A review of research on public attitudes to Genetically Modified foods and related areas and their implications for Genome Editing of Farmed Animals

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Note
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Executive Summary

Scope

- This work is intended to support the Nuffield Council for Bioethics' working group on genome editing (GE) and farmed animals and the societal issues around this topic.
- The focus of this particular review is on research that helps us to understand and predict the nature of public attitudes to GE and farmed animals. On the assumption that attitudes to Genetically Modified (GM) foods – as a forerunner issue/technology – is likely to provide the most salient analogies, the review initially focuses on this topic. However, the review extends beyond GM foods, to consider public attitudes to other potentially relevant issues that *overlap* this issue, notably, *novel foods and processes* and *farm animals*, as well as considering the few studies that have addressed attitudes to GE more broadly (including for human applications).
- The review *does not* consider research on more removed domains, such as attitudes to science in general and other biotechnologies (e.g. cloning), or attitudes to biotechnology applied to animals in non-food contexts (e.g. wild animals, lab animals or medical animals).

Findings

- The review first *briefly* surveys the broad landscape of the 'GM' debate, noting the apparent resistance of the public (and policy makers) to use of the technology, particularly for food purposes.
- The review proper then stats with consideration of what research actually reveals about *public attitudes* to GM foods. This confirms a degree of opposition and concern that has persisted over at least the last 20 years (though not universal opposition – there being considerable ambivalence too). GM foods have been seen as having questionable benefits along with a number of potential risks, with concern about their 'unnaturalness' and necessity. While there is *some* evidence of changes in attitudes across populations during this time, lack of large longitudinal (or even cross-sectional) research militates against making firm conclusions on this matter. However, with *perceived benefits* being a consistently strong factor linked to GM food acceptance, it is likely that 'second generation' products (with benefits for consumers in terms of health or environment)

are/ will be more acceptable than 'first generation' ones, that initially benefited producers more clearly than consumers.

- Research on attitudes to GM foods has also considered attitudes to different genetic engineering processes and applications. Regarding applications, research confirms that biotechnology applications seem to arouse more concerns than other technologies, and that medical biotechnology applications are perceived more positively than food applications (having more clear benefits). Furthermore, modification of crops is perceived more positively than of animals. Evidence of degree of approval of *specific* intervention purposes (e.g. whether intervention is to improve animal welfare, increase yield, improve human health, improve nutrition) is not extensive or consistent. Arguably, the more pertinent the *benefits* (and/or risks) of an application to a particular studied sample of the population (which may differ according to interest related to demographic, socio-economic or cultural aspects – see shortly), the better its approval.
- However, framing and terminology matter, with some evidence that approval/ opposition may vary depending upon what a process is named, and also, to some degree, how it is described and what it actually involves. One interesting issue is differences in public attitudes to cisgenic versus transgenic modifications, with *some* evidence that moving genes from within species (cisgenic) is better tolerated than moving them across species (transgenic) in terms, for example, of willingness to pay (WTP) for hypothetical products. However, differences, though often statistically significant, are generally of very small effect size and arguably not meaningfully relevant. This may have positive implications for the acceptability of GE that is non-transgenic, but it is clear that *applications* are much more strongly related to attitudes than differences in technical *processes*.
- The review goes on to consider the importance of other factors related to attitudes to GM foods. One of these is nationality. The Eurobarometer surveys (the source of the greatest data of relevant research on this topic, being iterated in largely similar form over many years) show that in Europe, *trends* in attitudes have generally been fairly consistent across European countries, though degree of support/ opposition has varied, for example, with Spanish respondents often being more supportive than others, which might be linked to the fact that Spain is one of the few countries in Europe that grows GM crops. There is also some evidence that US respondents are more positive (less negative) than European consumers, which again might be associated with such crops

being grown there (exposure/ familiarity) – though differences are again largely in degree/magnitude (i.e. US consumers requiring a lower premium to buy GM food over non-GM alternatives, but *still* requiring a premium). Research also shows relative opposition to GM crops in other parts of the world (e.g. Japan, and in developing countries) though lack of large scale cross-national comparisons makes drawing firm conclusions about the relative importance of national culture (etc.) for attitudes difficult to draw.

- Aside from nationality, differences in attitudes (degrees of support/opposition) have been found to be correlated to differences in various demographic and socio-economic factors. Evidence generally suggests that men are more positive about technology/ biotechnology/ GM foods than women, and that younger people tend to be more positive than older ones. But evidence on education levels and wealth is less clear cut. Note that interactions *between* these factors are also unclear though likely - along with interactions with specific GM application and *many* other factors. Thus, most research in this area involves correlating factors/ variables and identifying *main effects*, with interactions, when identified, often being difficult to interpret or inconsistent. Little research has delved more deeply into why, for example, men or younger people are more positive (when addressed, the main explanation seems to be that research into *risk perception* appears to show that women and older people are more *risk averse* than men and younger people, and there could be evolutionary/ biological and cultural reasons for this).
- Some research has considered whether certain values are related to attitudes to GM food. An ecological worldview that values *naturalness* seems to be associated with negative attitudes towards GM foods (e.g. perceptions of low benefits and higher risks), though other worldviews and values (e.g. related to political or religious values) have not been convincingly shown to be so related. There have been a few studies of how personality relates to GM food attitudes too, with some evidence that traits such as Openness and Conscientiousness may be so related.
- The relationship of knowledge to attitudes is an important issue in this area, with the 'knowledge deficit' model essentially assuming that ignorance is related to low support of science, and that this might be overcome through increased education. A considerable number of studies have considered relationships of knowledge to attitudes to GM foods. However, reported *awareness* of GM foods does not necessarily correlate

with *actual* knowledge of GM foods, and though there does seem to be some relationship between these aspects of knowledge and attitudes, it is complex and results are not consistent. It is possible that studies reporting no statistical relationship between these factors may in part be consequent on the deficiency of measures used, that is, objective knowledge has tended to be assessed by responses to small numbers of true-false questions in which average responses only slightly exceed scores obtainable by chance. On balance, we might tentatively suggest that higher awareness has a tendency to be related to negative attitudes, and higher objective knowledge to positive attitudes, but more research is still needed to confirm this.

- Our analysis then extends to the broader consideration of novel food products (NFPs) - a category that includes GM. This research seems to identify similar factors as of importance to attitudes of acceptance as do studies of GM foods, suggesting that GM is not especially unique in the food context, though these wider studies hint at other factors as of import for attitudes too, such as *disgust* and *perceived behavioural control*. Understanding GE applied to foods should acknowledge this broader frame of reference, and indeed, recognise that the *technological* aspect may be *relatively* unimportant for attitudes, with *novelty* being the key factor when considering foods.
- The report briefly considers the issue of public attitudes to *farmed animals* (irrespective of any technological manipulation or innovative component). Though *animal welfare* is at least a theoretical concern to many of the public (with evidence of public WTP for products associated with greater welfare), there is evidence of an attitude-behaviour gap (i.e. that professed intentions do not translate into actual purchase behaviour, where aspects like price may triumph). As such, how this concern might translate to attitudes to GE products in which increased animal welfare is one benefit (as opposed to, say, health or environmental benefits), and how this might trade-off against perceptions of risks or unnaturalness (etc.) in the formula of acceptability, is currently uncertain.
- Research on attitudes to genome editing (GE) is also reviewed. Most studies have been on human as opposed to non-human use. By and large, similar factors are identified as being important for/ associated with attitudes of acceptance as with the other topics considered in this report e.g. risks, benefits, unnaturalness. The biggest factor seems to be the purpose of applications, with applications for human health approved of more than for human enhancement, with use on animals and crops for food purposes more comparable to enhancement uses. For animal uses, the issue of animal welfare again

emerges as a factor in acceptability, albeit from very few studies. There is no evidence that GE is understood to differ from GM.

- A separate section considers the issues of trust, science communication, and public engagement. 'Trust' is identified as a factor related to attitudes to GM, novel foods, and GE, with low trust in stakeholders, communicators (etc.) related to higher concerns and lower acceptance. Trust appears to act as a surrogate for how people evaluate a topic, and would appear particularly important in contexts in which knowledge is low (e.g. GM/ GE). Effects of science communication appear mediated by prior attitudes, so of uncertain effectiveness when strong attitudes are already formed. Further, when people do seek information on a topic this is likely to be driven by prior attitudes ('confirmation bias'), though some searches may be easier than others and depend on the availability of information on a topic. For example, there is some evidence that GM information tends to be biased to the negative. Public engagement seeks to engage with the public in two-way processes, with balanced information and chances to respond to participant questions. The benefits of engagement in this domain are uncertain, however, with difficulty in accessing reports on exercises and potential inadequacies in report descriptions - though the process generically is likely to have some benefits in exploring reasons for attitudes and how they might be countered/ supported.

Limitations

- This review has considered research on disparate but related subjects. The research itself has a number of limitations. Much of it is quantitative rather than qualitative, in which respondents have been asked to respond to specific statements related to factors believed to be of relevance, which may miss other factors that are also of relevance (e.g. disgust, social norms). Because knowledge on the topic of issues like GM is generally low, there is also a risk that respondents generate answers at the point of questioning and that they do not reflect well-formed attitudes, while studies on intention (to pay, consume, behave) may also provide a biased picture on attitudes. Further, the complexity of the issue of attitudes - which are liable to be the result of complex interactions between many factors - means that we do not as yet have a clear answer to our fundamental research questions. As such, research on attitudes to GE should not assume full generalisability from areas like GM: qualitative research is needed to identify relevant factors that may be unique or differ from those found in related areas of research; and large-scale quantitative research is needed with validated and standard construct measures to confirm what factors are relevant and, importantly, their inter-relatedness.

Conclusions

- This review has identified a number of important factors likely to be important in the formation and maintaining of attitudes to GE with farmed animals. It is a matter of conjecture as to how generalizable the findings from past research will be to this new domain, but we posit four main conclusions: 1) that attitudes will be dependent upon how the public frame the matter, whether of technological fixes, novel foods, or the (mis)use of animals; 2) that applications are far more important than the technological differences between GM and GE, and that the findings on GM are thus liable to be highly pertinent to GE; 3) that perceived benefits (more than even risks - at present, in the absence of any significant crisis) are liable to be a critical factor for acceptance; 4) that the issue of naturalness and ecological views are liable to also be important.
- We conclude by noting that though this review has been extensive there are other areas that could be addressed in further work, not least the potential impact of significant social/ cultural movements related to the ‘organic revolution’, veganism, sustainability and food security.

1. Introduction and Terms of Reference

This work is intended to support the Nuffield Council for Bioethics' working group on genome editing (GE) and farmed animals. Specifically, this is an evidence review that is intended to aid the working group in identifying and examining the ethical dimensions of the impact of *genome editing technologies* on the *production, use and welfare of animals* for direct human consumption. With little existing direct evidence pertaining to perceptions and attitudes towards the use of GE in this context, this evidence review seeks to establish the nature and basis of public attitudes on *related technological applications for similar purposes*, notably, *genetic modification* as related to food (including but not limited to farm animals), although it also segues into related areas (e.g. novel foods and processes) where these might provide additional insights. It then attempts to draw lessons for GE – where possible - in realms such as research policy, regulatory policy and consumer behaviour.

Given time and resource constraints (as recognised by the funder) it has not been possible here to provide an extensive review of all of the many pieces of research on attitudes in the GM and related areas, such as through a systematic review using well-defined search terms, while a meta-analysis is similarly beyond the scope of this project (to put in context, a current proposal call for such a review on 'public engagement' by Nuffield offers approximately *30 times* the financial resources to this commission). As such, we have been guided by our own expert knowledge of the area, informing searches of relevant academic databases (notably Web of Science and Google Scholar). Our approach has generally been to search for the most recent examples of papers on the 'GM' topic, identifying critical papers cited in these, and then tracing forwards again from these key papers to other more recent ones that we may have missed. During these searches, links with related research – such as on novel foods and processes – became clear, necessitating (in our opinion) a broadening of the search space. Furthermore, our initial focus was on the academic literature rather than the grey literature, partly because of the resource issue, but also because of the questionable quality of research in reports that have not been peer-reviewed – although it soon became apparent that a number of major reports for the EC (the 'Eurobarometer' reports) actually provide some of the best and most consistent work, and in fact these formed a seed around which our discussion of GM foods coalesced. Nevertheless, in spite of resource limitations, this report has proven a significant endeavour, and we are confident that the key trends identified below *do* represent the current state of knowledge on the topic at hand; as to the quality of the extrapolations we make, we leave this for others to judge, and firmly contend that any questions from the funders that we haven't answered are simply because they are not currently answerable. In the final sections of the report, limitations of the reviewed research and our own analysis are discussed.

The report unfolds as follows. It begins with a *brief* consideration of the socio-political context of the issue of GM/GE applications in food. This highlights the currently difficult regulatory environment for GM, and discusses the prospects and limitations for GE, setting the scene for the subsequent review.

The following section summarises the key findings from the literature on attitudes towards molecular genetics technologies (positive and negative) in the context of food production generally, including (but not exclusively) for animals in products for human consumption. Various subsections discuss the *main factors* that have been found to be related to general attitudes of support/ opposition and the reasons underlying these attitudes. Because the *application* and *purpose* of technology is shown to be an important factor, subsequent sections consider research in overlapping domains that might also conceivably be informative, notably *novel food processes* more generally (given that the public might frame the issue primarily as one related to novel foods in the absence of knowledge about the technology *per se*), and non-engineered *farmed animals* (given that the public might frame the matter as about *animals* rather than *food* or *technology*). One further section discusses the limited research on GE and its various applications (mainly human), for what this might reveal about attitudes to the *specific technology* and its various extant and potential applications.

Following this walk-through of findings from these diverse areas, another section considers issues of trust, science communication, and public engagement. These matters appear to be related to people's *actual* and *potential* attitudes in all of the disparate domains covered in the review, which are particularly important given that research tends to reveal that the public (in the UK and more widely) have little understanding of GM/GE approaches. Enhancing 'trust' and providing relevant communication and public engagement may ultimately prove the most significant activities for gaining confidence in GE in the public - or at least, for allowing *considered* societal debate, even if that should lead to rejection of GE for farmed animals in *some* or *all* applications.

Methodological issues related to research are highlighted in one further section, considering the quality of past research and the difficulties of surveying people on topics about which they know little. This discussion leads to a number of thoughts on the kinds of research that ought to be attempted in the GE area.

Finally the report considers the exportability of the reviewed evidence to the current issue. That is, the report consequently advises on the applicability of the evidence collected in related domains to the formation of public perceptions and attitudes on GE applications on animals and food. Limitations in the extrapolation are noted; further research areas that might be informative are identified; and a number of tentative recommendations (on topics such as the role of social media) are provided.

2. Context: Genetic Modification and Genome Editing

According to WHO (2014), genetically modified organisms (GMOs) can be defined as organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination. The technology is often called "modern biotechnology" or "gene technology", sometimes also "recombinant DNA technology" or "genetic engineering". It allows selected individual genes to be transferred from one organism into another, also between nonrelated species. Foods produced from, or using, GM organisms are often referred to as *GM foods*.

Most *food* modifications have primarily focused on cash crops in high demand by farmers such as soybean, corn, canola, and cotton, engineered for resistance to pathogens and herbicides (e.g. BtMaize) and for better nutrient profiles (e.g. Vitamin A enriched Golden Rice) – either for consumption by humans or as animal feed. The first genetically modified *animal* to be approved for food use was the AquAdvantage salmon in 2015, modified to enable it to grow year-round instead of only during spring and summer (e.g. see Frewer et al, 2013). Livestock have been modified with the intention of improving economically important traits such as growth-rate, quality of meat, milk composition, disease resistance and survival, though these are not generally commercially available. Adoption of GM crops by farmers, however, has been rapid: between 1996 and 2013, the total surface area of land cultivated with GM crops increased by a factor of 100 (ISAA, 2013), although geographically the spread has been uneven, with strong growth in the Americas and parts of Asia and little in Europe (mainly Spain) and Africa (Qaim, 2016).

In spite of the expansion of GM foods throughout the world, there has been notable public and political resistance, particularly in certain parts of the world, such as Europe. A full history of this issue (and controversy) is beyond scope of this report, although it is worth highlighting some of the most salient incidents, starting in the 1990s, when some of the first consumer applications of biotechnology became available. The commercial sale of genetically modified foods began in 1994, when Calgene first marketed its Flavr Savr delayed-ripening tomato. This arrived in the form of tomato puree on UK supermarket shelves in 1996. The benefits of this, noted on the product packaging, was 'less waste' and 'reduced energy in processing' – typical of early applications that 'even by the admission of industry offered no direct benefits to consumers' (Gaskell et al, 2003, p.2). Although this product apparently sold well it was subsequently withdrawn for technical reasons, and induced little public discussion. However, 1996 ultimately proved to be something of a watershed year for the technology, beginning with controversy over the shipment from the US of genetically modified soya, developed by Monsanto, which entered the food chain *without labelling*. This coincided with the BSE/CJD crisis in the UK (1996) and other food scares around Europe, leading to critical press coverage (describing GM as 'Frankenfoods') and opposition by NGOs and some scientists (with the so-called Pusztai affair, in 1998-1999, suggesting that genetically modified potatoes had harmful effects on rats), culminating in a 1999 European moratorium on the commercialisation of GM crops. A further European Directive on deliberate releases (2001/18/EC) then led to the phasing out of antibiotic markers, transparency of risk assessments, more stringent follow-up evaluations, and labelling requirements (among other things). Further international tensions followed, including the US making a complaint to the World Trade Organisation about European barriers to GM agricultural products (see Gaskell et al, 2003), and Zambia rejecting donated aid comprising GM wheat in 2002. Aside from Europe, other countries ban the cultivation of GM crops, such as Japan (e.g. see Komoto et al, 2016).

The term 'Genome Editing' (GE here) is shorthand for a cluster of *new* scientific techniques that make it possible to make changes at specific sequences of DNA, by inserting, deleting, modifying or replacing DNA in the genome of a living organism. Genome Editing techniques such as *CRISPR-Cas9* make it much simpler, more predictable and cheaper than previously, and unlike early genetic engineering techniques that randomly insert genetic material into a host genome, genome editing targets the insertions to site specific locations. Applications currently include increasing crop yield and resistance, developing 'third generation' biofuels, and controlling insect-borne diseases (e.g. Bao et al, 2019; Smith and Samuel, 2018).

One focus of concern is the extent to which GE and GM are similar. For example, in April 2016, a white button mushroom (*Agaricus bisporus*) modified using the CRISPR technique received *de facto* approval in the United States, after the USDA said it would *not* have to go through the agency's regulatory process, as it considered the mushroom exempt because the editing process *did not involve* the introduction of *foreign DNA* (Waltz, 2016). However, the current regulation in the European Union (EU) on genetically modified organisms (GMOs) treats cisgenic plants (which essentially do not involve genes from a sexually incompatible species) the same as transgenic plants (which do) with both required to be mandatorily labelled as GMOs, implying gene edited products are similar to GM ones.

An underlying concern is thus whether public *attitudes* to GM – widely thought to be negative in the UK/Europe and (to a greater or lesser extent) elsewhere - will carry through to GE. The bulk of this report reviews research on attitudes to GM (and related domains) in order to make some extrapolations to the newer GE field.

3. Attitudes to GM Foods

The previous section noted the general socio-political reaction to GM technologies and their applications, particularly as regards foods. But what exactly does research tell us about public attitudes to these matters? This section focuses on perceptions of the technology of genetic modification of foods itself and in comparison to other biotechnologies.

3.1 General Attitudes of Support or Opposition to GM Food

Attempts to assess attitudes to GM generally appear to have taken two forms. The first is using surveys to ask people about their general attitude to the technology or to its applications, often in terms of whether they support or oppose these. Attitude questions often vary between studies in this area, with no one accepted ‘scale’, and as such some caution is required in assuming that different studies are actually assessing *exactly* the same concept, particularly since question framing and wording can play a significant role in affecting response (as may the mode of asking a question, whether face-to-face or online, etc.). The second is to ask whether people would be willing to buy, accept, or consume such products, generally using the ‘willingness to pay’ (WTP) approach (or similarly, ‘willingness to accept’, or WTA). This latter approach (often used by those from a marketing perspective) formally seeks to establish the maximum price at or below which a consumer will definitely buy one unit of a product - in order to establish whether there is a market for it - and this is usually done by comparing the target to other products (e.g. what is currently available, in this case, non-GM products). The method is well developed with various forms and procedures: these will not be discussed here in detail, although it is worth noting that WTP approaches often measure consumers' hypothetical, rather than actual, WTP and thus can generate 'hypothetical bias', where stated WTP differs from, and often exceeds, 'true' WTP (e.g. Lusk et al, 2005). (Often, but not always: sometimes actual 'auctions' can take place where people bid for real products, although these come with their own methodological issues that are too involved to consider here.) In this section, results from across different types of surveys are collated to give a general idea of public views on GM applications.

Perhaps the most extensive evidence on public attitudes comes from a succession of Eurobarometer surveys on 'biotechnology' using large representative samples of the public living in (many) different European countries, conducted in 1991, 1993, 1996, 1999, 2002, 2005, and 2010 (e.g. European Commission, 1997; INRA, 2000; Gaskell et al, 2003; Gaskell et al, 2006; TNS Opinion and Social, 2010). These surveys are particularly valuable in that they adopted *largely* similar questions, allowing comparison of changes over time. They also addressed various biotechnological applications – and we will consider differences in attitudes between these shortly – though our primary focus in this subsection is on views towards GM foods in particular. However, it is first useful to note that the early surveys asked about GM foods and GM crops separately (1996, 1999, 2002), with GM foods defined as 'using modern biotechnology in the production of foods, for example to make them higher in protein, keep longer or change the taste' and GM crops (also referred to as 'gene transfer') as 'taking genes from plant species and transferring them into crop plants to increase resistance to insect pests'. The 2005 and 2010 surveys dropped 'GM crops' although the definition of GM foods was amended to include a crop-related example, i.e. GM foods were: 'made from plants or micro-organisms that have had one or more characteristics changed by altering their genes. For example, a plant might have its genes modified to make it resistant to a particular plant disease, to improve its food quality, or to help it grow faster' (i.e. note that the example refers to crops instead of animals).

In spite of previously noting that the Eurobarometer surveys provide a good benchmark for understanding attitudes over time, even these are not perfect, with occasional variations and extensions over time that may have undermined comparability. For example, in 1999 a new question was added asking respondents whether or not they had *heard* about each application before giving their judgments, which was inserted to help distinguish between those respondents who were more likely to have an attitude formed *before* the survey, or at least some prior knowledge of the topic, and those who, it may be assumed, formed a judgment on the spot, probably without much relevant information (Gaskell et al, 2003). This seemed to have had the effect of changing the proportion of 'don't know' responses to other questions from 1999 onwards. This approach also led to the development of a classification of 'decided publics' by the survey authors – a smaller subset of the total number of respondents (typically around half when this manipulation was introduced) – into *Supporters*, *Risk Tolerant Supporters*, and *Opponents*, that arguably muddled the overall message from the surveys. Hence, when considering all responses, results tended to reveal over the range of surveys that Europeans, on average, were generally opposed to GM foods (in particular), whereas analysis of proportions of supporters and opponents sometimes gave more nuanced messages and a slightly different picture - seeming to generally increase the apparent amount of support when compared to the total datasets (e.g. amongst the 'decided public' in 2002, overall support and opposition for GM foods was equally divided).

Aside from asking about familiarity with the concept (discussed later), the technologies have been evaluated by asking a number of standard questions on whether respondents thought the technology is *morally acceptable*, *useful for society*, *risky for society*, and *should be encouraged*. The essence of results is that, in 1996 and 1999 there was 'widespread opposition' to GM food and crops in much of Europe (see Gaskell et al, 2000) - although a close look at results suggests that opposition may not have initially been that *deep*. The 1996 survey suggested that, on average, GM food was seen as mildly *useful* and of uncertain *moral acceptability*, though *risky* and *not to be encouraged*, as opposed to GM crops (referred to as 'gene transfer'), which was also *useful*, of uncertain *risk*, though *morally acceptable* and *should be encouraged* (INRA, 2000). In the 1999 survey, both GM foods and crops clearly dropped on three of these criteria (less so for perceived risk, where they were rated as of similar riskiness to previously). Thus, GM foods were the only application (of seven biotechnology applications) to score below the midpoint for *usefulness* (i.e. on average they were perceived as *not* useful), whereas for GM crops (gene transfer) they were rated as (only mildly) *useful*. Both GM foods and crops were seen on average as *risky* and *morally unacceptable* and should *not be supported* (food more so in every case). However, there was some variance across countries, in these and in later surveys – as will be discussed shortly.

Results from the survey of 2002 did (according to Gaskell et al, 2003), suggest growing 'ambivalence' (less negativity), although the majority of questioned Europeans still did not support GM foods, which were judged as *not useful*, to be *risky* for society, *morally unacceptable*, and not *supported*. Meanwhile, for GM crops support was better: while these were judged to be *moderately useful*, *morally acceptable* and were *mildly supported*, they were seen as almost as *risky* as GM foods, a difference that Gaskell et al (2003) suggested might be due to Europeans at that time being more concerned about food safety than the environmental impacts of agri-food biotechnologies. With the omission of the GM crops comparator, the 2005 survey again found that a majority of Europeans provided negative average evaluations of GM food against the four noted criteria, and indeed, in the final Eurobarometer survey on the topic (TNS Opinion and Social, 2010), similar results (albeit to different questions) led to its authors concluding that Europeans 'do not see benefits of genetically modified food, consider genetically modified foods to be probably unsafe or even harmful and are not in favour of (its) development' (p. 7).

A plethora of other surveys and studies have attempted to characterise the degree of support for *GM foods* though without Eurobarometer's longitudinal aspect. One paper that is worth noting, however, is a recent analysis by Cui and Shoemaker (2018) summarising a number of studies in China that have compared 'general attitude towards GM food' from 2002 to 2016, recording degree of support versus opposition (note that 17 studies were discussed: this review doesn't have space to review each in detail; see that paper for references). According to the authors, most of the previous surveys were limited to a few of the largest cities in developed areas of China, with little or no coverage of rural areas, and with respondents in most cases less than 1000, whereas their own study surveyed 2063 consumers from every province in China. In response to a question 'In general, will you support GM food?' the percentage of those who supported, opposed or were neutral were 11.9%, 41.4%, and 46.7%, respectively, yielding a 'support ratio' of 0.29 – one of the lowest amongst the studies discussed. However, it is difficult to say whether this represents a decrease in support over time given demographic differences between samples (recalling that Eurobarometer used procedures to ensure consistent sampling across years, while Cui and Shoemaker themselves report large differences according to the region from which respondents came), although it is interesting to note that the earliest studies appeared to demonstrate considerably higher support, with greater support than opposition (a ‘ratio’ over 1.0) in eight of the nine earliest studies (published from 2002-2011), and greater opposition than support (a ‘ratio’ below 1.0) in the latest eight (published from 2012-2016). These results suggest that the overall attitude of Chinese consumers is cautious towards GM food, with opposition growing rather than falling.

Many other studies over the last couple of decades have recorded high levels of ambivalence and/or low levels of acceptance for GM food, much as that recorded across Europe, in countries ranging from the US (e.g. Hallman et al, 2003; Hossain et al, 2003; Scott et al, 2016), to places such as Japan (Komoto et al, 2016) and South Korea (Kim et al, 2018), and to developing countries like Uganda (Kikulwe et al, 2011) and Zimbabwe (Chagwena et al, 2019). In most cases, the precise questions have varied, as have the wording or specificity of the GM foods to which attitudes have been assessed (i.e. sometimes GM food generically, sometimes a particular foodstuff, like GM rice or bananas).

Perhaps the most consistent and therefore comparable approach to assessing attitudes is using the WTP/WTA paradigm, since this provides a common attitudinal metric (a relative monetary value). Lusk et al (2005) conducted a meta-analysis of 25 (early) studies reporting 57 valuations for *GM food* (versus non-GM food), around half of which were conducted in the USA and a third in Europe. Their results suggested that valuations could be explained by three factors: (a) the characteristics of the sample of consumers studied, (b) the method for eliciting consumers' valuation (i.e. the way you ask questions matters), and (c) characteristics of the food being valued. We will return to these issues shortly, but for present purposes, the headline result of this analysis was that, across all studies, consumers on average placed anywhere from a 42% (unweighted average using all data) to a 23% (weighted average excluding one outlier) higher value for non-GM food relative to GM food, i.e., GM foods were significantly less attractive to consumers than non-GM foods and required a large *discount* to encourage people to buy them. A plethora of other WTP studies since Lusk’s review have generally confirmed consumers’ requirement for a discount to purchase GM foods, from Kenya (e.g. Kimenju and De Groote, 2008) to Russia (e.g. Delmond et al, 2018) and beyond.

The issue, then, is not so much that people from across the globe have indicated some opposition to GM foods, but rather why this is the case. Returning to the Eurobarometer surveys, these have provided some revealing insights that are worth elaborating. For example, the 1999 Eurobarometer survey (INRA, 2000) showed that respondents on average tended to agree with the following statements (in descending order, where a score of 3 represents a midpoint of neither agree nor disagree):

- Even if GM food has advantages, it is basically against nature (4.08),
- GM food threatens the natural order of things (3.96),
- If something went wrong with GM food, it would be a global disaster (3.88),
- GM food is simply not necessary (3.72),
- The idea of GM food causes me great concern (3.57),
- Even if it means doing without some of its advantages, GM food should be introduced in a more progressive manner (3.13),
- Whatever the risks involved in GM food, we can avoid them if we really want to (3.11).

In contrast, respondents tended to *disagree* with the following statements (in descending order from that with most disagreement):

- GM food presents no danger for future generations (2.22)
- The risks involved in GM food are acceptable (2.35)
- Taking a decision on the issue of GM food is so complicated that it is a waste of time to consult the public on this subject (2.6),
- GM food will benefit many people (2.73)
- Of all the risks we have to face at the moment, that of GM food is rather insignificant (2.73)
- If a majority of people were in favour of GM food, it should be permitted (2.73).

Note that disagreement tended to be with *positive* statements, and the overall assessment was negative: GM food was essentially seen as having *few benefits* yet being *unnatural* and potentially *risky*. These questions point to a number of concepts (like naturalness) that are apparent in the broader literature on *risk perception*, and have occasionally appeared in other surveys. (In fact, it is not entirely clear where these questions came from and their concepts can be identified in previous work on perceptions of GM food and food hazards more generally, such as Sparks et al, 1994; Frewer et al, 1996; Fife-Schaw and Rowe, 1996; Frewer et al, 1997). Indeed, some of these questions reappeared (with slightly different wording) in the 2010 survey (see TNS Opinion and Social, 2010), in which respondents were asked whether they agreed or disagreed with the following statements (with the proportion agreeing, on average, in brackets):

- GM food is fundamentally unnatural (70%)
- GM food makes you feel uneasy (61%)
- GM food benefits some people but puts others at risk (57%)

- GM foods is not good for you and your family (54%)
- GM food helps people in developing countries (43%)
- GM food is good for (your national) economy (31%)
- The development of GM foods should be encouraged (23%)
- GM food does no harm to the environment (23%)
- GM food is safe for your health and your family's health (22%)
- GM food is safe for future generations (21%)

Although responses to these questions did vary across countries, the general trends largely held across them, i.e. when the majority agreed or disagreed with a statement this tended to be so across all or most countries.

These more specific attitudinal issues have been explored in other studies, amongst which the issue of *benefits* appears to be crucial, having been highlighted in early research (e.g. Frewer et al, 1995). For example, Lusk et al's (2005) analysis indicated that when *benefits* were provided to consumers (such as enhanced nutrition), they were more accepting of GM food, that is, adding a direct benefit to a GM food reduced the premium for non-GM food by 49% (although there was *still* a premium). As Lusk et al (2005) pointed out, this result suggested that so-called "second generation" biotechnology might be more warmly received by the public than "first generation," which provided direct benefits to agricultural producers *only*.

Several of the Eurobarometer surveys explored the particular benefits that were of perceived value to respondents. In the 2002 survey (see Gaskell et al, 2003) the most persuasive reason for buying GM foods was the *health benefit of lower pesticide residues*, closely followed by *environmental benefit*, with a *lower price* apparently being the *least* good incentive for buying GM foods (though respondents tended to split into those who either rejected all of the benefits or accepted a relatively high number of these). Respondents to the 2005 survey also found that the health-related reasons for buying GM food were the most convincing (e.g. 56% would buy GM food if it were healthier, and 51% would buy it if it contained less pesticide residues), while lower prices again appeared to be the least persuasive reason in people's choice intentions. As Gaskell et al (2006) noted, however, economics tells us that price is a key determinant of people's *actual* choices, so it might be that, in this hypothetical situation, some might have been responding as 'citizens' rather than as 'consumers'.

Benefits have been identified as mitigating factors for accepting (or not opposing) GM food in other and more recent studies, particularly health benefits (in terms of nutrition), but also benefits from taste and price, while environmental benefits have also been related to support, i.e. when GM options reduce the usage of pesticide and chemical fertilizer (reducing environmental pollution), improve the ability of crops to resist pests and viruses, maintain yield, improve food quality, and extend food shelf life compared to traditional crossbreeding technology (e.g. Cui and Shoemaker, 2018; Kikulwe et al, 2011).

Reasons for *opposing* eating GM food have included that GM food may have unknown risk to human beings, particularly future generations, because of incomplete knowledge, because GM technology is mainly driven by a few private companies with a desire for profit maximization, and because there could be environmental impacts, such as reducing biodiversity (e.g. Cui and Shoemaker, 2018; Kikulwe et al, 2011; Chagwena et al, 2019; Akbari et al, 2019). And on top of this there is a general disquiet about the naturalness of GM foods (e.g. Delmond et al, 2018), which will be discussed more fully later in the context of *values*, and also in the context of *novel food products* generically.

However, the relationship between perceived 'risks' and 'benefits' is not straightforward: sometimes perceived risks and benefits are correlated and sometimes not. That is, in some studies, those perceiving GM food as risky tend to perceive few/no benefits (negative correlation), while other times they are more ambivalent and can see both risks and benefits (no correlation) (e.g. Prati et al, 2012; Pigeon et al, 2005), though generally, perceptions of benefits do seem to be more strongly related to acceptance than perceptions of risks (e.g. Gaskell et al, 2006; Prati et al, 2012; Connor and Siegrist, 2016).

In summary, a large number of studies using different approaches confirm that GM foods of various types are relatively unpopular compared to non-GM, although people are more willing to buy or consume GM foods as benefits increase, particularly when these are salient to the specific respondents, although there are other factors of import too, such as perceived naturalness of the products. The next subsections discuss other factors related to GM food acceptance.

3.2 GM Processes and Applications

The previous section focused on the application of GM biotechnology to food. The purpose of this review is intended to contemplate potential lessons for a *similar* (not identical) biotechnology applied to a *specific* subset of foods. As such it is worth considering public attitudes to different (bio)technologies and to biotechnological applications to different foodstuffs.

So what do the public think of GM in relation to other technologies? One common question throughout the Eurobarometer surveys has been about whether certain technologies 'will improve our way of life in the next 20 years', with one technology being 'biotechnology and genetic engineering'. Results from the different surveys revealed a decrease in optimism through 1996 and 1999 (perhaps most contiguous with the breaking of the GM storm discussed earlier), then a steady rise to 2005, though with a slight dip in 2010. However, it is still notable that in Gaskell et al's 'index of optimism' from 2010, the rating of 'biotechnology and genetic engineering' was little changed from 1991, and remained *lower than four of five comparator technologies* (solar energy, wind energy, computers and information technology and nanotechnology, though higher than nuclear energy - see Gaskell et al, 2011). Furthermore, it is important to note that the early surveys split the sample of respondents, asking half about 'biotechnology' and half about 'genetic engineering' (as two ways to express one concept), and then combining the results from both samples. Interestingly, evidence suggests that the terms appear to have different connotations for the public: for example, in the 2005 survey, 8% more Europeans saw 'biotechnology' as likely to improve their way of life in the future than those asked the same question about 'genetic engineering' (which was roughly similar to findings from 2002 and 1999). Indeed, Hallman et al (2003) similarly found that reactions to technology can depend upon what it is called: with a US sample, the term *biotechnology* evoked the most positive responses, while *genetic modification* was perceived most negatively, and *genetic engineering* was most often associated with cloning. Gaskell et al (2006) posited that the more positive connotation of the term 'bio' might be a result of the association with healthy and natural things, contrasting with 'engineering,' with its connotations of manipulating or tampering. Indeed, the slight fall in optimism in the 2010 survey might have been a consequence of asking respondents to rate 'biotechnology and genetic engineering' as a unitary concept (could the less appetising term have dragged down the rating overall?). The general point to take home here is that wording and framing are important.

However, of more interest here is the difference in attitudes found by the Eurobarometer surveys for *different* biotechnology applications, which have included GM foods, animal cloning, gene therapy and synthetic biology among others (the list has changed over the years), with all of these surveys recording consistent attitudinal differences (e.g. on 'optimism'). One important distinction that has been made is between so-called 'red' and 'green' technologies, that is, between 'medical' and 'agri-food' applications. The range of surveys have generally shown medical uses (such as gene therapy) to be rated more positively on a variety of criteria than green ones (e.g. GM food), which Gaskell et al (2006) interpreted as down to perceptions of relative *benefits*. That is, while both types of application are perceived as risky, medical technologies are perceived as also having benefits and being worth the risk, whereas agri-food applications are perceived as having a general absence of benefits (not necessarily worth the risks). Indeed, the difference between these two main forms of application has received support from elsewhere. For example, Cui and Shoemaker (2018) also asked their Chinese sample: "If GM technology is applied in (the) medical area to produce medicine, such as insulin and hepatitis B vaccine, what is your opinion?" and found that support for GM pharmaceuticals was considerably higher than that found for GM food, suggesting that some respondents were against GM food but not against GM technology *per se*. Connor and Siegrist (2016) also found that GM used for medical applications was perceived more positively than for food applications.

Another set of questions from the 2010 Eurobarometer survey (Gaskell et al, 2010) attempted to consider whether the specifics of gene transfer affected attitudes, notably, between *horizontal* and *vertical* gene transfer. Horizontal gene transfer is a process in which an organism incorporates genetic material from another organism without being the offspring of that organism, whereas vertical gene transfer is where an organism receives genetic material from its ancestor, for example, a parent or the species from which it was evolved. Arguably this issue – of subtle differences in the mechanism of genetic modification – has close parallels to one potential difference between GE and GM, and hence is worth more detailed consideration.

Respondents' awareness and attitude towards *horizontal* gene transfer was examined in Eurobarometer 2010 by using the example of the artificial introduction of a resistance gene from another species, such as a bacterium or animal, into an apple tree to make it resistant to mildew and scab, and towards *vertical* gene transfer using the example of artificially introducing a gene that exists naturally in wild/ crab apples that provides resistance to mildew and scab. Results suggested that European respondents did not see the *benefits* of horizontal gene transfer, had strong *reservations about safety*, thought that special *labelling* of food products is necessary, and thought that it should *not be encouraged*. In contrast, respondents (on average) accepted the potential *benefits* of vertical gene transfer, had some reservations about *safety* and the potential impact on the *environment*, and thought (marginally) that it should be encouraged (though that special labelling of food products was still considered necessary). Hence, evidence form this particular study points to a *technological manipulation* as being of import to attitudes, suggesting the story *does* go beyond *application* to also that of *process*.

The issue of 'horizontal' versus 'vertical' gene transfer has been examined in a number of other studies (mostly WTP ones), where the concepts have been framed instead as transgenesis versus cisgenesis (or 'intragenesis'). In their study, Delwaide et al (2015) defined transgenesis as using gene(s) from a non-plant organism or from a donor plant that is sexually incompatible with the recipient plant while cisgenesis involves the introduction of gene(s) from a crossable sexually compatible plant. As before they found evidence that *process* does matter, at least to some, as reflected in people generally being willing to pay *more* for products from the apparently less-unnatural process, albeit still paying a premium over comparable non-GM products (with the same characteristics). That is, Delwaide et al found that people from four of five European countries had a significantly higher WTP to *avoid* consuming rice labelled as 'GM' compared to rice labelled as 'cisgenic', although the difference in proportion between those *willing to consume* the different types was small and insignificant (across the entire sample, 38% would be willing to consume cisgenic rice versus 36% GM (transgenic) rice – although nearly half of respondents indicated that they did not have enough information to decide).

Likewise, Colson et al (2011) found that US consumers were willing to pay significantly more for fresh produce (broccoli, tomatoes and potatoes) with labels signalling enhanced levels of antioxidants and vitamin C achieved by *moving genes from within the species* (which they referred to as 'intragenic' as opposed to 'cisgenic'), as opposed to *across species* (transgenic). And similarly, Edenbrandt et al (2017) studied consumer preferences in Denmark (where data from a stated preference survey were enriched with actual purchase data from the same respondents to increase external validity) for rye bread alternatives based on transgenic or cisgenic rye, grown conventionally or without the use of pesticides, relative to traditionally bred rye, grown with conventional or organic farming methods. They found that respondents preferred pesticide-free production methods with the majority of respondents favouring traditional breeding methods, though cisgenics were preferred over transgenics. However, it is interesting to note that they also found that some respondents preferred bread from cisgenic crops produced *without* pesticides over traditional crops produced using pesticides.

Another interesting study is that of Schenk et al. (2011), who conducted a study in the Netherlands that focused on consumer perceptions of risks and benefits of cisgenic and transgenic GM foods using hypothetical apple profiles. In these profiles, GM or traditional breeding had been used to introduce two consumer benefits - one a personal health benefit (hypoallergenicity) and one an environmental benefit (fewer pesticides required in production). (As the authors noted, hypoallergenic GM foods are of interest because they are on the 'boundary' between medical- and food-related GM applications, i.e. perhaps somewhere between red-and-green GM.) As usual, traditional breeding was rated more positively than both GM strategies, though GM with genes from another apple (cisgenes) was rated more positively than GM with genes from another plant species. The difference between the two GM strategies was *significant*, but the *effect size* was approximately six times smaller when compared to the difference between the GM methods and conventional breeding. Schenk et al therefore concluded that it is questionable whether the difference between the two GM methods is *relevant* as far as consumer acceptance is concerned. Unsurprisingly, acceptance of hypoallergenic GM apples was higher among apple allergic consumers, showing the importance of personal relevance for acceptability.

Indeed, whether there is a meaningful difference between attitudes to the two processes was also questioned by results from Shew et al (2016) on Indian consumers, which found that respondents did *not* significantly value cisgenic and transgenic rice differently, though there was a positive WTP for no-fungicide provided by the cisgenic and transgenic rice types. It is also interesting that findings here indicated that 73% of respondents said they would consume cisgenic food, and 76% would consume GM food – much higher percentages than the European respondents of the Delwaide et al (2015) study also on rice (though samples and questions were not the same and caution should be used in comparing results across these: specific cross-country comparisons are considered in a following section). In short, the message from these studies in combination is that though the *process* of genetic manipulation in food products (the specific biotechnology) may be a factor in acceptance, it is at best a minor one.

It was earlier noted that medical applications of GM tend to be rated more positively than applications to food (see Frewer et al, 2013 for review). Connor and Siegrist (2016) surveyed consumers on a variety of GM applications, confirming that medical applications were viewed more positively, but they also found that GM uses for 'food and crop plant' applications (GM soy plants that produce more oleic acid and, therefore, have a higher content of unsaturated fatty acids; GM cereals that do not contain gluten (so that) bread and cakes made using their flour are suitable for people with allergies; GM corn that is resistant to pests) were perceived more positively than 'animal applications' (GM cows that produce milk similar to human breast milk; GM modified cows that produce milk without lactose; GM pigs that can produce human organs for transplantations). Essentially, plant/ crop based modifications were viewed as giving *greater benefits* and *fewer risks* than animal based modifications (though not all of the animal-based applications were food ones).

Indeed, the difference between plant and animal applications is reasonably well established. Frewer, Howard and Shepherd (1997) investigated people's perceptions of biotechnology applications including genetically modified (GM) microorganisms, plants, human DNA, and animals, revealing that applications involving microorganisms and plants were perceived to be *beneficial*, *advantageous*, and *necessary*, whereas applications involving human DNA and animals were perceived to be *unethical*, *harmful*, and *dangerous*. Likewise, Magnusson and Koivisto Hursti (2002) looked at nine different food applications of GM (soy, tomatoes, yoghurt, beer, strawberries, pork meat, wheat, salmon and rice), and found that 'Rice with a higher iron and b-carotene content which could help people in developing countries to meet their daily needs for those substances' was perceived most positively (*highest benefit*, *least unethical*, *most healthy*), while applications concerning pork meat and salmon were the ones that respondents were most negative towards (*most unethical*, *most concern*, *highest risk*). More generally, Hallman et al (2003) found that about half of Americans reported that they approved of plant-based GM foods, compared to about a quarter that approved of animal-based GM foods (see also Hossein et al, 2003). Furthermore, Lusk et al (2005) in their meta-analysis of 25 WTP studies found differences according to products by comparing 'meat', 'oil', 'fresh foods' (fruit, vegetables and rice) and 'processed foods' (bread, cereal, chips, cookies, muffins, or noodles). Of these, GM meat products were the *least* desired GM food with the highest WTP premium against non-GM alternatives and GM oil was the most desired (lowest premium). Most of these studies have been on animal products fed GM feed rather than GM animals *per se* (according to Lin et al 2019), although Chern et al (2002) found that GM-fed salmon was preferred (lower WTP) to actual GM salmon, suggesting consumer may have different preferences for animals fed GM feed and GM animal products themselves (which is perhaps not unexpected).

Frewer et al (2014) concluded from a review of 42 papers that risk and benefit perceptions as well as ethical concerns (e.g. related to animal welfare) may explain negative consumer attitudes towards animals in food production. Meanwhile, Van Eenennaam and Young (2018) have suggested that opposition to GM animals is often conflated with opposition to use of animals in research in general, as well as opposition to aspects of intensive animal agriculture (which will be discussed later), for example, Gabriel et al (2012) found that attitudes on animal research predict acceptance of genetic modification technologies with animals. In general, Van Eenennaam and Young (2018) suggest that concerns about animal biotechnology are influenced by (1) views around the moral status of animals, the boundary between "natural" and "unnatural," and perceived risks and benefits of GM animals to health and the environment (personal and cultural characteristics); (2) the purpose of the application, the method(s) being used, and the motivation of the research group making the genetic modification (research characteristics); (3) the species being modified (animal characteristics). They concluded that it is difficult to generalize about public perception of GM animals as a discrete category.

In summary, not all biotechnology is the same to people, with evidence that *framing* and the specifics of *process* do impact on attitudes to some degree. However, the particular *application* of a technology more clearly matters, with medical uses seen as more acceptable than food uses, and uses for plant/crops (and feed) viewed more positively than for animals/meat; these are explained by differences in perceptions of benefits (in particular), risks and ethics of the applications.

3.3 National Differences in General Attitudes

The Eurobarometer surveys also attempted to assess how attitudes varied with a number of demographic and socio-economic characteristics – with national differences being of primary interest. Naturally, some differences were detected between countries and across surveys (one would statistically expect a certain amount of variation anyway) – although the main trends reported in previous sections generally held to a large degree *across* the countries surveyed. It is not possible to recount here all of the differences across countries across the various questions the surveys posed, although we will attempt to give some flavour of the differences.

The 1999 survey found that respondents in Spain were generally the most positive for biotechnology applications like GM foods and crops (gene transfer), as opposed to others like those from Greece, who were generally considerably more negative (INRA, 2000). However, all of the EU countries, with the exception of Spain and Austria, showed moderate to large declines in support for *GM crops* from the 1996 survey. Thereafter (by 2002) support more or less stabilised in France and Germany and increased in all the other countries with the exception of Italy (Gaskell et al, 2003). There was a similar pattern for *GM food*: with the exception of Sweden and Austria, all of the European countries showed moderate to large declines in support over the years 1996-1999, though post 1999, the majority of countries showed an increase in support for GM foods with the exceptions of Germany and Finland, which were stable, and Italy, France and the Netherlands, which showed further declines. In fact, in the 2002 survey, overall 'support' for GM foods was seen in only four countries - Spain, Portugal, Ireland and Finland; by 2005, 'supporters' of GM foods outnumbered 'opponents' in Spain, Portugal and Ireland (as before), but also Italy, Malta, Czech Republic and Lithuania (Gaskell et al, 2006) (and note, by 'supporters' we mean those categorised by the authors as members of the 'decided publics' – see the earlier description).

Another example of differences between countries is in responses to questions on potentially buying GM foods. In the 2002 Eurobarometer survey, the proportion of respondents in the different countries that rejected *all* of the reasons provided for buying GM foods varied from 30% to 65%, with the highest percentage of rejecters being from Greece, Ireland and France, and with the lowest percentage being from the UK, Austria and Finland (Gaskell et al, 2003). In the 2005 survey, the proportion of respondents in the different countries who rejected the five suggested reasons for buying GM foods varied from 5% to 55% (and recall that the number of reasons differed in the two surveys). In this case, the countries with the highest percentage of rejecters were Austria, Greece, Hungary, Germany and Latvia, with the lowest percentage of rejecters being from Malta, Czech Republic, Netherlands, Spain, Belgium and Portugal (Gaskell et al, 2006). The variability in responding (e.g. notice that Austria went from amongst one of those countries with the lowest to highest proportion of 'rejectors') shows why the results should be treated cautiously and that attempts to read too much into specific figures from any one country should be resisted i.e. that confirmatory research looking in more depth into different national attitudes is required.

The 2010 Eurobarometer survey added attitude questions about specific aspects of GM foods and their potential impacts. Although results were largely consistent across countries (to a greater or lesser degree), there were some interesting differences. For example, in response to the statement 'GM food is safe for your health and your family's health', at one end of the scale were countries like Greece (85% disagreed) and Cyprus (83% disagreed), while at the other were several countries where fewer than half of respondents expressed such concern and where there were nearly as many agreeing with the statement as disagreeing (e.g. UK 39% disagreed versus 33% agreed; Netherlands 46% agreed versus 37% agreed) - though in no country did more respondents agree than disagree. Further, those from the UK and Czech Republic were the most positive (or rather, least negative) with regards the statement that 'The development of GM foods should be encouraged' (e.g. 35% of UK respondents agreed, versus an average of 22%). And with regards the statement 'GM food benefits some people but puts others at risk', Sweden was the only country where fewer respondents agreed than disagreed with the statement (36% vs. 48%).

Reading across countries over different years is difficult and few studies beyond Eurobarometer have specifically compared matched samples. Knight, Mather, Holdsworth and Ermen (2007) reported that European consumers from six different countries were similarly willing to consume GM food if the product was both cheaper and provided an environmental benefit (e.g., spray-free fruits), and Popek and Halagarda (2017) found no statistically significant differences between Polish and British respondents' attitudes to GM foods (bar on one of many comparisons). However, when Delwaide et al (2015) compared consumers' WTP for GM rice in Belgium, France, the Netherlands, Spain and the UK they found *some* significant differences across countries, although as before the differences were largely in degree rather than type, with all willing to pay a premium to avoid GM types, though the Spanish respondents had the lowest aversion and the French the highest (perhaps unsurprisingly as Spain was the only one of the five countries then growing GM crops).

Beyond Europe, a number of the questions from the Eurobarometer survey were included in the International Biotechnology Survey Group's 2005 studies in the US (sample of 1200) and Canada (sample of 2000) (see Gaskell et al, 2006) – albeit in revised format (e.g. differing in the number of points on their respective scales and the phrasing of certain questions), so that again caution is needed in result interpretation. Analysis of results from across the three surveys focused on technology optimism and attitudes to GM food and nanotechnology. The headline result from this analysis was that, for GM food, Europeans and Canadians had rather similar views, while people in the US saw it as much *more beneficial* and *less risky*.

Lusk et al (2005) provided some support for the difference between US and European consumers. In their meta-analysis of 25 WTP studies, they found that GM foods had a higher premium for European consumers than for consumers from North America, that is, European consumers had valuations for non-GM food 29% higher than US consumers. Indeed, an earlier study by Lusk et al (2003) that *directly* compared respondents in France, Germany, the UK and the US, found that European consumers placed a much *higher* value on beef from cattle that had *not* been fed genetically modified corn than US consumers did.

Chern et al (2002) widened the range of comparisons: they conducted a study in Japan, Norway, Taiwan and the US, and found that students in all countries were willing to pay higher premiums for non-GM food although American and Taiwanese students were more favourable to GM foods than Norwegian and Japanese students. Komoto et al (2016) also compared east and west: they studied consumer perceptions in Japan, France, the UK and the US, and found 'resistance' to GM foods in all countries, with strongest overall resistance in France, followed by Japan, which had stronger resistance than the US and the UK (with no statistical difference between these two). Japanese and French respondents showed the strongest 'fear' of hazards from GM food. Indeed, Japanese consumers tended to accept GM technology but rejected its application to food, and of those willing to purchase GM food, consumers in Japan required a discount of 30% compared with about 20% in other nations.

Arguably differences between countries would not be unexpected, given wide differences in relative level of *national* wealth, culture, familiarity with the technology, proportion of rural to urban population, and so on. Likewise differences *within* countries might not be unexpected. Thus, though Cui and Shoemaker (2018) only looked at China, they found considerable differences in attitudes within it. For example, in Western China 51.3% indicated that they were against GM food, compared to 29.7% from those located in the centre and in North-Eastern China. Large regional differences in views on GM foods have also been reported elsewhere (e.g. Kikulwe et al, 2011 in Uganda).

In conclusion, a number of studies have suggested that there *may* be differences in attitudes to GM foods across countries, which is not surprising, although differences don't tend to be great, and there are differences within countries as well as between them. Drawing broad conclusions is difficult because, aside from Eurobarometer, which focused on European countries, there have been few large systematic comparisons. In Europe, it *may* be that Spain is less antagonistic to GM food than other countries, perhaps consequent on it being one of the only growers of GM crops, and the UK *may* be towards the more accepting end of the range; it *may* be that US consumers are also more tolerant of GM foods, perhaps again because GM crops are grown there rather than being essentially stigmatised through regulatory restrictions; and it *may* be that certain Asian countries, like Japan (where again the technology is banned) are considerably more negative. Experience of benefits – or at least, experience of an absence of risks – would seem a logical correlate to acceptance; but research currently does not provide strong evidence one way or the other on this.

3.4 Demographic and Socio-Economic Characteristics and Attitudes to GM Food

It is fairly common in studies on attitudes to GM food to look for differences related to demographic or socio-economic aspects too. The main factor reported on is invariably sex. Some studies have shown no affect, for example, Cui and Shoemaker (2018), Delwaide et al (2015), McClusky et al (2003) and Dancer and Shiel (2019). However, others have found that men tend to be more supportive/ accepting than women, in terms of having a higher WTP for GM products or having a more positive attitude, such as Magnusson and Hursti (2002), Cook et al (2002), Hallman et al (2003), De Steur et al. (2010), Kikulwe et al (2011), Komoto et al (2016), Delmond et al (2018) and Öz et al (2018).

The Eurobarometer surveys (with much larger samples than other studies) also found that men are often more positive than women on GM. The 1999 survey found that men were generally the more positive about different biotechnology applications than women, and men agreed *more* with *positive* statements and *less* with *negative* statements about GM food specifically (e.g. that ‘the risks involved in GM food are acceptable’ and ‘GM food is simply not necessary’). In the 2002 survey, men also tended to be more supportive than women for most of the biotechnologies surveyed (including biotechnology and genetic engineering), with males also more likely to support GM food and crops. The 2010 survey further revealed that men were more likely to see biotechnology and genetic engineering as positive compared to women (58% vs. 48%), with women more often than men having ‘no opinion’ (24% vs. 16%), although it was largely notable in this survey how few differences between the sexes were identified. For example, for only one of a set of statements on GM food was a difference recorded i.e. that 57% of men agreed that GM food made them feel uneasy compared to 64% of women. However, the 2005 survey suggested some interaction with age, as the percentage of men who were ‘supporters’ of GM food increased with more years of education, while this effect was not seen in women. Both Siegrist (2000) and Baker and Burman (2001) have suggested this relationship is a result of women commonly having higher levels of concern regarding *food safety* and being more *risk averse* than men.

Age is another factor where significant differences have sometimes been shown. For example, the 2002 Eurobarometer survey found that, controlling for other factors, people aged between 15 and 39 were more supportive of industrial and agri-food biotechnologies than people over 55 (Gaskell et al, 2003), while the 2005 survey found that the younger people are, the more likely they are to state positive intentions towards buying GM food, under all of the conditions stated in the questions (Gaskell et al, 2006). However, in the 2010 survey, there was little evidence that age was related to attitudes, save in response to the statement 'GM food makes you feel uneasy', where those aged 15-24 years were less concerned than older respondents (but significant effects for one item amongst several should be treated with caution) (see TNS Opinion and Social, 2010).

Other studies have generally supported this the trend of age being related to attitudes, with older people (e.g. 60+) being more negative towards GM foods or less willing to buy it, in countries ranging from Sweden (e.g. Magnusson and Hursti, 2002) and the US (e.g. Hallman et al, 2003) to China (e.g. Cui and Shoemaker, 2018), Japan (e.g. Komoto et al, 2016) and Uganda (e.g. Kikulwe et al, 2011). However, the trend is sometimes confusing, for example, Dancer and Shiel (2019) found individuals between 46 and 60 were more likely to be against GM foods than those who were younger and older, and other studies have found limited correlations between attitudes and age (e.g. Cook et al, 2002).

Education level is one factor that is difficult to interpret. For example, the 2002 Eurobarometer survey suggested that education level had *no* strong association with levels of support for GM foods and crops (Gaskell et al, 2003), and other studies have also failed to find a difference (e.g. Schlapfer, 2008; Dancer and Shiel, 2019). However, some research has found that individuals with higher levels of formal education have expressed more positive attitudes towards GM foods than those with lower levels of education (Magnusson and Hursti, 2002; Hallman et al, 2003; Kimenju and De Groote, 2008; Komoto et al, 2016; Öz et al, 2018). On the other hand, Cui and Shoemaker (2018) found that the proportion of Chinese respondents with college degrees who supported GM food was the *lowest* relative to any other group, though the percentage of respondents with a positive attitude was higher for those with a science background (14.1%) compared to those with a liberal arts background (7.5%).

Similarly, Kikulwe et al (2011) found that increased education was related to a *decrease* likelihood of buying a GM banana and McClusky et al (2003) found higher education levels related to a greater discount needed in willingness to pay for GM foods.

Wealth or socio-economic status may also be a correlate with attitudes to GM foods, but results are unclear. For example, Cui and Shoemaker (2018) found that higher income was related to more negative views on GM food, whereas Kimenju and De Groote (2008) found that those with higher-income were *more* positive than those on lower income (more likely to purchase GM maize). Kikulwe et al (2011) provided ambivalent results, with respondents with higher incomes *less* likely to purchase GM bananas with an *agronomic trait* (leading to higher production) but *more* likely to purchase GM bananas with *nutritional and taste traits*. This latter result hints at the likelihood that acceptance of GM foods is liable to be consequent on complex interactions between multiple factors, including how particular applications are perceived on a personal level. That is, most research in this area involves correlating factors/ variables and identifying main effects, with interactions, when identified, often being difficult to interpret or inconsistent. Little research has delved more deeply into why, for example, men or younger people are more positive (when addressed, the main explanation seems to be that research into risk perception appears to show that women and older people are more risk averse than men and younger people, and there could be evolutionary/ biological and cultural reasons for this).

In summary, a number of demographic and socio-economic variables seem to be related to attitudes to the acceptability of GM foods, though findings are often contradictory and relationships do not appear to be strong. Indeed, Hossein et al (2003) – in a study U.S. consumers' acceptance of genetically modified foods – concluded that attitudinal variables have greater influence on the acceptance of food biotechnology than do consumers' economic and demographic attributes. We consider such ‘attitudinal’ variables next.

3.5 The Relationship of Values, Worldviews and Personality to Attitudes to GM Foods

To now, we have considered how attitudes to GM have varied with essentially physical attributes of process/ application/ sample characteristics; now we move on to variation (correlation) with psychological attributes, notably values and worldviews. Attitudes are essentially our likes and dislikes towards things, people and objects (e.g. GM foods) and include the emotional and the cognitive; values are belief systems that guide our behaviour and decide what we think as right, wrong, good, or unjust – they inform our attitudes, and tend to be more or less permanent (whereas attitudes can change with positive or negative experiences, whether actual or perceived). Worldviews are essentially ideological or philosophical *sets* of belief. Though people of different types (gender, nationality etc.) may share certain values (indeed, this is almost an implicit assumption in why we analyse according to these categories), values are liable to vary widely within and across demographic/ national (etc.) categories.

One set of values that has been studied in the context of GM attitudes is that related to *religious beliefs*. If we start with the Eurobarometer surveys, these have not found particularly compelling evidence for any relationship between these factors. For example, the 1999 survey found some sporadic differences in attitudes between those indicating that they were religious and those not, but for only a few items, and differences between average answers tended to be in *extent* of opposition or support, not actual *differences* in opposition or support (INRA, 2000). The 2002 survey again found only minimal evidence of relevance: for example, one finding was that, contrary to expectation, in catholic countries respondents had *higher* support for cloning human cells and tissues than in non-catholic countries - although no clear associations were identified with regards GM applications (Gaskell et al, 2003). The 2010 survey also considered the potential effect of religious beliefs, and found that 49% of respondents who believed in God were positive about biotechnology (in general) in contrast to 59% of non-believers, though there were no differences on the basis of religion apparent in the proportion of respondents who considered the science negatively (TNS Opinion and Social, 2010). This survey also found that slightly more people who believe in God agreed that 'GM food makes you feel uneasy' and slightly less that 'GM food is good for (your national) economy' - although given that these were two of a much larger set of items, and that the differences were not great, we should not read too much into them.

Hossain et al. (2003) and Onyango et al (2004) also found no evidence of a link between religiosity and GM attitudes in the US. Indeed, Hasell and Stroud (2019) concluded from a survey of the US public that 'the effect of knowledge (on attitudes to GM foods) is moderated by perceptions of the immorality of genetic modification, *rather than* political or religious views' (our italics). On the other hand, Amin et al (2014) found that perceptions that GM salmon is 'blasphemous' (religious acceptance) was the most important direct predictor of its acceptability in a Malaysian sample. It may thus be fairer to suggest that there is no *convincing* empirical evidence for a link between religious beliefs and GM attitudes, rather than that there is *no* link: studies on this matter are few and seem to have merely looked at differences between those claiming to be religious and those not within a particular country or relatively homogenous region (if one considers Europe to be generally mildly Christian/ secular), with few comparing across countries with widely different religious beliefs (and even then the issue would be whether any differences found were due to nationality/ culture or religion). In fact, organised religions have occasionally expressed views on the GM issue, though it is unproven whether these views have deeply affected their respective constituencies (see Ombowele et al, 2009, for example, for perspectives from the three main monotheistic religions).

Political beliefs were mentioned in respect of the Hassell and Stroud (2019) study as having little relationship to GM attitudes. Other studies have also looked into such beliefs and generally found no clear relationship to attitudes. For example, Onyango et al (2004) found that differences in social or political values (i.e., conservative or liberal) did not significantly correlate to consumers' willingness to accept GM foods, while ‘political interests’ had no clear relationship to support/ opposition to six applications of biotechnology (including GM crops and GM food) in the Eurobarometer 2002 survey (Gaskell et al, 2003).

Though there is little firm evidence for the role of certain worldviews and values in GM food attitudes, there is one set of values on which there does seem to be evidence of importance, and these may be broadly characterised as ‘green’ or ‘ecological’ values. That is, there is evidence that those concerned about the environment are less in favour of GM foods or less willing to buy/consume it (e.g. Dancer and Shiel, 2019, Akbari et al, 2019). Hallman et al (2003) similarly found that people who value *naturalness* in their foods are slightly less likely to approve of GM foods, as are those who have purchased organic foods in the past. Siegrist et al (2016) found that the lack of perceived naturalness of gene technology seemed to be the reason for Swiss participants' perceived lower benefits of a GM corn variety compared to traditionally bred corn. Tenbült et al (2005) found consumers more likely to accept a GM product if it is regarded as more natural compared with less natural, and similar results were found in a study that examined the acceptance of gene technology for various food products (Siegrist, 2003). Delmond et al (2018) found that Russian consumers’ food purchases were often motivated by the ‘naturalness’ of foods, with naturalness associated with healthiness. Their results indicated that information-seeking health-conscious consumers tend to be less likely to purchase GM foods, while more *money-conscious* consumers are more likely to purchase the GM product.

Beyond findings linked to these broad worldviews, there is sporadic evidence of other values being important. The 2002 Eurobarometer survey found that four factors were consistently associated with support for six applications of biotechnology (genetic testing of inherited diseases, cloning human cells and tissues, GM enzymes for soaps, transgenic animals for xenotransplantation, GM crops and GM foods) when a total of fourteen factors were considered simultaneously in a statistical model. These were *materialist values*, *optimism about technology*, *confidence in actors involved in biotechnology* and *engagement with the issue of biotechnology* (a complex measure involving talking/ reading about biotechnology). For GM foods and crops in particular, those scoring higher on value items: 'Economic growth brings better quality of life', 'What's good for business is good for the citizens' (for food, not crops), 'Exploiting nature is unavoidable if humankind is to progress', and 'technology optimism', were more likely to be supportive.

Yang and Hobbs (2019) provided some evidence from a study in Canada that individuals pre-disposed towards a hierarchical worldview (e.g. strong respect for authority) are more accepting of novel food technologies such as GM than those who are egalitarian, as are individuals with a communitarian worldview (emphasizing the connection between the individual and the community) than those who are more individualistic. Interestingly, this study also considered gene editing as a novel technology and found effects similar to, but not as large as, genetic modification.

It is worth noting that there has been some recent interest in *personality traits* and their relationship to GM food acceptance (it is difficult to know where to discuss this, but because personality traits are generally stable patterns of thinking, feeling, and behaving and may be linked in some way to broader values, we mention the matter in this section). Lin et al (2019) note how the concept of personality has been used to investigate consumer food choice (see that paper for examples and a discussion), though not for individual valuation of novel and controversial food products. They studied the role of personality on consumer demand for a GM animal product (pork) in the US, China and Italy, employing the Five Factor model, which measures five personality dimensions known as Openness (to experiences), Conscientiousness, Extraversion, Agreeableness, and Neuroticism. They added a sixth to this, Agency, which captures personality traits related to dominance and forcefulness. These factors correspond to a series of individual characteristics, e.g., someone with a high level of Conscientiousness is more likely to be organized and dependable; individuals with a high level of Extraversion are inclined to be sociable and lively; and those high on Agreeableness are more inclined to be sympathetic, cooperative and caring. Lin et al found that Openness was the only trait that consistently explained consumer acceptance in the three countries and Conscientiousness was found to be a good predictor in Western cultures.

Ardibili and Rickertsen (2020) likewise studied personality traits in a large Norwegian survey. They found that Neuroticism was associated with increased acceptance of GM soybean oil, while Conscientiousness was associated with increased acceptance of GM-fed and GM salmon (mirroring Lin et al, 2019), and Agreeableness was associated with increased aversion to these products. Coincidentally, as previously, they found that attitudes towards naturalness of foods were strongly correlated with increased WTP to avoid GM foods.

Though these studies on personality yield some interesting results much more research is needed in this area before we dare draw recommendations from this.

In short, an ecological worldview that values naturalness seems to be associated with negative attitudes towards GM foods (e.g. perceptions of low benefits and higher risks), though other worldviews and values have not been convincingly shown to be so related. A more comprehensive program of study based on a more coherent framework of worldviews would seem useful for further research (e.g. see De Witt et al, 2015).

3.6 Familiarity and Knowledge of GM and Associations with Attitudes to GM

The 'knowledge deficit model' has historically been the dominant explanation for the relationship between science knowledge and attitudes, with higher (factual) knowledge of a scientific issue being supposed to lead to greater support for that science, although evidence for this is not straightforward, with variations across issues (e.g. Allum et al, 2008). What of GM foods?

Recall that the 2002 Eurobarometer survey introduced a question asking whether respondents had *heard* of various biotechnology applications (including GM food and crops). The 2002 survey conducted limited analysis of responses to this question, which was largely used as part of a complex measure called 'engagement with biotechnology'. However, the 2005 survey used the data more extensively, and found that GM food was the most familiar of a variety of biotechnology applications across the European Member States. For GM food, those who said they had previously heard of GM food were more likely to *agree* that it was morally acceptable and useful, although there was no significant difference in levels of overall support, and only a small difference in terms of risk perception, with those indicating that they had heard of it being slightly more likely to say that it is risky (Gaskell et al, 2005).

The 2010 survey (TNS Opinion and Social, 2010) used awareness data more thoroughly, and found awareness associated with significant differences in responding for *some* questions, but not others. Thus, those who claimed to have heard of GM food were more likely to agree (than those who hadn't) that: GM food made them feel uneasy (64%-44%); GM food is *not* good for you and your family (57%-35%); GM food is good for (their national) economy (33%-20%); the development of GM foods should *not* be encouraged (64%-45%); GM food does... *harm* to the environment (56%-36%); GM food is (not) safe for your health and your family's health (63%-44%); GM food is safe for future generations (those who had heard of GM food were more likely to agree with this statement than those who hadn't, though no figures were given). However, no differences were reported with respect to answers to statements that 'GM food is fundamentally unnatural' and 'GM food benefits some people but puts others at risk'.

The general finding from the 2010 survey – that greater reported awareness is generally associated with more negative attitudes – has received only mixed support. For example, Rose et al (2019) found perceived familiarity was significantly correlated with 'negative attitudes' to GM food in a US sample – although when controlling for demographics, value predispositions, media attention, and 'food consciousness', they failed to find a significant main effect. On the other hand, House et al (2005) found perceived familiarity (measured as self-reported knowledgeability of GM food production) was positively related to consumer willingness to eat GM foods in a study of people from the United States, the UK, and France, and Koivisto-Hursti and Magnusson (2003) found a direct and positive relation between an increasing claimed knowledge of GM technology and increasing support for GM applications (with a Swedish sample).

However, some care needs to be taken in equating self-reported (or 'subjective') knowledge (e.g. asking people if they know about GM or have heard of it) with their *actual* understanding of the science and its applications ('objective' knowledge). People claiming knowledge may simply be mistaken or may have only slight or nebulous acquaintance with the topic (or may even be responding for reasons such as to avoid projecting ignorance). Indeed, Ladwig et al (2012) provide some evidence that perceived familiarity and scientific knowledge are not well correlated (for example, in the study by House et al. (2005), noted above, while perceived familiarity was positively related to consumer willingness to eat GM foods there was no such relationship for factual knowledge). The reason for caution is nicely demonstrated by Chagwena et al (2019), who found in a study in Zimbabwe that though 92% of respondents indicated that they had heard of GMOs prior to a survey, only 38% could define a GMO in simple and accurate terms, while more than half reported that they had consumed GM foods in the past - in spite of the fact that GM foods are not permitted in the country - and most seemed to (incorrectly) believe that a wide range of GM foods were available locally.

Some studies have tried to frame the 'awareness' question is a slightly more involved and sophisticated way. For example, rather than asking a very broad question on awareness of GM (food etc.), Cui and Shoemaker (2018) asked their Chinese respondents: "Do you know the principle of GMO such as introducing foreign genes, genetic recombination and gene expression?", and found that only around 12% of respondents self-reported that they were familiar with the general scientific principles of GM technology (much lower than awareness figures from the different Eurobarometer surveys, for example, where well over half claimed awareness). As those authors noted, in the absence of sufficient understanding of biotechnology, the public's attitude towards GM food safety can be misleading: they found positive correlations between 'know a lot' and 'support', and 'know nothing' and 'oppose', apparently opposite the general trend previously discussed, i.e., the lower the *understanding* of GM technology, the more hesitant the respondents were to accept GM food.

Various Eurobarometer surveys, from 1996, attempted to go further and to assess *actual* knowledge of *biotechnology* (not GM specifically), by including a set of (general knowledge) questions about basic biology and genetics. The results from these surveys won't be discussed in any detail here, mainly because the analyses tended to be limited to establishing proportions correct across sub-samples (nations), rather than being used as correlates to more-interesting variables, such as responses to attitude question to GM foods and crops (i.e. data *might* exist to address some interesting questions, but the relevant analysis doesn't seem to have been conducted or reported). Furthermore, average responses across the Eurobarometer surveys have been little different from what would be expected to be scored through chance (the questions required 'true' or 'false' answers, and hence 50% would be scored (on average) if respondents randomly selected their answers). For example, the mean scores for nine questions, averaged over all European countries surveyed, were 4.77, 4.78 and 4.93, for 1996, 1999, 2002 respectively, versus a 'chance' score of 4.5. (Such scoring, i.e. little better, or even worse, than chance, has been reported elsewhere, e.g. House et al, 2005.)

Other studies beyond Eurobarometer have also attempted to assess objective knowledge and relate this to attitudes. For example, Chagwena et al (2019) found those with increased knowledge on genetic engineering and GM foods were more receptive of GM foods in their diets – where knowledge was assessed according to responses to six statements about genetic modification of plants/ crops/ foods (essentially, true/ false questions). However, Rose et al (2019) found that factual knowledge (measured by response to two true-false questions) was not a significant predictor of attitudes to GM food (before or after controlling for other variables), nor did House et al (2005) (responses to four true-false questions) or Koivisto-Hursti and Magnusson (2003) (responses to five true-false questions).

Interestingly, Fernbach et al (2019) found (in a study of US adults) that as extremity of opposition to and concern about genetically modified foods increased, objective knowledge about science and genetics *decreased*, but perceived understanding of genetically modified foods *increased*. That is, extreme opponents appeared to know the least, but thought they knew the most. Moreover, the relationship between self-assessed and objective knowledge shifted from positive to negative at high levels of opposition. Similar results were obtained in a parallel study with representative samples from the United States, France and Germany, and in a study testing attitudes about a medical application of genetic engineering technology (gene therapy), although this pattern did not emerge for attitudes and beliefs about climate change.

Perhaps the main issue here is that different studies have assessed knowledge in different ways and partly because of this the impact of knowledge on public attitudes toward scientific issues like GM remains unclear (e.g. see Costa-Font et al, 2008). Indeed, Wunderlich and Gatto (2015) concluded that those who are more familiar with GMOs tend to be more resistant to bioengineering, whereas those with higher scientific knowledge scores tend to have less negative attitudes toward GMOs. In any case, the role of knowledge also appears complex and seems to interact with other factors. For example, Rose et al (2019) found that 'knowledge' interacted with factors such as 'food consciousness' in complex ways in correlating with attitudes – for example, those who were *food conscious and factually knowledgeable* held similar levels of "negative attitudes" as those of *low factual knowledge*.

In summary, reported awareness of GM foods does not necessarily correlate with actual knowledge of GM foods, and though there does seem to be some relationship between these aspects of knowledge and *attitudes*, it is complex and results are not consistent. It is possible that studies reporting no statistical *relationship* between these factors may in part be consequent on the deficiency of measures used, that is, objective knowledge has tended to be assessed by responses to small numbers of true-false questions in which average responses only slightly exceed scores obtainable by chance. On balance, we might *tentatively* suggest that higher awareness has a tendency to be related to negative attitudes, and higher objective knowledge to positive attitudes, but more research is still needed to confirm this.

4. Attitudes to New Food Products (NFPs)

The review to now has focused on attitudes to GM foods specifically, as these are clearly highly analogous to GE (animal) food products and might be expected to provide the clearest steer on how the public might perceive and respond to these. However, it is worth a diversion into a related domain that may also be informative, namely, attitudes to *new food products* regardless of their scientific genesis. That is, the public may form their views on GE products to some degree by (implicit) reference to this other, broader category of products or class of activities, rather than using a purely scientific frame. Indeed, it has been argued that dissatisfaction with GM/ GE products may be consequent on dissatisfaction with the more general food system, characterised by market power, the shift toward industrialized, monoculture-based cultivation, distributions of property rights perceived to be unfair and, more generally, an unequal distribution of risks and benefits across groups within a society (e.g. Gomiero, 2018; Bartkowski and Baum, 2019). Hence, development and commercialization of GM food may be understood to be entangled to some degree with the wider economic and societal circumstances into which these products may be introduced (see Sjöberg, 2002). In short, it may not necessarily be the *technology* itself that arouses societal unease but rather its (perceived) engagement with existing socio-techno-economic systems (Jasanoff et al., 2015).

The European Commission (1997) (Regulation (EC) No 258/97, Article 1) defines novel foods as foods containing or produced from genetically modified organisms; consisting of plants or animals not obtained by traditional propagating or breeding practices and having a long history of safe food use; and foods and food ingredients to which have been applied a production process not currently used, where that process gives rise to significant changes in the composition or structure of the foods or food ingredients that affect their nutritional value, metabolism, or level of undesirable substances. Widely known examples of such novel foods and technologies aside from GM food include functional foods, nanotechnology, high-pressure processing, and use of pulsed electric fields (Kamrath et al, 2019).

In terms of *direct* comparisons of GM with other novel foods, evidence is scant. Egolf et al (2019) conducted a study in Switzerland that was mainly interested in the concept of 'disgust', and how this varied across a number of novel technologies, notably GM meat, GM fish, edible nanotechnology coating films, nanotechnology food boxes, artificial meat, artificial milk, and a synthetic food additive (citric acid) for beverages. 'Disgust' is an interesting concept, seen as an evolved mechanism to protect humans from ingesting harmful agents – pertinent in our ancestral past when food was in short supply, necessitating experimentation, though perhaps less so today when new foods are rigorously tested before being made available to eat. Although the GM applications (along with the edible nanotechnology coating film) were perceived as the most 'disgusting' of the applications, with correspondingly lower willingness to eat/drink (WTE/WTD) and higher perceptions of risk and lower benefits, it is notable that 'taken together, ratings of WTE/WTD, risk and benefit perceptions, as well as disgust responses were quite similar for the different food technologies except for the synthetic food additive …' (p1554), and the latter was posited by the authors to differ from the other food technologies in being the only one the Swiss population had been exposed to. The authors interestingly concluded that 'new food technologies likely (possess) inherent common cues indicating a potential danger of eating a contaminated food (e.g., novelty or unnaturalness), but also technology-specific cues (that) might be perceived as a potential contamination (e.g., a foreign gene inserted in another organism like in gene technology)' (p1556). Scott et al (2016) also found evidence that disgust plays an important role in the rejection of GM foods *per se* (in a study in the US).

Interestingly, Vidigal et al (2015), in a study on food neophobia in Brazil with regards yogurts labelled as traditional, pasteurized, organic, genetically modified, enriched with bioactive proteins and nanotechnology, also found consumers were most wary of GM and nanotechnology applications compared to the others. Further, the most neophobic individuals were less likely to try foods produced by unconventional technologies (organic, bioactive, GM foods and nanotechnology) that are considered new or unknown to Brazilian consumers. Beyond this, Greehy et al (2013) conducted a qualitative study looking at irradiated foods, GM foods and nanofoods, the most interesting result from which, for our present purposes, being that the way in which these three New Food Technologies' (NFT) are evaluated by people were considered similar, consequent on complex interplays between personal orientations, individuals' perceived power/control (including issues of uncertainty and trust) and the perceived relevance of the product (including risk/benefit trade-offs).

Rather than comparing novel foods to each other directly, what has tended to happen instead in the literature is comparison across studies in order to highlight similarities in factors related to product acceptance – either through formal structured reviews or less formal narrative reviews. For example, Siegrist's (2008) analysis suggested that *perceived benefit*, *perceived risks* and *perceived naturalness* are important factors for the acceptance of new food technologies in general. While the risk-benefit correlation is clearly logical, the naturalness dimension perhaps needs some explaining in this context: in short, research suggests people tend to have confidence in natural food and the way it is produced, but they are suspicious of new foods and new food technologies (e.g. Rozin, 2005; Huotilainen and Tuorila, 2005). Indeed, because people may have difficulties in assessing risks associated with novel food technologies, and the benefits of such technologies may also not be obvious, 'trust' is important for the acceptance of new food technologies (Siegrist, 2008) - a matter we will consider in a separate section later.

The analysis of Frewer et al (2011) provides an interesting counterpoint to this. They reviewed studies of seven food-related technologies (including GM) associated with different levels of public acceptance, ostensibly looking for *differences* rather than similarities. Their main finding was that technologies characterised as being 'bioactive' (like GM) raise particular concerns related to *unpredictable effects*, *uncontrolled use*, and *ethical concerns*. However, within their analysis the same key factors were identified as significant for understanding acceptance across the technologies, and these were similar to those noted by Siegrist and elsewhere: perceived risk, benefits, controllability, public awareness, naturalness and trust. Indeed, Frewer (2017) provided an analysis of a different set of case studies of emerging agrifood technologies (including GM) that again highlighted similar factors as related to technology acceptance and rejection.

Perhaps the most fulsome comparison to date is that by Kamrath et al (2019), who conducted a systematic review of the evaluation of new food technologies (genetic modification, food fortification, and processing technologies) by supply chain actors. (By evaluation, they meant likelihood or intention to perform a behaviour, perceived benefits/ risks, willingness to pay, acceptance/ adoption, and attitudes.) The 183 studies analysed revealed a heavy focus on *genetically modified foods* (nearly two-thirds) evaluated by *consumers* in *developed countries*, mainly using surveys (i.e. there were very few qualitative investigations). With respect to consumers' evaluation, the key determinants were:

1. Information assessment (the more knowledge a consumer has about or is familiar with a new technology, the more positive is the evaluation)
2. Perceived risks and benefits (with a positive relationship for benefits and negative for risks)
3. Trust in institutions (higher trust is related to positive evaluations)
4. Attitudes toward the product or technology (if a general attitude toward a product or technology is positive, then evaluations are positive)
5. Quality perception of the product (e.g. appearance, taste, naturalness, and healthiness are associated with positive evaluations)
6. Impact of health (when perceived to be high then evaluations are positive)
7. Perceived behavioural control (essentially, an individual's belief that they can cope with a health threat by a recommended behaviour, for example, buying a new food product; when control is perceived to be high, evaluations are more positive).

Coincidentally, the analysis generally confirmed some of the conclusions noted previously about the main sociodemographic factors and their relationship to GM foods specifically, i.e. age, education and economic status had diverse and contradictory results, though analysis of gender seemed to show women do generally evaluate novel products more negatively than men.

One interesting further issue is - amongst these various common factors that seem to be related to public attitudes to GM and other novel food technologies - which are most important? One finding seems to be that perceived benefits are very important for acceptance: Frewer et al (1997) found that *tangible benefits* are more important for the acceptance of foods than the processing technology *per se* (they considered three processes: genetic engineering, protein engineering and selective breeding), while Ronteltap et al (2007) concluded from a literature review that there is considerable evidence showing that perceived costs and perceived benefits are both major determinants of consumers' acceptance of new food technologies. Indeed, risk and benefit perceptions may be linked, and the affect heuristic is often discussed in this regard (Finucane et al., 2000), whereby attitude is influenced by an *emotional* response to a stimulus: if feelings towards an activity are positive, then people are more likely to judge the risks as low and the benefits high, but if their feelings are negative, then they are more likely to perceive the risks as high and benefits low. However, in a meta-analysis of 26 studies conducted by Bearth and Siegrst (2016), undertaken in an attempt to understand the relative importance of risk and benefit perceptions for acceptance of innovative food technologies, the relationship between them was found to be complex (as to which is more important, or which influences which in what way). However, the relationship between the various main factors is not straightforward, and general affect may play a critical or mediating role – as perhaps demonstrated by Caporale and Monteleone (2004), who found that providing people with information about manufacturing processes appeared to have a psychological effect on the perception of products, with participants reporting liking the taste of a beer labelled as traditional better than the beer labelled as GMO (even though the products were the same).

In summary, research on a wider variety of novel food products and processes seems to identify similar factors as of importance to attitudes of acceptance as do studies of GM foods, though hinting at other factors too, such as *disgust* and *perceived behavioural control*. Understanding *GE* applied to foods should acknowledge this broader frame of reference, and indeed, recognise that the *technological* aspect may be *relatively* unimportant for attitudes, with *novelty* being the key factor when considering foods.

5. Attitudes to the Use of Animals for Food

Another area worth brief consideration is that of public attitudes to the use of animals as a source of food products. That is, in considering attitudes to biotechnologies and to novel food products we have found that novel forms and uses of animals for food purposes are generally opposed (more than various other applications) – but research has not particularly elaborated *why*, aside from perhaps a sense that this is a more unnatural activity with fewer clear benefits. What is it about animals that cause this relative negativity?

Animal welfare seems to be one concern that hasn't been directly discussed here until now, although this is an issue of concern to many consumers (e.g. see Cornish et al, 2018 for recent discussion and evidence). Certainly, the issue has been a concern to some researchers, mainly from the context of assessing WTP for farm animal welfare (FAW). Indeed, a couple of meta-analyses have confirmed a willingness by consumers to pay premiums for farm animal welfare and higher welfare products (Lagerkvist and Hess, 2011; Clark et al, 2017), and have identified further patterns within this data. One difference is between WTP for different animals, with the lowest average WTP estimate being for pigs and the highest for beef and dairy cows (see Clark et al, 2017). Demographics differences have also been identified. For example, both analyses found that an increase in age was related to a decrease in WTP, implying different preferences between older and younger individuals (i.e. younger consumers being more concerned about welfare), while regional differences have been found too, with Northern Europeans having a significantly lower WTP compared to all the other regions, including Southern Europe. However, consumers don't necessarily think of animal welfare when purchasing meat (e.g. TNS Opinion and Social, 2005), while research has also generally found a so-called *attitude-behaviour gap*, whereby consumers' concerns for animal welfare does not always manifest reliably as higher welfare purchase decisions at the supermarket checkout, where factors such as price may triumph concerns (e.g. Aschemann-Witzel and Niebuhr Aagaard, 2014; de Barcelos et al, 2011), and other research has suggested that consumers can even be somewhat perverse in their beliefs, for example, expressing support for vaccination programs against various diseases (enhancing animal welfare) then indicating that they are unwilling to consume meat from animals that have been vaccinated (Zingg and Siegrist, 2012).

In short, animal welfare is at least a theoretical concern to many of the public; how this might translate to attitudes to GE products in which increased animal welfare is one benefit (as opposed to, say, health or environmental benefits), and how this might trade-off against perceptions of risks or unnaturalness (etc.) in the formula of acceptability, is currently uncertain.

6. Attitudes to Genome Editing

Though public attitudes to genome editing have been considerably less-well-researched than attitudes to GM, a growing number of studies are being published on this issue, albeit most seem to be about uses in *humans* rather than in food or animal applications. Delhove et al (2020) recently produced a structured review of *gene therapy and gene editing* for *human use* to highlight the factors that influence *acceptability* - although most identified studies were on gene therapy, which has already been noted as a target of research (e.g. in Eurobarometer surveys). It is still worth recording details from this paper, given that the authors equated the two techniques at least in terms of purpose of application (and indeed, they did not specifically separate out the two approaches in their analysis).

Following detailed database searches, Delhove et al (2020) identified a total of 41 papers as appropriate to the topic with relevant details for analysis (25 quantitative, 2 qualitative, and 14 mixed-method, around a quarter of these conducted in the UK and another quarter in the US). Interestingly, the themes and results that emerged are highly similar to those already discussed with regards GM food attitudes, though with the odd notable exception:

- Attitudes were generally *positive* for medical reasons (e.g. over 50% positive), whereas non-medical reasons (such as for appearance/ enhancement) were in almost every case assessed less positively (indeed negatively, e.g. acceptance below 50%)
- As the severity of disease increased, so too did the acceptability of *gene therapy*
- Somatic therapies generally had higher levels of acceptability than germ line therapies (i.e. therapies on embryos that could lead to inherited changes)
- A total of 22 studies specifically examined a range of risks and benefits, with many noting that acceptability of gene therapy or human genetic manipulation was very closely related to the *risk* of the intervention, though in general there was broad support for the *benefits* of gene therapy for human use
- The most common *ethical* concern was that genetic modification was interfering with nature (unnatural) (11 studies) and that it was 'playing God' (four studies) (with gene therapy for diseases found to be significantly more morally acceptable compared with enhancement in nine studies that compared this)
- Aside from concerns very specific to human applications, which won't be recorded here (e.g. on human abilities, sense of self, role of parents), other moral concerns included the potential for *uneven distribution of resources* (one study) and the impact on *natural selection* (two studies)
- Other concerns *included* misuse (one study), safety (one), unacceptable health outcomes (five), adverse medical side effects (three) and unknown or unpredictable long-term consequences, such as undesirable mutations (eight)
- Many fears and concerns were accompanied by a lack of *trust* in research, scientists, the medical system, or government rules and those in charge

- The impact of respondents' career was mixed, with four studies finding that science-oriented careers were a significant predictor of greater levels of acceptance of gene therapy, while six studies found little to no relationship
- Self-reported and tested knowledge of genetics was generally found to positively impact the acceptance of gene therapy (but there was little evidence for gene editing)
- Increased education levels were found to be a significant predictor of greater levels of *gene therapy* support (seven positive, two no relationship, one negative)
- Eighteen studies examined the impact of gender, of which 14 found that women were less approving of gene therapy
- Religiosity was found to be a negative predictor of acceptability of *gene therapy* in eight of ten studies
- Only nine studies specifically reported on the relationship of age with perceptions of gene therapy, finding an inverse relationship between age and acceptability of gene therapy in four (younger participants being more accepting of gene therapy than older age groups), one the converse, and four finding no effects (two of which were on gene editing)

Aside from confirming that medical uses of such therapies are generally more acceptable than for food purposes (given respective levels in support from the studies in the Delhove et al review versus the studies discussed previously), the most notable apparent difference is that religiosity appeared a clearer correlate to (lack of) acceptance here, which might be due to the focus of manipulations on humans rather than food/animals, and hence might be less pertinent for GE on farmed animals. Again, it is worth emphasizing that most of the studies included in this analysis were on gene therapy. Of those on gene editing, Gaskell et al's (2017) survey in eleven countries showed that *application* rather than the *technology per se*, was the critical issue for the general public. For example, genome editing received consistently more support when applied to therapy rather than enhancement, and to adults rather than prenatals. Similarly, Scheufele et al (2017) in a survey in the US found higher approval for therapeutic as opposed to enhancement applications, and see also Critchley et al's (2019) study in Australia.

There have been a number of studies subsequent to the review of Delhove et al (2020), or understandably missed by the review for being in the grey literature. Muller et al (2019) – in a preliminary report – analysed the entirety of 'all tweets ever published' on CRISPR since the publication of the first gene editing application in 2013. Their results suggested that the mean sentiment of tweets was initially very positive, but began to decrease over time, and that this decline was driven by rare peaks of strong negative sentiments, which they were able to associate with specific events, such as a controversy over the supposed creation in China of the world's first gene edited baby. Wipperman and Campos (2016) reported a survey in the UK on patients' views on genome editing, the headline finding of which was (as previously) that genome editing in humans should be restricted to treating medical conditions and not for the enhancement or alteration of physical or cognitive attributes of healthy people. Meanwhile, Lakomý et al (2018) reported on a survey conducted under the ORION EU-funded project over a range of EU countries. They found that *prevention or cure of diseases*, *prevention of disabilities* and *organ transplantation* were the three most desired purposes, whereas improvement of *plant production*, *livestock production* and *changing non-life-limiting characteristics of human embryos* ranked lower. Interestingly, Spanish respondents were more positive in general (mirroring findings from Eurobarometer on GM foods), with there being more doubts on specific purposes found among respondents from Germany (organ transplantation), Sweden (livestock production) and the Czech Republic (improvement of human embryos). They also found some evidence of gender differences (e.g. males more supportive of different purposes), while as levels of self-declared interest rose, respondents in all of the countries tended to increasingly support genome editing for *all* purposes. As before, the purpose of genome editing that divided opinion the most is changing non-life-limiting characteristics of human embryos, with perceptions varying strongly across countries, age groups, gender, jobs related to research, and both interest and confidence in life sciences research.

Lakomý et al (2018) further found that the largest concern associated with genome editing was that the technique could be *misused*, with the second largest concern being that the technology could come with *unknown side-effects in humans*. Women were slightly more concerned about the potential side-effects and the risk of misuse whereas men were actually more concerned about *insufficient regulation* and *ethical implications* of the technology. They also found that all levels of concern seemed to *decrease* with rising age, while the level of interest in life sciences research seemed to be *negatively* correlated with concerns about genome editing - in the sense that the *more interested* an individual, the *higher* the level of concern they expressed (a result found across all four options of concern i.e. side-effects, potential misuse, ethical implications and insufficient regulation).

The latter study thus raised the issue of GE for plant and livestock production, and interestingly found attitudes placing them alongside changing non-life-limiting characteristics of human embryos, i.e. of lower desirability/ acceptability to treating diseases/ medical conditions in humans.

The absence of work on public attitudes to GE in non-human contexts is notable. Indeed, Smith and Samuel (2018) concluded from a rapid analysis of publically available published material that whilst non-human genome editing is attracting significant attention from technical and policy experts, there are few indications of any substantial public discussion of the topic. Further, they suggest that much of the formal public debate (engagement activities and attitude surveys) has revolved around *human* genome editing as opposed to its applications in non-human animals, plants and microbes, suggesting that non-human genome editing is 'a 'technical category' but not a 'public topic'' (p. 3).

Indeed, we have found very few studies of attitudes specifically towards non-human GE. Gatica-Arias et al (2019) conducted a survey in Costa Rica on attitudes toward the production and potential consumption of CRISPR/Cas9 *crops*. Very few of their respondents claimed any knowledge of gene editing via CRISPR/Cas9 (only 3.7%). However, a high percentage agreed they would accept the use of gene editing for nature conservation (84.5%), curing diseases in animals (83.0%), crop improvement (80.9%) and curing human diseases (80.2%). Respondents also agreed that CRISPR foods would increase crop production in the country (66.0%), improve the economy (63.7%), and bring benefits to their families (60.7%) and the environment (57.4%), and nearly half perceived low or no risk to quality of life, health, and the environment. A higher percentage would consume CRISPR foods if the nutritional quality were better (70.8%), if they were cheaper than conventional products (61.0%), and if they were available in the national market (59.4%). And finally, approximately half of the interviewees claimed they would be willing to purchase a kilo of rice or beans (traditional Costa Rican food products) if they were priced the same as conventional products - although this means about half would not, and hence implies a lower WTP for GE products.

Shew et al (2018) conducted a multi-country assessment of consumers' willingness-to-consume (WTC) and willingness-to-pay (WTP) for CRISPR-produced food compared to conventional and genetically modified (GM) foods, respectively. In the USA, Canada, Belgium, France, and Australia, 56%, 47%, 46%, 30%, and 51% of respondents, respectively, indicated that they *would* consume both GM and CRISPR food. They also found that *biotechnology familiarity* and *perceptions of safety* were the primary drivers for WTC CRISPR and GM food. Importantly, respondents valued CRISPR and GM food *similarly* – and substantially less than conventional food.

McConnachie et al (2019) specifically looked at attitudes towards the use of gene editing to spread the naturally occurring POLLED gene, to produce genetically hornless animals that would not need to experience painful procedures used to remove the horns or horn buds. Results from the US sample (recruited online) found that more people responded that the modification would be *good* than *bad*, and more would be willing to consume products from these animals versus not. Qualitative analysis of the text responses showed that participant reasoning was based on several themes including *animal welfare*, *uncertainty* about the technology, and *worker well-being*. The authors concluded that people may be more likely to support GM technologies when these are perceived to benefit the animal.

Finally, Ritter et al (2019) followed up on the issue of polled cattle, considering attitudes to the separate and combined use of GE to create dairy cattle *without horns* and with *increased resistance to disease* in another online survey in the US. Results found that participant attitudes were more favourable to *disease resistance* than to *hornlessness*. With regards 'disease-resistance', participants had more positive attitudes toward genetic modification when the described purpose was *animal welfare* versus *reduction of costs*. Attitudes were less favourable to the 'hornless' application if no purpose was provided versus when the stated purpose was either to improve animal welfare or when all purposes (improve animal welfare, reduce costs, increase worker safety) were provided. Similarly, attitudes were less positive when the stated purpose was to reduce costs versus either improving animal welfare or when all purposes were provided. Quantitative and qualitative analysis indicated that both the specific application and perceived purpose (particularly when related to animal welfare) can affect public attitudes toward GE.

In summary, studies on attitudes to GE are only just starting to emerge, with most focused on human as opposed to non-human uses. Results generally replicate previous results on GM for food (and more widely) i.e. *applications* matter, as do the nature of benefits, with animal welfare again being of note. There is no particular sense that the new technology is understood to differ from GM.

7. Trust, Science Communication and Public Engagement

One factor that appears to be related to public attitudes to, and acceptance of, GM foods, and that will undoubtedly have pertinence for GE used with animals leading to products for consumption, is that of *trust*. In fact, 'trust' is a more universal factor that is of relevance to attitudes to the food system in general, and to other technologies and applications, and indeed, quite probably, to every issue of policy in which people in authority are required to communicate with/to the public (which is why we discuss the matter in a separate section here). Many articles and books have been written on the topic – on its importance, on its dimensions, on how it is gained or lost, on who has it and how one might get it – and discussion of these are well beyond remit of this report. All that is worth emphasizing here is that *low trust* in those responsible for developing, distributing, managing and overseeing 'things' (insert issue here) has been related to negative attitudes and low acceptance – as has been briefly noted in the above sections on GM foods, novel food products, and gene editing (e.g. Siegrist, 2008; Frewer et al, 2011; Kamrath et al, 2019; Delhove et al, 2020). Trust is essentially seen as a heuristic that people use in order to judge affairs: if a trustworthy source, such as a person of authority, *communicates* that something is good or safe then there is no need to extend significant efforts looking into that matter and its quality can be accepted, but if trust is low then red flags are raised.

This issue of trust is thus intimately linked to the issue of science communication, that is, in how to communicate science to the public on issues such as GM or GE. The current zeitgeist eschews the so-called 'deficit model' (in which the public is essentially seen as ignorant, with the goal of science communication being to find ways to effectively educate the public into the truth of matters), moving towards public engagement, in which a two-way dialogue is enabled, with recognition that public attitudes (especially of resistance) may be understandable and even logical, given that value judgments often underlie policy choices (e.g. just because the science is safe, should it be done?). Again, these are major areas of academic endeavour and we have not the time or space to discuss their minutiae. One reason for a greater desire for public engagement from the policy community is that this is seen as a potential antidote to low trust, that is, if the public refuse to believe communications then another approach is needed, and listening to the public and responding to their actual concerns, and allowing them to voice their values, may be one way to increase trust in communicators and policy makers (somehow).

What this has led to in discussions on GM and novel foods is how to communicate with people to best enhance trust and (at least implicitly) enhance acceptance. One issue frequently highlighted is that of labelling. It is perhaps of absolutely no surprise that, when asked, most people concur that labelling is a good idea and should be done and that this might enhance their trust in some product (e.g. Costa-Font et al, 2008). The essence of this argument is that labelling is a way to provide information to enable consumers to make informed choices, and there have been a considerable number of empirical studies comparing labelling of different types and styles for different aspects of foods, including notification about GM links. However, GM labelling's effects are uncertain, with some finding it has negligible effects on purchasing (e.g. see Hakim et al, 2020), and others that it can reduce opposition to GM food (e.g. Kolodinsky and Lusk, 2018).

The issue is, do people who ought to read labels actually do so, and are they then appropriately informed? Does extra information actually help or have any notable impact? Does labelling actually stigmatise a food, causing concern that might not otherwise exist? And what of information provided in other, more-intensive ways, whether in studies or incidentally through the media? Results on this matter are not necessarily encouraging. For example, Siegrist et al (2017) found that laypeople receiving detailed information about *28 hazards related to food and everyday items* provided similar (highly correlated) risk rankings to laypeople performing the same rankings in a no-information survey method with no information about hazards i.e. the information seemed to have little effect. Other studies, including ones on GM food specifically, have also found negligible effects of balanced information on attitudes (e.g. Wuepper et al, 2019). Meanwhile, Fischer et al (2013) – on the admittedly different topic of nanotechnology in food – found that participants responded to risk and benefit information differently, with some becoming more positive others more negative, and some remaining ambivalent, seemingly related to initial attitudes. Pham and Mandel (2019) also found that consumers respond differently to persuasive messages regarding GM foods on the basis of their pre-existing attitudes, in their case, weakly anti-GM consumers tended to comply with a variety of pro-GM messages while strongly anti-GM consumers exhibited message-opposing behaviour, while responding just as negatively to a safety message (claiming that GM foods are safe) as to a risk message (claiming that GM foods are unsafe). Indeed, the well-established 'confirmation bias' is a potent finding from psychological research: that people tend to search for information in line with existing attitudes and/or selectively attend/interpret information to support their views, and there is evidence of this in the GM context (e.g. McFadden and Lusk, 2015).

In any case, the extent that people do actually search for information on subjects like GM is uncertain, and is likely to be lower than claims in studies (e.g. Cui and Shoemaker, 2018, found over a third of their Chinese respondents claimed to have searched for information on GMOs). If people do not currently spend considerable time self-educating on a topic like GM or GE, this may be just as well. There is some evidence that information present in the media can be biased against GM, for example, Vilella-Vila and Costa-Font (2008) found that early coverage of new GM food technology was generally negative; Mintz (2017) found a bias in articles and headlines in the US press regarding GMOs (207 favourable versus 250 unfavourable mentions); and Ventura et al. (2017) found a predominance of negative, or 'scary', images accompanying information on GMOs in Italian media. Cui and Shoemaker (2018) suggest that the debate around GM food has become increasingly one-sided in recent years, with activists spreading misinformation via social media about the human health dangers of GM food as well as the negative environmental impact of GM crops on transitional agricultural ecosystems (they provide examples from China). And beyond this, Baram-Tsabari and Schejter (2019) argue that many of the characteristics of contemporary media, such as an abundance of content, interactivity, mobility, and multimediality, act as a double-edged sword: while it provides 'enhanced affordance' over traditional media, it renders it more difficult for a non-expert audience to reach informed, science-related decisions.

In public participation or deliberation, efforts are generally made to provide balanced information on a topic in a more intensive and controlled space with some interactive elements, so that participant views can be elicited and also responded to. There have been several notable exercises on GM, perhaps the most large-scale being the 'GM Nation?' debate in the UK (2003/2004), which used a variety of ways to engage the public, but based its headline findings on responses by participants to a number of questions about risks and benefits available online, and provided dire conclusions about UK public views. However, this event has been much criticised, in large part because its lack of control of those involved meant it didn't attain the 'grass roots' participants intended, but rather got a self-selecting and anti-GM sample (see Pidgeon et al, 2005; Horlick-Jones et al, 2007). There have been a number of further efforts at engaging on GM topics. For example, Intelligence Squared U.S (a non-partisan, non-profit organization), held a TV debate in the US in 2014 on whether the world is better off with or without GM food. The discussion was on whether GM food is safe, how it impacts the environment, and whether it can improve food security. Both the positive and negative sides had experts debating for or against GM food. Among the attendees who were present, the percentages in favour or against 'genetically modified food' were 32% and 30%, respectively, before the debate, but this changed to 60% and 31%, respectively, after 100 min of debating the topic, suggesting that some opponents of GM food started to rethink their prior attitudes about GM food (see Cui and Shoemaker, 2018 for details, and see https://www.intelligencesquaredus.org/debates/genetically-modify-food). Unfortunately, though other engagements on GM have taken place, few are easy to access and many remain reports in the grey literature (indeed, we have been involved as evaluators in several of these, and have been unable to find any online footprint of our reports; and anecdotally, for what this is worth, we have also found initially uneasy participants becoming more positive following discussions with scientists). As an example of this low footprint, we initially missed - and were subsequently were alerted to - another engagement that was funded by the Royal Society (Van Mil, Hopkins and Kinsella, 2017), which was carried out on the potential future uses of genetic technologies in humans, crops and animals. This carefully conducted piece of work involved a two-stage process, with small numbers of participants from Norwich, London and Edinburgh, which confirmed the significance of many of the issues discussed previously in this report, from the role of risks and benefits for acceptability of an application, to the important role of 'trust'.

Furthermore, a word of caution is needed in interpreting results from participation exercises. These tend to be relatively small-scale with few participants, and hence the extent of their generalisability to the broader population (no matter how representative or indicative the participants) is questionable. On top of this, they are rarely *rigorous* in the same way as qualitative social science research, with common inadequacies in data recording and analysis, perhaps due to many (if not most) such exercises being conducted by non-academics (e.g. consultancy organisations) that have limited skills and motivation to actually *publish* results (i.e. subject their findings to peer review), while there are various reasons to question the impartiality of reported findings and evaluative results (see Rowe and Watermeyer, 2018). At best, then, the results of such procedures might be thought of as *existence demonstrations* - showing how people *might* think or behave in appropriate circumstances rather than how they necessarily *will*. To have more credibility - and potential for acceptance by the academic community and confident uptake by policy makers - future exercises should give considerably more attention to ensuring methodological soundness and rigorous analysis and dissemination of their research findings.

In summary, the issue of *trust* has been identified as an important factor related to attitudes to GM, novel foods, and other major scientific issues, and is used by people to help them evaluate communications about these (in low knowledge situations). The role of the media in helping form and shape attitudes about issues such as GM are thus topics of academic concern, and will need further study to chart how GE is framed and presented. Well-constructed public engagement may help us understand current and potential attitudes, though little can be said about this matter at present.

8. Methodological Issues and the Relevance of Existing Research to GE

Throughout this analysis of research findings on issues of potential relevance to GE in animal products, a number of caveats have been expressed. It is worth discussing the limitations of this research and its potential 'read-across' to our topic of fundamental interest.

The first issue to note is that most of the research discussed here has been of a *quantitative* nature, comprising mainly surveys and experimental (social) studies, with few *qualitative* studies (e.g. Kamrath et al, 2019). In such 'quantitative' work, respondents are typically presented with statements and asked to provide some judgment on these, and their responses are aggregated and analysed. The statements, however, pre-suppose comprehensive understanding of the issue at hand. For example, if – as is the case of many of the studies discussed here – respondents are asked to assess the *risks*, *benefits* and *naturalness* of some product, then the analysis can *only* draw conclusions about these concepts and their relative importance (magnitude, direction) and interrelationships. And then it is of no surprise when study after study (perhaps with different samples or applications) confirms the importance of these factors. While research confirming findings is laudable and indeed critical for the advancement of science and understanding, this approach means that, if alternative factors are actually of equal or greater relevance – such as the concept of 'disgust' – then these can be missed. Qualitative research, in which respondents are given more leeway to respond to open questions can reveal these additional factors, such as 'naturalness' itself (e.g. see Fife-Schaw and Rowe, 1996), although it can also provide results that are convoluted and difficult to interpret (e.g. see Greehy et al's, 2013 model). Indeed, the difficulty of drawing firm conclusions from qualitative research (boldly stating that it has 'found 'x'') may have led us to under-report such research as we have attempted to provide focused conclusions instead. Of course, none of this is to say that the corpus of extant research does *not* identify the most salient factors related to public attitudes to issues discussed in this report, it is just to sound a note of caution and suggest that research on GE should not eschew the qualitative or blindly adopt the same frames with the same questions used in the related areas, assuming that the pertinent issues are identical. Perhaps there is something special, even unique, about the combination of technology, purpose and application with regards GE for animal products, and if so it is crucial that sufficient qualitative, exploratory research is done first.

A second important issue concerns the validity and meaning of responses gained by research from respondents answering questions about which they actually know very little – as demonstrated to be the case in the GM domain. As noted by Slovic (1995), in the case of novel technologies (such as nanotechnology or new environmental hazards), it is likely that people construct their preferences (attitudes) during the process of responding to questionnaires (and in doing so take into account 'irrelevant information' that could strongly bias their constructions). In other words, it may be that most people do not actually have an established attitude to an issue like GM food, and while some will answer 'don't know' (if given the choice) others will construct an answer then and there, perhaps based on a general understanding of the concept, a vague affect, or even on the basis of the look of the word (e.g. Fife-Schaw and Rowe, 1996; Gaskell et al, 2003; Connor and Siegrist, 2016). Of course, none of this is to say that such questions should *not* be asked; they should, because they are informative and at least reveal people's automatic response when confronted with a novel issue; but rather, that we should be cautious in interpreting responses. That is, if people are implacably opposed to something, then dialogue and education may prove of little worth, but if they are uncertain and ambivalent, then dialogue and education may in some way be beneficial (to the people themselves and to society more widely). Again, we need to be cautious in assuming that current research results will accurately translate onto how people *may* respond to GE animal products, once the technology is better publicised than it is now.

Coincidentally, the WTP studies largely deal in hypothetical scenarios, as do other studies looking at behavioural intention (e.g. studies employing the framework of the theory of planned behaviour), hence their results should also not be taken at face value as indicators of likely *actual* behaviour (i.e. the results again may not be exactly as they seem). For example, research suggests that price is often a significant factor in purchasing behaviour, perhaps more so than suggested by studies that use this as one potential benefit of GM food/ novel foods (etc.) (Gaskell et al, 2006). Caution is the word.

A third issue concerns the size and scope of the research domain discussed. There has been a focus on the Eurobarometer surveys in this report, because these have been the largest and most consistent pieces of research on attitudes to biotechnology. However, a close reading of the various reports reveals that the comparability of findings of even these need to be accepted cautiously: along with changes in samples (as the EU has expanded), there have been subtle differences in wordings and framings that may have undermined these as a longitudinal analyses of Europeans' views (or strictly speaking, *cross-sectional* analyses, since longitudinal studies actually require repeated questioning of the same people on different occasions – see Connor and Siegrist, 2016). Other research on the topic of interest (GM food, novel foods, animals) has used different samples at different times using similar-but-usually-significantly different questions. It is for this reason, for example, that national differences (hence, differences due to culture, national history of GM, and so on) are difficult to convincingly declare, e.g. if a sample from rural Korea is asked about benefits of GM rice and its risks in 2010, how much valid read-across is there to findings from another sample from east coast USA asked about environmental benefits of GM wheat in 2001? Is it possible to conclude from these hypothetical cases that people from one country are more or less positive about GM in general, or have different risk/benefit profiles? What this report has done is essentially carve up the analysis to look for *main effects* of the different key factors, when the 'truth' about public attitudes to GM food (etc.) will undoubtedly be a result of the *interactions* between these factors, and yet findings on interactions are often disparate and partial, given the precise combination of factors considered in any one study, and undermined by having insufficient statistical power to find relationships that actually exist (the more factors analysed, the greater the sample size needed). And hence we must be careful in assuming that *absence of evidence* is equivalent to *evidence of absence*; it is not; and the true story of what factors determine attitudes to GM food (etc.) is still not fully known. Qualitative studies can present more complex pictures that *do* speak to interactions and interrelationships – such as the interesting model of Greehy et al (2013) – yet of a type that quantitative empiricists might feel uncomfortable in fully accepting for being narrative rather than statistical. For the GE domain, qualitative research needs to be followed by large-scale quantitative research that carefully chooses its factors of interest to ensure statistical success is achievable, and that then form a template for replication (as close as possible) in other locations or with other constituencies or applications of interest.

In summary, existing research has a number of gaps and difficulties that need to be acknowledged. The consistency of findings across many studies over several decades, however, suggests that some significant truths have been uncovered. But assuming a precise read-across to likely attitudes to GE used for animal products would be unwise: more, and more-appropriate, research is needed.

9. Conclusion: Implications for GE in Farmed Animals

This review has covered a lot of ground, attempting to look at research on attitudes to various issues the results of which might be generalizable to likely attitudes to genome editing of farmed animals. The main focus has been on attitudes to GM foods (the precursor to GE), but also attitudes to novel foods (regardless of biotechnology) and to farmed animals (again regardless of technology). Many factors of potential import for positive or negative attitudes have been identified, not least nationality/ culture, technology and foodstuff applications, demographics (particularly sex and age), values (especially ecological ones), personality, level of knowledge (subjective and objective), and trust in authority. Even so, the jigsaw is not complete: further research has hinted at the importance of other factors, such as *social norms* and *perceived behavioural control* (e.g. Cook et al, 2002; Prati et al, 2012; Akbari et al, 2019), that have been difficult to fit into the ontology of this report (and which have only been scantly studied anyway), while the *interactions* between these various factors has been difficult to construct – and it is these interactions that will ultimately determine acceptability of GE in farmed animals for any one particular place, point of time and population. In the end, short-cuts cannot be taken: it will be necessary to do relevant research, perhaps informed by the findings in this report and following the insights into required methodology discussed above. Nevertheless, if we had to make educated predictions on the basis of the discussed research, for our topic of concern, we would suggest the following:

- Attitudes will be heavily influenced by the *framing* of the issue in the minds of the public, which may vary according to time and circumstance: is the GE/ farmed animal issue primarily perceived as one of technological fixes, or food novelty, or the (mis)use of animals? Schema theory may be of use here, which emphasizes how people can simultaneously apply multiple conflicting schemata to the same information, with the one 'selected' depending on factors such as *current activation*, *accessibility*, *priming* and *emotion* (e.g. see Rumelhart, 1980).

- The fine detail of the technology used is likely to be less important than the nature or purpose of an application. As such, the findings on attitudes to GM foods are liable to be highly pertinent (have good generalisability) to GE (for example, note the minimal differences in public attitudes to transgenic and cisgenic manipulations). To break this link, significant 'education' of the public would be needed to emphasize the differences between the technologies and why these are important; though it is unlikely the majority of the lay public would be interested in such minutiae.
- Perceived *benefits* seem particularly important for the acceptance of a particular application - more than even *risks*, though this is perhaps consequent on there having been no clear and demonstrable downside (like a food scare) related to GM thus far.
- The issue of *naturalness* seems a general concern for many, and is likely to be as significant for GE as for GM or other novel food processes. Ecological values seem important from this perspective. Debate on the meaning of 'what is natural' and how GE applications might even be ecologically helpful, would seem a worthy issue for public engagement.

This review has had to sift through several different research areas - though it could have been bigger and considered even more. For example, it could have considered the psychology of food choice, and touched upon issues to do with habit formation and food neophobia; it could have delved into Science and Technology Studies (STS) to consider more general public views of science and technology and people's understandings of their concepts and purposes; it could have considered how technologies are represented in the media and especially how they are discussed in social media; it could have considered areas of cognitive psychology to attempt to explain where attitudes might come from and what factors (psychological and external) affect and account for them (including discussion of heuristics and biases, see especially Kahneman, 2011). It could also have considered important social and cultural trends, such as the 'organic revolution', veganism, sustainability, and food security - which would all seem to provide important social norms that could well impact attitudes to GE and its applications in the future. Relatedly, the topic of 'ethics' has not been particularly profoundly addressed, though this - as in other apparent omissions - is largely consequent on the nature of relevant accessible research.

For example, though ethical issues to do with novel foods have been discussed in the literature, this has mainly been at the theoretical/ conceptual level (e.g. Kaiser, 2005) rather than through a series of studies of the public. We leave the expanding of our analysis (even a second edition) to others.

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