Consumer Acceptance and Rejection of Emerging Agrifood Technologies and their applications.

Professor Lynn J. Frewer*

School of Agriculture, Food and Rural Development

Newcastle University

Newcastle Upon Tyne

NE1 7RU, UK

Email. Lynn.Frewer@newcastle.ac.uk

Twitter @lynn.frewer

Telephone +44(0)1912088272 /+44(0)7553 152 743

Abstract

Food insecurity represents a major global challenge. The development and application of agri-food technologies as routes to "sustainable intensification" of agrifood production may improve local and national food security. This paper will consider societal responses to various agri-food technologies. Consumer non-acceptance of enabling agrifood technologies, and their products, is an important barrier to their commercialisation. Case studies (pesticides, genetic modification of plants and animals, nanotechnology in agriculture, nutrigenomics in nutrition security, and synthetic biology) are considered along a temporal axis (from the 1950s to the present). Experts and regulators have increasingly recognised the importance of the role of risk *and* benefit perceptions. The normative assumption that consumers are "anti-agrifood technology" is rejected.

Key words. Agrifood Technology; Consumer Acceptance; Risk Perception; Benefit Perception; Attitude

Running Head. Consumers and Emerging Agrifood Technologies

JEL codes. Q16 R&D; Agricultural Technology; Biofuels; Agricultural Extension Services

Q180 Agricultural Policy; Food Policy

1 Introduction

The problem of food insecurity has been identified as a major societal challenge which, if not addressed, may have global negative impacts (Godfray, et al 2010). Food insecurity has been explicitly addressed as one of the targets of the UN Sustainable Development Goals. [1] In the context of projected population increases, and growth in food consumption, it is anticipated that the global demand for food will continue to increase for at least another 40 years, resulting in greater competition for agricultural resources. At the same time, ensuring reduction in the environmental impacts of agricultural practices, from the perspective of land use and effects on biodiversity, is an important factor in seeking environmental sustainability. The issue of environmental protection is further compounded by agricultural practices both contributing to, and being negatively affected by, climate change. These requirements have resulted in the need to develop innovative solutions to food production (Fedoroff et al, 2010), including those associated with novel agrifood technologies in the context of sustainable intensification (Beddington, 2010). However, societal and consumer acceptance and rejection of food products of innovative agri-food technologies has been identified as a barrier both to the implementation of these technological agricultural innovations, and to their subsequent exploitation and commercialisation in the form of tangible food products which

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[1] https://sustainabledevelopment.un.org/?menu=1300, accessed 20th January 2017.

can be sold to consumers. This paper will consider societal responses to various agri-food technologies through analysis of case studies focused on societal rejection and acceptance of enabling agrifood technologies from the 1950s to the present.

It should be noted that many technologies, including those applied in the agrifood sector, are acceptable to society, citizens and consumers, despite the potential for them to be associated with risk, or even uncertainties about potential risks. An example is mobile phone technology, which has been widely adopted by consumers because the benefits are perceived by end-users to outweigh any potential risks (e.g. see Burgess et al, 2002; Van Kleef et al, 2010). In the agrifood sector, the use of Pulsed Electric Field processing is presented as a case where there has been little consumer concern (Frewer et al, 2011). High intensity pulsed electric field (PEF) processing[2] involves the application of pulses of high voltage (typically 20 - 80 kV/cm) to foods placed between 2 electrodes, and has similar effects to thermal processing. PEF technology has been considered better than traditional heat treatment of foods because it avoids or greatly reduces the detrimental changes of the sensory and physical properties of foods, but may appear highly unnatural and technological to non-experts. Other food technologies, including those linked to food processing, are associated with negativity and rejection (see, inter alia, Bearth et al, 2014 Szűcs,et al, 2014).

One way of avoiding societal, citizen and consumer rejection of agrifood technologies is to design them in line with stakeholders' priorities and preferences. This will mean understanding societal preferences for implementation of technologies, as well as delivery of *socially desirable* benefits and implementation of *effective and transparent* mitigation strategies to deal with any potential risks. Understanding stakeholder priorities and preferences in this regard, and addressing these in the technological innovation process, is

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[2] https://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm101662.htm, accessed 20th February 2017

an essential part of implementing an effective commercialisation trajectory for technologies (Raley et al, 2016).

A starting point for discussion is, of course, understanding why some agrifood technologies have been rejected, and some accepted, by society. The focus of research has tended to be on those technologies which have been associated with societal concern. In other words, examples of technological innovation which have been rejected by some segments of society are frequently presented as exemplifying a more generalised consumer negativity towards technological innovation across the entirety of the agrifood sector. The assumption that consumers tend to reject agrifood technologies appears to drive many research agendas, particularly as enabling technologies reach higher levels of technology readiness. However, this assumption can be questioned. First, as discussed previously, not all food technologies and/or their applications are rejected by consumers. However, research into consumer responses tends to focus on understanding why the public in general, and consumers in particular, *reject* emerging technologies rather than *accept* them, or even enthusiastically seek out their products. Other barriers to technological innovation can also be identified within more specific stakeholder communities (for example, within farming communities or by retailers), and these also need to be considered as part of the development of an innovation trajectory for novel agri-food technologies. Here, historical societal responses to agrifood innovation, in particular the cases of pesticides applied to food production and genetically modified foods, and implications for more recent innovations (nanotechnology applied to food production, synthetic biology, precision agriculture and digital technologies applied in the context of agrifood innovation) merit further consideration.

1,1 Risk and benefit perception

"Risk perception" is the subjective judgement that people make about the characteristics and severity of a potential hazard, which may be informed by factors other than the technical risk estimate provided by experts (Slovic, 1987). It has been long established that that public perceptions of both risks and benefits associated with technological innovation processes are crucial for the future acceptance of a technology or product (Verbeke et al, 2007). "Public understanding" of technical risk will not explain the risk-related behaviours of citizens and/or consumers, nor will risk "education" align public views to those of experts (Kleef et al, 2007). In the absence of credible and understandable food safety signals or information, consumers face uncertainty and incur specific information search costs. The prediction of consumer attitudes is made more difficult because consumers are individuals with highly variable psychological, attitudinal and cultural characteristics, which cause them to react in a specific manner when making decisions about agrifood risks and benefits. In addition, of the various food safety incidents which have occurred over the last 50 years, (which have peaked in the 1990s and first decade of the current century), many have been linked to the unintended or unexpected effects of technological innovations (Lofstedt, 2013). Societal trust in the motivations of stakeholders in institutions with responsibility for protecting human and animal heath, the environment, and negative socio-economic impacts of technologies is an important factor determining societal acceptance of agrifood technologies (Frewer et al, 2011). Social distrust may be particularly relevant within the agrifood sector, as recent food safety incidents have resulted in a decline of public trust in food safety regulation and management (see, *inter alia*, Houghton et al., 2008; Lang, 2013; Wilson, 2013). There has been considerable debate about the potential public health consequences of different food safety incidents, which has, in turn, focused public attention on the regulatory systems which have been established in order to optimise consumer protection. Recent examples of such incidents include BSE (Miller, 1999), genetically modified foods (Frewer et al., 2004), dioxins (Verbeke, 2001) and acrylamide (Renn, 2003). As a consequence a policy need has emerged regarding approaches and activities focused on improving the regulatory and institutional processes associated with food risk analysis and regulation designed to promote and protect human and environmental health.

1,2 Theoretical background

Much of our understanding regarding the issues associated with societal acceptance of food technology acceptance is linked to the seminal research performed by Slovic and colleagues examining risk perceptions, how these are shaped, and subsequently inform attitudes and behaviours. The difference between expert and lay assessments of technological, and other, risks has been well established (e.g. see Fischhoff et al, 1978; Slovic, 1987; Slovic, 2000). This body of research has indicated that, that while technical experts make judgements about the severity of the risk based on technical risk assessments, lay people perceive risks multi-dimensionally, (for example, utilising cues such as the extent to which a hazard is perceived as unnatural to signal risk) or utilise heuristics or decision rules to evaluate riskiness, (for example, *trust* in those responsible for controlling the risk or protecting society from its impacts can be used as a cognitive “short cut” to evaluate the quality of the information, such that greater trust in the information source, the more the information will be believed and people will be acted upon, see Lobb et al, 2007; Hardy, and Sillence, 2013, Slovic et al, 2004; Slovic et al, 2007; Slovic et al, 1991). In their daily lives, people make risk assessments based on a number of factors. These include, for example, uncertainty, dread, catastrophic potential, controllability, equity, and risk to future generations (Slovic, 1999). It has been posited that experts fail to understand the psychological factors which determine citizen and/or consumer responses to specific hazards (for example, in relation to technological advances in food innovation), which has resulted in poorly thought-through commercialisation policies, (see, inter alia, Eiser et al, 2002; Costa-Font et al, 2008). In addition, the impact of moral or ethical concerns of the public have been underestimated in food risk regulation, including those associated with food technologies (Shaw, 2002; Konig et al, 2008; Coles and Frewer, 2013). It has been reported that research in this area has tended to focus on high-profile and dramatic potential hazards at the expense of familiar ones (Hawkes & Rowe, 2008).

2.1 Societal responses to various agrifood technologies

The evidence to be considered will focus on the relationship between consumer and/or citizen perceptions of risk and benefit associated with different agrifood technologies. The hypothesis that the public are inherently risk adverse, and high levels of risk perception are a normative response to agrifood technologies, will be challenged, and it will be posited that the future of responsible research and innovation in the agrifood sector, lies where information pertinent to the co-production of innovative, purposeful and socially desirable agrifood technologies is gathered to deliver societal benefits and accelerated innovation trajectories. For example, societal responses to pesticide use and genetically modified foods, and the impact this has on potential societal adoption of these technologies, can provide information relevant to the introduction of novel technologies such as nanotechnology and applications of synthetic biology. Adoption by other end-users and stakeholders will also be considered.

2.1. The use of pesticides. The starting point for societal development of institutional distrust?

Although other technological innovations have been associated with societal unrest and concerns about impacts of technology on human, animal and environmental health**,** the seminal work detailing the potentially negative impacts of technology in relation to agricultural technologies is arguably the publication of “The Silent Spring”, by Rachel Carson, in 1962). Carson presented evidence not only that pesticides were having negative ecological impacts, but also suggested that injudicious use of these chemicals ultimately leads to pesticide resistance (Heckel, 2012) and consequently food insecurity. The publication also provided the public with evidence that science, and scientists, were at best introducing technologies with uncertain health and environmental impacts, at worse developing technological innovations which delivered short term gains and aligned with the vested interests of a few powerful stakeholders. Evidence that pesticide residues were retained on foods destined for human beings further fuelled concern. This is not surprising as there is a considerable body of evidence to suggest that risk perceptions associated with food may be particularly high.

There is some evidence that pesticide residues in foods have represented a major source of cancer and toxicity for consumers and those exposed to them (Bolognesi and Morasso, 2000; Bonner et al, 2016). Exposure to pesticides through misapplication or misuse by farmworkers has also been well documented and the negative health impacts publicised, which leads credence to the notion that exposure will lead to negative health impacts (see Remoundou et al, 2014, for review). Thus there are two issues which need to be understood in relation to pesticides. The first relates to the issue of safe pesticide residues in foods eaten by consumers, and whether this aligns with toxicological risk assessments, as well as risk perceptions held by consumers. The second focuses on misapplication of pesticides, which may have negative environmental and agronomic impacts (for example, in relation to human health, negative impacts on biodiversity, and the emergence of pesticide resistance). Continued appropriate and safe use of existing and novel pesticide applications is important in order to promote and secure food security globally.

With regard to consumers, there is a body of literature which indicates that risk perceptions associated with pesticide residues and food is characterised by a range of psychological factors likely to exacerbate concern, including perceptions that the risks are unnatural and added to the risk environment by human agency (e.g. Brun, 1992), and are unnecessary, given the possibility of alternative production systems or approaches being available (e.g Miles and Frewer, 2002).

The scientific controversy associated with the possible impacts of pesticides potentially signalled that their use may be “out of control” (Aklin and Urpelainen, 2014), and thus human health and environmental impacts may be unanticipated, unintended and unpredictable. Affective factors influence peoples’ acceptance of pesticide use, disgust being an influential factor associated with consumer decision-making across different applications of agri-food technologies (Lusk and Bieberstein, 2014). There is also evidence to suggest that the extent to which consumers accept pesticides varies geographically, across different demographic segments, and with time (Yindoe et al, 2005; Simonne et al, 2016; Thøgersen et al, 2016). Risk communication has infrequently taken the concerns of the public into account, rather focusing on the irrationality of consumer risk perceptions and dismissing non-technical concerns as irrelevant. In the context of pesticides, affective responses by consumers, which are important in determining consumer acceptance of agrifood technologies, have been dismissed as irrational. This has further fuelled public distrust in regulators and the associated industries, and, as a consequences further communication about the topic are likely to be disregarded (e.g see Houghton et al, 2008). A key message from the pesticides case is that that once established, negative risk perceptions are difficult to change. A second message related to the targeting of information to different audiences. In the case of farmers, farm workers and operators, it may be desirable to heighten risk perceptions to increase the adoption of self-protective behaviours and reduce the emergence of pesticide resistance in target species through repeated or overzealous application (Remoundou et al, 2014), or increase the likelihood of adopting appropriate protective measures and safety equipment (Obopile et al., 2008). Perceived or actual work pressures may also result in inappropriate behaviours in these stakeholder groups (Arcury et al., 2002). Peer pressure (Heong et al., 2002) may also influence the behaviours of workers and operators. Lack of knowledge, for example, in relation to when treatments should be applied, or regarding the extent to which pesticides represent a hazard, may also discourage adoption of self-protective behaviours (Obopile et al., 2008). Similarly, the perception that resistance to pesticide risks will occur after years of exposure, or that a person's ability to control their own exposure to pesticides is limited, is likely to result in lower adoption of protective behaviour (Flocks et al., 2012, Arcury et al., 2002). The development of effective risk communication strategies is dependent on first, understanding the needs of the target audience, and developing risk communication strategies in line with peoples information needs, including values, and ethical concerns, in addition to changing actions to promote human or animal health. Best practice in how to do this is provided by FAO/WHO[3].

2.2 Genetically modified foods and the global controversy regarding their consumption

Genetic modification has been applied to a wide range of agrifood applications, ranging from insects and microorganisms to animals used in food production (for recent reviews, see *inter alia*, Forabosco et al, 2013; Prado et al, 2014). A considerable body of research exists with regard to citizen/consumer attitudes to genetically modified plants and animals utilised in agri-food systems and food production. This literature has been reviewed elsewhere, for example, see Costa-Font et al, 2008; Lusk, et al, 2005; Frewer et al, 2013). The main findings of the aggregated research will be summarised here. First, public perceptions of both risk and benefit associated with GM applications appear to be increasing with time, across the countries where data has been collected. At the same time, perceptions that the technology is unnatural, (a particularly pertinent factor in driving consumer decision-making in relation to food choice) has also increased with time. Ethical concerns appears to be more important in North America and Asia compared to Europe, although how the latter drives consumption decisions is not fully understood. Second, public perceptions of GM animals tend to be more negative than that associated with GM plants. Within the category of GM animals, the latter are perceived more negatively if utilised in the development of novel foods, independent of, for example, the nutrition or safety benefits, compared to genetically modified animals applied in pharmaceuticals, assuming ethical and economic issues are addressed in policy, and these applications are linked to tangible and desirable societal benefits. The societal tendency to reject GM foods has led to private sector rejection of the technology in food production, including the use of genetically modified ingredients in processed foods. For example, UK supermarkets have driven “GMO-free labelling” (Leitch,

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[3] http://www.fao.org/3/a-i5863e.pdf, accessed 20th January 2017.

2007). Public concern was a driving force for the introduction of GM traceability systems within the Agrifood supply chain [4]. However, it is also of interest to note that most research in this area was conducted between 1997 and 2011, (Frewer et al, 2013), the thirteen years following the intense publicity associated with the introduction of genetically modified soya into Europe by the US Monsanto company in 1996 (Fincune and Holup, 2005). It has been suggested that research funding has followed societal protests and technological rejection of technologies (Frewer et al, 2011). For this reason, *the drivers of consumer rejection of novel technological agrifood applications are better understood than factors which drive acceptance.* If the benefits (tangible or otherwise) are perceived as irrelevant or undesirable by *consumers* (as opposed to those who have been developing the technology), reasons for consumers to accept or adopt the application of the technology will be further diminished. Second, societal rejection of genetically modified foods may be regarded as a normative response to *all* agri-food production technologies by technology developers and regulators. These two issues will now be considered further in the context of emerging agrifood technology applications.

2.3 Does nanotechnology and agri-food production represent an overestimation of societal concerns by experts?

Despite evidence that consumers and/ or citizens are not necessarily adverse to technological innovation applied in the agri-food sector, the role of societal response to emerging technologies is still an important element in technological commercialisation trajectories. On one hand, it is still important to conduct primary research into existing attitudes and perceptions across different stakeholder, end-user and civil society constituencies, to compare the views of different groups and assess how these change in time, for example in association with a specific event (whether this has had positive or negative impacts), and to revaluate conclusions made at a particular in terms of emerging

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[4] https://ec.europa.eu/food/plant/gmo/traceability_labelling_en, accessed 20th January 2017.

social trends. Against this, scientific experts, policy makers and industry stakeholders may also act as “gatekeepers”, facilitating or blocking the development of specific applications. Historically, expert communities have tended to assume that consumers and/ or citizens were illogical, and that their views could be dismissed. However, following the realisation that societal adoption of the products of emerging food technologies was dependent on end-user uptake, experts began to take notice of the views of the public, heralding the rise of the “consumer-citizen”. As has been described in the case of genetically modified foods, experts tended to react badly to consumer rejection, dismissing perceptions and attitudes as “irrational”, rather than proactively understand societal concerns and preferences for application development. The expert perception that non-experts were irrational with respect to technology implementation catalysed the “Public Understanding of Science” movement (which was particularly prominent in the 1980s and 1990s), which in reality represented an ill-founded attempt to align public views of the risks associated with existing and emerging technologies with those held by experts. A second response by expert communities was to slow down the development of potentially beneficial technologies (including within the agri-food sector) on the basis that the applications under consideration would not be acceptable to consumers, and hinder other technological developments. Thus it is important to consider expert views of how acceptable they *think* specific technological applications are to the public, and their reasons for making these judgments, and how these compare to public perceptions of, and attitudes towards, the same issues. The case to be considered will be nanotechnology applied within, and beyond, the agrifood sector.

2.4 Expert and public views regarding the societal introduction of foods produced using nanotechnology

Nanotechnology is the manufacture and use of materials and structures at the nanometre scale (a nanometre is one millionth of a millimetre). Many large scale manufacturers of foods and agricultural products have already invested heavily in nanotechnology research and development (Scrinis and Lyons, 2007) and nanotechnology is already being used in some countries in the production of agricultural products, processed foods and drinks, and in food packaging. Agricultural applications include, for example, pest management through the formulations of nanomaterials-based pesticides and insecticides, enhancement of agricultural productivity using bio-conjugated nanoparticles (encapsulation) for slow release of nutrients and water, and use of nanomaterials in biosensors and remote sensing devices required for precision farming (Rai and Ingle, 2012). In foods, applications include smart and targeted delivery of nutrients, bio-separation of proteins, rapid sampling of biological and chemical contaminants, and nano-encapsulation of nutraceuticals in functional food production (Sozer and Kokini, 2009). However, most nano-related applications in the agricultural sector have not yet been commercialised (Parisi, Vigani, and Rodríguez-Cerezo; 2015), in part because of concerns about societal resistance to their application, and so economic implications in the future are difficult to assess.

Various studies have considered what experts believe to be the public views of nanotechnology and its applications (for example, see Corley and Scheufele; 2009; Ho et al, 2011; Yawson and Kuzma, 2010). Very broadly, this body of research suggests that experts are cognisant of the role that attitudes, risk and benefit perceptions, and trust play in determining societal acceptance of nanotechnology and its applications. However, the assumption is that lay people are likely to reject nanotechnology applied to food production and within some application sectors, in line with societal responses to genetically modified foods, and this is supported by some of the literature focused on these issues. For example, Capon et al (2015) considered the Australian citizen perceptions of the impacts of nanotechnology in the context of environmental health issues, risk, chemicals and trust in 2000 and 2013. The authors report that Australians have a relatively low level of concern about the risks of nanoparticles to health when compared to their concerns about other environmental health issues. Against this, the results suggest that if the issues associated with nanotechnology are reframed with a focus on ‘chemicals’, this may have a negative effect on risk perceptions. In this context, public opinions towards nanotechnologies remain largely inchoate, although it is postulated that this is likely to change with increasing public exposure to relevant information. An experimental approach was used to assess attitudes of British citizens before and after the provision of risk–benefit information on nanotechnology applications linked to food production (Fischer et al, 2013). The results demonstrate that some individuals become more positive and less ambivalent, whereas others become more negative and less ambivalent towards nanotechnologies. A third group (around 40%) maintained a neutral attitude and became more ambivalent. i.e. *more convinced that they did not have an opinion about the advantages or disadvantages of nanotechnology applied in the agrifood area.* Thus it is unlikely that these individuals would be involved or interested in the debate surrounding its development and application, but may be interested in adopting only applications which are perceived to be both beneficial and attractive. In other words, people will accept nanotechnology applications which they perceive to deliver useful and tangible benefits. These cognitions are not stable with time. For example, Van Giesen et al (2016) report that in the early stages of the technological innovation process, people rely relatively more on affect or emotional responses than cognition to make decisions about the acceptability or otherwise of nanotechnology. Over time, reliance on affect decreases, whereas reliance on cognition increases. This suggests that information about nanotechnology and its applications has become more integrated within peoples' already existing knowledge. However, for conventional technologies the influence of affect and cognition on overall attitude remained stable over time, as if attitudes had stabilised and were no longer amenable to influence by external changes in the information environment.

There is also evidence that people are less likely to reject even agrifood applications of nanotechnology if there are concrete and tangible benefits. For example, Gupta et al (2012) report that experts based in Western Europe believe that the public will accept the different applications of nanotechnology based on the extent to which each application is perceived by individuals to be at a real and tangible level, beneficial, useful, and necessary. The relationship between perceived risk and benefit has been confirmed in subsequent research. Agrifood applications were rated by experts as being less acceptable than other applications, for example in the domain of materials science and medicine. Broadening the geographical inclusivity of the expert stakeholder group (to Australia, Singapore and North America) resulted in similar results and conclusions (Gupta et al, 2013). This suggests that experts represent a fairly homogenous community with respect to how they perceive public perceptions of technologies. However, conducting methodologically similar research with consumers yielded different results. The results suggested that people differentiate nanotechnology applications based on the extent to which they perceive them to be beneficial, useful, necessary and important, a view which aligns with that held by experts. As part of this decision-making process, the results suggested that the benefits may be offset by perceived risks focusing on fear, again a result not dissimilar to that resulting from the expert analysis. However, consumers emphasised ethical issues as being important. A key finding is that consumers perceived fewer risks and ethical concerns associated with food applications than experts thought they would. An important point is therefore that, if commercialisation strategies are informed by expert views on what consumers will accept and/or reject in terms of specific applications of technological innovations, this will, in turn, need to be informed by research into consumer attitudes. It is also important to note that attitudes, and the factors which drive these, are not fixed in time, and are likely to change. For example, van Gierson et al note that attitudes towards applications of nanotechnology are more driven by cognitive, as opposed to affective, factors as the technology matures in terms of application. For more established technologies, the relative importance of affective and cognitive factors as drivers of decision making regarding acceptability remain constant with time. The occurrence of an external event which amplifies concerns, or demonstrates that benefits are desirable or essential, may also have impacts on the relative contribution of affect and cognition. This may partially explain social amplification and attenuation effects which are commonly observed following high levels of societal exposure to risks (amplification) and benefits (attenuation), which may be differentially operationalised through affective or cognitive routes. However, to date, the high levels of societal negativity associated with genetically modified foods have not been associated with nanotechnology. If and when, a high profile media event occurs linked to nanotechnology applied to food production, this may have impacts on consume perceptions of risk associated with the domain under consideration (food production and technology), the enabling technology underpinning the application more generally (nanotechnology applied across a range of sectors) or to the use of technology applied in food production systems *per se*. If such a change occurs, it will be necessary to understand whether changes in perceptions and/or attitudes are driven by affective or cognitive factors, or a combination of both of these.

2.5 Personalised nutrition and genetic privacy

Personalised diets based on people's existing food choices, and/or phenotypic, and/or genetic information hold potential to improve public dietary-related health. The most advanced form, "nutrigenomics", focuses on explaining the interactions between genes and nutrients at a molecular level, which can lead to precise knowledge about which foods will benefit or otherwise) the health of individuals with specific genotypes, assuming specific dietary recommendations are followed (Sales, Pelegrini, and Goersch, 2014). The field is in its infancy, and the direct and indirect economic benefits associated to public health systems are difficult to estimate at the present time as there is uncertainty as to how personalised nutrition will be implemented (for example, through existing health services or through the private sector (Stewart-Knox et al, 2016), which may influence its adoption by individuals if they are required to pay for personalised services. Researchers currently reference the costs of an individual utilising a nutrigenomics serve to be equivalent to those associated with obtaining personal dietary advice from a qualified dietician (Ronteltap et al, 2013), although this is a rough approximation given rapid changes in relevant technologies and regulatory infra-structures. While improved public health will have direct and indirect economic benefits, in terms of, for example, reduced incidence of non-communicable diseases, at the present time it is difficult to predict the relative advantage which will be delivered by wide-scale adoption of personalised nutrition and nutrigenomics over and above that which would be delivered by people simply making better and healthier dietary choices.

It is important to understand which factors, including attitudes and perceptions, determine the uptake of personalised nutrition in order to better target policies to encourage uptake, and optimise the health benefits of such a technological innovation. Compared to the other case studies in this analysis, the attitudes and perceptions of consumers towards personalised nutrition are associated with a low number of published papers, (Stewart-Knox et al, 2016), although relatively large data sets are available to analyse the interrelationships between different attitudes, perceptions and behavioural intention associated with potential technological adoption (Poinhos et al, 2014). This particular case demonstrates the importance of researching qualitative differences, and the drivers of technological adoption, associated with specific agrifood technologies, as communication about potential benefits and risks needs to take account of these if it is to be trusted by, and appear relevant to, consumers (Kahlor et al, 2003; Gerrard et al, 2008; Frewer et al, 2016). The issue of ethical concern has also been raised, along with other genomic technologies involving human data (Ries and Castle, 2008; Kolmeier et al, 2016; Shoenbill et al, 2014), with the public raising data privacy and deliberate or inadvertent sharing or “selling on” of human DNA data as potentially problematic. The public are also concerned that DNA testing will reveal that individuals will develop untreatable diseases in the future. The negative impacts of having the disease will be potentially exacerbated, if the information is passed on or made available to employers, insurers etc. Other ethical issues, such as the *unequitable distribution* of the human health benefits of a technological innovation such as personalised nutrition, may also need to be addressed, although this of course is not uniquely associated with genomic technologies but extends to almost every area where health advantages associated with a specific technological innovation can be identified. However, in the case of personalised nutrition, the perceived barriers tended to be linked to social structures and practices rather than ethical concerns. Questions arise as to whether the perceived risks of personalised nutrition outweigh the perceived benefits. The literature suggests that peoples‘ intention to adopt personalised nutrition depends on predictable psychological and sociodemographic factors, which are not necessarily related to personalised nutrition as a technology, but reflect more pragmatic factors affecting adoption. For example, individuals with awareness of health problems associated with a metabolic syndrome held positive attitudes towards nutrigenomic intervention, although public concerns about how genetic information is used and held were also identified (Stewart-Knox et al, 2009). Similarly, Stewart-Knox et al (2013) report that barriers to adoption of personalised nutrition are linked to broader technological issues associated with data protection, trust in regulators and service providers, and that an efficacious, transparent and trustworthy regulatory framework for personalised nutrition is required to alleviate consumer concern. People who perceive more benefit associated with personalised nutrition perceive fewer risks, and those with a high internal locus of control (i.e. who perceive that their own actions can influence their health status express a greater behavioural intention to adopt it (Poinhos et al, 2014). Other barriers may relate to actual or perceived financial costs of adopting personalise nutrition. For example, Fischer et al (2016) report an analysis of survey data collected across eight European countries (N = 8233). Participants reported their willingness to pay (WTP) for different types of personalised nutrition, ranging from advice based on lifestyle information alone, lifestyle and blood test results, and lifestyle, blood tests and DNA information. Thus their WTP reflected an increased level of “diagnostic” testing, at the same time reflecting increased potential genetic “privacy” issues if these data were shared. Pragmatic issues were also discussed by consumers as potentially problematic. For example, the ability of an individual to adopt “prescribed diets” when travelling, or eating with others in the context of social events, were also identified as being potentially problematic. WTP was elicited by contingent valuation with the price of a standard, non-PN advice used as reference. About 30% of participants reported being WTP more for personalised nutrition advice (about 150% of the reference price) compared to general dietary advice, although some differences were associated with socio-demographic factors. Men with higher incomes appeared particularly WTP for such a service. However, there is also an argument that suggests that, in order to maximise benefits to public health, the access to diet related technologies such as these need to be made available through health services as well as private companies. These findings raise questions as to what extent personalized nutrition can be left to the market or should be incorporated into public health programs. Independent of whether public, private, or public – private partnerships are the optimal route to delivering personalised dietary advice to the public, a need to utilise health professionals as part of this process has been identified. Their attitudes and perceptions towards the technology need to be addressed, as well as technological knowledge, in the development of relevant education programmes (Abrahams et al, in press). One conclusion is that adoption of personalised nutrition will be facilitated by the effective targeting of potential adopters through the development of effective communication programmes, as well as developing a transparent and trusted regulatory framework in which to embed genomic technologies, and practical solutions to the social problems associated with adopting personalised nutrition.

The case of personalised nutrition suggests that the notion that consumer / societal rejection of agri-food technologies represents a normative response to technological innovation processes is not accurate. Rather, adoption is likely to be driven by the extent to which personal or societal benefits are perceived to results from its application, pragmatic factors linked to technological uptake (such as convenience of use, cost or availability), and trust in the regulatory system designed to protect people, the environment and economic functioning of society from harm.

2.6 The future: Synthetic biology and agricultural production

It is envisaged that synthetic biology has potential to play an important role in future agriculture both for traditional crop improvement, and in enabling novel bio-production in plants, including modification of plants through application synthetic sensors, synthetic metabolic pathways, and synthetic genomes (Liu and Stewart, 2015). A broad range of potential applications in the agrifood sector has been identified, including the production of biopharmaceuticals and functional foods, food and dairy quality monitoring, packaging, and storage of food and dairy products (Tyag et al, 2016). The societal debate about the future of synthetic biology has largely been confined to the NGO community, for example by the ETC group[5]. Much of the debate within these communities focuses on issues not dissimilar to those associated with genetic modification. Examples include the patenting of life forms [6], the notion that the technology is in some way "playing god" or is in unethical because it is unnatural, (although most technologies, including those which have been accepted by society, could also be described in similar terms (Dabrock, 2009)). At the time of writing, little popular media attention has been paid to the potential impacts, whether negative or beneficial, associated with synthetic biology. Avellaneda and Hagen, (2016) confirm that the factors which influence public perceptions of synthetic biology are almost identical to other enabling technologies, most notably genetic modification. , In addition to perceived risk and ethical concerns, the authors report that the extent to which an individual trusts in science and the associated regulatory frameworks in which the technology is embedded is also important, again drawing similarities with genetic modification. While synthetic biology may conflict with the public's preference for "naturalness" in various areas of application, this is at present "dormant" due to low levels of media attention focused on genetic modification, together with the absence of societal discussion associated with potentially controversial impacts. Increased media attention may not be negative, nor is societal rejection inevitable, although the issue of effective regulation has been raised as an essential component of societal acceptance (Bubela et al, 2o12).

Societal responses to the application of synthetic biology may distinguish between "top-down" and "bottom up" applications (e.g. see Bedau et al., 2009), where top down

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[5] http://www.etcgroup.org/issues/synthetic-biology, accessed 21st January 2017

[6] https://www.semanticscholar.org/paper/Synthetic-biology-Attempt-to-patent-artificial-Kaiser/cface53403febe4edfb9d8cb8f6c53656efa8b84

applications are generally regarded as being initiated from a pre-existing natural living system which is then re-engineered to obtain a specific goal (Ro et al., 2006), through genome synthesis (e.g. Gibson et al., 2008), or genome transplantation (Lartigue et al., 2007). “Bottom up” synthetic biology attempts to develop minimal chemical cellular life (or “protocells”) from inanimate raw ingredients (Rasmussen et al., 2008). The latter is less developed scientifically compared to the former, and at the same time may result in more controversy if the issue of “creating life” enters centre stage in the societal debate. There has been speculation that it is “bottom-up” synthetic biology which will be the primary focus of societal risk perceptions, negativity and ethical concerns (Cranor, 2009), although this has not to date had consequences in the social world. Frewer et al (2011; 2016) note that the release of living, manipulated organisms which are both “bioactive” and uncontrollable may have important consequences for risk perceptions, and societal applications of a range of enabling technologies. However, it may also be important to ask whether there are additional issues raised over and above those associated with other enabling technologies applied to food production and beyond. And if there are, will they have negative impacts of human, animal or environmental health, or result in negative socio-economic consequences. In turn, societal acceptance may depend on the development of “bespoke” features of the regulatory framework, for example differentially linked to agrifood or pharmaceutical applications, which may be required for social acceptance to occur. It may be relevant to consider market entry of products in terms of potential societal benefits, and how these are prioritised. For example, the development of novel antibiotics may represent a greater societal priority for the application of synthetic biology compared to the development of novel flavour enhancers, (Hayden, 2016), but understanding whether this is the case will require research and not just speculation.

3 Regulation and governance

The on-going societal discussion about GM applied in particular to food and agriculture has had negative impacts on the successful exploitation of GM technologies, and hence potentially beneficial effects and impacts. In Europe, the regulatory base associated with emerging agrifood technologies has focused on potential risks, and assessment of these. Discussion about the positive and negative socio-economic impacts of such enabling technologies has remained an informal part of the approval process. However, innovation in agrifood needs to deliver products and processes which will benefit society, and it is arguable that this should be formally addressed within the regulatory approvals process. At the same time, public opinion and preferences regarding technological innovations associated with emerging technologies may change. For example, within Europe, there has been less societal criticism of a range of technologies (biotechnology and genetic engineering, computers and information technology, nanotechnology, nuclear energy, solar energy, and wind energy) in recent years, potentially associated with reduced distrust in government and industry. This trend has been accompanied by increased enthusiasm within Europe for novel technologies, including biotechnology and genetic engineering, and a more sophisticated societal appraisal of what these technologies offer in terms of benefits (Gaskell et al, 2011). It would therefore be appropriate to include assessment of the benefits of enabling agrifood technologies as a formal part of regulation and approvals processes. Regulation within Europe is focused on risk assessment, and benefit assessment is not considered within the regulatory framework or associated governance processes (Waigmann, *et al.* 2012). It is of interest to consider whether formal benefit assessment might be included in governance frameworks (König et al, 2010). Furthermore, within Europe, there has been a shift in focus away from the assessment of specific risks associated with technologies, towards more holistic understandings of the entire innovation process and associated governance strategies. This might, for example, include discussion of which innovation produces the least risk per unit of benefit (Fischhoff, 2015). For such an analysis to be conducted, both risks and benefits need to be assessed in order to evaluate the trade -off between the two. A broader, more inclusive, approach to shaping future research agendas and programs is required, including obtaining the evidence necessary for regulation and policy development. Although benefit assessment is implicitly incorporated into the decision-making stage of governance and policy processes, making benefit assessments (including socioeconomic and ethical analyses) explicit is likely to facilitate the innovation trajectory of enabling agrifood technologies and their applications. This will allow due consideration of risks and benefits in regulation, governance, and policy practices, increasing the transparency of the regulatory and policy framework in a way that is more acceptable to all stakeholders, including the general public.

4 Conclusions

The drivers of societal responses to different agrifood technologies have been reviewed. It can be concluded that consumer and/or citizen acceptance is driven by a range of psychological factors, as well as the “temporal context” into which the technology is being introduced. Lessons from the past introduction of novel agrifood technologies can also be identified. Prominent among these is the need to understand societal preferences and priorities for technological innovations applications (in particular first generation consumer products). Given the potentially diverse range of applications derived from a range of enabling technologies, assessment of societal and consumer priorities need to be on a case by case basis. Risk-benefit assessment (including impacts on human and environmental health, and potential socio-economic impacts) should be an integral part of governance, Ethical issues may also need to be considered, in particular, but not exclusively, where technologies deliver “living” applications which can continue to evolve independently and uncontrolled in the outside world. Such analysis may also need to be integrated into Risk Analysis and associated governance strategies. While the normative assumption that consumers and/or citizens are “anti-agrifood technology” is rejected, it is essential to co-develop applications of agrifood technologies with stakeholders and other end-users, including consumers. Failure to do so may result in consumer rejection of agri-technological products, citizen rejection of the enabling technology, and stakeholder concerns about how to operationalise an effective implementation strategy. In turn, our ability to ensure a safe and secure food supply may also be compromised.

As food security is increasingly compromised, society must utilise innovative technological solutions to ensure a healthy and safe food supply, while at the same time reducing the negative environmental impacts of agricultural production. This can only be achieved through ensuring that agricultural technologies and their products align with societal expectations, requirements and priorities.

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