidence of heteroscedasticity. Heteroscedasticity can arise because of associations between independent variables, where an unaccounted for variable is associated with the outcome variable

Table 4 Explanatory power of demographic and socio-cultural measures on personal acceptance of GM-food from regression modelling

Personal acceptance of GM-food β (SE)		R^2
Belief in the sanctity of food	−0.39*** (0.02)	18.8
Investment in science is important for the future	0.18*** (0.02)	10.6
Food neophobia	−0.16*** (0.02)	3.4
Science has benefited the world	0.11*** (0.02)	0.8
Knowledge of the GM-debate	0.10*** (0.02)	1.0
Gender	−0.07*** (0.02)	0.3
Average age	−0.06** (0.02)	0.2
Age.Squared	0.04* (0.02)	0.1
Green behaviour	0.03 (0.02)	0.1
Annual Household Income	0.03 (0.02)	0.1

β = Standardised regression coefficients and SE = standard errors; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

3.2 What influences acceptance of GM-food?

We used regression analysis to produce two models to identify which of the summary factor measures had greatest effect on acceptance of GM-food: the first model used both demographic variables and socio-cultural attitudinal measures as well as knowledge of the GM-debate as predictor variables, while the second model used only the GM-attitudinal measures (Tables 4 and 5). Our first regression model revealed that of the socio-cultural factor measures, belief in the sanctity of food had the strongest impact on acceptance of GM-food (Table 4). This sanctity of food measure did not include GM-food, instead encompassing a set of generic beliefs that extolled purity, naturalness and integrity in food, as realised by avoidance of processed food and that containing additives, rejection of artificially flavoured food and pesticide use, and support for organic food. A recent Australian survey showed that GM acceptance was inversely related to concern about food integrity covering five areas: microbiological contamination, pesticides, additives, food preservatives, and food colourings (Mohr and Golley 2016). Other surveys report that consumers of organic food have greater concern about GM-food than non-consumers (Funk and Kennedy 2016; Saher et al. 2006), while a preference for natural foods was descriptively associated with acceptance of GM-food, but not in a multivariate model (Connor and Siegrist 2010). While perceptions of naturalness in food are known to be fluid and indeed nebulous (Shewfelt 2017), a recent cross-cultural survey reported that naturalness in food was universally interpreted as no processing or an absence of additives (Rozin et al. 2012). Moreover, it has been suggested that people who prefer natural foods have a heightened perception of unobservable risk from food hazards (Siegrist et al. 2006). The set of metaphysical beliefs underpinning the sanctity of food measure tallies with the values of the alternative food movement (Johnston 2016), which eschews industrialised agriculture, promotes local and organically produced food and conflates naturalness with superiority. This conflation exemplifies the naturalistic fallacy (Moore 1903).

Glorification of pure and natural food is long-standing; legislation to limit food adulteration in Victorian Britain led to food marketing on the basis of purity (Burnett 1989) and was current throughout the latter half of the twentieth Century, particularly in advertising claims for food being “additive-free” (Barker et al. 2014). Slovic et al. suggest that food labelling using descriptors like “natural” are affective tags, which manipulate consumers’ affective reaction (Slovic et al. 2007).

A belief in the sanctity of food also echoes the values of the British wholefood movement of the 1960s and 1970s, which rejected mass-produced foods on grounds of animal welfare, pesticide use and health (Humble 2005). It is likely that a belief in the sanctity of food and concern about the safety of food has been fuelled by multiple European-wide “food scares” which gained widespread media interest. Such anxiety has previously been suggested as a possible issue in acceptance of GM-food at a European level (Frewer et al. 2013).

Food neophobia, which is a measure of mistrust of new and different foods showed a negative relationship with acceptance of GM-food (Table 4); this inverse association is congruent with other research (Traill et al. 2004). Although food neophobia independently predicted acceptance of GM-food alongside belief in the sanctity of food, both measures are underpinned by a public discourse about food that demonises the synthetic and the new and reveres the natural and the traditional. The prominence of this discourse in our analysis resonates with an Italian survey, which identified that a construct of food technophobia, as measured on a psychometric scale, was an important predictor of consumer confidence in various types of food (Coppola and Verneau 2014).

Contrastingly, attitudes to science impacted positively on acceptance of GM-food: investment in science is important for the future; science has benefited the world and knowledge of the GM-debate (Table 4). Scientific literacy and having family members employed in science has previously been shown to be positively associated with support for GM-foods (Costa-Font and Gil 2008; Gaskell et al. 2010). It seems that engagement with science fosters openness to GM-technology in food production.

Separately, we modelled the influence of the GM-attitudinal summary factor measures on acceptance of GM-food (Table 5). Emotional dislike of GM-food was overwhelmingly and inversely related to acceptance, explaining 54.2% of the variance on its own. This measure was based on responses to questions that attributed GM-foods with extreme negative qualities and detrimental and far-reaching import, as epitomised by populist construction of GM-foods as Frankenfoods. These questions used emotional language to describe an individual's beliefs e.g. GM-foods are alien, GM-foods could harm nature, GM-foods could harm future generations, GM-foods are unnatural. Such malevolent terminology is emotive and fits with the assertion (Slovic et al. 2007) that descriptors used in food labelling like "natural" are affective tags, which manipulate readers' affective reaction. The predominance of emotional dislike for GM-foods in our model is congruent with risk perception research showing that choice and decision-making has an affective component (Connor and Siegrist 2011; Finucane et al. 2000a).

Contrastingly benefits-to-risk rating, which may be considered as a quasi-rational measure (Scott et al. 2016) positively impacted on acceptance, while trust in governments and MNCs also had an influence, albeit minor on acceptance. The importance of benefits-to-risks perceptions concurs with other research (Frewer et al. 2013; Lucht 2015), but the role of trust seems to have been overstated (Connor and Siegrist 2010; Lucht 2015). Importantly an emotional response to GM was dominant in predicting acceptance of GM-food.

3.3 Interplay of socio-cultural factor measures with GM-attitudinal factor measures

Though GM decision-making is often portrayed as a rational process, our models indicate higher levels of affective influence (emotional dislike of GM-food and food neophobia). Furthermore, decisions about GM-food can be viewed as moral judgements, which have been suggested to follow a social intuitionist model that integrates reasoning, emotion intuition and social influence. Accordingly, we sought to explore how socio-cultural attitudinal factor measures interplayed with GM-attitudinal factor measures to influence acceptance of GM-food using mediation analysis. We modelled how the two strongest socio-cultural factor measures (Table 4) were mediated by the four dominant GM-attitudinal measures (Table 5). Mediation models for the impact of the other predominant sociocultural measures (food neophobia and science has benefited the world) are given in supplementary material.

Figure 3 partitions the association between the sociocultural measure of belief in the sanctity of food and personal acceptance of GM-food. It shows that 39.0% of the overall association cannot be explained by the four dominant GM-attitudinal measures. This result suggests that people's personal acceptance of GM-food is strongly underpinned by a metaphysical belief in the sanctity of food. The most potent mediators in the model are emotional dislike of GM-food and benefits-to-risks rating, accounting for 27.7 and 21.3% respectively of the mediation effect. This interplay between a metaphysical belief in the sanctity of food and the rationally-based benefits-to-risks rating of GM-food echoes experimental studies showing that cognitive assessment of risks and benefits of a hazard is altered when people employ an affect heuristic in decision-making (Finucane et al. 2000a). Unexpectedly, belief in the eco-friendliness of GM agri-food and trust in the regulation and production of GM-food have an independent influence on decision-making. Food neophobia was also mediated by benefits-to-risk ratings and emotional dislike of GM-food to determine acceptance of GM-food (see fig. 1A in the supplementary material). However, food neophobia had less direct influence on acceptance compared with belief in the sanctity of food.

Figure 4 partitions the association between beliefs about the value of investment in science and personal acceptance of GM-food. The four dominant GM-attitudinal measures accounted for 77.6% of the overall association. It seems that a belief in investment in science predominantly acts through evaluation of the benefits-to-risks of GM-food to determine acceptance. This mediation effect suggests that favourable benefits-to-risks judgements are strengthened by a positive belief in the value of science; there is a positive reinforcement across different cognitive domains. A similar pattern of mediation was apparent for science has benefited the world (see fig. A2 in the supplementary material).

Table 5 Explanatory power of GM-attitudinal measures and acceptance of GM-food from regression modelling

Personal acceptance of GM-food β (SE)		R^2
Emotional dislike of GM-food	−0.38*** (0.02)	54.2
Benefits-to-risks rating	0.35*** (0.02)	9.9
Trust in the integrity of government and MNCs regarding GM	0.15*** (0.02)	2.5
GM agri-food can be eco-friendly	0.11*** (0.01)	0.6
Trust in information about GM from media sources and friends	0.05*** (0.01)	0.1
Trust in information about GM from universities, medical professionals, NGOs and campaign groups	−0.02 (0.01)	0.0

β = Standardised regression coefficients and SE = standard errors; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

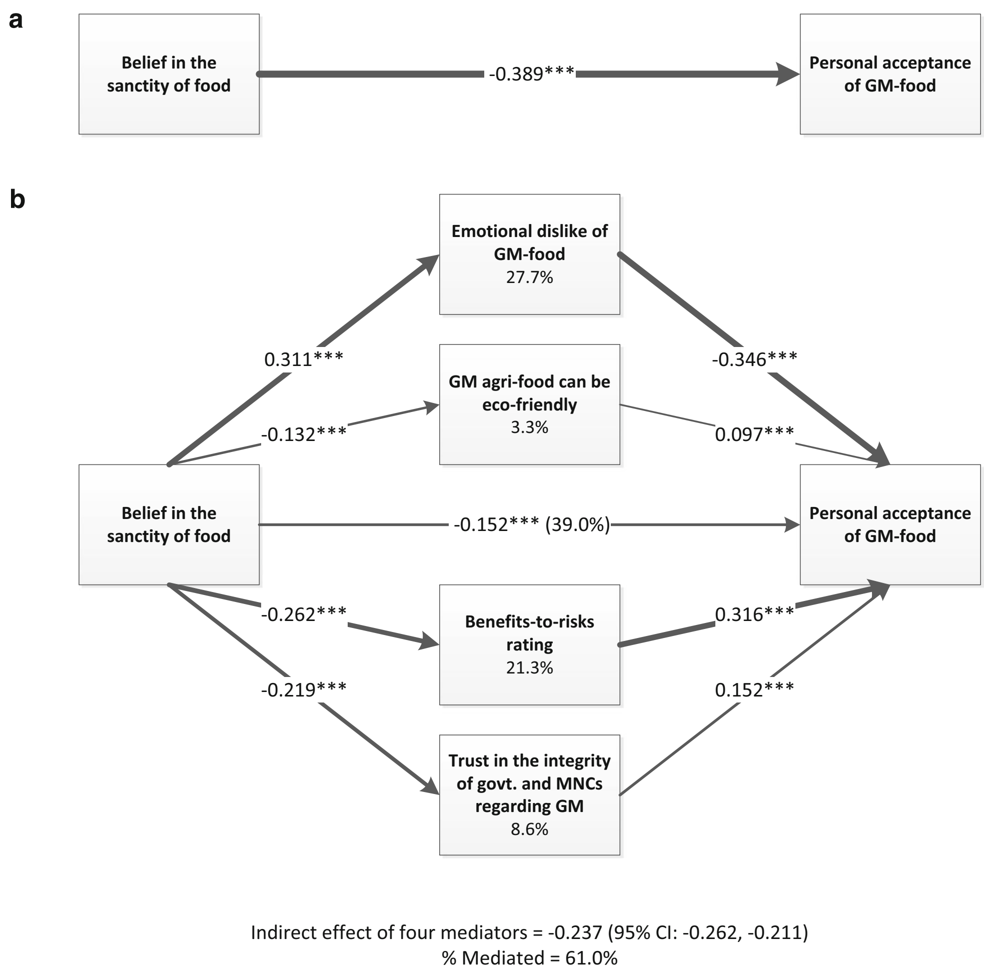

Fig. 3 Results of the mediation analysis for the effect of belief in the sanctity of food on personal acceptance of GM-food. **a** Shows the total effect. **b** Shows the model with emotional dislike of GM-food, GM agri-food can be eco-friendly, benefits-to-risks rating and trust in the integrity of government and MNCs regarding GM as mediator variables. Both **a** and **b** pathways are adjusted for investment in science is important for the future, food neophobia and science has benefited the world. All paths are significant, ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

The central influences of a negative affective response to GM-food and socio-cultural beliefs about industrialised food production in these models is in keeping with the cognitive psychological model of dual process, which posits that rational and affective thought work together to influence decision-making (Finucane et al. 2000a; Haidt 2001; Slovic et al. 2007). The strong mediating role of affective responses and social-cultural beliefs in determining acceptance of GM-food also concurs with anthropological research as to the influence of community-based metaphysical beliefs in determining food choice (Goode et al. 2003). Furthermore it resonates with findings from a recent Australian survey (Mohr and Golley 2016) which reported that concern about food integrity strongly predicted negativity to GM-content, suggesting that a belief in the sanctity of food as an influence on acceptance of GM is not UK-centric. Future studies would be well advised to deliberately include questions that assess perceptions of GM-food from a purely emotional stance such as "There is something about GM-food that I just don't like," or, "Genetically modifying the plants and animals we eat just seems wrong." or "Genetically modifying plants and animals is like playing God." Such inclusion would enable researchers to quantify more precisely an emotional element within rejection of GM-food. Campaigns aimed solely at changing people's knowledge of GM-process will have little impact on acceptance of GM-food without consideration of the metaphysical and affective aspects of food choice.

3.4 Exploring differences in acceptance between groups of consumers

Given the importance of socio-cultural beliefs (sanctity of food and value of science), it is thus likely that people sharing affective maps and characteristics have similar views on GM-food. The second step of our analysis was to examine how interpersonal anxieties and socio-cultural measures mapped across our sample in relation to acceptance of GM-food. We carried out k-means cluster analysis

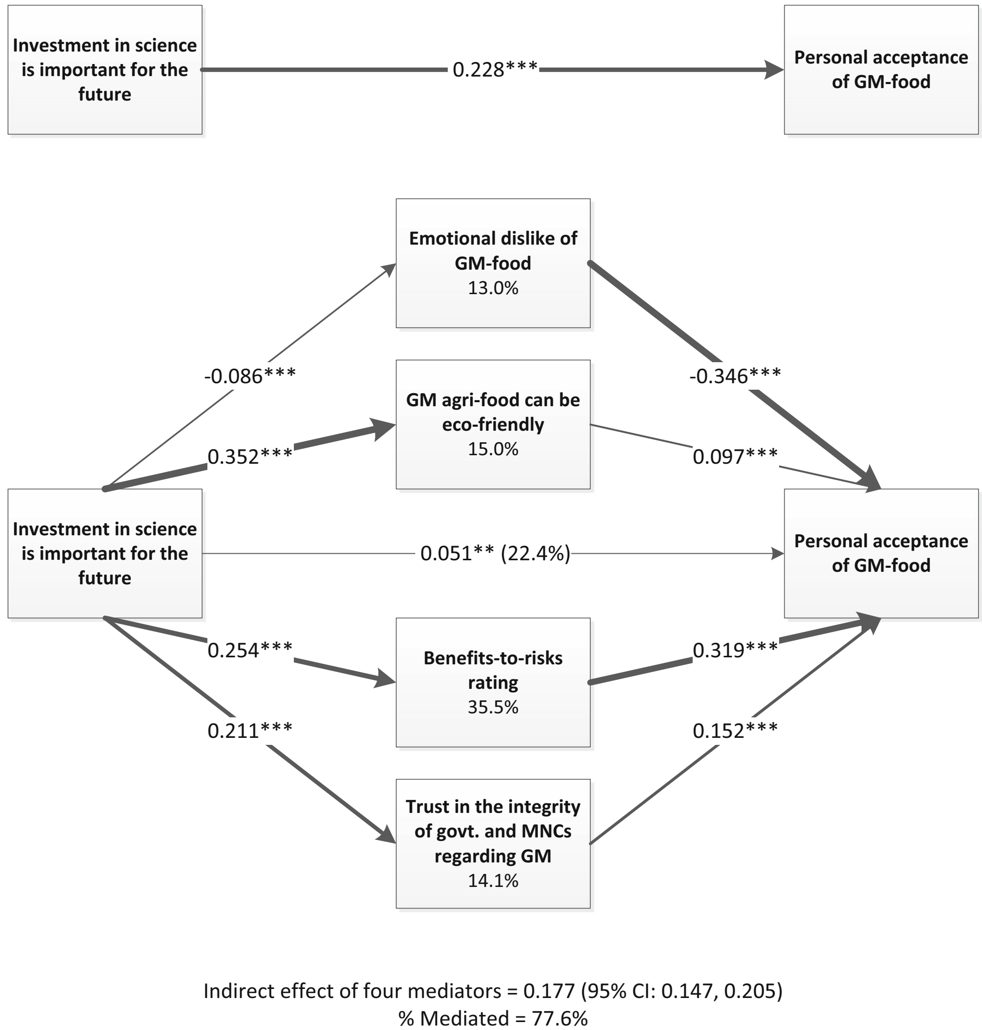

Fig. 4 Results of the mediation analysis for the effect of investment in science is important for the future on personal acceptance of GM-food. **a** Shows the total effect. **b** Shows the model with emotional dislike of GM-food, GM agri-food can be eco-friendly, benefits-to-risks rating of GM-food and trust in the integrity of government and MNCs regarding GM as mediator variables. Both A and B pathways are adjusted for belief in the sanctity of food, food neophobia and science has benefited the world. All paths are significant, $***p < 0.001$, $**p < 0.01$, $*p < 0.05$

using only the socio-cultural measures as segmentation variables. This analysis identified a best cut of seven distinguishable clusters: Science-philes ($n = 499$, 16.0%), Scientific Greens ($n = 466$, 15.0%), Unconcerned ($n = 520$, 16.7%), Disaffected ($n = 330$, 10.6%), Risk-takers ($n = 358$, 11.5%), Neophobes ($n = 566$, 18.2%) and Cautious Greens ($n = 377$, 12.1%). The demographic characteristics of the seven clusters and distribution frequencies are presented in Table 6. Despite not using the GM-attitudinal measures as clustering variables, we observed statistically significant differences in personal acceptance of GM-food among clusters (see Tables 7 and 8 for the mean cluster score for each of the measures).

Figure 5 plots each cluster's mean score for personal acceptance of GM-food in relation to the GM-attitudinal measure of benefits-to-risks rating; benefits-to-risks rating was chosen because this measure reflects the traditional cognitive approach to changing risk perception. The Science-philes cluster showed the most positive attitude towards GM-food; this cluster had the best understanding of the GM-debate and an affirmative attitude to science in general. The cluster was demographically weighted towards white men (62.7% of the cluster). The "white male" effect is a recognised phenomenon in risk perception studies: white males perceive a variety of hazard items, including food-related items such as GM-foods, as lower-risk compared to women and non-whites (Finucane et al. 2000b). In keeping, our white male-dominated cluster of Science-philes recorded a high benefits-to-risks rating for GM-food. It has been shown empirically that white males' socio-cultural attitudes or worldviews, which tend to be hierarchical, individualistic, anti-fatalistic and pro-technology shape their judgements of risk (Finucane et al. 2000b). Notably, our Science-phile cluster had negative scores on beliefs about the sanctity of food, which may reflect its gender composition. Furthermore, only 1.4% of this cluster was vegetarian, consistent with the food values of hegemonic masculinity (Cook et al. 2014).

Table 6 Demographic characteristics of 3116 respondents by cluster membership: gender, education and diet identity (number and %); age (mean and SEM)

	Science-philes $n = 499$		Scientific Greens $n = 466$		Unconcerned $n = 520$		Disaffected $n = 330$		Risk-takers $n = 358$		Neophobes $n = 566$		Cautious Greens $n = 377$	
Gender:														
Male (%)	340	(68.1%)	257	(55.2%)	200	(38.5%)	169	(51.2%)	223	(62.3%)	192	(33.9%)	130	(34.5%)
Female (%)	159	(31.9%)	209	(44.8%)	320	(61.5%)	161	(48.8%)	135	(37.7%)	374	(66.1%)	247	(65.5%)
Average age (yrs) (SEM)	39.8	(0.6)	42.5	(0.6)	42.3	(0.6)	38.0	(0.7)	37.0	(0.6)	44.3	(0.5)	44.4	(0.7)
Highest level of education:														
G.C.S.E. or equiv.	108	(21.6%)	71	(15.2%)	112	(21.5%)	114	(34.5%)	70	(19.6%)	209	(36.9%)	89	(23.6%)
AS/A Level or equiv.	124	(24.8%)	97	(20.8%)	121	(23.3%)	96	(29.1%)	82	(22.9%)	125	(22.1%)	77	(20.4%)
Further Education	61	(12.2%)	66	(14.2%)	75	(14.4%)	47	(14.2%)	58	(16.2%)	89	(15.7%)	63	(16.7%)
Undergraduate degree	144	(28.9%)	158	(33.9%)	143	(27.5%)	59	(17.9%)	97	(27.1%)	104	(18.4%)	105	(27.9%)
Postgraduate degree	62	(12.4%)	74	(15.9%)	69	(13.3%)	14	(4.2%)	51	(14.2%)	39	(6.9%)	43	(11.4%)
Science based education (AS/A level and above):	194	(38.9%)	212	(45.5%)	172	(33.1%)	69	(20.9%)	161	(45.0%)	101	(17.8%)	109	(28.9%)
Dietary Identity														
Vegetarian	7	(1.4%)	34	(7.3%)	35	(6.7%)	7	(2.1%)	31	(8.7%)	27	(4.8%)	40	(10.6%)
Non-vegetarian	492	(98.6%)	432	(92.7)%	485	(93.3%)	323	(97.9%)	327	(91.3%)	539	(95.2%)	337	(89.4%)

At the other extreme, Cautious Greens were least accepting of GM-food and had lowest scores on benefits-to-risks rating. This cluster comprised 65.5% women and contained the highest proportion of black and ethnic minority respondents. Cautious Greens tended to be older and a high proportion identified as vegetarians (10.6%). This cluster pursued green behaviour, held strong beliefs about the sanctity of food, scored highly on emotional dislike of GM-food, was food neophobic and distrusted government and MNCs. A separate Irish survey also identified an anti-GM-food cluster that was concerned about environmental issues and particularly valued health and naturalness in food choice (O'Connor et al. 2005).

Scientific Greens also pursued green behaviour, but while scoring relatively highly on benefits-to-risks rating were only marginally accepting of GM-food. Having a pro-science stance, feeling that UK food security was important and having strong beliefs in the sanctity of food characterised this cluster. This group appear to hold dissonant views combining a strong belief in science with a belief in the sanctity of food.

Neophobes' rejection of GM-food is a complex mix of belief responses towards both science and food. This cluster was food neophobic and scored highly on emotional dislike of GM-food. Neophobes were characterised by low educational

Table 7 Mean scores (SD) for socio-cultural measures and GM-knowledge by cluster membership

Socio-cultural measures and understanding of GM-science	Science- philes $n = 499$	Scientific Greens $n = 466$	Unconcerned $n = 520$	Disaffected $n = 330$	Risk-takers $n = 358$	Neophobes $n = 566$	Cautious Greens $n = 377$
Scale: 1 – 'Strongly disagree' to 7 –'Strongly agree'							
Investment in science is important for the future	6.2 (0.5)	6.2 (0.5)	5.9 (0.5)	4.9 (0.8)	5.5 (0.6)	4.8 (0.7)	5.3 (0.8)
Science has benefited the world	5.4 (0.9)	5.4 (0.9)	5.3 (0.8)	4.4 (0.9)	3.7 (1.0)	4.2 (0.8)	3.7 (0.9)
Personal interest in science	5.3 (0.9)	5.8 (0.7)	5.0 (0.8)	3.6 (0.9)	4.8 (0.8)	3.7 (0.9)	4.6 (0.9)
Green behaviour	3.6 (0.8)	5.2 (0.7)	4.4 (0.8)	3.2 (0.8)	4.3 (0.7)	4.0 (0.7)	5.1 (0.7)
UK food security is important	4.7 (1.3)	5.7 (1.0)	3.8 (1.2)	3.8 (1.1)	5.2 (1.0)	4.9 (0.9)	5.6 (1.0)
Belief in the sanctity of food	3.5 (0.8)	5.2 (0.8)	5.0 (0.7)	3.7 (0.7)	4.4 (0.7)	4.4 (0.7)	5.5 (0.7)
Food neophobia	2.6 (0.9)	2.7 (0.8)	3.6 (0.8)	3.4 (0.9)	3.7 (0.8)	4.0 (0.8)	4.1 (0.9)
Scale: 1 – 'Extremely unlikely' to 5 – 'Extremely likely'							
Willing to take health risks	2.3 (0.7)	1.9 (0.6)	1.6 (0.5)	2.5 (0.7)	3.2 (0.7)	1.6 (0.4)	1.6 (0.5)
Possible score - 44 to +44							
Knowledge of the GM-debate	14.2 (6.8)	13.3 (6.8)	7.6 (5.5)	5.0 (5.0)	6.9 (6.1)	4.7 (5.0)	9.1 (6.0)

Table 8 Mean scores (SD) for GM-attitudinal measures by cluster membership

GM-attitudinal measures	Science-philes *n* = 499	Scientific Greens *n* = 466	Unconcerned *n* = 520	Disaffected *n* = 330	Risk-takers *n* = 358	Neophobes *n* = 566	Cautious Greens *n* = 377
Scale: 1 – 'Strongly disagree' to 7 – 'Strongly agree'							
Trust in the integrity of government and MNCs regarding GM	4.3 (1.3)	3.9 (1.5)	4.0 (1.3)	3.8 (1.2)	3.7 (1.3)	3.7 (1.2)	3.2 (1.5)
Trust in the information about GM from universities, medical professionals and NGOs and campaign groups	5.1 (1.0	5.2 (1.1)	4.9 (1.0)	4.5 (1.0)	4.6 (1.0)	4.4 (1.0)	4.4 (1.3)
Trust in the information about GM from media sources and friends	3.4 (1.2)	3.7 (1.3)	3.7 (1.1)	3.5 (1.0)	3.8 (1.1)	3.6 (1.0)	3.5 (1.2)
Emotional dislike of GM-food	3.1 (1.1)	3.7 (1.3)	4.0 (1.1)	4.0 (1.0)	4.3 (1.0)	4.3 (0.9)	4.9 (1.2)
GM agri-food can be eco-friendly	5.4 (1.0)	5.2 (1.1)	4.7 (1.0)	4.4 (0.9)	4.8 (0.9)	4.4 (0.8)	4.5 (1.1)
Benefits-to-risks rating	5.0 (0.8)	4.7 (0.9)	4.3 (0.8)	4.2 (0.5)	4.1 (0.6)	4.0 (0.6)	3.8 (0.8)
Acceptance of GM-agri-medical applications	5.3 (1.2)	4.6 (1.4)	4.1 (1.3)	4.0 (1.2)	4.1 (1.0)	3.7 (1.1)	3.2 (1.3)
Personal acceptance of GM-food	5.4 (1.2)	4.4 (1.6)	4.1 (1.5)	4.2 (1.3)	4.1 (1.3)	3.7 (1.2)	2.9 (1.4)

attainment and were generally disenfranchised from science education and the benefits of science. The demographic make-up of this group was diametrically opposite to the Science-philes, collectively comprising over 69% women and non-white men. This cluster's disengagement with science seems to inhibit acceptance of GM-food.

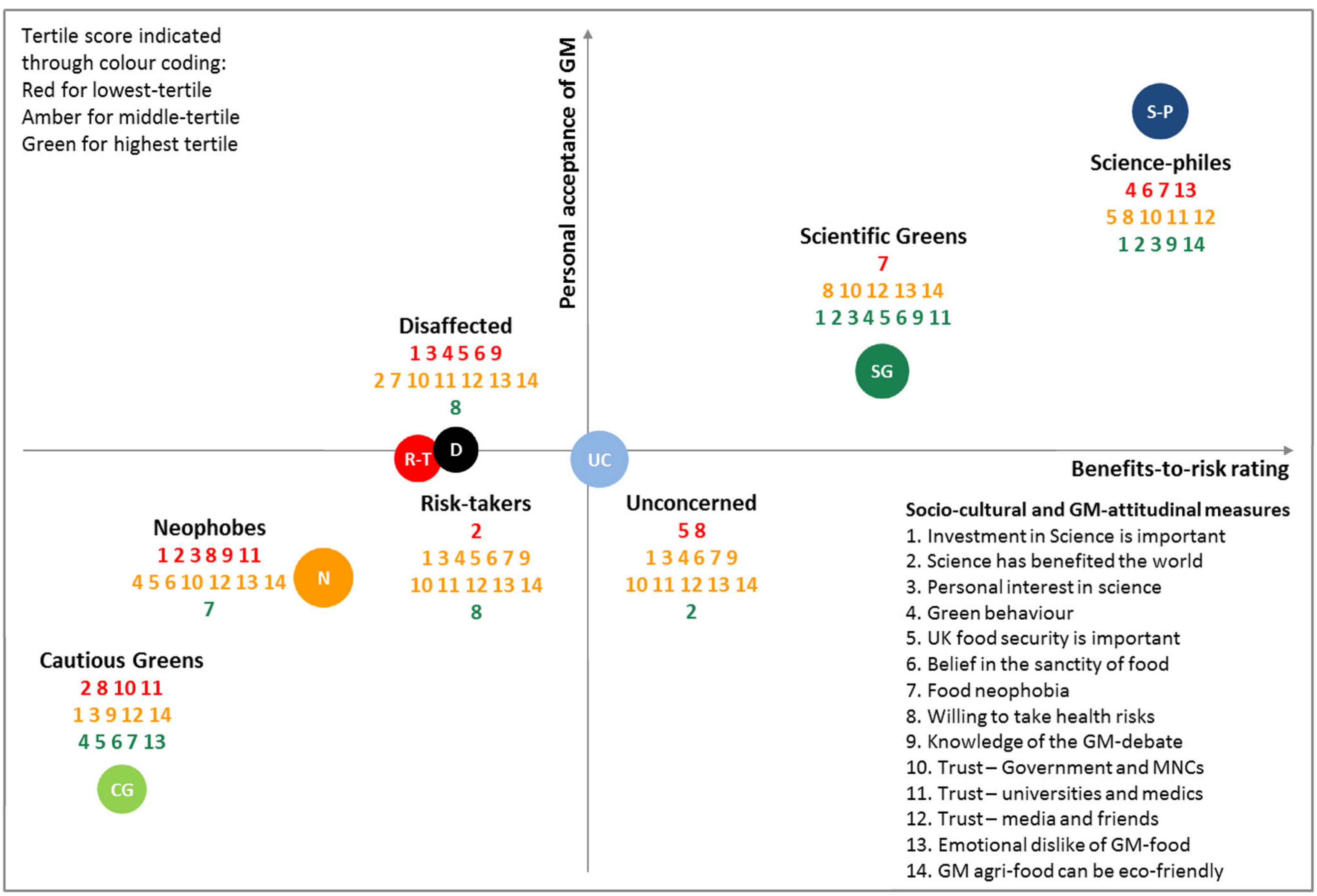

Fig. 5 Personal acceptance of GM-food versus benefits-to-risks rating by cluster. Tertile score for each socio-cultural and GM-attitudinal measure is indicated through colour coding (red for lowest-tertile, amber for middle-tertile, green for highest tertile) alongside each cluster point. Point size is relative to magnitude of cluster membership

The remaining three clusters, the Unconcerned, the Disaffected and Risk-takers, all congregate relatively closely around neutral in both acceptance of GM-food and benefits-to-risks ratings. The neutrality of Risk-takers differs from that found in a North American segmentation study, which reported that risk aversion was an important negative factor in acceptance of GM-food (Baker and Burnham 2001). Notably these three clusters tended to be neutral on most socio-cultural- and GM-measures, aside from the Disaffected who did not engage with green behaviour and were unconcerned about both the sanctity of food and food security. In addition the Disaffected cluster had a low score on knowledge of the GM-debate and were generally dismissive of the importance of science.

4 Conclusion

In conclusion, it is evident that UK consumers' decision-making about GM-food is founded on a mixture of rational and affective responses, some of which seem to have socio-cultural and ideological roots. The most important influence on acceptance of GM-food at all levels was belief in the sanctity of food, which appears to be predicated on a public discourse extolling the pure and the natural in food. A belief about the value of investment in science was also an important influence in decision-making and evaluation of risk. We observed interplay between affective beliefs and rational evaluations.

Although UK consumers as a whole appear fairly ambivalent about GM-food, there were substantial differences in acceptance between different consumer groups when we segmented the data. Science-philes and Cautious Greens represented extremes in acceptance; these clusters were weighted towards white non-vegetarian men and older vegetarian women, respectively. Affective and rational thought about food, science, and the environment and the benefits and risks of GM-food has different currency across clusters influencing how GM-food is perceived. This variation has sociocultural underpinnings. Clearly public information campaigns that rely on factual reassurances about the negligible risk posed by GM-food or explanations of the science underpinning GM-crop development will provide little or no reassurance to people who lack confidence in industrialised food production, who have strong negative affective reactions to GM-food and who are disenfranchised from the benefits of science. It is also evident that public rejection of GM-food is emotionally driven. Rational argument that fails to connect with people's emotional response to GM-food and does not address wider culturally-based food beliefs including fear of agri-food technology will have little impact on the concerns of most of the segments identified in this study.

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Authors' Contributions The second and sixth authors designed the study; all authors contributed to development of the questionnaire. The first author oversaw the data collection between 12 February and 13 March 2016 using the Qualtrics platform. The first and second authors carried out the statistical analysis of the data. The first, second and sixth authors interpreted the results and wrote the first draft of the manuscript; all authors contributed to the final draft.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Ammann, K. (2014). Genomic misconception: A fresh look at the biosafety of transgenic and conventional crops. A plea for a process agnostic regulation. *New Biotechnology, 31*(1), 1–17.

Baker, G. A., & Burnham, T. A. (2001). Consumer response to genetically modified foods: Market segment analysis and implications of producers and policy makers. *Journal of Agricultural and Resource Economics, 26*(2), 387–403.

Barker, M. E., McNeir, K., Sameer, S., & Russell, J. (2014). Food, nutrition and slimming messages in British women's magazines, 1950-1998. *Journal of Human Nutrition and Dietetics, 27*(SUPPL2), 124–134.

Baulcombe, S. D., Dunwell, J., Jones, J., Pickett, J., & Puigdomenech, P. (2014). GM Science Update: A report to the Council for Science and Technology. http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/292174/cst-14-634a-gm-science-update.pdf.

Blais, A., & Weber, E. U. (2006). A domain-specific risk-taking (DOSPERT) scale for adult populations. *Judgement and Decision Making, 1*(1), 33–47.

Burnett, J. (1989). *Plenty and Want: A Social History of Food in England from 1815 until the Present Day (3rd editio.)*. London: Routledge.

Connor, M., & Siegrist, M. (2010). Factors influencing people's acceptance of gene technology: The role of knowledge, health expectations, naturalness, and social trust. *Science Communication, 32*(4), 514–538.

Connor, M., & Siegrist, M. (2011). The power of association: Its impact on willingness to buy GM food. *Human and Ecological Risk Assessment: An International Journal, 17*(5), 1142–1155.

Cook, T. M., Russell, J. M., & Barker, M. E. (2014). Dietary advice for muscularity, leanness and weight control in Men's health magazine: A content analysis. *BMC Public Health, 14*, 1062.

Coppola, A., & Verneau, F. (2014). An empirical analysis on technophobia. *Agricultural and Food Economics, 2*(2), 1–16.

Costa-Font, M., & Gil, J. M. (2008). Consumer acceptance of genetically modified food (GM) in Spain: A structural equation approach. *Risk Management, 10*(3), 194–204.

Costa-Font, M., Gil, J. M., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy, 33*(2), 99–111.

Dreezens, E., Martijn, C., Tenbült, P., Kok, G., & de Vries, N. K. (2005). Food and values: An examination of values underlying attitudes toward genetically modified- and organically grown food products. *Appetite, 44*(1), 115–122.

European Academies Science Advisory Council. (2013). Planting the future: Opportunities and challenges for using crop genetic improvement technologies for sustainable agriculture. EASAC Policy Report 21.

Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster Analysis* (5th Editio.). Chichester: John Wiley & Sons Ltd.

Finucane, M. L., & Holup, J. L. (2005). Psychosocial and cultural factors affecting the perceived risk of genetically modified food: An overview of the literature. *Social Science and Medicine, 60*(7), 1603–1612.

Finucane, M. L., Alhakami, A., Slovic, P., & Johnson, S. M. (2000a). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making, 13*(1), 1.

Finucane, M. L., Slovic, P., Mertz, C. K., Flynn, J., & Satterfield, T. A. (2000b). Gender, race and perceived risk: The "white male" effect. *Health, Risk and Society, 2*(2), 159–172.

Frewer, L. J., van der Lans, I. a., Fischer, A. R. H., Reinders, M. J., Menozzi, D., Zhang, X., et al. (2013). Public perceptions of Agri-food applications of genetic modification – A systematic review and meta-analysis. *Trends in Food Science & Technology, 30*(2), 142–152.

Funk, C., & Kennedy, B. (2016). *The new food fights: U.S. public divides over food science*. Washington: Pew Research Centre http://www.pewinternet.org/2016/12/01/the-new-food-fights/.

Gaskell, G., Stares, S., Allansdottir, A., & Allum, N. (2010). Europeans and biotechnology in 2010 - winds of change? *A report to the European Commission's Directorate-General for Research*. http://ec.europa.eu/public_opinion/archives/ebs/ebs_341_winds_en.pdf.

Goode, J. G., Curtis, K., & Theophano, J. (2003). Meal formats, meal cycles and menu negotiation in the maintenance of an Italian-American community. In M. Douglas (Ed.), *Food in the Social Order: Mary Douglas Collected Works Volume 9* (9th Editio., pp. 143–218). Oxford: Routledge.

Green, S. B. (1991). How many subjects does it take to do a regression analysis. *Multivariate Behavioral Research, 26*(3), 499–510.

Gupta, N., Fischer, A. R., & Frewer, L. J. (2012). Socio-psychological determinants of public acceptance of technologies: A review. *Public Understanding of Science, 21*(7), 782–795.

Haidt, J. (2001). The emotional dog and its rational tail; a social intuitionist approach to moral judgement. *Psychological Review, 108*(4), 814–838.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York: The Guilford Press.

Humble, N. (2005). *Culinary pleasures: Cookbooks and the transformation of British food*. London: Faber and Faber.

Joffe, H. (2003). Risk: From perception to social representation. *British Journal of Social Psychology, 42*(Pt 1), 55–73.

Johnston, E. L. (2016). Agrarian dreams and neoliberal futures in life writing of the alternative food movement. *Food and Foodways, 24*(1–2), 9–29.

Loner, E. (2008). The importance of having a different opinion Europeans and GM foods. *European Journal of Sociology, 49*(01), 31–63.

Lucht, J. M. (2015). Public acceptance of plant biotechnology and GM crops. *Viruses, 7*(8), 4254–4281.

Mohr, P., & Golley, S. (2016). Responses to GM food content in context with food integrity issues: Results from Australian population surveys. *New Biotechnology, 33*(1), 91–98.

Moore, G. E. (1903). *Principia ethica*. Cambridge: Cambridge University Press.

National Academies of Sciences Engineering and Medicine. (2016). *Genetically Engineered Crops: Experiences and Prospects (Vol. xlv)*. Washington: The National Academies Press.

O'Connor, E., Cowan, C., Williams, G., O'Connell, J., & Boland, M. (2005). Acceptance by Irish consumers of a hypothetical GM dairy spread that reduces cholesterol. *British Food Journal, 107*(6), 361–380.

Rozin, P., Fischler, C., & Shields-Argelès, C. (2012). European and American perspectives on the meaning of natural. *Appetite, 59*(2), 448–455.

Saher, M., Lindeman, M., & Hursti, U.-K. K. (2006). Attitudes towards genetically modified and organic foods. *Appetite, 46*(3), 324–331.

Scott, S. E., Inbar, Y., & Rozin, P. (2016). Evidence for absolute moral opposition to genetically modified food in the United States. *Perspectives on psychological science: a Journal of the Association for Psychological Science, 11*(3), 315–324.

Shewfelt, R. L. (2017). *In defense of processed food*. New York: Springer International Publishing.

Siegrist, M., Keller, C., & Kiers, H. A. L. (2006). Lay people's perception of food hazards: Comparing aggregated data and individual data. *Appetite, 47*(3), 324–332.

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2007). The affect heuristic. *European Journal of Operational Research, 177*(3), 1333–1352.

Traill, W. B., Jaeger, S. R., Yee, W. M. S., Valli, C., House, L. O., Lusk, J. L., et al. (2004). Categories of GM risk-benefit perceptions and their antecedents. *AgBioForum, 7*(4), 176–186.

Wesseler, J., Smart, R. D., Thomson, J., & Zilberman, D. (2017). Foregone benefits of important food crop improvements in sub-Saharan Africa. *PLoS One, 12*(7), 1–12.

Whitty, C. J. M., Jones, M., Tollervey, a., & Wheeler, T. (2013). Africa and Asia need a rational debate on GM crops. *Nature, 497*(7447), 31–33.

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