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Review

Consumer response to novel agri-food technologies: Implications for predicting consumer acceptance of emerging food technologies

L.J. Frewer[a,b,*,1], K. Bergmann[c], M. Brennan[a], R. Lion[d], R. Meertens[e], G. Rowe[a], M. Siegrist[f] and C. Vereijken[g]

[a]School of Agriculture, Food and Rural Development, Rm. 207, Agriculture Building, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, UK (e-mails: lynn.Frewer@newcastle.ac.uk; Mary.Brennan@newcastle.ac.uk)

[b]MCB Group, Wageningen University, The Netherlands

[c]Dr. Bergmann Food Relations, Sommerstraße 10, 82178 Puchheim, Germany (e-mail: karin.bergmann@food-relations.de)

[d]Sensation, Perception and Behaviour, Unilever R&D Vlaardingen, Vlaardingen, The Netherlands (e-mail: Rene.Lion@unilever.com)

[e]Department of Health Promotion, Nutrition and Toxicology Research Institute Maastricht (NUTRIM) and Care and Public Health Research Institute (Caphri), Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands (e-mail: r.meertens@maastrichtuniversity.nl)

[f]ETH Zurich, Institute for Environmental Decisions (IED), Consumer Behavior, Universitätsstrasse 22, CHN J76.3, CH-8092 Zurich, Switzerland (e-mail: msiegrist@ethz.ch)

[g]Danone Research – Centre for Specialised Nutrition, Bosrandweg 20, 6704 PH Wageningen, The Netherlands (e-mail: carel.vereijken@danone.com)

The issue of consumer acceptance of food technologies, and their applications, needs to be addressed early in technology development. However, whether extensive assessment of consumer acceptance is necessary for *all* food-related technologies *a priori* is uncertain. A review of studies of seven food-related technologies associated with different levels of public acceptance suggests that those characterised as being 'bioactive' raise particular concerns - related to unpredictable effects, uncontrolled use, and ethical concerns. Perceptions of 'unnaturalness' alone are unlikely to raise a food technology to high levels of public rejection. Trust in regulation and effective labelling are also important considerations.

Introduction

Historically, research into the determinants of public acceptance of emerging technologies (including those applied in the agri-food sector) has occurred *subsequent* to public rejection of a particular application. For example, the European public's rejection of genetic modification of food and crops is frequently interpreted as representing the normative societal response to new technology (Mehta, 2004). One conclusion that might be drawn is that determinants of consumer acceptance identified in the literature are better predictors of consumer *rejection* than of *acceptance*. The aim of this review is to examine what is known about consumer responses to food-related technologies that have been associated with different levels of consumer rejection in order to draw broad conclusions about the potential determinants of both acceptance and rejection. These conclusions will be discussed in the context of the development of emerging food technologies. Future research needs will be identified.

* Corresponding author. ILSI Europe, 83 Avenue E. Mounier, Box 6, BE-1200 Brussels, Belgium. Tel.: +32 2 771 00 14; fax: +32 2 762 00 44.

[1] E-mail: publications@ilsieurope.be

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Case studies: consumer responses to food technologies

Research on risk perception has tended to focus on high-profile and dramatic potential hazards at the expense of familiar ones (Hawkes & Rowe, 2008). In this review, a *range* of technologies, from those that have been received negatively and those that have the potential to be received negatively in the future, to those that have had more favourable societal response, are analysed, characterised, and compared. Patterns in their trajectories of societal acceptance are identified, from the perspective of both the technologies and consumers. The seven selected technologies are first discussed individually and then compared and contrasted (see Table 1 for summary, and the supplementary data file for the references on which the conclusions are based).

In addition, the publications included in the review have been categorised according to their style/methodological focus. More detailed information about how individual papers were categorised can be found in the supplementary data file.

Genetically modified foods and crops

Genetic modification (GM) has been applied to various crops, including those intended for food and animal feed, and to production animals. The process involves the transferring of one or more genes from one plant/animal to another using various processes, conferring various advantages in terms of nutrition and environmental impact. In 1998, a *de facto* moratorium led to the suspension of approvals of new genetically modified organisms in the European Union, following consumer concern and rejection of products, and pending the adoption of revised rules to govern the approval, marketing and labelling of GM foods.

Public perceptions of GM technology have been the focus of considerable research (see, for example, Frewer *et al*., 2004; Costa-Fonta, Gila, & Traill, 2008, for reviews, and for summary details on this and the other technologies, see Table 1). Typically, results suggest that GM agri-food technology is associated with high perceived risks and relatively low perceived benefits (e.g. Pidgeon *et al*., 2005). Perceptions of unnaturalness, ethical concerns, failure to implement an efficacious traceability policy, and disparity between developing and developed countries (in terms of economics and sovereignty over decisions) have also been associated with negative societal responses (Hu, Veeman, & Adamowicz, 2005; Lassen, Madsen, & Sandøe, 2002; Miles, Ueland, & Frewer, 2005). Some of these issues may be common to other novel food technologies. Public concerns have also focused on technical risk assessment (and hence regulatory systems) being based on incomplete levels of scientific knowledge. The public tend to reject economic arguments for GM technology implementation as being inadequate to 'legitimise' its introduction, especially where the perceived balance of benefits is inequitably distributed in favour of the agri-food industry (Houghton *et al*., 2008; Wagner & Kronberger, 2001) (Table 1).

Nutrigenomics and personalised nutrition

Nutrigenomics is underpinned by functional interactions between nutrition and the human genome (Kaput & Rodriguez, 2004). Experts and other stakeholders predict that nutrigenomics will deliver improvements in public health by identifying genetically determined differences in how diet impacts on chronic disease, both in terms of food and food components as a cause of disease, and as a preventative or curative agent, although there is uncertainty regarding the concrete form such developments will take (Komduur, Korthals, & te Molder, 2007). The technological possibilities regarding the identification of genetic sequence deviations are more advanced than the knowledge of their significance regarding possible health-related applications (Joost, 2005). Applications of nutrigenomics are now reaching the commercialisation stage (Muller & Kersten, 2003).

Public awareness of nutrigenomics has, to date, been low and research into consumer acceptance of nutrigenomics has primarily focused on consumer evaluations of potential future scenarios (Table 1). The biggest risk in the use of genetic information is its scientific misinterpretation (Bergmann, 2002), and the introduction of new risks in relation to dietary changes. Ethical, social, and data protection questions have arisen, requiring consideration before widespread commercialisation can occur (Bergmann, Görmann, & Mathers, 2007; Rimbach & Minihane, 2009). Other consumer concerns relate to differential distribution of benefits to different societal sectors.

Animal cloning

Cloning was originally used in microbiology and agriculture, and is the process of multiplying single organisms by means of asexual reproduction to create a population of identical individuals (EGE, 2008). By 1996 the first fully cloned domesticated farm animal, Dolly the Sheep, was born (Suk *et al*., 2007). Since 1996, cows, goats, poultry and fish-based clones have been created, primarily through application of Somatic Cell Nuclear Transfer (which does not involve genetic modification) and transgenic cloning, which allows the breeding of hybrid animals using genetic material from different species. The scientific and commercial factors driving animal cloning technology in agriculture relate to improving the quality, productivity and environmental impact of breeding stock (Butler, 2009). Future commercial agri-food opportunities may include the development of animals that are more efficient at converting feed and growing, or disease resistant/tolerant to climatic changes. Public awareness of animal cloning is not, at time of writing, high. The public, however, have personal concerns relating to the biological, toxicological, environmental and health-related risks posed by animal cloning technology, but also by what the technology means for society more generally, and perceive that benefits will accrue to industry rather than individuals or society as a whole (see Table 1). In addition, the issue of permanent impacts on

Table 1. A summary of the key factors related to public acceptance of seven novel food technologies. References associated with the numerical codes in table cells are provided in a supplementary data document, available on-line at the journal, or from the corresponding author upon request. The review is not systematic, insomuch as not all of the papers applicable to all technologies are included, but papers supporting the key findings are reviewed.

Issues impacting on acceptability	GM Foods	Animal Cloning	Nutrigenomics	Food Irradiation	Nanotechnology	High-pressure processing (HPP)	Pulsed electric field processing (PEF)
Perceived personal benefits (health, economic, social, environmental)	More acceptable where personal benefits are concrete, tangible, and personally relevant. Less research on trade-off between perceived risk and benefit (most focus on perceived risks). Acceptance may occur where perceived benefit outweighs perceived risk. Other factors (e.g. attitudes to technology or concern about nature) may determine both constructs. Research on willingness to pay has indicated price may be a benefit for some consumers. [1]	More acceptable where personal benefits are concrete and tangible. Consumers are more positive about perceived benefits from medical applications, companion and sporting animals, but less for production animals. [2]	People perceive benefits if products have a clear health advantage.Positive emotional (affective) response predicts perceived benefit. Consumer attitudes are more favourable where there is potential for individuals to use the information for their own health benefit. [3]	Perceived personal benefits do not drive acceptability, though recent experiences with food-borne illnesses are associated with increased acceptance. However, many consumers do not know what irradiation is. [4]	Perceived benefits increase willingness to buy food produced using nanotechnology. Some population groups are less ambivalent following information provision about benefits. Food applications are less accepted than applications in other domains. Nanotechnology food packaging is more accepted than nanotechnology foods. [5]	Perceived benefits relate to those envisaged by the proponents of the technology, and primarily relate to better food safety and quality with extended shelf life. [6]	Perceived benefits relate to those envisaged by technology proponents similar to HPP. [7]
Perceived societal benefits (health, economic, social, environmental)	As with personal benefits, societal benefits need to be perceived to outweigh the risks. It Actual purchase behaviour may be driven by perceptions of concrete benefits. [8]	Benefits are perceived to accrue mostly to industry, e.g. Improving efficiency/yield of production; reducing production costs. Wider societal benefits may be associated with improved animal welfare reducing the environmental impact of food production. Few perceive any benefits to the wider public [9]	There is little evidence that societal benefits (e.g. reduced health service costs) increase acceptance of nutrigenomics, though some stakeholders have assumed this. [10]	Some research indicates that people think beef irradiation is unnecessary. [11]	For most applications, perceived benefits for society are low. [12]	Perceived environmental benefits are associated with environmental impact. Environmental impact of process and worker safety issues also mentioned as influential in positively evaluating HPP. [13]	Perceived as environmentally friendly with less waste. Environmental impact of process was mentioned as influential in evaluating PEF. [14]

Differential accruement of risks and benefits (fairness)	Benefits perceived as accruing to producers and industry, particularly in producer countries (e.g. the US), despite technology proponents arguing for socio-economic benefits accruing to disadvantaged populations (in terms of food security or nutritional advantages). [15]	Benefits perceived as accruing to industry. Concerns about fairness of international trade in cloned animal–based products. Industry benefits do not figure in consumer's cost-benefit evaluations of animal cloning. [16]	Some discussion of whether the availability of nutrigenomics will result in unfair distribution of benefits to those who can afford the treatment, or disadvantage those with genetic illnesses once diagnosed. Public perception data is not available. [17]	Consumers see the benefits of irradiation mostly accruing to manufacturers/ retailers. [18]	NLA*	NLA	NLA	
Ethical concerns	Differential accruement of benefit (e.g. to developed as opposed to developing countries). Possible impact on biodiversity or the biosystem and sustainability. These tend to be articulated in general rather than specific terms. [19]	Ethical concerns relate to animal welfare,the integrity of nature and living animals. [20]	Consumer concerns about how human genetics research can have a negative impact on privacy, e.g., related to the management of DNA banks and how sensitive personal information is handled. [21]	NLA	Some nascent concerns appear similar to GM. [22]	Reported to have no impact. [23]	NLA	

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Table 1 (*continued*)

Issues impacting on acceptability	**GM Foods**	**Animal Cloning**	**Nutrigenomics**	**Food Irradiation**	**Nanotechnology**	**High-pressure processing (HPP)**	**Pulsed electric field processing (PEF)**
Perceived personal risks (health, economic, social, environmental)	Perceived personal risks vary according to application. Generally, applications relating to animals are perceived as riskier than those involving plants/micro-organisms and to food as riskier than those associated with non-food applications (e.g. medicine). People willing to pay more to avoid “risk” of GM foods than acquire “benefits”, and will pay less for GM foods generally. [24]	Some perceived safety risks (e.g. microbiological) and concern about long term effects from consumption and inadvertent consumption without choice (need to pay more for non-cloned products). [25]	Consumer interest groups and scientists are afraid of non-participation of lower income groups (opinion leaders not consumers). [26]	Consumer health concerns (e.g. carcinogenicity of irradiated food products) and impaired food quality. [27]	Some evidence that risk perception reduces willingness to buy. [28]	Perceived risks rare and not high, related to safety and allergenicity,. [29]	Perceived risks rare and not high, related to safety and allergenicity.[30]
Perceived societal risks (health, economic, social, environmental)	Perceptions of societal risks exhibit a similar pattern to personal risks, ethical concerns and equity issues. Some members of the public are ambivalent. [31]	Perceived societal risks include: animal welfare; environmental (biodiversity); new animal diseases; genetic selection risks; technology transfer to humans; threat to ‘natural order’; traceability of cloned products; regulation and control of the technology. [32]	Opinion leaders perceive moderate risks though less data is available for consumers, in part because the technology is not yet “on stream”. Some concerns regarding data privacy protection and misinterpretation of genetic information. [33]	Concernsfocus on the risks to factory workers and environment (e.g. escape of radiation from irradiation facilities and risks associated with the transportation of radioactive materials). [34]	Early studies in the US and Canada report nanotechnology was perceived as less risky/ more beneficial than GM. Recent research suggests considerable variation in attitudes according to predictable individual differences. The level of risk perception varies across applications, with food associated with higher risks. [35]	NLA	NLA

Perceived efficacy of regulatory framework	Consumer trust in the regulatory system represent an important part of societal and consumer acceptance. Opaque risk analysis systems and decision-making practices are not helpful in reassuring the public, nor is the lack of effective communication about governance. [36]	Regulatory positions complex: some cloning techniques involve genetic manipulation and others do not. No animal cloning specific regulatory framework in the US or the EU. Public expect an appropriate regulatory framework that considers safety and labelling, so current approach is untenable. [37]	The debate over the regulation of nutrigenomics focuses on issues associated with formed consent, biobanking, and the sales of genetic tests directly to consumers. Thus regulatory issues relate to those associated with genetic testing in general. [38]	NLA	Societal debate about the adequacy of existing governance structures for nanotechnology, including for food. Whether this will influence public opinion (as with GM) remains to be seen. From public engagement research, some public concerns about the effectiveness of public regulation, oversight and control, including for agrifood applications. [39]	Attitude towards food producers (positive and negative) was mentioned. 'Institutions that evaluate process safety' influential in consumer evaluation of HPP. [40]	Attitude towards food producers (negative) was mentioned. 'Institutions that evaluate process safety' influential in consumer evaluation of PEF. [41]
Cognitive associations/ attitude activation	Associations are linked to technologies being perceived as "being uncontrolled", or unknown in terms of effect (e.g. BSE and pesticides). Negative attitudes to technology or high environmental concern are associated with negative attitudes to GM foods. Uncertainty (regarding health and environmental impact) also relevant. [42]	Associations made with other reproductive and genetic technologies, including applications to humans. Many similarities with GM. In addition, human cloning; Assisted Reproductive Techniques (IVF); animals as commodities (animal welfare); alliance between industry and government/regulators concern consumers. [43]	Some consumers link nutrigenomics with GM foods. This is only really relevant if GM foods contribute to personalised diets. [44]	Cognitive associations appear primarily linked to the concept of radioactivity and/or/radioactive contamination. Some consumers do not make these associations. [45]	Many opinion leaders and academics have suggested that consumers will activate existing attitudes towards GM and apply these to foods produced using nanotechnology, a contention currently unsupported. Affective or emotional responses may play a key role in determining acceptance for nanotechnology in general. [46]	Name of technology mainly positive for HPP, though some activation of attitudes related to irradiation' and 'GMO'. [47]	Name of technology has mainly negative associations - similar to 'irradiation' and 'microwave ovens', with some fear of 'electricity' or 'electrical impulses' and their consequences. [48]

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Table 1 (*continued*)

Issues impacting on acceptability	GM Foods	Animal Cloning	Nutrigenomics	Food Irradiation	Nanotechnology	High-pressure processing (HPP)	Pulsed electric field processing (PEF)
Public awareness (familiarity)	Public awareness was low at time of technology introduction. This has changed following extensive media coverage about key issues. Some equivocal evidence that low knowledge is linked to low acceptability, but not supported generally – e.g. greater knowledge is associated with either more positive or more negative attitudes.[49]	Public awareness not high. Survey responses appear semi-formed and unlikely to be a good indicator of actual purchase. Past food crises (e.g. BSE and GM food) seem to influence the public's initial assessment of animal cloning. [50]	Public awareness is not high at the population level. This is likely to change as the technology is commercialised. [51]	Public awareness is not high. There is evidence to suggest that many consumers are ambivalent. [52]	Most people are not familiar with nanotechnology. [53]	Awareness low. [54]	Awareness low. [55]
Perceived scientific knowledge/ uncertainty	Some perceived uncertainty associated with scientific knowledge, in particular associated with risk and negative impacts. [56]	Public knowledge limited. Perception that there are high levels of uncertainty associated with long term safety of cloning and for the genetic diversity of farm animal breeds (e.g. cloning humans). [57]	Uncertainty regarding implementation is high. At the present time this reflects the statements of opinion leaders not consumers. [58]	NLA	NLA	HPP orange juice was perceived as having unknown consequences. [59]	Perceptions of unknown long term consequences. [60]
Perceived naturalness	Consumer values, such as concern about the integrity of nature, contribute to societal and consumer acceptance/ rejection. [61]	Animal cloning viewed as unnatural and interfering with nature and the natural order. [62]	Not a consumer issue at present. If GM foods are included in personalized dietary advice in the future, this issue may need to be discussed. [63]	NLA	Benefits from natural additives are preferred to nanotechnology additives. The issue of naturalness may become a more relevant issue for specific applications (for example, smart pesticides). [64]	Naturalness/ unnaturalness often mentioned regarding HPP. [65]	Naturalness/ unnaturalness often mentioned regarding PEF. [66]

Controllability/ Choice (labelling/ traceability)	Control over consumption of GM foods important to European consumers, necessitating the labelling of GM foods and implementation of effective traceability systems. This did not happen when GM foods were introduced. [67]	Clear labelling/ traceability of cloned animal products considered key to allowing consumers to make informed choices between cloned and conventional animal products. [68]	Not currently an issue. Some stakeholders have raised the issue of compulsory genetic testing (e.g. in order to obtain health insurance) but at present this future scenario seems unlikely. [69]	There is some evidence to suggest that consumers have a preference for labelled products.[70]	NLA	NLA	NLA
Level of consumer/public involvement in technology/ product development	Whilst public engagement into the key issues occurred, but not always conducted systematically. The policy impact was often negligible or untenable because of changes in (inter) national policy. [71]	Some public engagement has occurred, but generally low levels of (European) public controversy have resulted in low levels of public participation. [72]	There is little published literature focused on public participation. Available data focuses on consumer responses to future scenarios. [73]	NLA	There has been some public engagement in nanotechnology, including that applied to the agrifood sector. Issues arising from public engagement are broadly similar to those linked to GM foods. There is some argumentation that public participation will avert the problems associated with the implementation of GM foods. [74]	NLA	NLA
Trust in science and regulation	Lack of consumer trust in science and/ or those responsible for developing or legislating the technology an important determinate of consumer negativity. [75]	General attitudes to science and technology and confidence, and trust in government and their regulatory agencies are key to the debate about animal cloning. [76]	Trust appears to be a less important predictor of consumer acceptance than affective response. [77]	NLA	Trust in science and industry influences risk and benefit perception. Trust in industry low. [78]	Scepticism/mistrust have been found. [79]	Scepticism/mistrust have been found. [80]

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Table 1 (*continued*)

Issues impacting on acceptability	GM Foods	Animal Cloning	Nutrigenomics	Food Irradiation	Nanotechnology	High-pressure processing (HPP)	Pulsed electric field processing (PEF)
Socio-cultural differences (socio-economic, demographic, cultural)	Systematic geographical or regional comparison is limited, but available evidence suggests consumer negativity is greater in Europe. Some systematic differences within national populations For example, women are more negative than men. [81]	Limited evidence on socio-cultural differences. Some suggest possible gender, geographical; age, income and educational effects for acceptance of novel food technologies also apply to animal cloning. [82]	Consumers with health problems, or who are older, are more positive. Some regional differences (e.g. Australians base decisions on cognitive analysis, Dutch on affective responses. [83]	Overall, consistent differences have not been found specifically for food irradiation. There seems to be a group of people that are sceptical about it are generally sceptical about scientific and technological innovation. [84]	Europeans are less optimistic compared with people from the US. [85]	No difference in acceptance between Finnish, Dutch/ Belgian and Spanish samples. Willingness to buy HPP products varied between German, French and UK samples. No salient differences between E. European and N. European samples. Women more concerned about HPP than men.[86]	East-European respondents seemed more concerned about 'electrical impulses' than Northern European respondents. Women more concerned about PEF than men. [87]

*NLA indicates "No literature available".

biological systems may represent an important societal and consumer issue.

Nanotechnology

Nanotechnology (engineering very small particles, usually defined at a scale of between 1 and 100 nm) has resulted in properties of materials at this scale having different functionalities to 'conventionally sized' equivalents (Royal Society and Royal Academy of Engineering, 2004). Nanotechnology is being used in the development of new foods and food packaging with an array of benefits (for example, prevention of micro-organism growth or stronger mechanical and thermal performance - Chowdry, 2010). Nanotechnology may also be used in food production, for example, to produce healthier foods, or to enhance organoleptic properties. Delivery systems could be employed in functional foods so that food ingredients are delivered to their specific sites of biological action (Weiss, Takhistov, & McClements, 2006).

Nanotechnology foods and food packaging are already commercialized, though the number of products is still low. In the near future, nanotechnology may become increasingly important in the food sector (Allianz & OECD, 2005), with governmental agencies and industry investing considerable resources in its development and implementation (Kuzma & VerHage, 2006). However, toxicology studies have suggested that some nanomaterials may have unintended effects on human health (Oberdörster, Oberdörster, & Oberdörster, 2005) and the environment (Chowdry, 2010). It has been suggested that new risk assessment frameworks are required for effective risk regulations to be developed and applied (Renn & Roco, 2006).

Evidence suggests that most people are not, at present, familiar with nanotechnology (Lee, Scheufele, & Lewenstein, 2005). Early studies in the US and Canada found that nanotechnology was perceived by consumers in a more positive light (Cobb & Macoubrie, 2004; Priest, 2006), as less risky and more beneficial than GM (Currall, King, Lane, Madera, & Turner, 2006), although food-related applications in general are viewed less positively, or at least differently, to other areas of application (Cobb & Macoubrie, 2004; Siegrist, Cousin, Kastenholz, & Wiek, 2007). This may vary between individuals (Kahan, Braman, Slovic, Gastil, & Cohen, 2008). The European public seems to be less optimistic about nanotechnology compared with consumers in the U.S. (Gaskell *et al.*, 2004) (Table 1). The commercialisation trajectory of emerging applications of nanotechnology has been frequently compared to that of genetic modification of foods (Mehta, 2004).

Food irradiation

Food irradiation is a preservation method that involves exposing food to gamma rays, X-rays or electrons. Its main benefits are that it kills pathogenic organisms, including salmonella, Listeria, Campylobacter and E. Coli, whilst otherwise having minimal impact on the quality of food products (Diehl, 1993). Food irradiation is permitted in a number of countries internationally. In Europe, it is allowed for dried herbs, spices and vegetable seasonings, and in individual countries for chicken/poultry (as is the case in the US), and other meat products (EU, 1999, 2009).

Most research into public acceptance of food irradiation was conducted in the 80s and 90s (see, for example, Bruhn, 1998). The majority of studies were US based, on meat. Exceptions include studies in Brazil (Behrens, Barcellos, Frewer, Nunes, & Landgraf, 2009), Turkey (Gunes & Tekin, 2006), and Europe (Sparks & Shepherd, 1994; Siegrist, Keller, & Kiers, 2006 - see Table 1). The research evidence suggests that people tend to be unfamiliar with food irradiation. Despite this, they hold negative views about its application. The main consumer concerns focus on the perceived "carcinogenicity" of irradiated foods, impaired food quality, and risks to factory workers and the environment incurred during production. Some consumers believe that the benefits accrue differentially to manufacturers compared to consumers (Table 1). The negative associations that consumers have with food irradiation have restricted widespread implementation of the technology by industry, as it requires significant investment in infrastructure (Henson, 1995).

High-pressure processing (HPP)

In HPP, food is subjected to high (usually hydrostatic) pressure. This results in micro-organisms and enzymes being inactivated, leading to a longer shelf life. Vitamin content, flavour and colour are unaffected. Currently, HPP food products are commercially available in Europe, Japan and the U.S., and include dressings, fruit juices, beef, ham and fish products (Welti-Chanes *et al*., 2005). There seems to be no published reports on toxicity of HPP-treated food although allergenicity has been considered a potential problem (Hugas, Garriga, & Montfort, 2002; cf Oey, Van der Plancken, Van Loey, & Hendrickx, 2008).

In general, public awareness about HPP is low. Research suggests that the public is neutral to slightly positive about HPP, with only small cultural differences in acceptance (for example, see Butz *et al*., 2003) (see Table 1). The perceived personal and societal benefits of HPP may play a considerable role in consumer acceptance (Olsen, Grunert, & Sonne, 2010). Perceived risks (personal and societal) do not seem to play a salient role in acceptance, although possible risks are often *implicitly* referred to, for example, in terms of 'unknown consequences', 'unnaturalness', 'unfamiliarity', or through negative associations with HPP or a general lack of trust in regulators and industry. Results of research may be biased as study participants have not usually been familiar with HPP before being enrolled in studies, only being informed of potential HPP (dis)advantages at the outset of research.

Pulsed electric fields (PEF)

High intensity PEF are used to inactivate micro-organisms and enzymes. High-voltage pulses break the cell membranes of the micro-organisms, making them permeable to small molecules, causing the micro-organisms to swell and rupture. PEF can be applied to liquid and semi-liquid food products, such as fruit juices, soups and liquid eggs. Longer shelf lives are achieved whilst maintaining organoleptic properties. In 2005, PEF-processed fruit juices were introduced to the U.S. market (Ravishankar, Zhang, & Kempkes, 2008). The PEF process is considered safe because no dangerous chemical reactions have been detected (Soliva-Fortuny, Balasa, Knorr, & Martín-Belloso, 2009; Vega-Mercado *et al*., 1997).

As for HPP, public awareness of PEF is low and public responses to PEF vary from slightly positive to slightly negative (Cardello, Schutz, & Lesher, 2007). Consumer concerns about PEF are not considered significant, although it is perceived to have relatively few benefits (Nielsen *et al*., 2009). PEF has more negative associations than HPP (for example, linked to electricity, irradiation, and microwaves) (Sonne *et al*., 2009). As for HPP, a bias may arise, given that participants have responded *after* the provision of information about PEF.

Comparing the technologies: general trends

Table 1 summarises the issues identified by this review that impact upon public acceptance of the seven technologies examined. The research on which the conclusions are based can be found in the supplementary data for this article. Several cells contain the text 'NLA' (no literature available). This should not necessarily be taken as meaning that a particular issue has no role in influencing public acceptance or rejection of the associated technology: it may simply indicate absences of research focused on the issue under consideration. In addition, the review of the literature is by no means inclusive. Gupta, Fischer, and Frewer (2011) report that published research papers in the area of GM Foods dominate this literature, possibly a consequence of associated public controversy. To include all relevant literature on GM foods is beyond the scope of this paper. In contrast, the relative paucity of published research in the areas of HPP and PEF has resulted in a more conclusive review of issues. More research funding, and hence published literature, has been available for controversial technologies compared to those generally accepted. None-the-less, some broad conclusions can be drawn from what is currently understood regarding public acceptance of food technologies.

A closer inspection of Table 1 provides two general insights. The first finding is that the seven food technologies possess different characteristics in lay people's perception. These differences could be the reason that there is some public debate about some of the technologies, but not about others. The second finding is, that for the various food technologies different issues have been examined. There is a need for comparative studies that focus not only on one food technology, but simultaneously on several food technologies. Studies utilizing large sets of predictors for explaining acceptance of different food technologies would be of interest.

What are the main differences between food technologies that are accepted by consumers and food technologies that are not? Table 1 provides some answers to this important question. A high percentage of the public are against GM foods and the associated technology, in particular in Europe. Public awareness of food irradiation is low, but despite this acceptance is low. Both technologies, GM foods and food irradiation, can be characterized as technologies for which the public perceives not many personal benefits. The view that industry and producers mainly profit from these technologies shapes consumers' perceptions. It should be noted, however, that in the case of GM foods the public perception is different for various applications. Both technologies, GM foods and food irradiation, evoke rather negative associations, due to the name and the perception of uncontrollability. HPP seems to be an accepted food technology. It has been introduced in various markets without stirring much controversy: consumers seem to perceive benefits, but no risks with this technology. Furthermore, consumers seem to associate environmental as well as work safety benefits with this technology. The name of the technology also evokes mainly positive associations. Research results summarized in Table 1 suggest, that it is difficult to predict consumers' reactions towards nanotechnology foods, animal cloning and nutrigenomics. There are findings that could be the basis for risk attenuation and there are findings for risk amplification.

Consumer acceptance of cloned animals may be low if the derived animal products are allowed to enter the food supply chain under current regulatory/market conditions. Acceptance will be dependent on development of a robust, clear and reliable regulatory system for managing the technology, taking on board the ethical concerns that have been raised. In the case of nutrigenomics, acceptance may be dependent on perceived personal (health) benefits. Similarly, at present, public awareness regarding agrifood nanotechnology is low. The current state of development regarding commercialisation and implementation in the agrifood sector is similar to GM in the early 1990's. Attitudes are currently uncrystallised, but this may change as products are made available. For both HPP and PEF, there is little evidence to suggest high levels of consumer negativity. Whilst this may reflect fewer studies being conducted, and hence reduced availability of relevant data, this in turn may reflect lack of societal controversy. Despite this, some consumer concerns have been identified.

From this analysis, research questions related to what determines acceptance or rejection of different food technologies, and how this varies between individual consumers, arise (see Table 3). At the 'conceptual' stage, where the idea/potential of the technology is examined, it may be possible to identify which technology characteristics will lead to societal controversy (Kuznesof, 2010). At the commercialisation and application stage, where the concrete applications of the technology are made available to consumers, individual characteristics of consumers may be relevant.

Table 2. Categorisation of reviewed publications according to style/methodological focus.

Style of Article	No of Articles
1. Hypothetical Survey based Quantitative Studies	44
2. Experimental based Quantitative Studies	12
3. Mixed Hypothetical and Experimental Quantitative Studies	7
4. Mixed Quantitative and Qualitative Studies	3
5. Qualitative Studies (incl. Focus group; in depth interviews; expert/stakeholder workshops)	15
6. Ethnographic based Studies	0
7. Secondary Analysis	2
8. Economic Analysis	2
9. Theoretical/Conceptual Articles	3
10. Commentary Articles	19
11. Review based Articles	20
12. Book – mixed	7

The following table provides a summary of the categorisation process conducted on all the reviewed publications. Based on an analysis of the style/methodological focus, each publication was assigned to one of 12 categories outlined in Table 2 below. A superscript number corresponding to the allocated category has been inserted into the supplementary data file for each reviewed publication.

While perceived risks and benefits were important for all the technologies, the public may trade these off against other issues, such as to whom the majority of the perceived risks and benefits accrue (i.e. are they equitably distributed), whether consumers perceive they have control over their exposure to a technology, and the ethical dilemmas such technologies raise. In the case of GM food, food irradiation and cloning, public concerns are linked to the perception that potential benefits are weighted towards industry. The perceived risks associated with GM food, cloning and irradiation appear to be more varied, potentially profound, and extend beyond risks of personal harm into biosystems and bioactivity, compared to those associated with the other technologies. Ethical concerns are associated with GM food, nutrigenomics and cloning. Manipulating food and animals using 'unnatural' biological techniques seem to strike a major negative, fundamental chord with many people, in particular when coupled with the concept of "bioactivity". Food irradiation is associated with 'radioactivity', which is of major public concern. A greater number of 'degrees of freedom' in terms of diversity of application appear to signal increased uncontrollability (both by science and those exposed). In this respect, the least controversial technologies (HPP and PEF) were both highly contained and potentially limited in both time and space in terms of their perceived impact, in particular in terms of bioactive effects. In other words, while food is bio-actively altered in HPP and PEF, the technologies themselves are not considered to be 'bioactive' in

Table 3. Key research questions relevant to assessing public acceptability of novel food technologies.

Technology Characteristics	Consumer Characteristics
Intrinsic issues	
Are there characteristics of the technology that may generate negative societal responses? For example, is it perceived to be "bioactive", uncontained, and uncontrollable?	What individual and cultural differences can be identified in consumers' responses to these characteristics?
Risk assessment and risk management	
To what extent are regulatory systems relevant to human and environmental health perceived to be adequate? To what extent are broader socio-economic and ethical issues incorporated into risk assessment and management?	Do different individuals prioritise different potential (perceived) technology outcomes (e.g., related to environmental impact, animal welfare, bioactivity)?
Need and benefit	
Is there an identified societal need for the technology?	Do individuals consider specific applications to be useful to themselves and others within society?
Regulatory transparency	
Is there a clear, transparent and robust regulatory framework capable of managing and controlling the technology?	What societal, cultural and historical factors can be identified that influence people's trust in the regulatory framework? Are there individual differences in the extent to which people trust risk regulators and industry?
Associations and complexity	
Is the technology similar to other technologies and applications?	Does the technology activate existing attitudes held by an individual about (food) technologies and related issues?
Societal involvement	
Have key stakeholders and end-users been involved in regulation, policy and commercialisation strategies associated with the technology?	What is the impact of societal engagement on the trust in policy and acceptance of the novel technology? How should societal engagement be realized effectively?

a way that may impact on current and future generations of humans, animals and plants. This also suggests that perceived 'unnaturalness' of a technology *in itself* does not reduce consumer acceptance, but that perceptions of "uncontained bioactivity" associated with technological application may result in rejection. In addition, the issue of consumer choice, traceability or personal control over exposure appears to be a key issue for the least accepted technologies. Facilitating consumer choice through efficacious labelling may support an acceptable compromise for more controversial technologies.

Acceptance of nutrigenomics appears to link to perceived personal health status and how individuals perceive personal benefits to be associated with individualised nutrition. Moreover, at present, the lack of concrete examples of personalised nutrition, and in particular, nutrigenomics applications developed to an individual's genetic profile, suggests that societal discourse about the more controversial aspects (for example, 'genetic privacy') has not yet emerged. PEF and HPP are also not well known by the public, although the evidence available suggests that they are of potentially lesser concern. Nutrigenomics, PEF and HPP are also associated with far fewer potential applications than, for example, GM foods, or nanotechnology (simplifying regulation and containment of use), and are unlikely to be perceived as bioactive. As noted, their application is relatively easily contained.

Table 1 also suggests that individual differences in acceptance of different technologies need to be taken into account. This may be of particular relevance in the identification of an effective commercialisation strategy, where specific products are developed to meet individual consumer preferences and priorities. In-depth consumer research (for example, using a range of psycho-social measures and consumer research methodologies) is needed to develop predictive models of consumer acceptance of novel food technologies. In particular, consideration of how consumer acceptance varies between different individuals, socio-political contexts, and cultures, and their interactions with technology characteristics, may be needed for technologies that are associated with potentially controversial characteristics. Differences in risk and benefit perceptions may shape consumer reactions to specific applications, although other factors - such as affective response, attitudes to technology overall, prioritization of environmental conservation, and trust in governments and industry actors - may be influential. Simultaneous examination of multiple potential predictors in predictive models has infrequently been the focus of research, in particular across different socio-political contexts and between technologies. Longitudinal analysis of how acceptance or rejection changes in time (for example, following presentation of technology related issues in a crisis context, or after the concrete applications of specific products have entered the market place) is also required.

With the exception of GM foods, public knowledge regarding food technologies is generally low. For animal cloning and food irradiation (and possibly in the future for nanotechnology), consumer acceptance is driven by associations with other technologies perceived to have similar characteristics – in other words, acceptance is driven by generalised attitude towards food technologies that are perceived to share common characteristics. This suggests that perceptions of uncontrolled use and potential for bioactive impact beyond the original intentions of the technology proponents may be shaping societal responses.

An additional factor relates to the extent to which a transparent regulatory framework focused on risk assessment and management, in particular in the context of human health and environmental impact, is perceived to have been put into place. Inclusion of factors that are relevant to consumers needs to be taken into account as part of this framework. This was particularly apparent in the case of the introduction of GM agri-food technologies. Public and stakeholder engagement in governance and strategic technology development may be more relevant for those technologies that are perceived to be 'bioactive' and uncontrollable (and hence societally controversial).

Conclusions

This review has indicated a number of factors that may be associated with consumer responses towards food technologies. Technologies characterised as being 'bioactive' raise concerns related to unpredictable effects and uncontrolled use, as well as ethical concerns. Trust in regulation and other important food chain actors, such as those associated with the food industry, is also important. Simultaneous assessment of the predictive value of multiple potential determinants of consumer acceptance is needed, together with longitudinal analysis of how consumer responses are shaped by external events and experience with products. The review appears to suggest that there are fewer research papers published which utilise experimental, hypothesis-driven research methodologies– rather research tends to be exploratory or survey based methodologies tend to be applied- and this may be relevant to the development of future research in this area, particularly given that brad conclusions regarding consumer acceptance of food technology can be made from the existing body of literature (see also Table 2).

Approaching the development of novel food technologies through investigation of psychological, social, political and historical issues is an essential element of commercialisation. If consumers can control consumption of associated products (and of course this requires more widespread industry acceptance of regulated labelling strategies, and international harmonisation of labelling requirements) then it is anticipated that consumer acceptance is likely to be higher compared to situations where applications are uncontained (in particular in terms of environmental release) and untraceable. Such measures may not address the more general societal concerns associated with the 'bioactive' characteristics of certain technologies, and their potential for impact on biological systems. In the case of the latter, proactive and engaged risk assessment and governance may be the necessary prerequisite for consumer acceptance to occur.

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Supplementary material

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