Synthetic biology applied in the agri-food sector: Understanding societal responses

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Abstract

Synthetic biology (SB) has the potential to deliver various novel agri-food applications. However, a mapping review of the existing literature on public attitudes indicated that agri-food applications may be less acceptable to the public, compared to medical and environmental applications. Research into public attitudes, at present, is limited, and is mainly focused on SB *per se* rather than on its specific applications. This research seeks to address this knowledge gap.

As scientific experts in the area of SB contribute to innovation trajectories and regulatory frameworks linked to SB, semi-structured interviews were conducted to understand how Chinese (n = 9) and EU experts (n = 13) think the public may respond to SB applications. The results suggested that experts were concerned about public rejection of SB in the agri-food sector. In contrast, according to the focus group research (6 groups) among Chinese citizens (n = 32), most participants evaluated SB agri-food applications on a case-by-case analysis, and did not reject SB as an enabling technology.

Subsequently, online surveys were conducted to investigate Chinese public responses to genetically modified (GM) (n = 1,411) and SB-based (n = 1,330) agri-food applications, respectively. The results showed that participants had positive general attitudes towards SB food, despite the influence of their prior beliefs about GM food. A framework that explained public attitude formation towards SB agri-food applications was developed and tested using structural equation modelling. The results demonstrated that benefit perceptions were the most important in predicting participants' application acceptance compared to general attitudes, affective responses and risk perceptions. Future SB-related agri-food policy- and communication strategy-making, as well as application development, should consider public attitudinal differences across applications and contexts. Co-production of applications and polices with the public was identified as an important part of the technological innovation process.

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List of abbreviations

AVE	Average variance extracted
CB-SEM	Covariance-based structural equation modelling
CI	Confidence interval
CNY	Chinese yuan
EC	European Commission
EU	European Union
GM	Genetically modified / genetic modification
HTMT	Heterotrait-monotrait ratio
PLS-SEM	Partial least squares structural equation modelling
R&D	Research and development
RRI	Responsible research and innovation
SB	Synthetic biology
SD	Standard deviation
SRMR	Standardised root mean square residual

List of publications

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Publications arising from the research:

- Jin, S., Clark, B., Kuznesof, S., Lin, X., & Frewer, L. J. (2019). Synthetic biology applied in the agrifood sector: Public perceptions, attitudes and implications for future studies. *Trends in Food Science & Technology*, *91*, 454–466. https://doi.org/10.1016/j.tifs.2019.07.025
- Jin, S., Clark, B., Li, W., Kuznesof, S. and Frewer, L.J. (2021). Social dimensions of synthetic biology in the agrifood sector: The perspective of Chinese and EU scientists, *British Food Journal*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/BFJ-12-2020-1142
- Jin, S., Clark, B., Liu, Z., & Frewer, L. J. (2021). Drivers of Chinese public attitudes towards agri-food applications based on synthetic biology: The results of qualitative exploratory research. (Submitted)
- Jin, S., Li, W., Dawson, I., Clark, B., Chen S., & Frewer, L. J. (2021). Consumer responses to genetically modified food in China: The influence of prior attitudes, affect and perceptions of risks and benefits. (Submitted)
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Publications arising from research conducted during the period covered by the PhD candidature

- Jin, S., Li, W., Cao, Y., Jones, G., Chen, J., Li, Z., Chang, Q., Yang, G., & Frewer L. J. (2021). Identifying barriers to sustainable apple production: A stakeholder perspective. (Submitted)
- Jin, S., Li, W., Naab, F., Coles, D., & Frewer, L. J. (2021). Consumer attitudes towards novel agri-food technologies: A critical review on genetic modification and synthetic biology. (Accepted)
- Kendall, H., Clark, B., Li, W., Jin, S., Jones, G., Chen, J., Taylor, J., Li, Z., & Frewer L. J. (2021). Precision agriculture technology adoption: A qualitative study of small-scale commercial "family farms" located in the North China Plain. (Revision & Resubmission)

Chapter 1. General introduction

1.1 Introduction

Novel agri-food technologies have the potential to improve food security and simultaneously reduce the use of natural resources and synthetic agricultural chemicals, therefore bringing benefits to the environment and society (Brookes & Barfoot, 2017; Pretty et al., 2018). However, social responses to different technologies might differ, with some being easily accepted and others rejected by the public, or subgroups within the population. This may, in turn, affect the development and commercialisation trajectories of these technologies and relevant products (Cardello, 2003). For example, in the case of food preservation techniques, high-pressure and pulsed electric field processing of food were more acceptable to consumers, while food irradiation was associated with more negative public views (Frewer et al., 2011). Another case in point is exemplified by genetically modified (GM) food, which has been generally less accepted when compared to conventionally produced food. European consumers tended to have higher risk perceptions of, and more negative attitudes towards, GM food compared to Northern American and Asian consumers, while ethical and moral concerns were greater in Northern America (and possibly Asia) compared to Europe (Frewer et al., 2013).

Synthetic biology (SB), a novel multidisciplinary area of research, has attracted considerable academic attention due to its numerous potential applications across different domains (Benner & Sismour, 2005). The global SB market is expected to reach $28.91 billion in 2025 (The Business Research Company, 2021). So far, there have been around 700 organizations engaged in SB-related research across 40 countries; and more than 350 companies have been established, which apply SB as part of their activities (Bueso & Tangney, 2017). The recent technical advances (for example, new/cheaper ways of DNA synthesis and tools for DNA assembly) and more open sourcing (e.g. circulation of foundational tools and reusable synthetic parts) of SB have facilitated development of applications in different sectors, such as healthcare, energy, environment and agri-food. It is anticipated that these applications can provide new and cost-effective ways of disease treatment, drug and clean energy production, waste recycling, environment enhancement, among many others (Polizzi, Stanbrough, &

Heap, 2018). Within the agri-food sector, SB offers better ways to improve crops, control pests and crop diseases, enhance the environment and manage livestock. It also has the potential to deliver advantages to novel food and food ingredient production, food processing, food safety diagnosis, food waste processing and food packaging development (Table 1.1). However, research on social responses to SB including its application to the agri-food sector is, to date, limited.

1.2 Technical issues associated with SB

In common with other emerging technologies (e.g. nanotechnology), there is no standardised definition of SB available at the present time. The European Commission (2005) has defined SB as "applying the engineering paradigm of systems design to biological systems in order to produce predictable and robust systems with novel functionalities that do not exist in nature" (p. 10). The Royal Academy of Engineering (2009) has proposed that SB involves "the design and construction of novel artificial biological pathways, organisms and devices, or the redesign of existing natural biological systems" (p. 13). Alternatively, SB can be described as "the design and construction of new biological parts, devices, and systems, and the redesign of existing, natural biological systems for useful purposes" (Springer Nature, n.d.).

All definitions encompass the notion that applications of SB involve the creation of novel living systems through synthesising and assembling artificial and/or natural components, which makes SB different from GM that is focused on the insertion of DNA from other organisms into host organisms to produce desired traits (Colwell, Norse, Pimentel, Sharples, & Simberloff, 1985). Consequently, SB may involve the use of larger amounts of DNA, which can be naturally occurring or synthetic. The constructed living systems could be standardised and shared within the community to establish more complex systems (Cameron, Bashor, & Collins, 2014). The sharing and rebuilding based on standardised living systems could facilitate the development of new applications, but may simultaneously increase the risks of releasing synthetic biological agents into the environment (Polizzi et al., 2018). A serious challenge for scientists and policy-makers is that of how to effectively assess risks and develop effective governance practices, as the complexity of SB-based applications is constantly increasing, including within the agri-food sector (Pauwels et al., 2013). In addition, the "bottom-up" approach of SB, which aims to create artificial or semi-artificial life *de novo*, might evoke strong ethical controversy (Bedau, Parke, Tangen, & Hantsche-

Tangen, 2009). Thus, it is important to investigate public perceptions of, and attitudes towards, SB separately from other technologies such as GM, rather than assume that societal responses to SB will be the same.

Area of application		Host	Traits/product	Examples	Stage	References
Agriculture	Crop improvement	Plant	Productivity increase	Improved carbon fixation in crops.	Laboratory	Bar-Even, Noor, Lewis, & Milo, 2010; Gonzalez-Esquer, Shubitowski, & Kerfeld, 2015.
		Plant	Production of novel substance or increased content of existing substance	Nutraceuticals such as carotenoid; Increased content of lignocellulose, oil, soluble sugar as bioenergy.	Laboratory	Fraser, Enfissi, & Bramley, 2009; Shih, Liang, & Loqué, 2016.
		Plant	Reduced need for inputs into agriculture	Engineered crops with reduced demands for inputs such as pesticide, water and nitrogen.	Laboratory	Abbas, Zafar, Khan, & Mukhtar, 2013; Park et al., 2015; Rogers & Oldroyd, 2014.
		Plant	New ways of self-incompatible crop breeding	Diploid potato breeding.	Laboratory, trial	Ye et al., 2018.
		Microbe	Biofertilizer or biopesticide production	Provide biofertilizer or biopesticide through plant-microbe interaction.	Laboratory, trial	Farrar, Bryant, & Cope-Selby, 2014; Project Auxin from iGEM (http://2011.igem.org/Team: Imperial_College_London).
	Pest/crop disease control	Microbe	Biosensors	Pathogen detection in plants and soil.	Laboratory	Damiati, Mhanna, Kodzius, & Ehmoser, 2018; Ostrov et al., 2017; Van Der Meer & Belkin, 2010.
		Microbe	Bio-insecticides	Fusion protein toxic to certain insects.	Laboratory	Abbas et al., 2013.
		Microbe	Synthetic microbe killing specific pests	Synthetic virus/fungus targeting and killing specific pests	Envisioned	Inceoglu, Kamita, Hinton, Huang, Severson, Kang & Hammock, 2001.
		Insect	Sterile pests with synthetic gene drive system	Synthetic gene drive for sex-ratio distortion of certain pest group	Laboratory, trial	McFarlane, Whitelaw, & Lillico, 2017.
	Environmental enhancement	Microbe	Biosensors	Pollutant test such as heavy metal.	Laboratory, trial, commercial	Joshi, Wang, Montgomery, Elfick, & French, 2009; Kim, Jeong, & Lee, 2018.
		Microbe	Bioremediation	Bioremediation of metal, radionuclides and other substances.	Laboratory, trial	Marques, 2018; Tay, Nguyen, & Joshi, 2017.
		Microbe	Tackling soil erosion	Engineered bacteria for promoting root growth and protecting the soil from erosion.	Laboratory, trial	Project Auxin from iGEM (http://2011.igem.org/Team: Imperial_College_London).
		Microbe	Biofuels	Production of cellulosic ethanol, diesel, etc.	Laboratory, trial, commercial	Mascoma (http://www.mascoma.com); Solazyme (http://solazyme.com).
	Livestock management	Microbe	Biosensor and biotherapeutics	Whole cell-mediated health monitoring and disease treatment	Laboratory	Krishnamurthy, Moore, Rajamani, & Panchal, 2016; Slomovic, Pardee, & Collins, 2015; Sola-Oladokun, Culligan, & Sleator, 2017.
		Microbe	Function of facilitating feed processing	Engineered microbe or enzyme for feed processing.	Laboratory, trial, commercial	Mascoma (http://www.mascoma.com); Metabolic Explorer SA (https://www.metabolic-explorer.com).

		Animals	Animal breeding	Breeding of new lines depending on synthetic gene drive, genome editing, synthesised genes, etc.	Envisioned	Gonen et al., 2017; Bhat et al., 2017.
Food	Food products	Microbe, plant	Novel foods	Casein for milk production from yeast; Egg white from yeast.	Laboratory, trial, commercial	Perfect Day (http://www.perfectdayfoods.com); Clara Foods (https://www.clarafoods.com).
		Microbe, plant	Food additives	Colorant and flavours (vanillin, raspberry ketone, Stevia et al); nutraceuticals (vitamins, carotenoid et al.).	Laboratory, trial, commercial	Evolva (https://www.evolva.com); Hanson et al., 2018; Leonard et al., 2010; Nigam & Luke, 2016; Prima et al., 2017; Wang, Zada, Wei, & Kim, 2017.
	Food processing	Microbe	Improved fermentation process	Higher fermentation efficiency or better flavour products.	Laboratory, trial, commercial	Jagtap, Jadhav, Bapat, & Pretorius, 2017; Lee, Lloyd, Pretorius, & Borneman, 2016; Mays & Nair, 2018; iGEM Munich Team (http://synbio.info/display/synbio/ Beer+with+caffeine).
	Food safety diagnosis	Microbe	Biosensors	Food toxin, pathogen, parasite or other substance detection.	Laboratory, trial	Sample6 (https://www.sample6.com); De Mora et al., 2011; Webb et al., 2016.
	Food waste processing	Microbe	Waste degradation and useful substance extraction	Engineered microbe for phosphorus recovery from food waste.	Laboratory, trial	Lakhundi, 2012; Tarayre et al., 2016.
	Food packaging	Microbe	Material production	Biodegradable material such as biopolymer.	Laboratory, trial, commercial	Jung, Kim, Park, & Lee, 2010; Yield10 Bioscience (https://www.yield10bio.com); Bioamber (https://www.bio-amber.com); GC Innovation America (https://www.gcinnovationamerica.com).

Table 1. 1: Applications of SB in the agri-food sector

1.3 Scope and outline of thesis

Despite a variety of SB agri-food applications being developed, future commercialisation of these applications could be uncertain due to societal concerns about potential risks and ethical issues (Polizzi et al., 2018). In this context, this thesis aims to understand societal responses to SB applied in the agri-food sector in consideration of SB food in general and specific applications in particular, thereby providing information that benefits future relevant product development and commercialisation, communication with the public, and policy-making. This aim has been achieved by addressing the research objectives and associated research questions outlined in Table 1.2.

Research objectives	Research questions
Chapter 2: To review the existing literature for understanding public perceptions and attitudes associated with SB, including those linked to agri-food applications	▪ What are the risks in relation to SB within the agri-food sector? ▪ Are there specific issues raised that distinguish SB from other enabling agricultural technologies regarding public concerns? ▪ What factors may potentially affect the public's perceptions of, and attitudes towards, SB and its applications? ▪ What applications might the public and/or consumers prefer to be developed and commercialised within the agri-food sector?
Chapter 3: To understand perspectives of EU and Chinese scientists regarding social implications associated with SB	▪ What are scientists' perceptions of social dimensions pertinent to SB in particular its applications in the agri-food sector? ▪ What are the similarities and differences between the EU and Chinese scientists concerning their perceptions of social dimensions? ▪ What are scientists' understandings of the potential public response to SB?
Chapter 4: To explore the drivers of public acceptance and rejection of SB agri-food applications, and to compare these with GM foods	▪ What are Chinese public attitudes towards SB applied to agri-food production? ▪ How do Chinese people make decisions about accepting or rejecting SB agri-food applications? What are the similarities and differences compared to GM foods? ▪ What SB agri-food applications may the Chinese public prefer?
Chapter 5: To develop and test a framework to explain attitude formation towards GM agri-food applications in China, and to inform the SB related research model	▪ What are Chinese people's attitudes towards GM food in general and specific agri-food applications? ▪ What are the key factors that drive public acceptance of specific GM agri-food applications? ▪ How do the key factors interact and inform public decision-making about accepting or rejecting the applications?
Chapter 6: To develop and test a framework to explain attitude formation towards SB agri-food applications in China	▪ What are Chinese people's attitudes towards SB food in general and specific agri-food applications? ▪ What are the key factors that drive public acceptance of specific SB agri-food applications? ▪ How do the key factors interact and inform people's decision-making about accepting or rejecting the applications?

Chapter 7: To make evidence-based recommendations for policy-makers and the industry in relation to SB food	▪ What are the theoretical implications of the research? ▪ What are the policy implications of the research? ▪ What are the research limitations and implications for future research?

Table 1. 2: Research objectives and questions of this thesis

Following on from Chapter 1, i.e. the general introduction to SB and its agri-food applications, Chapter 2 reviewed the current literature related to public perceptions of, and attitudes towards, SB and its applications including those within the agri-food sector. The results were also compared with research on other emerging technologies (e.g. GM and nanotechnology) to learn about the barriers to and facilitators of effective communication and regulation of different applications of SB from other enabling technologies. Taken together, the findings enabled an overview of current knowledge about public perceptions and attitudes to be developed, and current research gaps to be identified.

Chapter 3 employed semi-structured interviews to investigate Chinese and EU scientists' perspectives on public responses to SB applied in the agri-food sector, and the potential for co-innovation with the public regarding the implementation of pathways associated with SB including its agri-food applications. There are three main reasons for conducting this study. First, scientists help frame regulatory and implementation policies and commercialisation trajectories of novel technologies including SB. Second, to date, there is limited research into public attitudes, while scientists may affect public attitudes through engagement activities. Third, SB applications may pose some transboundary risks which require international collaborations to address in the future, which need to accommodate similarities and differences in public views.

Chapter 4 used focus group discussions to explore factors that drive Chinese people's acceptance or rejection of SB agri-food applications, to enable a comparative analysis with the views of scientific experts. Similarities and differences in terms of research participants' attitudes towards SB and GM have also been assessed. As there was potential for GM and SB to represent complex concepts to Chinese public, the use of focus group methodology enabled active group interactions within a quasi-social context. This potentially facilitated the elicitation of participants' views on both technological innovations. The qualitative nature of this study helped achieve more in-depth understanding of people’s attitude formation towards SB foods, and informed the development of the attitudinal models and the survey tools to validate these in Chapters 5 and 6. In these chapters, frameworks were developed and tested to explain Chinese people’s attitude formation towards specific agri-food applications derived from GM and SB. These frameworks investigated how risk and benefit perceptions, and general attitudes towards GM and SB technology *per se*, and the affect evoked by specific applications informed people’s final acceptance of specific applications. The impacts of different factors on application acceptance were quantified and compared. Notably, the two chapters employed larger samples for data collection and quantified impacts of factors affecting public attitudes using structural equation modelling. This has increased the validity of generalising the findings from Chapters 5 and 6 compared to the qualitative work in Chapter 4. Chapter 7 integrated key findings from the preceding chapters, proposed recommendations for future policy- and communication strategy-making, and identified new research directions.

1.4 Selection of methods and interalationship between chapters

Figure 1.1 presents an overview of this thesis and interrelationships between different chapters. Chapter 1 briefly introduces the definitions of SB and its applications within the agri-food sector. This indicates the importance of understanding social responses to SB in general and its specific agri-food applications, and thus Chapter 2 employs a mapping review to present an overview of current knowledge about public perceptions and attitudes. The research gap identified in Chapter 2 shows the need of considering different stakeholders’ views on SB food, which leads to the investigations of scientists’ views based on semi-structured interviews (Chapter 3) and public views based on focus group discussions (Chapter 4). Chapter 4 involves a variety of factors affecting public attitudes towards SB foods, based on which Chapter 5 and 6 use online surveys to further quantify some identified factors and at the same time test frameworks that explain Chinese people’s attitude formation. Finally, the findings from Chapters 2, 3, 4, 5 and 6 together inform policy- and communication strategy-making as well as future research directions.

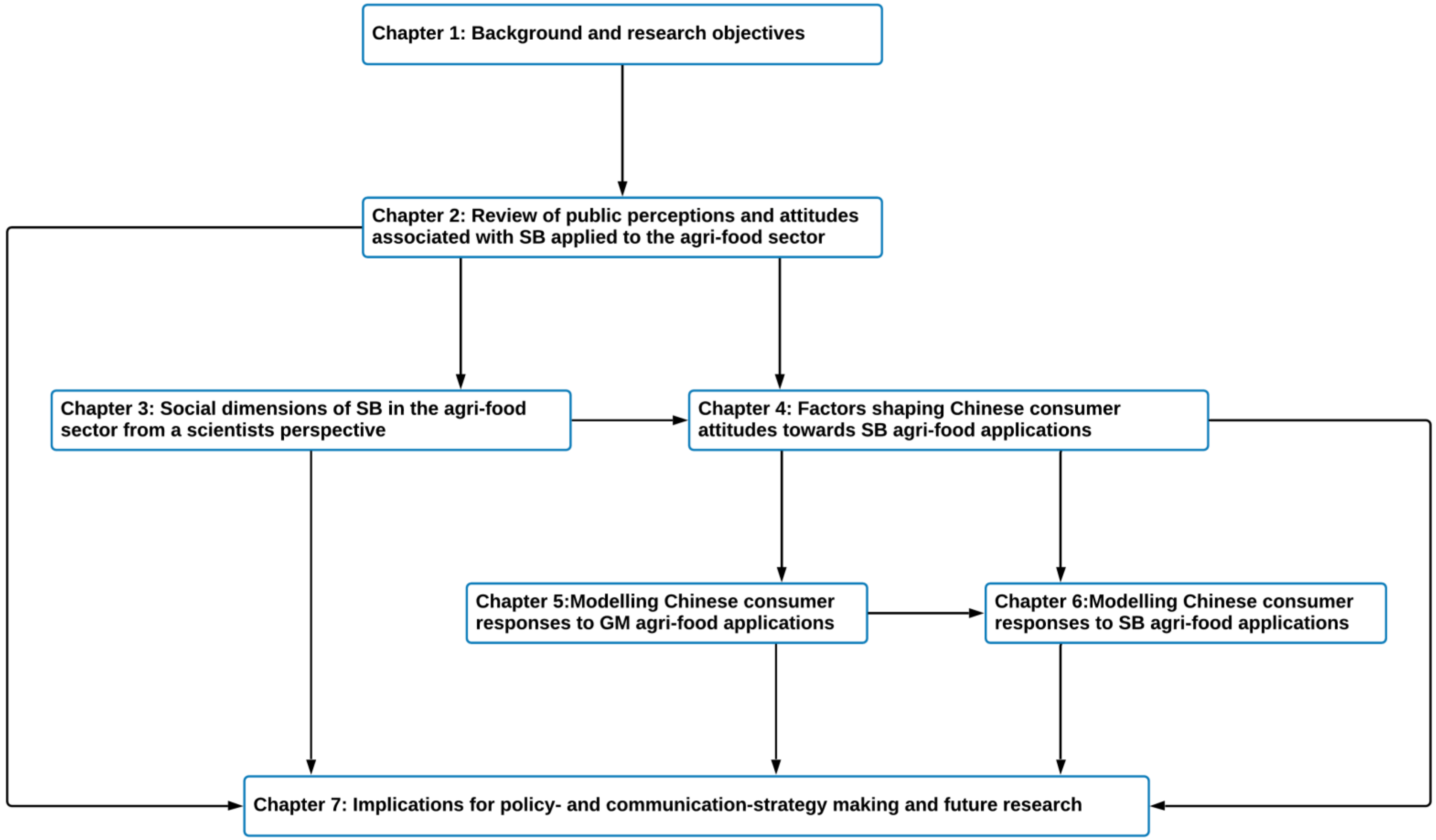

Figure 1. 1: Objectives and interrelationships of thesis chapters

Chapter 2. Public attitudes towards SB applied to the agri-food sector: A mapping review

2.1 Introduction

As future commercialisation of SB applications could be uncertain due to societal concerns about potential risks and ethical issues (Polizzi et al., 2018), and companies which align their products with consumer preferences and priorities may gain commercial success (Raley, Ragona, Sijtsema, Fischer, & Frewer, 2016), this chapter attempts to review the existing literature for understanding public perceptions and attitudes regarding SB, including those linked to agri-food applications. In addition, it attempts to compare the results with research on other emerging technologies, such as GM and nanotechnology, to identify differences and similarities in public perceptions and attitudes, and to assess whether it is possible to learn how best to commercialise different applications of SB from other enabling technologies in the agri-food sector (see Frewer et al., 2011).

This chapter therefore aims to address the following questions:

- Are there specific issues raised that distinguish SB from other enabling agri-technologies regarding public concerns?
- What factors may potentially affect the public's perceptions of, and attitudes towards, SB and its applications?
- What applications might the public and/or consumers prefer to be developed and commercialised within the agri-food sector?

This information will provide knowledge of direct relevance to those with interests in applying SB in the agri-food sector, in particular in relation to which applications can be developed, how products should be designed, and how governance can be optimised in the light of public and environmental health as well as societal preferences (Frewer et al., 2011).

2.2 Methodology

This chapter applied a mapping review methodology to answer the proposed research questions by analysing and integrating existing research findings, and simultaneously identifying current knowledge gaps (Grant & Booth, 2009). The relevant literature was identified using a two-stage search strategy between 1st July and 30th October 2018. In the first stage, 3 databases (Scopus, Web of Science and ProQuest) were searched to retrieve literature published between January 2004 and December 2018. The terms, (a) “synthetic biology”; (b) “attitude”; (c) “perception”; (c) “media coverage”; and (d) “press coverage” were used, in which (a) was separately combined with the other keywords. The returned references were screened and literature that was technical (i.e. which discussed the process and application of SB as a scientific process), unempirical, in languages other than English, or “misunderstood” the concept of SB (for example, equating it with GM) were excluded. In the second stage, additional references were obtained from the reference list of eligible studies identified in the first stage. A total of 24 studies were included, of which 8 were focused on analysis of media reportage of SB, and 16 were empirically-based public attitudes related research. A comparison of the retrieved studies was conducted, which focused on their methods used and research findings to address the proposed research questions.

2.3 Results

2.3.1 Risks and ethical issues of SB agri-food applications

There is evidence to suggest that emerging technologies have the potential to establish new industries or transform existing ones, delivering both benefits and risks (e.g. human health, environmental and socio-economic impacts) (Myers, 2007). These all need to be considered during their development and implementation processes and integrated into the regulatory framework for technological governance. Previous studies have shown that benefit and risk *perceptions and attitudes* drive societal acceptance of innovative food technologies, such as GM (Frewer et al., 2013) and nanotechnology (Giles, Kuznesof, Clark, Hubbard, & Frewer, 2015). Specifically, different trade-offs between perceived potential risks, benefits and other issues may be made during people’s decision-making of such technologies (Bearth & Siegrist, 2016; Hu, Hünnemeyer, Veeman, Adamowicz, & Srivastava, 2004; Mather et al., 2012), and this may extend to SB (Akin et al., 2017; Pauwels, 2013).

Despite the potential benefits, multiple risk issues have been raised in relation to human health, environmental, socioeconomic, and ethical impacts of SB. It is sometimes difficult to make precise risk calculations as the occurrence and consequences of a risk are associated with uncertainty (Rosa, 1998). This may indeed be the case for SB applied in the agri-food sector. For example, novel foods or food ingredients derived from synthetic organisms may be linked to public concerns about the uncertainties associated with their long-term impacts on human health, including increased allergenicity, as has been the case with GM and other novel foods (van Putten et al., 2006). The release of synthetic microbes or plants may have adverse environmental impacts through affecting other natural species, and subsequently cause negative impacts on human health after entering the food system (Polizzi et al., 2018). An example is the use of a synthetic gene-drive system to distort the sex-ratio of target pests, thereby reducing their ability to reproduce. Given the possibility of this system irreversibly entering other species, and the choice of insects as hosts, the application could be highly uncontrollable once released to the environment and subsequently damage the ecosystem more generally (Oye et al., 2014). In addition, upgraded techniques and open source platforms of SB make it easier to establish biological agents by people within or outside research institutes. It increases the possibility of intended (e.g. "bioterror") and unintended (i.e. "bio-error") release of dangerous biological agents (Polizzi et al., 2018), and may in turn affect the perceived and actual potential for adverse effects on human health and the environment.

Socioeconomic risks in relation to SB could also occur. For example, novel applications may negatively impact existing supply chains, within which stakeholders might suffer from negative economic consequences. The antimalarial drug (artemisinin) production by synthetic yeast may help stabilize the drug supply and decrease the cost, but traditional producers growing *Artemisia annua* for artemisinin extraction could be put out of business (Polizzi et al., 2018). In addition, the unbalanced adoption of SB-based agri-food applications, such as excessive growth of energy crops, may pose threats to food security if competition with food crops results (Harvey & Pilgrim, 2011). Ethical issues have also been frequently studied by ethics experts, in particular the raised concern about "playing God" or "tampering with nature" (Rogers, 2011). The potential for secondary use or misuse, together with other issues such as bio-error, bioterror, patent management, benefit distribution, research integrity, and regulations, have also been identified as containing potentially negative consequences (Newson, 2015; Rogers, 2011).

2.3.2 Media portrayal of SB

In contrast to technical assessment of risks and benefits, public responses to emerging technologies may be highly context-dependent, for instance, influenced by risk framing and market interaction (Falk & Szech, 2013; Kahneman & Tversky, 2000). Kasperson et al. (1988) suggested that social context, such as the information transfer system and response mechanisms of society, could lead to the amplification or attenuation of risk, and in turn impact behavioural responses. GM foods, for example, were presented as hazardous in a crisis context by the British media, which subsequently "amplified" or increased peoples' risk perceptions and negative attitudes (Frewer, Miles, & Marsh, 2002). The way in which SB is portrayed in the media may also affect public attitudes, in particular given that people know little about it at the current time (Kinder & Robbins, 2018; Oliver, 2018).

Table 2.1 identifies empirical studies that have analysed media portrayals of SB between 2003 and 2016 in North America and Europe. They have employed qualitative and quantitative content analysis to investigate themes, metaphors and tones of the media reportage. A substantial increase of SB-related coverage was seen in particular in 2008 and 2010 (Ancillotti, Holmberg, Lindfelt, & Eriksson, 2017; Pauwels & Ifrim, 2008; Pauwels, Lovell, & Rouge, 2012). The focus of the increased reportage was more associated with prominent events rather than potential risks and benefits of SB, mainly underpinned by events related to elite scientists' visions (J. Craig Venter Institute, 2008) and significant technical advance (Gibson et al., 2010). With respect to the identified coverage concerns, American and European media mainly presented bio-error, bioterror and ethical issues, of which ethical concern was a greater focus in Europe, and bio-error in America (Pauwels, Lovell, & Rouge, 2012). Benefits of potential applications in healthcare, energy and environmental sectors were also introduced. Overall, media coverages describing only benefits, or balanced benefits and risks, outnumbered those predominantly underlining risks and/or ethical issues in both Europe and America (Ancillotti et al., 2017; Pauwels & Ifrim, 2008; Pauwels et al., 2012).

Metaphors applied in SB related coverage also have been studied. The results showed that the frequency of "religious" metaphors, such as "playing God" and "creating life", is substantially lower than engineering and information technology related metaphors (Ancillotti & Eriksson, 2015; Ancillotti et al., 2017; Borgers, 2017; Braun, Fernau, & Dabrock, 2018). Hellsten and Nerlich (2011) argued that engineering-related metaphors might suggest the controllability of applications, and potentially reduce readers' perceived risks. In addition, tone of published stories in the European media was categorised according to their normative impression (Ancillotti & Eriksson, 2015;

Ancillotti et al., 2017; Borgers, 2017). For example, media reportage highlighting benefits, or with an overall “approving” tone was assigned as “positive”, and media coverage objectively introducing benefits and risks without value judgement was regarded as “neutral”. Media reportage that portrayed SB as a negative development associated with negative implications was labelled as “negative”. The findings indicated that the percentage of neutral or/and positive coverage was much higher than negative coverage in European media (Ancillotti & Eriksson, 2015; Ancillotti et al., 2017; Borgers, 2017).

Thus, the current media reportage about SB appears not to have negatively portrayed the technology in a manner that may amplify public risk perceptions or foster their negative attitudes. The relatively positive introduction of healthcare and energy applications by the media may possibly trigger public interest in SB. However, several issues associated with media coverage still need to be considered. For example, SB may have been “over-promoted” in terms of what it can potentially deliver, at least in the short term. This might decrease public trust in SB and associated research programmes, impeding its future development (Ancillotti, Rerimassie, Seitz, & Steurer, 2016). Verseux et al. (2016) have attributed the “hype” and presentation of far-future scenarios in the media to the lack of understandable documents about the current state of technological development which are targeted at non-biologists. Another issue relates to the demand for clarity in defining and framing SB, which, once met, may facilitate public engagement and risk communication (Ancillotti et al., 2017; Giordano & Chung, 2018). As a result, better communication between academia and the media community is required to help develop clearer framing of SB and conduct effective science communication to the public in the light of specific applications and their current state of development.

Origins of reportage	Search method	Sample size	Period of media reportage	Data analysis	Research focus	Major findings	References
US and **Europe**	“Synthetic biology" was searched in major US newspapers based on ***LexisNexis***; multilingual search for the term "synthetic biology" in major European newspapers (articles in English, French, Dutch, German, Spanish and Italian).	309 from US; 841 from Europe.	January 2003 to December 2011	Not reported	Change in the amount of coverage in relation to SB; key issues mentioned in media.	Coverage of SB in press grew in the 2008–2011 period when compared with the 2003–2008 period; A significant increase of coverage was seen in 2008 and 2010; energy and health applications were reported as benefits; the media reported concerns focused om biosafety, biosecurity and ethics.	Pauwels & Ifrim, 2008; Pauwels et al., 2012
Austria, **Germany** and **Switzerland**	Terms such as "synthetic biology", "artificial life", "designer AND organism", "minimal organism", "minimal genome", "bioengineer", "biomachine", "biobrick", "artificial DNA", "artificial proteins", "artemisinin", "biorobot", "synthetic bacterium", "synthetic virus" and "DNA AND synthesis" (German equivalents) were used to search the media database ***APAdefacto*** and ***Google Alerts***.	233 in German	January 2004 to December 2009	Qualitative and quantitative content analysis	SB topics covered by media coverage; framing of SB; related risks, benefits and applications.	Engineering metaphors are more prominent in media coverage; a new aspect of “playful description” of SB was identified in coverage compared with GM; ambiguities exist between the description of SB and GM.	Gschmeidler & Seiringer, 2012
English and **German** speaking countries	***GBI-Genios*** database was searched using the term "Synthetische Biologie"; ***LexisNexis*** database was searched using "synthetic biology".	10831 in English; 1036 in German.	January 2004 to December 2015	Qualitative and quantitative content analysis	Framing of, and metaphors for, SB discussed in the media discourse.	A substantially higher frequency of engineering and IT related metaphors were identified in media coverage compared to religio-cultural expressions, such as "playing God" or "creating life".	Braun et al., 2018
US	News articles were collected from ***The New York Times*** using the term "synthetic biology".	32	January 2005 to July 2015	Qualitative and quantitative content analysis	Framing of SB in the media; relationship between low reporting volume and public knowledge of SB along with the high level ethical, moral and political implications.	Ambiguity about potential ethical issues and the relation between SB and genetic engineering were identified, which might act as a barrier public engagement.	Giordano & Chung, 2018
Denmark, Finland, Norway and **Sweden**	Terms such as "Artemisinin", "artificial life", "synthetic life", "bio-brick", "bioterrorism", "DNA synthesis", "iGEM", "synthetic	146	January 2009 to December 2014	Qualitative and quantitative content analysis	The tone of the articles analysed was assessed by the authors according to their interpretation of the	Potential benefits of SB were highlighted; the media portrayal of SB tended to be very positive; minor risks were mentioned mainly related to bioterror and bio-error;	Ancillotti et al., 2017

	biology", *inter alia* (equivalents in four national languages) as well as names of renowned scientists were used for searching in newspapers' archives and through the media databases ***Mediearkivet***, ***Infomedia***, and ***PressText***.				narrative provided by the story; other issues assessed included the SB topics covered by media coverage; framing of SB; metaphors used for SB.	public involvement was rarely suggested as relevant.	
Sweden and **Italy**	Terms such as "Artemisinin", "artificial life", "synthetic life", "bio-brick", "bioterrorism", "DNA synthesis", "iGEM", "synthetic biology", *inter alia* (Swedish and Italian equivalents) as well as names of renowned scientists were used for searching in newspapers' archives and through the media databases ***Mediearkivet*** and ***PressText***.	131	January 2009 to December 2013	Qualitative and quantitative content analysis	The tone of the articles analysed was assessed by the authors according to their interpretation of the narrative provided by the story; other issues assessed included the SB topics of media coverage; framing of SB; metaphors used for SB; issues related to technology oversight or public interest or public engagement.	The portrayal was very positive, describing SB as a "biotechnology with great benefits and minor risks"; risks were mainly related to bioterror and bio-error; coverage of SB was more "event-driven", i.e. linked to novel developments etc. rather than about the technology *per se*; public involvement was rarely suggested as relevant.	Ancillotti & Eriksson, 2015
Netherlands	Terms such as "synthetic biology", "synthetic cell", "synthetic genome", "minimal genome", "iGEM", *inter alia* (Dutch equivalents) were used to search for newspaper articles in ***LexisNexis*** database.	261	January 2000 to November 2016	Qualitative and quantitative content analysis	The tone of the articles analysed was assessed by the authors according to their interpretation of the narrative provided by the story; other issues analysed included the SB; topics of media coverage; applications, risks, and ethical issues; and the use of metaphors in articles.	Dutch newspapers paid limited attention to SB; when it occurred, the coverage was more event-driven; The Dutch press tended to be neutral or positive about SB; healthcare and environmental applications were discussed in terms of potential benefits rather than in terms of risk and ethical issues; engineering related metaphors were more frequently used which potentially suggested that the technology is "controllable".	Borgers, 2017

Table 2. 1: Analysis of media portrayal about SB

2.3.3 Public perceptions of and attitudes towards SB per se

Research on public responses to SB has been relatively infrequent and mainly conducted in Europe and America (see Table 2.2). Participants often made sense of SB by comparing it with GM technology, while, for example, nanotechnology was less frequently mentioned as a "comparator" technology in public perception and attitude research (Kronberger, Holtz, Kerbe, Strasser, & Wagner, 2009; Kronberger, Holtz, & Wagner, 2012). Despite the ambiguous information about SB presented to research participants, another potential explanation is that the two technologies may be both perceieved to involve deliberate changes to cells at the genetic level. Consequently, public concerns about SB were expressed in a similar way to those associated with GM, although SB sometimes was perceived more negativly as people regarded it as a technological "upgrade" of GM (Steurer, 2015). In existing studies, people are mainly concerned about potential risks (e.g. potential environmental and human health impacts, bioterror), moral, emotional or value-related issues (e.g. "unnaturalness", "creating life" and "playing God") and increased control of technology and patents by large companies (Betten, Broerse, & Kupper, 2018; Hart Research Associates, 2013; Mandel, Braman, & Kahan, 2008). The public distrust of major stakeholder groups (e.g. scientists, industry and government) was also identified in research (Betten et al., 2018). However, research participants expressed more optimism when applications benefiting human health, energy and environment were presented to them (Betten et al., 2018; Pauwels, 2009).

Individual attitudes towards SB were not only associated with their risk and benefit perceptions, but also "value predispositions" (e.g. religiosity and deference towards scientific authority) and trust in scientists (Akin et al., 2017). Deference towards scientific authority represents the long-term and stable belief that scientific enterprise focuses on the best interests of the public, which is correlated with individual's support for other technologies, such as nanotechnology (Anderson, Scheufele, Brossard, & Corley, 2012). Trust in scientists has been defined as the short-term and individual confidence in scientists' motivation and competency (Akin et al., 2017). Dragojlovic and Einsiedel (2012) reported that more religious respondents are less supportive of SB. However, the influence of religiosity on people's attitudes decreases when they have higher confidence in the institution of science. Among those less deferential towards scientific authority, higher-level trust in scientists could positively affect support for SB (Akin et al., 2017).

The association between public attitudes towards SB and their demographic characteristics, such as gender and educational background, was also studied (see Table 2.2). Men in the US perceived lower risks associated with SB in comparison to women (Braman et al., 2008), a demographic difference also reported for other technologies (Finucane, Slovic, Mertz, Flynn, & Satterfield, 2000). Finucane et al. (2000) attributed the “white male effect” to men’s perceiving themselves to be more involved in controlling and benefiting from technologies than women in the US. People with higher educational level were reported as exhibiting a tendency to be more supportive of SB (Akin et al., 2017), as were students with natural science backgrounds, compared to those studying humanities and social sciences (Ineichen, Biller-Andorno, & Deplazes-Zemp, 2017). The influence of educational level and gender on public attitudes, however, was sometimes found insignificant in quantitative studies into SB, as is the case for what has been found in GM-related studies (Akin et al., 2017; Frewer, Howard, & Shepherd, 1996; Kahan, Braman, & Mandel, 2009; Verdurme & Viaene, 2003). There is evidence that gender differences in public attitudes to GM disappeared after the tangible benefits of specific GM foods have been presented to participants (Frewer et al., 1996). It again implicates the importance of contexts during assessment of attitudes, which may shape perceived perceptions of benefit associated with specific products or applications

Research method	Data analysis	Participants	Sample size	Demographic differences assessed	Information provided to participants	Participants' perceptions and attitudes	References
Observation on stakeholder discussion	Discourse analysis	Prospective politicians and synthetic biologists from Netherlands	Not reported	Not assessed	General introduction about SB and the current academic discussion. Information about specific applications was not presented.	The issues discussed focused on the need for SB and participant concerns about deliberate release, moral boundaries and political control.	Rerimassie, 2016
Focus group	Thematic analysis	Dutch citizens	46 (8 groups)	Not assessed	Although both a general introduction and applications (in relation to health, environment and food) were provided, the paper analysed participants' opinions about the technology *per se* and its development rather than upon different applications.	Participants discussed concerns about human health effects, the uncontrollability of applications, and ethical issues, although the results indicate that people are not inherently against or for SB.	Betten et al., 2018
Citizen panel	Content analysis; frame analysis	Austrian citizens	67 (8 panels)	Differences in responses to the introduced applications were almost not found across age groups, gender, or educational and residential backgrounds.	A general introduction and examples of applications were presented to participants (including synthetic yeast-based artemisinin, a modified organism for pest control, and synthetic algae-based biofuel) were provided to participants for discussion.	The anti-malaria drug production presented invoked concerns about potential long-term health effects and potential for bio-error, but the application was still assessed as "acceptable" to study participants However, participants tended to oppose the use of synthetic organisms for pest control due to perceived uncontrollability, potential for long-term impacts and potential for bioterror; some participants expressed distrust in scientists, industries and authorities; "playing God" and unnaturalness were not mentioned by participants.	Steurer, 2015
Focus group	Descriptive and inferential statistics	Austrian citizens	49 (8 groups)	The degree of attitudinal change did not differ for participants of different age, education or sex.	A general introduction about SB developed from the available media coverage was provided without discussion of specific applications.	Concerns were mainly focused on bioterror and potential environmental and health impacts; participants expressed skepticism about manipulating human and animal cells; values related to a group's identity may collectively affect their examination of technologies such as SB.	Kronberger et al., 2012
Interview	Thematic analysis	Stable patients in German-speaking part	36	Not assessed	A general introduction and information about specific	Participants expressed concerns about "playing God" before being provided with information	Rakic et al., 2017

		of Switzerland			applications (engineered autologous cells for disease treatment) were provided.	about specific applications; their attitudes became more positive after learning about specific applications.	
Observation on stakeholder discussion	Not reported	Non-synthetic biologists in disciplines (e.g. social sciences, philosophy and biology) mainly from Europe	23	Not assessed	The paper does not report on whether any information has been provided to participants, and there is no presentation of about specific applications.	Participants (stakeholders) exhibited unrealistic expectations of what SB can deliver, at the same time expressing fears about the potential for bioterror; participants' attitudes depend on their values and interests, in line with their stakeholder interests.	Verseux et al., 2016
Observation on stakeholder discussion	Not reported	Scientists, members of NGOs, funding agencies, and industry mainly in Europe and America	124	Not assessed	A general introduction to SB was provided without discussion of specific applications.	“The creation of life” was expressed as a concern by the participants; participants were also concerned about potential threats associated with biohackers who conduct biological experiments individually or in small organizations.	Schmidt et al., 2008
Focus group	Grounded theory	German and Austrian citizens	69 (9 groups)	Age had no effects on the discussions about SB; groups with higher educational level focused more on the benefits and regulation of SB compared to those with lower educational level.	A general introduction to SB was presented, together with information about specific applications (including synthetic yeast-based artemisinin, a modified organism for pest control and synthetic algae-based biofuel).	Synthetic organisms intended for medical production are considered to be more beneficial and necessary than those developed for pest control and energy; participants are more concerned about bio-error than bioterror; in relation to ethical concerns, equitable benefit distribution across different beneficiary was the issue most discussed.	Starkbaum et al., 2015
Survey and focus group afterwards	Descriptive statistics for survey data; not reported for focus group data	American citizens	3,004 surveys and 8 focus groups	Not assessed	A general introduction to SB was presented, together with information about specific applications (including a synthetic virus for vaccine production, synthetic yeast-based artemisinin and altered pigs and cows with accelerated growth).	Medical and biofuel applications were accepted by most participants; Applications which facilitated animal growth were less acceptable to participants than medical production using animals; potential long-term effects on human health and environment were a focus of concern.	Pauwels, 2013
Survey	Descriptive and inferential statistics	American citizens	1,500	An analysis of demographic differences indicated that American males or those having higher income had lower risk perceptions regarding SB; no significant	A general introduction to SB was provided, but no information about specific applications was included.	Over 80% respondents reported knowing little about SB; the majority of participants perceived benefits to be more relevant than risks; people's risk perceptions were, however, associated with their cultural dispositions.	Mandel et al., 2008

				attitudinal differences were associated with education level or income.			
Survey	Descriptive statistics	American citizens	804	An analysis of demographic differences indicated that American males, participants with higher incomes or those with higher educational level tended to be more supportive of SB.	A general introduction to SB was provided, together with information about specific applications (altered mosquito for disease control, and a synthetic microbe for facilitating crop growth or food additive production).	People trusted scientists more than industry and government; concerns were expressed about the enabling technology in relation to its potential capacity to create harmful things, the "creation of artificial life" and potential for adverse human health effects; medical applications were more acceptable to participants than agri-food applications.	Hart Research Associates, 2013
Survey	Descriptive and inferential statistics	Canadian citizens	1,201	Not assessed	A general introduction to SB was provided, together with information about a specific application (synthetic yeast-based food additive).	Perceived unnaturalness reduced people's acceptance of sweetener production using synthetic yeast.	Dragojlovic & Einsiedel, 2013
Survey	Descriptive and inferential statistics	People from 32 European countries	15,588	Not assessed	A general introduction to SB was provided, but no information about specific applications was included.	Most participants' attitudes towards SB tended to be supportive or neutral; belief in God is associated with participants' opposition to SB.	Dragojlovic & Einsiedel, 2012
Survey	Descriptive and inferential statistics	University students in Switzerland	1,474	Female students perceived higher risks to be associated with SB and its applications; students in the humanities and social sciences perceived higher risks and lower benefits to be associated with SB than those in natural sciences.	A general introduction to SB was provided, together with information about specific applications (a synthetic microbe for pollutant sensing, and land bioremediation).	Participants showed more support for medical and environmental applications of SB than for GM crops; SB as an enabling technology is more accepted than GM, but less than nanotechnology.	Ineichen et al., 2017
Survey	Descriptive and inferential statistics	American citizens	1,771	Participants with higher educational level are supportive of SB; no significant attitudinal difference was found in	A general introduction to SB was provided, but no information about specific applications was included.	A range of factors influence people's attitudes towards SB. These include risk perceptions (reduced acceptance), benefit perceptions (increased acceptance), higher trust in scientists (increased acceptance), deference to science (increased acceptance), educational	Akin et al., 2017

				terms of gender, income and age.		level (increased acceptance) and greater religiosity (reduced acceptance).	
Survey	Descriptive and inferential statistics	Indonesian students majoring in life science	50	Not assessed	A general introduction to SB was provided, which also addressed its potential for protecting biodiversity and developing healthcare products. However, no specific applications were presented.	Participants perceived both benefits and risks to be associated with SB; participants' attitudes varied between different applications; in particular respondents showed optimism about potential applications of SB in biodiversity conservation.	Kemal, 2018

Table 2. 2: Literature focused on public perceptions of, and attitudes towards, SB

2.3.4 Public perceptions of SB-based applications in the agri-food sector

Public attitudes often varied according to different applications of emerging technologies. A recent systematic review indicated that people held more positive attitudes towards GM plants and their derivative products compared to attitudes towards GM animal products (Frewer et al., 2013). GM animals were less accepted if these were modified for food use rather than for medical reasons, as medical applications were possibly perceived to be more “necessary” than those related to food (Frewer, Coles, Houdebine, & Kleter, 2014). In the case of nanotechnology, medical and environmentally beneficial applications tended to be viewed as more acceptable by consumers (Priest & Greenhalgh, 2011). Within the food domain, nanotechnology for developing food packaging is more likely to be supported than food products for consumption (Giles et al., 2015).

The pattern of results for SB applied in the agri-food sector is not greatly different to other technological applications, although differences in study design across technologies have made comparisons more complex. In the case of SB, more positive perceptions were found to result among research participants after concrete examples of applications were introduced (Ineichen et al., 2017; Rakic, Wienand, Shaw, Nast, & Elger, 2017). People expressed more optimism about medical applications, such as synthetic microbes used for the production of medicine (Ineichen et al., 2017; Pauwels, 2013; Starkbaum, Braun, & Dabrock, 2015; Steurer, 2015), and disease treatment using engineered autologous cells (Rakic et al., 2017). However, concerns about the unknown long-term impacts of such medicines on human health, unintended release of synthetic microbes, and economic interests were still raised. Also, environmental applications were more acceptable to participants than agricultural applications. Although released synthetic microbes are more uncontrollable regarding their reproduction and spread, participants still showed more support for those applied in pollutant sensing and bioremediation compared to GM maize (modified to faciliate reduced application of herbicides/insecticides) and rice (modified to increase levels of pro-vitamin A) (Ineichen et al., 2017). As a result, SB-based applications for environmental enhancement (e.g. synthetic microbes as biosensors and for bioremediation) might be preferred by the public compared to those for crop improvement (e.g. productivity increase and reduced needs for inputs in agriculture).

Generally, people tend to express more negative attitudes to SB applied in agricultural and food production (Pauwels, 2013; Steurer, 2015). Synthetic organisms (e.g. virus, bacterium and insect), developed either for pest control or boosting plant growth, raised concerns for research participants due to their uncontrollability, unknown long-term health impacts and their potential for bio-terroristic use (Steurer, 2015). It is notable that mosquitos engineered by synthetic gene-drive systems for facilitating the eradication of malaria were perceived to be highly uncontrollable, but people did not express strong opposition to this application (Hart Research Associates, 2013), again suggesting that medical applications were perceived to be more "necessary" than agricultural applications (Starkbaum et al., 2015). Other agri-food applications, such as animals with accelerated growth and synthetic microbes applied to facilitate food production (e.g. production of food additive), were viewed more negatively by research participants (Hart Research Associates, 2013). This could potentially relate to consumers' concerns about their unknown long-term impacts as well as perceived unnaturalness of the food production process (Román, Sánchez-Siles, & Siegrist, 2017). A study by Dragojlovic and Einsiedel (2013) indicated the negative influence of perceived unnaturalness on participant acceptance of synthetic yeast-based sweetener, in particular among participants who regarded nature as sacred or spiritual.

The above evidence suggests that people's attitudes appear to vary between different applications of SB, either across sectors or within the agri-food sector. Medical and environmental applications could be more acceptable than those applied in food and agricultural production. However, agri-food applications with tangible and desirable benefits may also be accepted, such as novel food products with health benefits (e.g. nutraceuticals), since they could evoke more positive perceptions compared with those delivering no health benefits. Application of SB for food packaging development may also be supported according to people's preferences for nanotechnology applications (Giles et al., 2015). So, of different agri-food applications, the public may prefer those for environmental enhancement, producing healthy food products and food packaging to be developed and commercialised. These findings also imply that public perceptions and attitudes regarding SB are linked to attributes of specific applications, as is the case for GM and nanotechnology (Frewer et al., 2013; Giles et al., 2015).

2.4 Discussion

At present, there are no specific issues identified from existing research which distinguish SB from other enabling technologies, in terms of public perceptions and attitudes (Akin et al., 2017; Steurer, 2015). However, some issues uniquely associated with SB may need further consideration. For example, open-sourcing of SB improves accessibility of technology development to non-professionals, which may increase risks in relation to both bioterror and bio-error. When applied as a "bottom-up" approach, ethical aspects become more prominent in societal discussions (Bedau et al., 2009). Therefore, it is important to study the influence of these two issues on public attitudes and associated governance practices by linking them to specific applications and other contexts. In addition, as more novel applications are being developed, ambiguities in regulation may occur, and improvement of regulation and governance is therefore needed. Taking the arsenic biosensor (where synthetic bacteria contained in a secure casing) as an example, the developers' application for exemption from The Contained Use Directive (2009/41/EC)[1] and The Deliberate Release Directive (2001/18/EC)[2] was not approved in the European Union. This was because the application was technically "contained" but applied outside of a laboratory (European Food Safety Authority, 2015).

With respect to the public attitudes towards SB, social amplification of perceived risks does not seem to have arisen, as the media portrayal is, to date, relatively positive. There is also little evidence showing an "inherent societal aversion" to SB as an enabling technology (Betten et al., 2018; Pauwels, 2009). While a number of agri-food applications have been identified as potentially preferred by the public for development, there is still a lack of relevant studies to support this in practice, which makes it difficult to more accurately predict public priorities and preferences.

A limited number of studies have identified factors that may affect public attitudes, such as perceptions of risks, benefits and ethical issues, trust in scientists, industry and government, and individuals' socioeconomic, demographic and value attributes. Although findings in relation to the influence of individual socioeconomic and demographic characteristics as reported in the literature is somewhat inconsistent, ongoing research that assess how perceptions and attitudes in different demographic

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0041 (accessed 12 June 2021).
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32001L0018 (accessed 12 June 2021).

groups vary is required in order to develop more targeted risk communication strategies (Frewer et al., 2013). Integrating findings of research on SB as well as GM and nanotechnology, participants' perceptions and attitudes were linked to specific characteristics of applications, and they tended to hold more optimism after being informed of concrete benefits of applications. Metaphors such as "Playing God" and "creating life" were infrequently mentioned in the context of specific applications of SB, and perceived "unnaturalness" was only identified in food production (Dragojlovic & Einsiedel, 2013). These results suggest that, in common with other agri-technologies, risk and benefit perceptions may contribute in shaping public attitudes towards SB and its specific applications. Notably, these studies have tended to focus on SB *per se* rather than specific applications, and no research, so far, has investigated *how* trade-offs between benefits, risks and other issues are made by people during decision-making.

Previous research has shown that the benefits of GM technology perceived by research participants were often discounted (Siegrist & Sütterlin, 2016), and that risk and benefit perceptions of the same product can differ due to diverse personal characteristics (W. Hu et al., 2004). Individuals' trade-offs between perceived benefits, risks and other issues in decisions-making were also heterogeneous regarding the innovative food technology acceptance (Bearth & Siegrist, 2016). In other words, the role of different perceptions in determining public attitudes could be highly variable, and may be affected by various factors, such as the type of technology, socio-demographic, cultural or geographical differences between participants, and even regional differences in legislation of the studied food technology (Bearth & Siegrist, 2016; Costa-Font & Gil, 2009). The review also suggests that the public's actual responses/behaviour towards SB could be dependent on different contexts, such as the product type, media reportage, peer influence, risk framing and types of market interaction, rather than a rational cost and benefit assessment (Falk & Szech, 2013; Kahneman & Tversky, 2000; Oliver, 2018). Altogether, these differences highlight the need to consider a range of different factors that contribute to the context in which the technology is considered. Also, public perceptions and their influence on people's attitudes need to be investigated in the context of specific applications, in particular those with concrete and tangible benefits, so as to avoid unnecessary scares and encourage the acceptance of SB applied in the agri-food sector (Hansen, Holm, Frewer, Robinson, & Sandøe, 2003). Specifically, it is important to understand *how* people make trade-offs between their perceived benefits, risks and other issues of SB, together with contextual factors that may impact the decision-making process.

The process of reviewing the literature also highlighted some problems in experimental design. Some studies over-emphasised the origins of genes, which is a defining characteristic of GM, rather than the attribute of SB applications (Amin et al., 2013; Dragojlovic & Einsiedel, 2013). Fischer and Frewer (2009) argued that people's risk and benefit perceptions of unfamiliar foods are more dependent on the *ad hoc* affect or attitude shaped by the information initially presented, whilst prior attitudes may play a major role regarding foods that are familiar to people. In other words, if the presentation of SB to the public is framed primarily based on attributes of GM, people's attitudes towards SB-based applications could be biased due to their affect or prior attitudes relevant to GM products, in particular when people think these applications of SB are equivalent of GM products and are familiar to them. Furthermore, when developing experimental information interventions, the introduction of SB should be clear, and selected examples of application should be realistic rather than "blue sky ideas".

It is also notable that previous research on the factors that drive agri-food technology acceptance has tended to occur after societal rejection, delivering greater understanding of drivers of public rejection as opposed to acceptance (Frewer et al., 2014). In the case of SB, it is important to ensure societal and consumer engagement occurs throughout the research and development process. That is, as the technology evolves, a number of research questions need to be further answered prior to, and during, the commercialisation process associated with agri-food applications. These include:

- What are the public preferences for potential applications of SB in the agri-food sector? And what "features" or characteristics of products will align with societal preferences and priorities?
- What influences peoples' decisions about the acceptability or otherwise of specific applications of SB? Will factors such as "open sourcing" and perceptions that "life is being created" impact people's decisions?
- How can key stakeholders in SB development (including scientists, industries and policy makers) "fine tune" the development and commercialisation process in line with societal priorities and expectations? What information and knowledge needs to be exchanged with societal stakeholders, and how might this be achieved?

2.5 Research limitations

At present, and as has been noted, there is limited literature available for review. Despite extrapolating from research into public attitudes of GM and nanotechnology, it has failed to further identify public priorities for development from different agri-food applications. The lack of empirical research has also impeded comparisons of attitudinal differences across regions and time. As a consequence, important research gaps have been identified, which, once filled, will benefit the development of commercialisation trajectories for different agri-food applications, as well as the development of effective governance practices.

2.6 Conclusion

SB has undergone considerable growth in recent years, with various potentially beneficial applications in the agri-food sector under development. However, the future commercialisation of these applications could be uncertain due to public risk perceptions and ethical concerns. Given the relatively positive media portrayal at the present, public attitudes appear to be uncrystallised. Also, people's attitudes and perceptions are likely to vary according to traits of applications. For instance, the public are inclined to accept applications for environmental enhancement, healthy food production and food packaging development. However, current studies into public attitudes towards SB have focused more on the technology *per se*, but have failed to contemplate application types, which has impeded further identification of public priorities. This is also an important research gap which merits investigation, as it can guide "fine-tuning" characteristics of applications in particular those at critical development points and in turn optimise the commercialisation process. Other contextual factors, in particular those affecting the impacts of perceptions on people's acceptance or rejection of SB, should also be investigated. This information, together with the public priorities, could provide the basis for more effective public risk communication and regulatory mechanisms establishment, for example, in relation to identification and discussion of potential (socially prioritised) benefits in agri-food governance. In summary, better framing of SB needs to be developed for conducting relevant research and effective public engagement. More studies into public responses to SB are also required, which may provide information for "fine tuning" technical researchers' experiments, companies' product design and commercialisation, and forming the basis for more effective regulation mechanisms.

Chapter 3. Social dimensions of SB in the agri-food sector: The perspective of Chinese and EU scientists

3.1 Introduction

It has long been observed that emerging technologies including those within the agri-food sector interact with social and economic factors, which may result in intended and unintended consequences (Grunwald, 2018). It is therefore necessary to integrate social dimensions at the early stages of agri-food technology development in order to allow the co-production of technological innovations in line with societal priorities and preferences (Li et al., 2020). SB, an emerging area of research, combines science and engineering principles to synthesise and assemble artificial and/or natural components to create novel living systems, which can be more predictable, efficient and off-the-shelf than traditional genetic modification due to improved standardisation and an open-source approach within the community (Canton, Labno, & Endy, 2008). These established systems are expected to generate applications across different sectors (e.g. healthcare, energy and agri-food) (Polizzi et al., 2018), and contribute to the bio-economy by transforming existing industries or creating new ones (OECD, 2011). However, societal concerns about heightened risk, ethical issues and regulatory issues may impede the development of SB, and these need to be addressed during the process of scientific innovation (Jin, Clark, Kuznesof, Lin, & Frewer, 2019).

3.1.1 Anticipated risks and ethical issues

In terms of SB as a whole, upgraded techniques and the open-source approach in recent years have facilitated the creation of knowledge and novel applications including those within the agri-food sector. This, however, has increased the complexity of regulation required to ensure safe implementation. For instance, DNA synthesis and genome assembly techniques may increase the generation of pathogens or toxins, whereas intentional or unintentional release (a.k.a. "bioterror" and "bio-error" respectively) could harm the environment and human health (Garfinkel, Endy, Epstein, & Friedman, 2007; Polizzi et al., 2018; Wang & Zhang, 2019). The difficulty of regulating experiments, in particular those conducted outside research institutes, further intensifies risks by increasing the likelihood of adverse events and the unpredictability of their effects (Jin et al., 2019). Some risks may directly relate to specific applications. Novel food or food additives produced by synthetic organisms may pose high-uncertainty risks, as no established scientific evidence exists regarding their long-term impacts on human health. Such concerns also apply to other agri-food technologies, for instance, food products using genetic modification (GM) technology and nanomaterials (van Putten et al., 2006; Tyagi et al., 2016). Synthetic organisms designed for non-food uses may threaten natural species, thereby endangering biodiversity and even human health by entering the food chain (Polizzi et al., 2018).

Socio-economic risks of SB are associated with the consequences of how specific applications are adopted. “Synthetic” crops for biofuel production, for instance, can be more environmentally friendly and economically attractive to farmers. However, biodiversity and water/food security can be threatened if the large-scale cultivation of energy crops results in competition with food crops (Harvey & Pilgrim, 2011). In addition, SB may benefit some stakeholders but harm others’ interests (OECD, 2011). For instance, using synthetic yeast to produce semi-synthetic artemisinin was initially expected to stabilize the drug supply and decrease the cost of malaria treatment; however, farmers cultivating *Artemisia annua* might be driven out of business (Polizzi et al., 2018).

Any emerging technology has the potential to raise ethical issues and to generate concern among its stakeholders, including the general public (Frewer et al., 2011). Most research into ethical issues associated with SB has considered the technology overall, rather than focusing on specific applications, due to some unifying features across SB and the limited information available about applications at the early stage (Heavey, 2014; Newson, 2015; Rogers, 2011). Ethical issues were mainly associated with “life creation” and with the regulation in the light of biosafety and biosecurity, benefit sharing and research development (Anderson et al., 2012; Douglas & Savulescu, 2010; Weir & Selgelid, 2009). These identified ethical issues appeared to be “unexceptional” compared to other emerging technologies (Newson, 2015).

3.1.2 Public responses to SB

Limited studies into public perceptions of SB have been conducted, mainly in Europe and North America. Surveys have indicated that 39% of European participants approve the use of SB, either with strict regulation or without special laws (Dragojlovic & Einsiedel, 2012); and 31.2% of respondents in the United States support the use of SB (Akin et al., 2017). However, over 20% of the participants showed neutral attitudes (i.e.

neither support nor rejection) towards, or did not know whether they support, the use of SB (Akin et al., 2017; Dragojlovic & Einsiedel, 2012). This highlighted low certainty of these participants' attitudes, partly due to a lack of information and media attention (Fischer, van Dijk, de Jonge, Rowe, & Frewer, 2013). In research into specific applications, it has been reported that applications for medical and environmental use tended to be more in line with public preference than agricultural and food products (Ineichen et al., 2017; Starkbaum et al., 2015; Steurer, 2015).

Perceived benefits and risks were considered to be main determinants of people's attitudes towards SB (Akin et al., 2017). The unknown long-term impacts of applications may be more relevant to the general public, including "bioterror" or "bio-error" incidents (Betten et al., 2018; Kronberger et al., 2012). Perceptions of naturalness and ethicalness; individual attributes (e.g. demographic characteristics; religiosity; trust in scientists, industry and government; deference to scientific authority); and characteristics of the product are also known to shape public attitudes (Akin et al., 2017; Braman et al., 2008; Dragojlovic & Einsiedel, 2012, 2013; Ineichen et al., 2017). Jin et al. (2019) argued that there is little evidence showing people inherently hold negative perceptions of SB, despite expressing concerns about certain risks and ethical issues.

3.1.3 Scientists' role in the regulation of SB

Scientists help frame regulatory and implementation policies and commercialisation trajectories of novel technologies as well as shaping public attitudes through engagement activities (Gupta, Fischer, George, & Frewer, 2013). Previous studies have indicated that scientists often exhibited higher benefit perceptions and lower risk perceptions towards technologies associated with their specialism compared with the lay public (Ho, Scheufele, & Corley, 2011; Kato-Nitta, Maeda, Inagaki, & Tachikawa, 2019). This expert-lay discrepancy was initially attributed to laypeople's deficit of knowledge by scientists, which popularized the "deficit model" among scientists for public communication of science and technology (Hilgartner, 1990). While this model for science communication has been widely discounted by subsequent studies (Sturgis & Allum, 2004), it is still the dominant model promulgated by experts across different domains (Seethaler, Evans, Gere, & Rajagopalan, 2019; Simis, Madden, Cacciatore, & Yeo, 2016). Scientists' perceptions of risks and ethical issues, as well as their predictions regarding public reactions to SB, may impact on their support for current science communication models and future development of this area.

The precautionary principle is applied to the regulation of biotechnologies in particular those within the agri-food sector in the EU and China, although the application of rules and measures in China tends to be less transparent (SEHN, 1998; Sun, 2019). In recent years, a growing number of EU projects (e.g. the Horizon 2020) have required scientists to integrate social dimensions into all stages of research projects, for instance, identifying and evaluating the potential influence of benefits, risks and ethical concerns, undertaking effective public engagement and science education, so as to achieve responsible research and innovation (RRI) (European Commission, 2015; Ribeiro, Smith, & Millar, 2017). In contrast, Chinese scientists are required to undertake "social responsibility", which is limited to the popularisation and communication of science only near the end of research projects (Dijkstra & Yin, 2019). The aforementioned regulatory discrepancies, together with the influence of cultural difference (Ho et al., 2011), may lead to differences between EU and Chinese scientists in terms of their perceptions of the social implications of SB.

In view of the significance of integrating social dimensions and the role of scientists in shaping technical development trajectories, this chapter adopts a qualitative approach to understanding perspectives of EU and Chinese scientists regarding social implications associated with SB, and in so doing, addresses the following research questions:

- What are scientists' perceptions of social dimensions pertinent to SB in particular its applications in the agri-food sector? Is the precautionary or proactive principle more in alignment with scientists' cognitive structures?
- What are the similarities and differences between the EU and Chinese scientists with respect to their perceptions of social dimensions?
- What are scientists' understandings of the potential public response to SB?
- Is the "deficit model" still dominating the scientific discourse, and does this differ between China and the EU, given the greater emphasis on RRI in research activities in the latter?
- What are the implications for future research into SB?

3.2 Methodology

A semi-structured interview methodology was employed in this study based on two primary considerations. First, some issues in relation to SB are highly complex and ambiguous, and semi-structured interviews are a suitable tool for exploring respondents' perceptions and views and probing for more information regarding complex issues

(Barriball & While, 1994). Second, scientists in SB come from diverse disciplinary backgrounds, and the adaptable nature of semi-structured interviews allows further clarification of responses after initial answers to interview questions (Sankar & Jones, 2007). This methodology has been widely used to investigate perceptions of other biotechnologies, and has demonstrated cross-cultural validity in this context (e.g. see Edmondston et al., 2010; Zalewska-Kurek, 2016).

3.2.1 Procedure

First, the literature on social issues surrounding SB and other technologies (e.g. GM technology, nanotechnology) was critically reviewed to elicit research questions. Based on this, a semi-structured interview guide was generated (see Appendix A), covering the following topics: the potential applications for commercialisation including those within the agri-food sector; benefit and risk perceptions; understanding of public response; and attitudes towards regulation and public opinion (Figure 3.1). Meanwhile, technical articles about SB were reviewed to establish participant selection criteria (based on subfields of SB and domains of application). Then, interviews with the selected scientists were conducted, and data were transcribed and analysed. Ethical approval for the study was granted by the lead researcher's university in 2017 (Ref: 2581/2017).

3.2.2 Sample

Twenty-two scientists from the EU (n = 13) and China (n = 9) were selected for semi-structured interviews during March 2018 and January 2019. All participants are leaders of research teams in different organisations and specialise in certain subfields of SB (see Table 3.1). Their work relates variously to applications linked to agriculture, food, energy, the environment, human health and medicine, and genome synthesis. The interviewer (SJ) has a background in both social and natural sciences: this reduced the potential for misunderstanding of technical terms and strengthened the interviewer's ability to probe for in-depth information relevant to the respondents' expertise.

3.2.3 Data collection and analysis

Interviews with the EU and Chinese scientists were undertaken using English and Mandarin respectively. Each interview lasted approximately 40 minutes and was digitally recorded and transcribed verbatim in English or Chinese. Here, the number of interviews was determined according to the requirement for data saturation in inductive thematic analysis (normally six interviews to reach 80% saturation), when no new themes could be identified from the last interview (Guest, Namey, & Chen, 2020). The thematic analysis method was then employed, following the phases: data familiarisation; code generation; constructing, reviewing, and defining themes; and report production (Braun & Clarke, 2006). The coding process of this study involved both inductive and deductive orientations and was undertaken using QSR International's NVivo 11 software. Quotes from Chinese scientists have been translated idiomatically into English for this paper.

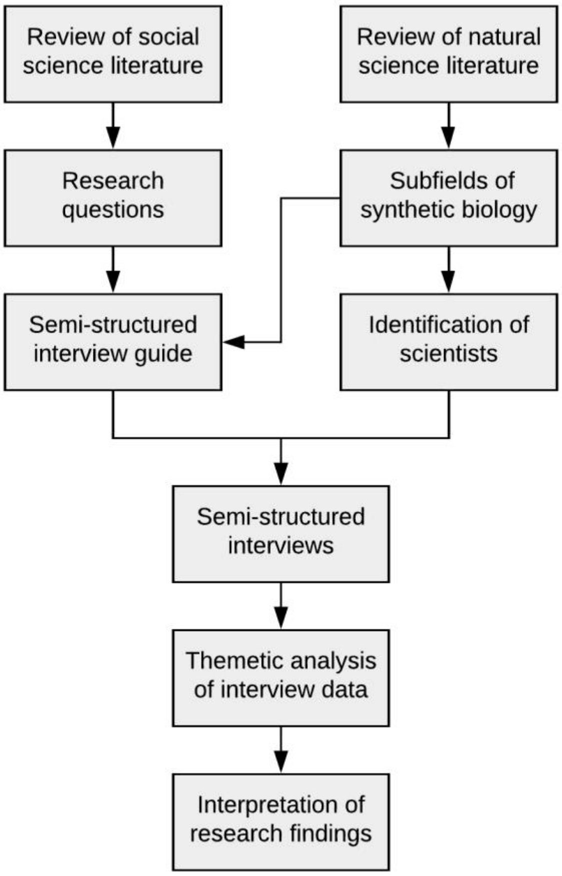

Figure 3. 1: Schematic overview of the research methodology

Location	Participant no.	Gender	Affiliation	Subfield of research
	E1	Male	University	Plant SB
	E2	Female	University	Plant SB
	E3	Female	Research institute	Plant SB
	E4	Female	Industry	Plant SB
	E5	Male	University	Computational SB
	E6	Male	Industry	Microbial SB
Europe	E7	Male	University	Microbial SB
	E8	Male	University	Microbial SB
	E9	Male	University	Microbial SB
	E10	Male	University	Microbial SB
	E11	Male	University	Microbial & Computational SB
	E12	Male	University	Microbial & Mammalian SB
	E13	Female	University	Plant & Microbial SB
	C1	Male	Research institute	Microbial SB
	C2	Male	University	Microbial & Computational SB
	C3	Male	Research institute	Computational SB
	C4	Male	University	Microbial & Mammalian SB
China	C5	Male	Research institute	Computational SB
	C6	Male	Research institute	Microbial SB
	C7	Male	Industry	Microbial SB
	C8	Male	Research institute	Plant SB
	C9	Male	Research institute	Plant & Microbial SB

Table 3. 1: Interview sample characteristics

Note: Despite strenuous efforts to achieve a gender balance among participants, we failed to recruit female Chinese scientists for this study.

3.3 Results

The interviews provide a wide range of insights into how scientists understand SB-related issues and the potential societal response. Six prominent themes emerged from the data, supported by quotes from participants (labelled by participant's location: 'E = EU scientists, C = Chinese scientists', accompanied by a unique identifying number).

3.3.1 SB: a vague concept in the scientific community

A similarity between EU and Chinese scientists was the lack of a universal definition of the term "SB" as understood by the scientific community. Most scientists regarded SB as a novel area, but they differed in how they distinguished SB from other technologies, in particular GM technology. For instance, some scientists emphasised the tools employed in creating applications (e.g. using synthetic genes rather than those from other lifeforms), while others pointed to the importance of *"system design, combining the functional parts in a predictable manner"* (C6).

"In reality, another basis is DNA synthesis technology, because having this technique means that we no longer need to rely on the original organism; we can design DNA and then develop various applications." (C5)

"SB" (described as "*too broad"* a term by one participant, E10) was interpreted with reference to distinct technological terms (e.g. gene editing and GM). Very few scientists referred to SB as the combination and/or upgrade of other biotechnologies.

"I guess it depends how you have interpreted the terminology 'SB' … we re-engineered part of the pathway that makes serotonin in rice by gene editing" (E13)

"I think CAR–T therapy, for instance, is actually an application of SB and essentially of genetic engineering as well." (C4)

"Actually, it's not a novel field. I think SB is just an inevitable stage in the evolution of biotechnology." (C9)

3.3.2 Benefits and risks perceived by scientists

Participants anticipated that various SB-based applications will be technically ready for commercialisation in the next 10 to 15 years, including in the agri-food, environment, energy, and healthcare sectors and as advanced experimentation tools (see Table 3.2). These applications were expected by both Chinese and EU scientists to provide new production methods across sectors, bringing potential financial gains to different stakeholders, and health and environmental benefits to the broader public. Very few scientists mentioned the risks associated with SB-based applications. Most participants stressed the importance of scientific evidence in evaluating an application's risk and assessed the risks of SB-based applications as very low or even nil. For instance, the use of microbes as hosts either for chemical production or pollutant detection was regarded to have "*approximately zero risk"* (E9, C3).

"I'd say the risk is essentially zero for both of them because they're very sick microorganisms, they can't compete in the environment. It's really just a matter of regulation and concern about public opinion, but I would say the actual risk is zero for cell-free systems and approximately zero for cell-based systems". (E9)

"The risk of manufacturing energy and food depending on microbe is approximately zero. I think it's completely controllable and shows no difference in nature compared with common industrial manufacturing." (C3)

There seemed to be a consensus among both Chinese and EU scientists that the technology per se is "*neutral"* (C9), but the question of who uses it was thought to be relevant. Future risks were therefore mainly considered to originate from the motivations of the users, for instance, the illicit use or misuse of technology by individuals or extremely profit-driven companies. Uncertainties around SB-related risks, and long-term effects in particular, were rarely discussed by the scientists. Only two scientists (C3, C9) pointed out the uncertain health risks of some food and medical applications.

"There is a lack of assessment of the long-term health effects because it's very complex and related to the brain, immune system, metabolism and other aspects. You may cure one disease but produce other diseases at the same time, right? We must admit that there are many unknown risks." (C3)

"But if you modify the microbial strain and use them for fermentation and let them indirectly enter the food chain or use them to adapt human gut microbes, what effects will they have on humans, livestock, and the environment? We don't know, which means there are many uncontrollable and unknown things in science, and we know nothing about the risk." (C9)

One difference in perceived risks between the EU and Chinese scientists was the awareness of ecological risks. For instance, the potential ecological risk caused by the release of synthetic lifeforms was discussed much more by the EU scientists than by the Chinese scientists. However, the EU scientists labelled the risk level as essentially low, as the released lifeform typically could not outcompete or replace the natural population.

"From my perspective, there are no definite risks. I know that people are somehow scared of releasing engineered organisms into the environment, but chances for these organisms to do something that we don't want them to do is very very low, very very low…… So, I don't think there are risks at the top of the list." (E5)

"But I don't think it's a big deal because normally the modified microbe remains worse performing than the natural ones. So, normally in the wild, they are probably going to die first." (E10)

3.3.3 Ethical considerations

Both the Chinese and the EU scientists thought SB to be essentially ethical. One difference between the European and Chinese scientists was their ethical boundary in the choice of experimental materials. European scientists thought the use of animals or even plants in experiments could be off-limits, which therefore required careful ethical consideration, while Chinese scientists' ethical boundary located at the use of human cells, in particular human embryonic stem cells. The other difference relates to the fair distribution of benefits, which was mainly discussed by the European scientists; for instance, the benefits of applications to people in underdeveloped regions or from poorer communities. The concern over growing technology injustice, such as *"the* *technology gap between rich and poor countries"*, was raised by a European researcher (E3).

"If I were to confine my answer to agricultural uses on plants and crops, there are no ethical issues in my opinion. Ethical issues are only pertinent in human and animal research." (E1)

"I think we'll probably see more of a technology gap between rich and poor countries. I think most of these things are going to be very available in rich countries and I think the more technologies we have, the bigger the gap becomes then." (E3)

Application Sectors	Origin of material	Product traits	Confined use	Perceived benefits	Perceived risks
Agriculture	Plant	Crops with increased resistance to biotic and abiotic stress, reducing their needs for inputs (e.g. fertilizer, pesticide and water)	No	The improved crops and new ways of pest/crop disease control may provide higher-quality foods and possibly cheaper products with reduced environmental impacts. The reduced needs for inputs and increased productivity may bring economic benefits to farmers.	The use of gene-drive system in insects for population control may pose ecological risks.
	Plant	Crops with increased productivity (e.g. improved photosynthesis)	No		
	Plant	Crops with improved quality (e.g. nutrition level)	No		
	Plant	New ways of self-incompatible crop breeding (e.g. diploid potato breeding)	No		
	Microbe	Provide biofertilizer to facilitate crop growth through plant-microbe interaction	No		
	Microbe	Biopesticide	Yes		
	Microbe/cell free system	Biosensors for pathogen detection in plants and soil	No		
	Insect	Change the insect population with synthetic gene-drive system	No		
Food	Animal cell/microbe	Novel food (e.g. artificial meat and yeast-based milk)	Yes	New ways of food additive and enzyme production can be obtained. Novel foods may reduce the animal killing and land sue.	The long-term effect of food applications is uncertain.
	Microbe	Food additives (e.g. flavourings and aroma)	Yes		
	Microbe	Enzymes for food processing	Yes		
Environment & energy	Microbe/plant	Carbon dioxide fixation	No	Applications may help address pollution issues and produce	The released microbe may pose ecological risks.
	Microbe/plant	Bioremediation for polluted lands/water	No		

	Microbe/plant	Biofuel production	‘Yes’ for microbe-based; ‘No’ for plant-based	energy with reduced environmental impacts.	
	Microbe	Waste processing and recycling (e.g. transformed into energy)	Yes		
Healthcare	Microbe/plant/insect/animal	Medicine production (e.g. artemisinin and vaccines)	Yes	Novel ways of medicine or natural products production may reduce the price and stabilise the supply of products. These new options for disease treatment can benefit patients.	Engineered human cell and microbe for disease treatment might have side effects on human health.
	Human cell/microbe	Disease treatment (e.g. CAR-T for cancer treatment and synthetic microbe for chronic disease treatment)	No (used in human body)		
	Microbe/plant	Nutraceutical products	‘Yes’ for microbe-based; ‘No’ for plant-based		
Fundamental research	Not Applicable	Advanced tools for DNA/genome synthesis and sequencing	Yes	Advanced tools can boost development of applications in different sectors.	Not mentioned

Table 3. 2: Scientists’ anticipated applications and benefit/risk perceptions

3.3.4 Scientists' prediction of societal responses

Both the EU and Chinese scientists in this study expressed pessimism about the overall societal acceptance of SB, in particular its applications within the agri-food sector. The factors/issues they proposed as potentially affecting public responses were relatively similar and can be assigned to three major categories, namely: perceived benefits, perceived risks and negative impacts caused by various stakeholders (e.g. NGOs and politicians). The scientists considered the general public's perception of benefits to be shaped largely by attributes of applications per se (e.g. function and applied sector of products) and personal needs and preferences. Medicine-related applications, for example, were see evaluated as more acceptable to consumers than applications in the agri-food sector. Also, applications with tangible and immediate benefits were expected to be more acceptable to laypeople than those with delayed benefits, representing a perceived lack of long-term and global views among the general public.

"They need new drugs for old and new diseases because this is the urgent need. Of course, I mean there could be some people willing to taste new food applications, and they are not reluctant to do that, but we are talking about the majority. It's very, very conservative and very, very careful attitude." (E4)

"You should tell people what is probably beneficial to them and give them the thing in a good way. Then they may accept it." (C1)

"I think they want tangible benefits for them rather than profit margins or these kinds of things for companies and I think people are concerned about what's the point of creating risk when we don't need it." (E3)

"I think possibly people are very, you know, inward looking and maybe selfish. They look at things that will benefit them and their families immediately rather than looking at long-term or more global views." (E2)

Personal needs might be associated with socio-economic status. For instance, people in underdeveloped countries were assumed to prioritise applications that address hunger and food security issues, which may be rejected by those from developed economies. However, as some participants identified (C3, E12), beneficial applications as perceived by scientists might not bring actual benefits to the public or might not align with laypeople's preferences and needs; this was regarded as a disconnect between scientists and the public that could impede future development of SB-based applications.

"You could say, well, people shouldn't need it because they should be eating mixed diets…… But the reality is in poor communities, they don't have the option necessarily of mixed diets. That is an ethical consideration, absolutely." (E13)

Regarding the public's risk perceptions, the most frequently mentioned factors by participants in this study was laypeople's irrationality and their lack of knowledge about SB per se and relevant applications, suggesting that scientists still perceived the "deficit model" to be relevant to the introduction of SB.

"Consumers are not rational and so we don't know, and this is why the companies changed their names from the SB companies to fermentation companies." (E8)

"I think the controversy must be over food and agriculture. I think there might be some irrational panic among the public and this is very difficult to change in a short period of time." (C3)

"... Somehow, the discussion is not scientific as they are not willing to eat genes. But all the organisms you eat have genes, so you eat genes all the time." (E6)

The negative impacts of stakeholders on public responses were mentioned by both the EU and Chinese scientists. A consensus among them all seemed to be the low public trust in biotechnology companies due to previous GM products delivering little public benefit. However, a striking difference emerged concerning whom the scientists perceived as the most influential stakeholders in European and Chinese societies. Among the EU scientists, politicians, NGOs and the media were assumed to exaggerate the risks of SB, leading to resistance to SB-based applications among the public. In contrast, the Chinese scientists emphasised the importance of government attitudes towards the development of certain technologies or applications. Only Chinese participants were concerned about the decline of public trust in scientists due to their joint interest in associated businesses, which could adversely affect people's acceptance of SB-based applications.

"To be realistic, no biotechnology or other company will invest in research and development in Europe. The issue is not social opinions per se, they more have to do with political expedience at the highest level and the vested interests of anti-GM NGOs who also do not like GM." (E1)

"There is a lack of transparency in academia. Actually, I can now understand why GM is questioned by the public. There is some joint interest in science communication as some scientists have their own companies, making people feel the connection to interests. But in fact, it is also strongly associated with the public's lack of knowledge." (C6)

3.3.5 Demands to upgrade the regulatory framework

The EU scientists showed low satisfaction with the current regulation of SB, seeing it as overregulated and not based on scientific evidence. Most of them argued that regulation should be implemented based on the end products, rather than on the process or the technology per se. In other words, if a product is evaluated to be safe through rigorous safety assessment, it should be approved for further development. Such controversy is particularly heated with regard to gene-editing technology, since it can produce the same crops as traditional breeding, yet its products are regulated as GM crops.

"Products should be regulated according to the risk, not according to how they were made. So, this is something that we've seen with this recent decision of the European Court of Justice for genome-edited plants is that they want to regulate them according to how they were made. But you could make exactly the same product using technology in mutagenesis technology that's not regulated. So, you can have two things that were made in different ways, but the products are exactly the same. Why will one be regulated and the other not? That's completely stupid." (E3)

In contrast, the Chinese scientists showed limited knowledge of the national regulation of SB. They suggested establishing a more rigorous and trustworthy safety assessment system for broader biotechnology-based research and products, since this might increase public acceptance. In addition, the field of biotechnology in China has been damaged by the "gene-edited babies" scandal[3], leading to a decline in public trust. Some participants therefore expressed demands to develop reasonable standards and mechanisms for ethical evaluation within this field.

"I think we can establish a national ethics committee or safety committee, make it authoritative, and then inform people that any technology will be evaluated by the committee." (C1)

3.3.6 Scientists' views on public communication

Some participants were aware of a lack of communication between scientists and laypeople in the field of SB and assumed that this could impede public acceptance in future. However, most participants advocated educating the public, ideally from an early age, about the technology, its applications, and scientific evidence-based thinking. Decisions in relation to technical issues were still required to remain in the hands of experts or scientists. Only one participant (C9) pointed out the need to communicate with other stakeholders (e.g. the government and media) and inform the public of potential risks and relevant mitigation strategies associated with certain applications. This again suggests that the deficit model is perceived by most scientists in both China and the EU as a potential route to the implementation of SB.

"I've said earlier, we should increase certain argument and education, start the education at an early age so that the kids in school don't get the first message about gene technology there, maybe from somewhere else." (E6)

[3] https://www.bbc.co.uk/news/world-asia-china-46382662 (accessed 1 March 2020).

"Absolutely, I always think you should listen to people. I don't think you have to agree with them, we'll do what they say, because you are allowed to disagree, you're allowed to say that's all very well, but you're wrong." (E7)

"Actually, the development of SB requires good communication with the government, the media and the public, rather than ignoring the public's reasonable requests." (C9)

3.4 Discussion

This study showed that there is currently no consensus on the definition of SB among scientists, which can be partially attributed to its being a combination of multiple disciplines. This has raised the question of how SB should be described in public communication. Framing SB primarily based on GM characteristics could bias people against SB and associated applications, due to prior attitudes towards GM products, particularly for people who regard SB-based applications as the equivalent of GM products (Fischer & Frewer, 2009). Thus, there is a need for a more reasonable introduction to SB which is both scientifically accurate and understandable by laypeople. Such an introduction would strongly benefit social scientists particularly when they investigate public responses and make targeted science communication strategies.

Despite disparities in definition, scientists in our study anticipated a large number of SB applications across different sectors (see Table 3.2), and expected these to deliver economic, health and environmental benefits to society in future. Both the EU and Chinese scientists judged SB to be essentially high-benefit, low-risk and ethically acceptable; this aligns with findings among US synthetic biologists (Rose et al., 2018). Benefits of different applications were expected to target distinct groups of stakeholders. For instance, biofortified crops may help address food security issues, in particular in underdeveloped regions; crops with reduced input requirements may directly benefit farmers, through reduced costs, and indirectly benefit the broader public, through the mitigation of environmental impacts. In the healthcare sector, chimeric antigen receptors T-cell therapy, for example, provides a new cancer treatment method and improves patients' quality of life (Table 3.2).

Compared with the numerous benefits, only a limited number of risks were mentioned, which were in reference to specific applications (see Table 3.2). Scientists perceived that ecological risks may arise from the unconstrained use of applications (e.g. the release of synthetic microbe), and these risks have been evaluated as very low or even nil; few participants acknowledged the unknown long-term effects of food-related applications on human health. In contrast, our review of the relevant literature showed various health, environmental and socio-economic risks. Specifically, these risks may have a non-quantifiable presence of events or consequences; and can be divergently evaluated due to multiple societal actors and the diversity of value judgements; they have been described as "risk uncertainty" and "risk ambiguity" respectively (Klinke & Renn, 2012). Previous studies sometimes found limited influence of information provision on laypeople's attitudes towards GM food, implying the potential confirmatory bias (Poortinga & Pidgeon, 2004). In this study, confirmatory bias seemed to exist among scientists as well, given their dependence on scientific results showing no negative impacts of SB or GM applications. In addition, natural scientists need to account for the identification and evaluation of technical risks in their own research projects, and uncertainties can often emerge as part of the risks. Surprisingly, while most participants assumed that people may worry about the long-term health effects of food applications, few of them acknowledged the uncertainties associated with the risks. As more risk governance frameworks have demanded the inclusion of risk uncertainty and ambiguity (Renn, Klinke, & Van Asselt, 2011), it should be extended to future risk assessment and communication in SB projects.

Public concerns about SB and its applications may increase if scientists' biased risk perceptions of SB are learned by the general public. Therefore, a consensus regarding how to estimate, evaluate and manage these risks must be reached, in the light of scientific uncertainty and ideally on a case-by-case basis; this also calls for better involvement of synthetic biologists, the public, and broader stakeholders, such as risk researchers and government representatives. With respect to risk communication, researchers have investigated whether and how risk uncertainty should be communicated with the public. Some studies showed that experts perceive biotechnologies as less risky compared with the public (Ho et al., 2011; Savadori et al., 2004). Experts also believed that laypeople were incapable of conceptualising scientific uncertainty, and that information about uncertainty could result in the decline of public trust in science and scientific institutions (Frewer, Hunt, et al., 2003). However, there is evidence that the general public is familiar with scientific uncertainty and wants information about it, and that in cases where scientific uncertainty has been identified, the failure to provide uncertainty-related information can reduce people's trust in scientific and regulatory institutions (Frewer, 2003; Frewer, Miles, Brennan, et al., 2002). In order to ensure effective communication about SB-based food applications, the public's preferences and expectations about risk information need to be investigated and integrated into risk communication; this should include the interpretation of risk uncertainty and "what is being done to reduce uncertainty".

Two major different ethical issues were perceived by the Chinese and EU scientists, including the moral use of organisms as experiment material and consideration of technological justice. The EU scientists are more cautious when selecting organisms experiment material, as they believed using animals or sometimes even plants needs moral considerations. The Chinese scientists thought only the use of human cells, in particular human embryonic stem cells, might be off-limits. In addition, the need to consider the technology gap between developed and underdeveloped economies was only proposed by EU scientists. Schroeder and Kaplan (2019) argued the need and potential of using RRI, including moral responsibilities outside Europe to tackle grand challenges globally. In future SB-related research collaboration between the EU and China, researchers must also address the possible nuance of ethical standards when selecting ethical principles or standards for particular projects.

In this study, both Chinese and EU scientists expressed overall pessimism about public acceptance of SB applied to agriculture and food production. The issues/factors which they considered influential included laypeople's benefit perceptions, laypeople's risk perceptions, and the impacts of other stakeholders. A striking difference between the Chinese and EU scientists lay in the types of stakeholders they mentioned as potentially influencing public attitudes. The EU scientists argued that politicians, NGOs and the media might exaggerate risks in relation to SB, thereby reducing social acceptance. The Chinese scientists, however, stressed the lack of support from the government for commercialising certain applications, which could diminish public confidence in SB. The main reason for this difference could be the discrepancy between Chinese and EU society with regard to the relative power of various stakeholders in policy-making surrounding the adoption of novel technologies. However, the impact of the government support on public acceptance of SB might have been overestimated by Chinese scientists. For example, despite a positive attitude of the Chinese government towards GM technology at the early stage, GM food still failed to be widely accepted by Chinese citizens (Cao, 2019; Huang & Peng, 2015). The "associationist" view even showed people's trust in authorities might be not the cause of people's attitudes towards a food technology (e.g. GM). Instead, it might be the consequence of people's prior attitudes towards the technology, again showing the limitation of depending on government trust to promote risky technologies (Eiser, Miles, & Frewer, 2002; Poortinga & Pidgeon, 2005).

Some participants argued that there exists a mismatch between application attributes and public needs and preferences, which may diminish the benefits people perceive in specific applications. This mismatch may need to be addressed in future via effective communication with the public which provides information to guide scientists' "fine-tuning" of applications, in particular those at critical development points. Another important finding in this study related to the frequent claims by both the EU and Chinese scientists about laypeople's irrationality and knowledge deficit, which were assumed to increase public perceptions of risk in relation to SB. Little evidence was presented to support the opinion that laypeople's perception of risk is based on irrationality. Conversely, previous studies have consistently shown that the public has its own way of evaluating risks, and technical risk information alone plays a limited role in the public response (e.g. see Slovic, 2000; Frewer, 2004).

Public involvement has been an integral part of developing new technologies in line with democratic ideals, which may also play a great role in the development of SB. Moreover, different modes of public engagement may lead to distinct trajectories for specific applications. Most participants in this study believed that the public should be educated about the technology and about scientific evidence-based thinking, claiming that laypeople are irrational and ill-informed. This confirmed that the "deficit model" for the public communication of science and technology is still operational in the scientific community. An important issue is that both Chinese and EU scientists appeared to endorse the "deficit model" of public acceptance as the dominant route to societal introduction of SB, despite a considerable emphasis on the adoption of co-production and RRI approaches, in particular in the EU. Inclusion of fundamental training in RRI approaches may be required as part of graduate curriculums and should be a compulsory part of funding programmes, if a more pragmatic approach to addressing societal acceptance is to emerge (Seethaler et al., 2019).

Some participants recognised consumers' diverse needs and scientists' possible misunderstanding of these needs; they therefore stressed the importance of accurately understanding people's actual needs and preferences in order to better resolve associated problems. This points to another model of engaging with the public, with one-way information flow from the public to experts, i.e. public consultation (Rowe & Frewer, 2005), which is similar to the "dialogue model" for science communication (Trench, 2008). While some participants expressed a belief in the importance of public needs and preferences, they still persisted in the view that decisions should be in the hands of experts. This stance could be counterproductive, as it has been shown to lead to public rejection of novel technologies (e.g. GM technology) (Frewer et al., 2013). As such, to improve the public acceptance of SB-based applications, it is necessary to expand the inclusion of stakeholders and jointly shape relevant issues and agenda, such as the development and commercialisation of applications.

3.5 Research limitations

Some limitations in this study may need to be considered. This research focused only on scientists in two regulatory regions and used a relatively small sample size. Meanwhile, in this study, there were more scientists from the area of microbial SB involved as it is a dominant subfield of SB. Future research should identify and engage more scientists from other subfields as well as other stakeholder groups across a broader geographical range. Also, existing studies into public responses to SB, in particular its specific applications, are still insufficient, which has limited further identification of scientists' misunderstandings of public attitudes. However, we believe that the results provide some insights which can support increasingly responsible innovations within the area of SB.

3.6 Conclusion

SB has seen much progress in creating novel tools and agri-food applications, but the limited attention paid to its social implications may hinder its long-term development. In this study, both Chinese and EU scientists believed that SB is essentially high-benefit, low-risk and ethically acceptable. These scientists therefore tended to support the proactive principle rather than the precautionary principle for the regulatory process. However, most of the participants were pessimistic about the public response to SB, in particular its agri-food applications, which they considered to be driven by laypeople's perceptions of risks and benefits, and by other stakeholders. The results revealed far more similarities than differences between the two participant groups' views on social implications, despite the greater emphasis on RRI approaches in EU research activities as compared to China; one relatively clear difference lay in their perceptions of the relative impacts of various stakeholder groups on public attitudes. In addition, this study underlined some issues that should be investigated in future research, including the definition of SB, the assessment and communication of risk uncertainties, and the selection of suitable communication models. All the findings raise the need to involve the public, scientists and broader stakeholder groups so as to jointly shape SB-related issues and agenda on a case-by-case basis.

Chapter 4. Drivers of Chinese public attitudes towards agri-food applications based on SB

4.1 Introduction

SB is an area of scientific development where novel living systems are constructed by synthesising and assembling DNA components to obtain desired phenotypic traits. These synthesized pieces of DNA could be existing genes found in other organisms, or entirely novel and produced by humans, such that an organism's entire genome can be synthesised (Cameron, Bashor, & Collins, 2014). The application of SB within the agri-food sector is aimed at producing improved crops/microbes/livestock that offer new ways of controlling pests and crop diseases, managing livestock, and to facilitate novel food and food ingredient production, food processing, food safety diagnosis, food waste processing and food packaging development (e.g. see Fraser, Enfissi, & Bramley, 2009; Nigam & Luke, 2016; Park et al., 2015). These applications may make great contributions to achieving sustainable agricultural and food production, an integral part of the Sustainable Development Goals, thereby improving human lives and protecting the environment (United Nations, 2015). However, risks associated with these SB agri-food applications could be lined to implementation of SB technology, and could relate to negative human health, environmental, socioeconomic, and ethical impacts (Polizzi, Stanbrough, & Heap, 2018).

In order to align application development with social preferences and priorities, as well as facilitate future policy- and communication strategy-making, public responses to the SB agri-food applications, including their associated benefits and risks, must be understood. At present, there is limited literature into public attitudes towards SB, which has indicated that most research participants do not express inherently negative perceptions of SB (Jin et al., 2019). However, there is evidence that they tended to have more negative perceptions associated with application of SB to the agri-food sector compared to those which potentially deliver medical and environmental benefits (e.g. see Ineichen, Biller-Andorno, & Deplazes-Zemp, 2017; Pauwels, 2013; Rakic, Wienand, Shaw, Nast, & Elger, 2017; Steurer, 2015). Negative perceptions of SB are frequently related to potential risks (e.g. potential environmental and human health impacts) and ethical issues (e.g. “playing God”, “creating life” and “unnaturalness”)

(Betten, Broerse, & Kupper, 2018; Braman, Mandel, & Kahan, 2008). An overview of research into public attitudes towards SB is provided in Table 4.1. This body of research suggests that public perceptions and attitudes towards SB. including its application to the agri-food sector, are unlikely to be influenced by one single factor. Rather, they are shaped by a combination of potentially interacting, multiple factors such as affect/emotions, general attitudes towards SB, social trust, application attributes, personal values, information to which people are exposed, and subjective knowledge. This body of research, however, has tended to focus on SB as an enabling technology, rather than consider participants' responses to its specific applications, and has mainly been conducted in Europe and North America.

Previous research has shown that people's attitudes could vary across geographic regions due to the potential socio-economic and cultural difference (Frewer et al., 2013), and across applications due to different application characteristics (e.g. the host organisms involved and new traits resulting from application of SB) (Hess, Lagerkvist, Redekop, & Pakseresht, 2016). This research targets attitudes in a specific society, China, and seeks to understand people's decision-making about accepting or rejecting SB based on their perceptions of, and attitudes towards, specific agri-food applications. China has, in recent years, undertaken a massive expansion of research investment and policy support to help develop leading-edge capabilities in emerging fields, including in SB (Shapira, Kwon, & Youtie, 2017; Zhou, 2015). This has enabled a rapid growth of SB research and a variety of SB-based applications to be developed including those in the agri-food sector (Pei, Schmidt, & Wei, 2011; Shapira et al., 2017). Biosafety and biosecurity issues, as well as broader implications in relation to SB, have been infrequently discussed in China, although there are examples of dialogues between technical and policy experts (Inglesby, Cicero, Rivers, & Zhang, 2019; Wang & Zhang, 2019). However, no systematic approaches to addressing social implications about SB have been established. This includes the lack of explicit measures to foster responsible research and innovation, and active public engagement (Li & Shapira, 2015).

As Chinese public attitudes towards SB including its application to the agri-food sector have not been investigated so far, this chapter has attempted to extrapolate predictions about attitudes towards SB food from research which has investigated Chinese attitudes to GM food (Table 4.2) as both GM and SB deliberately change organisms at the genetic level. Here, GM represents the process of altering the genetic makeup of an organism to produce novel, desirable traits (Colwell, Norse, Pimentel, Sharples, & Simberloff, 1985). Technical similarity between GM and SB has led to some similar applications in the agri-food sector (Zhang, Wohlhueter, & Zhang, 2016). There is also evidence that research participants "made sense" of SB using GM as a "comparator" technology, which has resulted in similar concerns being identified in relation to the two technological innovations (Kronberger, Holtz, Kerbe, Strasser, & Wagner, 2009; Kronberger, Holtz, & Wagner, 2012). However, differences at the technical and application level could lead to different public perceptions and attitudes. For example, some ethicists have emphasised that SB may evoke stronger ethical concerns than GM due to its artificial gene and genome synthesis (Häyry, 2017), while some Austrian citizens regarded SB as a negative "upgrade" of GM technology (Steurer, 2015).

Although research into attitudes towards SB in China is uncommon, there are more publications which have investigated Chinese public attitudes towards GM foods (Table 4.2). Notably, the role of ethical concerns, the evoked affect/emotions and prior beliefs or attitudes associated with GM food in decision-making about accepting or rejecting specific applications of GM foods has been rarely studied in China (Sun et al., 2019), although this is not the case elsewhere (e.g. see Bredahl, 2001; Huffman, Rousu, Shogren, & Tegene, 2007; Laros & Steenkamp, 2004; Rozin, Fischler, & Shields-Argelès, 2009; Siegrist, Hartmann, & Sütterlin, 2016; Sjöberg, 2000). It is unclear as whether this is because these factors have little effect on public attitudes in the Chinese social context, or have been neglected by researchers.

The research presented in Chapter 4 aimed to investigate the potential drivers that inform Chinese public' decision-making about accepting or rejecting specific SB agri-food applications, and to compare these with the drivers which inform decision-making about GM foods.

Factors		Description	References
Perceptions	Benefit and risk perceptions	Benefit and risk perceptions have positive and negative effects on attitudes, respectively. People could perceive different types of benefits and risks and make trade-offs between those, leading to the final attitudes.	Akin et al., 2017; Betten et al., 2018; Kronberger et al., 2012; Starkbaum et al., 2015; Steurer, 2015
	Ethical concerns	Ethical concerns about SB were mainly expressed using "playing God", "artificial life", or "unnaturalness", which may negatively affect attitudes. The justice of benefit distribution was also mentioned.	Betten et al., 2018; Dragojlovic & Einsiedel, 2013; Kronberger et al., 2012; Starkbaum et al., 2015; Steurer, 2015
Affect/emotions		Positive/negative affect or emotions may lead to more positive/negative attitudes towards SB.	Mankad, Hobman, & Carter, 2021
General attitudes towards the technology		Some people "make sense" of SB by anchoring their prior attitudes or beliefs associated with GM technology or biotechnology. In other words, if they have negative prior attitudes towards GM technology or biotechnology, their SB associated attitudes are more likely to be negative.	Kronberger et al., 2012; Steurer, 2015
Social trust		Trust in scientists, industry, governance authorities may positively affect attitudes. However, distrust could sometimes emerge due to perceived lack of information and transparency.	Akin et al., 2017; Betten et al., 2018; Steurer, 2015
Application attributes		Applications that address medical and sustainability needs could evoke more positive perceptions.	Ineichen et al., 2017; Pauwels, 2013
Personal values		Greater religiosity might be associated with higher level of perceived unnaturalness and more negative perceptions and attitudes. People who regard scientific knowledge and technological artefacts as neutral means or tools to realise human goals (i.e. instrumentalism) tend to have more positive attitudes towards SB, despite discussing both benefits and risks; people perceiving science and technology to develop autonomously but under limited human control (i.e. determinism) tend to express more concerns about negative impacts of SB on their lives and the world as well as their / human control being limited, thereby leading to more negative attitudes.	Akin et al., 2017; Betten et al., 2018; Dragojlovic & Einsiedel, 2012, 2013
Information to which people are exposed to		Research participants' attitudes polarise, and tend to feel more certain about their opinions after exposure to balanced scientific information about SB.	Kronberger et al., 2012
Knowledge	Subjective knowledge	Subjective knowledge has a weak positive impact on the acceptance of SB.	Mankad et al., 2021
Socio-demographic attributes	Age	No significant attitudinal difference was found in terms of age.	Akin et al., 2017; Dragojlovic & Einsiedel, 2012; Starkbaum et al., 2015; Steurer, 2015

	Gender	Some research showed that men had lower risk perceptions of, and/or higher support for, SB, while some showed no gender difference.	Akin et al., 2017; Braman et al., 2008; Dragojlovic & Einsiedel, 2012; Ineichen et al., 2017; Steurer, 2015
	Education	One study showed that people with higher educational level are more supportive of SB, while others showed no difference across educational levels.	Braman et al., 2008; Dragojlovic & Einsiedel, 2012; Steurer, 2015
	Income	No significant attitudinal difference was found in terms of income.	Akin et al., 2017; Braman et al., 2008

Table 4. 1: Factors affecting attitudes towards SB applications

Factors		**Description**	**References**
Perceptions	Benefit and risk perceptions	Higher benefit perceptions and lower risk perceptions are associated with more positive attitudes towards GM foods.	De Steur et al., 2010; Guo, Yao, & Zhu, 2020; Zhang & Liu, 2015; Zhang et al., 2018; Zhu & Xie, 2015
Affect/emotions		Negative emotions could lead to higher risk perceptions.	Sun et al., 2019
Social trust		Trust in the government has positive impacts on accepting GM foods.	Lu, Xie, & Xiong, 2015; Qiu, Huang, Pray, & Rozelle, 2012
Application attributes		GM foods that potentially address food safety and nutrition problems may be acceptable to some consumers.	Zhang, Huang, Qiu, & Huang, 2010
Personal values and personality traits		People with the personality trait of openness to experience tend to have more positive attitudes towards GM food.	Lin, Ortega, Caputo, & Lusk, 2019
Information people are exposed to		Providing mixed (both risk and benefit) or risk information has a negative effect on attitudes. Providing benefit information has either positive or no effects on attitudes.	Ho, Vermeer, & Zhao, 2006; Hu & Chen, 2004; Hu, Zhong, & Ding, 2006; Huang, Qiu, Bai, & Pray, 2006; Yang, Xu, & Rodriguez, 2014; Zheng, Gao, Zhang, & Henneberry, 2017; Zhu & Xie, 2015
Personal knowledge	Objective knowledge	Objective knowledge has positive or no impacts on attitudes in different studies.	De Steur et al., 2010; Li, Curtis, McCluskey, & Wahl, 2002; Zhang & Liu, 2015; Zheng et al., 2017
	Subjective knowledge	Subjective knowledge has positive, negative, or no impacts, on attitudes in different studies.	
	Age	Most research has shown no attitudinal difference across age groups. Two regional studies (i.e. Taiyuan, Shanxi province and	De Steur et al., 2010; Li et al., 2002; Lin, Somwaru, Tuan, Huang, & Bai, 2006a; Zhang et al., 2010

		Beijing) showed that the older consumers were less likely to accept GM foods.	
Socio-demographic attributes	Gender	Most research has shown no attitudinal difference across gender, although some research indicated that women tended to have lower acceptance of GM foods compared to men.	De Steur et al., 2010; Huang & Peng, 2015; Lin et al., 2006a; Zhang et al., 2010
	Education	Most research has shown no attitudinal difference across educational levels. Some, however, indicated a positive impact of higher educational levels on attitudes, while some indicated the reverse.	De Steur et al., 2010; Huang & Peng, 2015; Zhang, Chen, Hu, Chen, & Zhan, 2016
	Income	Most research has shown no impacts of income on attitudes, although both positive and negative impacts of higher income on attitudes have been identified in some research studies.	Chen, Liu, & Liu, 2017; De Steur et al., 2010; Lin, Somwaru, Tuan, Huang, & Bai, 2006b; Zhang et al., 2010

Table 4. 2: Factors affecting Chinese public attitudes towards GM food

4.2 Methodology

Focus group methodology allows participnats to express views in their own words and at the same time involves active group interactions within a quasi-social context. This enables the elicitation of people's attitudes associated with new or abstract concepts, and in-depth understanding of the decision-making process (Kitzinger, 1994; Krueger & Casey, 2014). Given that research participants were potentially unfamiliar with GM and SB, and the applications of these technologies within the agrifood sector, focus group methodology was considered a suitable method for collecting data on participants' attitudes towards both technological innovations. This methodology has previously been applied to investigate people's responses to food-related issues such as food fraud and novel food production technologies in the cultural context of China (e.g. see Kendall et al., 2019; Lee, Lusk, Mirosa, & Oey, 2014; Perrea, Grunert, & Krystallis, 2015). The ethical approval was granted by the lead researcher's university in January 2019 (Ref: 10230/2018).

4.2.1 Protocol design

The focus group protocol was developed from the existing literature and was refined in a pilot study using a convenience sample of five Chinese citizens in April in Nanjing (see Appendix B, Section One). The protocol had two sections focusing on GM and SB respectively, with each section addressing participant perceptions of different applications of both technologies, including those using plants, microbes and animals as host organisms, with the application of each technology resulting in various novel traits (e.g. crops with reduced need of inputs, foods with enhanced human nutrition, or increased yield). An introduction to each technology was presented to participants, followed by information about each application. The participants rated their acceptance level of each application using a seven-point scales (1 = "fully unacceptable" to 7 = "fully acceptable", and 4 represents a neutral attitude) and provided their own opinions about different applications. After discussing each section, participants were asked to rerate their acceptance of the selected GM and SB applications, using seven-point scales.

4.2.2 Participants

A total of six focus groups (*n* = 32) were conducted in April 2019 in two Chinese cities, with three groups in a Tier 1 city (Shenzhen, Guangdong province) and the other three in a Tier 2 city (Nanjing, Jiangsu province) [4]. Each focus group included 5 to 7 participants, lasted about 1.5 hours, and was audio-recorded and transcribed *verbatim* in Chinese. Table 4.3 shows demographic information of the focus group participants, of which women accounted for 53%.

4.2.3 Data analysis

Data analysis began with open coding of the transcripts using an inductive approach, undertaken by two members of the research team (SJ and ZL) independently (Corbin & Strauss, 2008). The coding process initially analysed the transcript of the first focus group (Group A), until completion of the final group (Group F), which resulted in different key codes, or themes. Subsequenly, two team members (SJ and ZL) discussed and consolidated themes, which established a robust coding scheme (Braun & Clarke, 2006). Finally, all the transcripts were coded in detail by the lead researcher (SJ).

4.3 Results

4.3.1 Consumer attitudes towards GM and SB applications

Table 4.4 shows participants' initial and final attitudes (after group discussion) towards different GM and SB applications. These results suggest that participants tended to have positive attitudes towards most selected applications. Only GM livestock with faster growth was associated with negative attitudes by the participants. Those applications within the medical and environmental sectors (i.e. GM microbes for medicine production and SB microbes for bioremediation) were associated with more positive attitudes compared to the agri-food applications, although the average acceptance level of SB microbes for bioremediation slightly reduced after discussions (Table 4.4). Attitudes towards SB crops with the capability of producing new nutrients and SB livestock with improved immunity had the largest positive increase after discussions.

There were 17 attitudinal changes regarding six GM applications, of which 9 (53%) were from positive or neutral attitudes to negative attitudes, indicating positive and

[4] Tier 1 cities in China represent the most economically developed regions. Tier 2 cities represent fast developing regions in China.

negative impacts of discussions being relatively equal. In contrast, there were 35 attitudinal changes regarding six SB applications, of which 29 (83%) moved from negative or neutral attitudes to positive attitudes (Appendix B, Section Two). Overall, group discussions tended to have more strong positive impacts on participants' attitudes in particular towards SB applications.

Location	Group A				Group B				Group C			
	Participant No.	**Gender**	**Age Group**	**Monthly Income (CNY)**	**Participant No.**	**Gender**	**Age Group**	**Monthly Income (CNY)**	**Participant No.**	**Gender**	**Age Group**	**Monthly Income (CNY)**
Nanjing	**A1**	Male	40-49	> 1,5000	**B1**	Male	18-25	0 - 5, 000	**C1**	Female	18-25	0 - 5, 000
	A2	Female	18-25	0 - 5, 000	**B2**	Female	18-25	0 - 5, 000	**C2**	Male	18-25	0 - 5, 000
	A3	Male	18-25	0 - 5, 000	**B3**	Female	18-25	0 - 5, 000	**C3**	Male	26-30	10,000 - 14,999
	A4	Male	31-39	0 - 5, 000	**B4**	Female	18-25	0 - 5, 000	**C4**	Male	26-30	0 - 5, 000
	A5	Female	18-25	0 - 5, 000	**B5**	Female	18-25	0 - 5, 000	**C5**	Female	18-25	0 - 5, 000
	A6	Female	18-25	0 - 5, 000								
	A7	Male	26-30	> 15,000								
Location	**Group D**				**Group E**				**Group F**			
	Participant No.	**Gender**	**Age Group**	**Monthly Income (CNY)**	**Participant No.**	**Gender**	**Age Group**	**Monthly Income (CNY)**	**Participant No.**	**Gender**	**Age Group**	**Monthly Income (CNY)**
Shenzhen	**D1**	Female	26-30	10,000 - 14,999	**E1**	Male	18-25	10,000 - 14,999	**F1**	Male	40-49	5,001 - 9,999
	D2	Male	31-39	10,000 - 14,999	**E2**	Male	26-30	> 15,000	**F3**	Male	18-25	5,001 - 9,999
	D3	Female	31-39	5,001 - 9,999	**E3**	Female	18-25	10,000 - 14,999	**F4**	Female	26-30	5,001 - 9,999
	D4	Male	18-25	5,001 - 9,999	**E4**	Female	26-30	5,001 - 9,999	**F5**	Female	18-25	5,001 - 9,999
	D5	Male	31-39	10,000-14,999	**E5**	Female	26-30	10,000 - 14,999	**F6**	Female	18-25	5,001 - 9,999

Table 4. 3: Focus group participant characteristics

Note: Participant F2 dropped out the discussion half-way.

Applications		Initial attitudes				Final attitudes				Significant changes
		Mean	**Median**	**Range**	***SD***	**Mean**	**Median**	**Range**	***SD***	
Plant	GM crops with improved resistance	5.3	6	5	1.7	5.5	6	5	1.6	4 (3P)
	GM crops with increased content of certain nutrients	5.1	5	5	1.5	5.1	5.5	5	1.6	3 (0P)
	SB crops that require reduced inputs	5.0	5	5	1.7	5.2	5	5	1.4	5 (4P)
	SB crops that produce new nutrients	3.8	3.5	5	1.5	4.7	5	5	1.6	10 (9P)
Microbe	GM microbes for producing food additives	4.8	5	5	1.6	4.8	5	5	1.6	2 (2P)
	GM microbes for medicine production	5.6	6	6	1.5	5.7	6	5	1.4	2(1P)
	SB microbes for producing food additives	4.6	5	6	1.6	4.8	5	5	1.3	4(2P)
	SB microbes for bioremediation	6.1	6.5	4	1.1	5.9	6	4	1.1	4 (3P)
Animal	GM livestock with faster growth	3.1	3	6	1.4	3.3	3	6	1.4	2(1P)
	GM livestock with improved immunity	4.5	4.5	5	1.6	4.4	4	5	1.6	4 (2P)
	SB pests without fertility for pest control	4.2	4	6	1.7	4.2	4.5	6	1.8	3 (2P)
	SB livestock with improved immunity	4.0	4	6	1.6	4.8	5	4	1.2	9 (9P)

Table 4. 4: Attitudes towards specific applications before and after discussions

Note: Attitude was rated using a seven-point scale ranging from 1 = "fully unacceptable" to 7 = "fully acceptable". "P" represents positive significant attitudinal changes (from negative or neutral attitudes to positive attitudes), and the rest represent negative changes (from positive or neutral attitudes to negative attitudes), after discussion.

4.3.2 Application-specific attitude formation

The thematic analysis elicited seven categories of factors which interacted and influenced participants' attitudes towards GM and SB agri-food applications (Table 4.5). These were: 1) perceptions of specific applications, 2) affect/emotions evoked by applications, 3) general attitudes associated with SB, 4) features or traits of application, 5) personal experience and values, 6) the social context of China (i.e. social trust and food safety concern), and 7) information to which individuals are exposed. The analysis is supported by examples of illustrative quotes from participants.

Participants made trade-offs between perceived benefits, risks and ethical issues associated with specific applications, thereby informing their final attitudes. For instance, participants often questioned whether it was necessary or worth taking risks to obtain the benefits of certain applications, in particular when participants perceived alternative choices were available.

"The SB crops that require reduced inputs can contribute to ensuring national food security, which is good. However, it might be unnecessary to the public as there are other choices. So, I wouldn't take the risk." (Participant D4)

Some participants' affect/emotions evoked by applications directly informed their perceptions and attitudes, implying they were dependent on experiential thinking in decision-making about accepting or rejecting certain applications. Similarly, general attitudes towards SB also informed application acceptance and rejection, in particular among those who have strong positive or negative attitudes. These participants were more unlikely to change after group discussions (see Participants E1 and F3 in Appendix B, Section Two). For instance, Participant F3, who had very negative attitudes towards GM and SB food in general, frequently used perceived risks as the argumentation on which to justify application rejection. This suggests that consumer attitudes towards an application could be driven by risk perceptions reinforcing an existing negative prior attitude towards the technology.

"I strongly oppose GM technology. It may produce toxic proteins, which humans cannot control, and we do not know the impact on future generations." (Participant F3)

The analysis also showed that participants have views about which applications they preferred, and which were they found unacceptable. This might be a consequence of how participants perceived features or traits of application, a participants' own experience and values, social contextual factors and the information to which participants were exposed. In particular, a good fit between features or traits of certain applications and participants' needs and preferences can lead to more negative affect/emotions, perceptions and attitudes associated with these applications. In the context of Chinese society, applications that mitigate or prevent the occurrence of food hazards of public concern (e.g. pesticide residues in food), and environmental pollution potentially align with people's needs and preferences, while those using animals as host organisms may be less acceptable.

4.3.3 Comparisons between participants' responses to GM and SB

Participants tended to be more familiar with GM food compared to SB applied to the agri-food sector. Some participants thus formed their general attitudes towards SB by drawing on GM food related belief or prior attitudes. Overall, most participants had neither extremely positive nor negative attitudes towards GM and SB, and expressed different levels of acceptance across applications. Most participants assessed the acceptability of applications on the basis of specific attributes such as the type of host organisms to which the technology was applied, the reason for applying the application, and the "product" of the application. There were fewer attitudinal changes after group discussions for GM applications compared to those involving SB (Table 4.4).

Despite the same broad categories of factors being identified which influenced both GM and SB application-specific attitudes, there were nuances in terms of attitude formation. One difference related to the process by which the technology was implemented, e.g. the origin of transplanted genes. The perception that the technologies represented "tampering with nature" or "*violating the laws of nature*" was identified in particular for those using animals as host organisms (Participant B2). This increased the perceived unnaturalness of certain applications and their products, and, in turn, reduced application acceptance. The larger evolutionary distance between gene donor and host organisms of an application increased perceived unnaturalness, while developing synthetic genes using SB tools in the absence of a donor organisms had potential to reduce these concerns.

"After all, to accelerate the growth of animals violates the laws of nature. It's just like injecting ripening agents, which is obviously bad. You won't accept injecting ripening agents into your own body. This strongly violates the laws of nature." (*Participant B2)*

"I would feel assembling genes from different organisms a little unacceptable. If it is a synthetic gene, I don't know which organisms it came from, and at least there is no ethical concern." (Participant A2)

However, some participants less accepted applications which involved “synthetic genes” that did not arise in nature, which led to their higher acceptance of GM crops than SB crops. This might relate to the concern that SB is “playing god” identified by some ethicists as a potential ethical issue.

“Humans might not even know what the synthesized genes are. How could they ensure the safety of SB crops? GM crops at least use genes that exist in nature.” (Participant D2).

In addition, some participants regarded SB as a positive “upgrade” of GM, which might lead to more positive general attitudes towards SB compared to GM. There were also participants who regarded SB as a brand-new technology, and therefore having a less crystallised attitude compared to GM. This implies that Chinese public attitudes towards SB food in general could be shaped by *how* SB food is introduced and applied to society in the future.

“I think SB is similar to GM and may actually be a bit more advanced than GM. It is only a matter of time before I accept this. When it becomes mature, we may all accept it.” (Participant B4)

“Although I don't understand this new technology (i.e. SB), I remain neutral and decide whether to accept after have more information about its applications.” (Participant C2)

Factors		Description	Example quote from focus group
Perceptions	Benefit and risk perceptions	Participants perceived benefits and risks associated with different SB applications, which had positive and negative impacts on their attitudes, respectively. The benefits included, for example, potential economic, nutritional, environmental and health benefits, while the risks mainly related to the negative impacts on human health and the environment including the uncertain long-term or/and unknown impacts.	*"The SB crops can probably reduce the costs in agricultural production, so I'm very likely to accept them, and I'm not so concerned about the risks." (Participant C1)* *"The SB microbe can deliver benefits to the environment, which is really good. Although it may pose some risks to the environment as well, I would still accept it." (Participant D3)* *"Although SB crops that require reduced inputs can potentially deliver economic and environmental benefits, they can also break ecological balance and do harm to human health as well. You don't know what will happen in the long term, which is such a big risk. I won't accept it." (Participant E2)*
	Ethical concerns	Participants' ethical concerns mainly related to their perceived SB and/or its applications as "violating the laws of nature" and/or being unnatural, which negatively affected application-specific attitudes.	*"… to accelerate the growth of animals violates the laws of nature." (Participant B2)* *"I probably will accept the SB livestock with improved immunity, but still feel a bit concerned. I still think being natural is the best, and human interventions are only covering up but not solving the problem." (Participant C1)*
Affect/emotions		Although focus group discussions may facilitate more cognitive, analytical or in-depth, thinking, negative affect/emotions evoked by SB applications were still identified, which could lead to more negative perceptions and attitudes. Some participants rejected the SB crops that require reduced inputs singly because of the negative affective response these applications evoked.	*"The SB crops for producing new nutrients are emotionally unacceptable to me. All the creatures have their own attributes that shouldn't be changed." (Participant C4)* *"I felt a bit uncomfortable when I heard that the chicken's genes were changed. It was no longer the chicken in my thinking. I cannot accept it." (Participant C1)* *"I am a bit scared of the new SB crops that require reduced inputs. So, I would not accept them." (Participant A3)*
General attitudes		Most participants had overall neutral attitudes towards SB, leading to more case-by-case judgements of different	*"I think SB is similar to GM and may actually be a bit more advanced than GM. It is only a matter of time before I accept this. When it becomes mature, we may all accept it." (Participant B4)*

towards the technology *per se*		applications. Some participants "made sense" of SB food by drawing on attitudes and beliefs about GM food.	
Features or traits of application		Different application attributes might be connected to different types and levels of perceived risk, perceived benefit or ethical concerns. Using animals as host organisms could evoke stronger ethical concerns, e.g. "tampering with nature", compared to those using plants and microbes. Despite both using animals as host organisms, participants were less accepting of livestock with faster growth compared with that with improved immunity to disease (see Table 4.4). Also, releasing SB pests which were infertile into the environment for pest control evoked more participant concerns about ecological risks than human health risks. Such difference was also observed for plant-based applications, where SB crops producing "novel" nutrients were associated with stronger concern compared to GM crops with a higher content of existing nutrients. The "novel" nutrients were perceived to be more unnatural or unnecessary.	*"I think if scientists now use animal cells, they may modify humans in the future. After all, there are mad scientists in every country." (Participant F3)* *"I think there is a balanced relationship between pests and crops. This system has its own regulation function, and manual intervention may cause systemic problems in the food chain." (Participant C1)* *"This kind of thing does not exist in certain crops. Why should it be created artificially? It is unnatural and unnecessary." (Participant C3)*
Personal experience and values	Personal experience	Personal life experience potentially influenced participants' affect, perceptions and attitudes. For instance, a participant who grew up in a farming family was supportive of GM/SB crops that could benefit farmers in reducing labour costs and increasing incomes.	*"I grew up in a rural area, and my grandparents are farmers. To prevent pests, they have to spray pesticides every other time. It is very inconvenient. Moreover, my hometown is not very developed. So, I think the insect-resistant GM crops are worth a try." (Participant A5)*
	Personal values	A more dominionistic environmental worldview was associated with more positive affect, perceptions and attitudes concerning different applications. For example, participants with a more dominionistic environmental worldview were less likely to regard changing organisms at the genetic level as representative of "tampering with	*"Human beings dominate the world, so I can accept people making some changes to those animals. I know it's a bit selfish." (Participant B4)* *Humans are the most advanced species on the earth, so all the needs should be considered from humans' perspective, including*

		nature", which could shape more positive attitudes towards different applications.	*using new technologies to meet the huge demand for foods and energy. (Participant E1)*
Social context	Social trust	Distrust in institutions regulating novel food technologies was mentioned by some participants, mainly in relation to perceived institutional disregard of the public interest. This could negatively affect their acceptance of GM and SB applied to the agri-food sector. However, some participants expressed trust in associated scientists and regulatory institutes, which tended to increase their acceptance of applications.	*"I don't trust the food safety management department very much. Sometimes it feels as if you can get a stamp and solve the problem as long as you spend money." (Participant F4)* *"I trust scientists and relevant regulatory departments in our country, so, I would accept the SB crops that require reduced inputs." (Participant C3)* *"Nowadays, GM foods are finally obtained through thousands of experiments by scientists, so their safety can be trusted." (Participant F6)*
	Food safety concern	Study participants expressed concerns about the current food safety in China, which seemed to result in some caution about accepting novel food technologies including SB food. However, if the application was perceived by a participant to tackle a food safety problem about which they were concerned (e.g. pesticide residues in food), this potentially increased acceptance.	*"There have been a series of food safety issues in China. However, GM foods continues being developed, which may result in more food safety problems in future." (Participant A7)* *"In real life, the risk of pesticide residues is much higher than GM food. We don't know whether the relevant departments have actually tested pesticide residues. So, if the GM application can reduce pesticide use, why not accept it?" (Participant A7)* *"Compared with the risks associated with GM food, I am more worried about whether there are excessive pesticides or hormone residues in my current diet." (Participant F4)*
Information that individuals are exposed to	Media	Negative media reporting about GM food could lead to more negative perceptions, suggesting that the media had the potential to amplify risk perceptions. Although SB has been rarely discussed in Chinese media, negative media reporting about certain biotech companies also negatively affected participants' SB-related attitudes.	*"Some TV commercials often emphasize their oil produced by non-GM vegetable. So, I usually go to the supermarket and buy the oil that is labelled non-GM." (Participant D1)* *"I may not accept the SB crops with increased production, not because of safety issues, but because news reports say that Monsanto has an economic monopoly, which harms the interests of farmers and national food security." (Participant A3)*

Exposure to others' opinions	Focus group discussions acted as a quasi-social context, where participants were exposed to others' opinions. The observed attitudinal change after discussions, either becoming more positive or negative, implied the potential influence of social groups on individuals' perceptions and attitudes.	See Table 4.4

Table 4. 5: Factors affecting application-specific attitudes

4.4 Discussion

A rapid technical development of SB in China has occurred, but this has infrequently been accompanied by social science research, including that which investigates public responses to applying SB within the agri-food sector. The research presented here indicates that, despite the potential risks and ethical concerns (Häyry, 2017; Polizzi et al., 2018), Chinese people are unlikely to have extremely negative attitudes towards SB as an enabling technology, as has been found in some other countries (e.g. the Netherlands and the United States) (Betten et al., 2018; Pauwels, 2013). The different acceptance levels of SB applications in this research indicates that Chinese public potentially evaluate agri-food applications on a case-by-case basis when making decisions about the acceptability of these applications (see also Ineichen, Biller-Andorno, & Deplazes-Zemp, 2017; Pauwels, 2013; Rakic, Wienand, Shaw, Nast, & Elger, 2017; Steurer, 2015). Socially preferred SB agri-food applications can thus potentially be developed by considering what factors are important, and *how* they shape public attitudes.

Whilst some participants in this research used GM as a "comparator" technology to evaluate SB (see also Kronberger et al., 2012; Steurer, 2015), the results did not confirm that research participants perceived SB to be a riskier, ethically problematic, or a negative technological "upgrade" of GM. Rather, participants might regard the technological innovation offered by SB as a *positive* upgrade, resulting in more positive attitudes towards SB in general. Despite some ethicists' predicting more extensive negative ethical concerns over SB expressed within society (Häyry, 2017), the use of synthetic genes was potentially considered by some participants to be more ethically acceptable compared to GM using genes from other organisms.

Despite some evidence to suggest that participants were drawing on their prior attitudes associated with GM to make decisions about the acceptability of SB, this research suggested that general attitudes towards SB are, at present, uncrystallised in China. For example, the number of significant attitudinal changes of SB more than doubled that of GM after group discussions. One reason might relate to participants' more certain prior attitudes towards, and the perceived familiarity with, GM compared to SB, which led to their perceived "information sufficiency" and in turn, overrode the impacts of further information from discussions on attitudes (Dunwoody, Neuwirth, & Griffin, 1999; Fischer & Frewer, 2009). This resonates with previous GM related research on Chinese consumers' responses to information, where providing information about specific GM foods had positive led to positive attitudinal changes in earlier studies conducted in 2002 and 2003 (Hu & Chen, 2004; Huang et al., 2006), while subsequent studies found no impacts after providing positive information but negative impacts of balanced information which included both positive and negative information (Yang et al., 2014; Zhu & Xie, 2015). Confirmation biases might also exist for those participants with a negative prior attitude towards GM food, who tended to believe the negative part of the balanced information, leading to negative impacts on individual attitudes (De Steur et al., 2014; McFadden & Lusk, 2015; Zhu & Xie, 2015). This may be particularly relevant in the Chinese context with predominately negative media coverage of GM and increasing social opposition to GM food (Cui & Shoemaker, 2018).

This research demonstrated that the acceptability of GM and SB agri-food applications in China could be largely driven by the extent to which the public perceived benefits, risks and ethical issues as well as the trade-offs between these. Participants' ethical concerns mainly related to perceptions that SB and/or its applications are tampering with nature (expressed as "*violating the laws of nature*" by Chinese people) and unnaturalness, which is congruent with findings from studies conducted in other geographical regions (e.g. see Betten et al., 2018; Dragojlovic & Einsiedel, 2013; Kronberger et al., 2012; Mielby, Sandøe, & Lassen, 2013; Rozin et al., 2009; Sjöberg, 2000; Starkbaum et al., 2015; Steurer, 2015). Research in China has tended to focus on perceived benefits and risks associated with GM food (e.g. see De Steur et al., 2010; Guo, Yao, & Zhu, 2020; Zhang & Liu, 2015; Zhang et al., 2018; Zhu & Xie, 2015), with ethical issues being rarely investigated. Affect-based experiential thinking, as opposed to analytical thinking, also plays an important role in shaping perceptions of SB and other novel food technologies (see also Mankad et al., 2021; Siegrist, Cousin, Kastenholz, & Wiek, 2007; Siegrist et al., 2016; Wilks, Hornsey, & Bloom, 2021). This has, again, been rarely addressed in existing research on Chinese people's responses to GM foods.

In order to ensure more positive perceptions and higher acceptance of SB agri-food applications, it is important to achieve a better fit between application attributes and public needs and preferences. This research indicates that it requires a systemic consideration of multiple factors such as features or traits of applications in themselves, *how* these applications are presented to people, individual experience and values, and the specific social context to which these applications are introduced. Two social contextual factors, social trust and food safety concern, have been identified in this research. The results showed that social (dis)trust in scientists and regulatory institutes could affect some participants' attitudes associated with SB foods. This might be attributed to participants' limited knowledge of SB, resulting in them relying on social trust in institutions to reduce the complexity of decision-making about accepting or rejecting certain SB agri-food applications (Siegrist, 2000). However, caution is needed when interpreting the effect of social trust, as social trust may result from consequence of an individual accepting a technological process applied to food production rather than causing this acceptance (Poortinga & Pidgeon, 2005).

Food safety concern has sometimes been interpreted as negative affect, which could increase Chinese consumers' risk perceptions of food additives (Miao, Chen, Li, & Xie, 2020). Here, some participants with stronger food safety concerns had more negative perceptions of applying SB to food production, although when SB was applied to mitigate food safety threats of concern, acceptability increased. This might represent a good example of a "fit" between application functions and public needs, thereby evoking more positive affect and perceptions associated with these applications. For instance, both GM and SB crops that have the potential to reduce pesticide use were acceptable to most participants as they were more concerned about pesticide residues in food (see also Zhang et al., 2010). Liu, Pieniak and Verbeke (2014) reported that Chinese consumers were less worried about GM food compared with other food-related hazards (e.g. counterfeit food, inferior quality food, food containing residues of pesticides or veterinary drugs, and nutritionally imbalanced food). Technological applications which mitigate or prevent other food safety risks might evoke more positive perceptions and therefore be more acceptable than those which deliver other non-public preferred benefits.

4.4.1 Research implications

The results of this research can benefit both policy-makers and industry in ensuring product development and commercialisation, risk regulation and communication strategies align with societal preferences and priorities. First, it is necessary to assess public concerns about different food hazards within the socio-cultural context in which they are to be introduced. This helps refine socially preferred directions of SB agri-food product development which, in turn, guides agri-food policy support and private and public research and development (R&D) investment. In China, developing SB applications that prevent or mitigate food-related hazards such as counterfeit food, inferior quality food, and food containing residues of pesticides or veterinary drugs, may be a priority for the public over other technology application "outcomes", given the strong consumer concerns over these hazards (Liu et al., 2014).

Second, during the whole process of R&D, consumers and other stakeholders such as social scientists, consumers, natural scientists and other application developers should be involved to co-develop SB agri-food products that align with societal preferences. Ideally, application attributes that evoke more positive reactions should be incorporated into product development, while ensuring that consumers can choose whether or not to consumer these products though effective labelling and information strategies. This will also require the implementation effective stakeholder engagement mechanisms to facilitate collaborations and communications between different stakeholders. It is still a limitation in the area of SB in China (Jin, Clark, Li, Kuznesof, & Frewer, 2021), and suggests that there needs to be financial support from the government and industry for social science research into SB within the agri-food sector.

Finally, policy-makers, should inform the public of both benefits and risks, as well as any ethical issues associated with SB technology and its specific applications in a transparent way, which can (re)build higher social trust in relevant regulatory institutes. Product development and commercialisation, and communication about these with the public, is an iterative process which occurs in a changing food security environment, in which attitudes may change according to external pressures and social changes. The food technology trajectory needs to be responsive to these external pressures, and the design of new products, regulations, and communication strategies needs to be regularly updated in response.

4.4.2 Limitations of the research

This qualitative research has enabled an in-depth understanding of perceptions of, and attitudes towards, SB foods. Generalising the findings to the whole Chinese population could be problematic however, given the relatively young participants in the research, the small sample size, and limited geographical locations where the research was conducted. Future research could elicit consumer views in consideration of more age groups, larger samples and diverse cultures across regions. In addition, this research could not assess actual purchase and consumption of SB food products as they were not available. Future research can identify and quantify factors that shape actual behaviour when products become available on the market.

4.5 Conclusion

This research has identified different categories of factors that interacted and shaped Chinese public acceptance of SB agri-food applications. It has particularly addressed that general attitudes towards SB could be partly formed by drawing on prior attitudes or beliefs associated with GM, and *how* social contextual factors might shape public attitudes towards SB food in general and specific agri-food applications. Despite dependence on GM to do “sense-making” of SB, Chinese people’s general attitudes towards SB were less crystallised, which were then more affected by further information than GM-related attitudes. Perceptions of ethical issues associated with SB using synthetic genes could also differ from GM which uses genes from other organisms. All the findings from this research have provided information for making more effective strategies for SB product development and commercialisation and communication with the public.

Chapter 5. Public responses to GM food in China: The influence of prior attitudes, affect and perceptions of risks and benefits

5.1 Introduction

Novel agri-food technologies have the potential to improve global food and nutrition security (Pretty et al., 2018). However, it has been established that negative public attitudes towards different agri-food technologies, such as GM technology, may act as a barrier to their implementation. Attitudes may also vary according to socio-cultural factors, e.g. European citizens have been shown to be more reluctant to accept GM food compared with those living in North America and Asia (Frewer et al., 2013). In China, the central government issued the state's No. 1 Central Document on 31st December 2009, pledging more support for GM-related research in the agricultural sector in 2010 (The Chinese Central Government, 2009). Subsequently, negative media portrayal of GM food increased, which amplified societal concerns (Wang, 2015). In 2002, 13% of Chinese consumers perceived GM food as unsafe for consumption, which increased to 45% in 2012 (Huang & Peng, 2015). A Chinese nationwide survey conducted in 2016 showed that only 12% of respondents accepted GM food (Cui & Shoemaker, 2018). The Chinese government's efforts to develop an effective risk communication strategy has been impaired by inaccurately understanding public concerns. The objective of the research presented in this chapter is to develop and test a framework to explain public attitude formation towards GM agri-food applications in China, which can accommodate concerns as well as technical information. The relative influence of prior attitudes towards GM food, and affective responses and associated concerns (perceptions that GM food is "tampering with nature" and "unnatural") that are invoked by specific GM food applications are examined within an attitudinal model which incorporates risk and benefit perceptions in the "risk-benefit-acceptance" model.

5.2 Literature review and framework development

5.2.1 Affect heuristic

According to the dual process theory, two interacting modes of human decision-making exist, which can be described as "analytical" (or "rational") and "experiential" (Epstein, 1994). Analytical thinking requires justification using logic and evidence and involves slower information processing. Experiential thinking is intuitive, affect-based and more efficient in responding to uncertain and complex situations (Epstein, 1994). Affect refers to a person's positive or negative feelings about specific objects, ideas or images. Through learning and experience, images (i.e. perceptual and symbolic interpretations) can be attached to different affective or feeling states, thereby forming an individual's "affect pool" (Finucane, Alhakami, Slovic, & Johnson, 2000). By consulting the affect pool, people can efficiently make judgements when the issue under consideration invokes certain images. Affect used as a mental shortcut in human judgement has been termed as the "affect heuristic", which plays a critical role in the choices and decisions made by an individual (Slovic, Finucane, Peters, & MacGregor, 2004).

Research has examined how the affect heuristic might explain people's judgements of benefits and risks associated with (potentially) controversial technologies such as self-driving cars (Raue et al., 2019), stratospheric aerosol injection (Merk & Pönitzsch, 2017), GM technology (Siegrist et al., 2016), and nanotechnology (Siegrist et al., 2007). The results indicated that when a technology or its application elicits positive/negative affect, this leads to a higher/lower level of perceived benefit and acceptability, and a lower/higher level of perceived risk. Wilks, Hornsey, and Bloom (2021) reported that people's affective responses underpin the extent to which people perceive cultured meat, for example, to be unnatural, which is associated with more negative attitudes and greater opposition to cultured meat.

5.2.2 Prior attitudes towards GM food

An attitude can be defined as "*a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour*" (Eagly & Chaiken, 1993, p. 1). In the research presented here, the prior attitude towards GM food was defined as "an individual's overall tendency to approve or disapprove of the application of GM technology to food production". Bredahl (2001) reported that prior attitudes towards GM food have a strong impact on their product-specific risk perceptions, benefit perceptions and attitudes, and that there are no differences in the attitudes towards different types of GM food products. Research conducted in Denmark, Germany, Italy, and the United Kingdom showed that research participants' prior attitudes appear to "over-ride" information about GM technology and/or products, and so the provision of any type of information did not result in consumer attitude change (Scholderer & Frewer, 2003). An individual's reference to their prior attitudes towards GM food may lead to *a priori* judgements that are subsequently generalised to all GM food applications.

More recent studies, however, showed that there are some GM food characteristics that people are more likely to accept (e.g. food with enhanced nutrition and health benefits), and others that people are more likely to resist (e.g. modifications which result in increased yields, reduced prices and extended shelf-lives) (Hess et al., 2016; Mucci & Hough, 2004). This implies that people are evaluating GM food products on a case-by-case, or at least a categorical, basis. Questions thus arise as to *whether* and *to what extent* prior attitudes affect people's judgements of risks and benefits of, and acceptance of, specific GM food applications.

5.2.3 Perceived tampering with nature and unnaturalness

Some characteristics of food are often considered to be unnatural, including, for example, the presence of additives, contaminants, or specific processing attributes (Rozin, Fischler, & Shields-Argelès, 2012). Román, Sánchez-Siles, and Siegrist (2017) identified three categories of perceived characteristic which were relevant to the perceived (un)naturalness of food; the way of growing food, the way of producing and processing food, and the (perceived) attributes of the final product. The perceived unnaturalness of GM food may relate to the way of producing and processing food, in which modifying the genome of producer organisms reduces the "purity" of the food's original form (Rozin et al., 2009). The perceived unnaturalness of GM food may increase people's risk perceptions and reduce the acceptability of products (Mielby et al., 2013). In terms of potential effects on the perceived benefits of GM food, the results have been equivocal, sometimes reducing perceptions of benefit (e.g. Siegrist et al., 2016), or having no significant effects on benefit perceptions (Bredahl, 2001).

Deliberate human intervention in nature may be perceived as contributing to, or increasing, the perceived unnaturalness of GM food products (Rozin et al., 2012). In previous research, this has been expressed in different ways, such as "playing God", or "interfering", or "tampering with nature and natural processes" (Corner, Parkhill, Pidgeon, & Vaughan, 2013). People's perceptions that GM food "tampers with nature" is linked to people's moral and ethical concerns (Sjöberg, 2000), and may also relate to the perceived sentience of the target organisms associated with the GM application. For example, GM technology applied to animals for food production may invoke stronger moral and ethical concerns, compared to microbes and plants (Frewer, Coles, et al., 2014). Sjöberg (2004) reported that a tendency to associate GM food with tampering with nature is strongly correlated with higher risk perceptions. Wolske et al. (2019) reported that the perception that carbon dioxide removal strategies (e.g. bioenergy with carbon capture and storage, and direct air capture) "tamper with nature" is negatively related to people's support for these strategies. However, there is limited research that assesses whether perceptions of "tampering with nature" reduces the benefit perceptions associated with specific applications of GM technology to food production.

5.2.4 Risk and benefit perceptions

It has been established that risk perceptions reduce, and benefit perceptions increase, the acceptability of GM food (e.g. see Amin, Azad, Gausmian, & Zulkifli, 2014; Connor & Siegrist, 2010; Costa-Font & Gil, 2009; Frewer et al., 2011; Siegrist, 2000). Higher risk perceptions associated with GM food have been associated with lower benefit perceptions (Costa-Font & Mossialos, 2007; Costa-Font & Gil, 2009; Poortinga & Pidgeon, 2005). Those who have negative prior attitudes towards GM food also tend to refer to the perceived risks of specific GM food applications in their explanations of the final rejection of these applications. This implies that prior attitudes towards GM food may have a moderation effect on the relationship between risk perceptions and the acceptance of a specific food application (Jin et al., 2021).

5.2.5 Acceptability of GM applications

Bearth and Siegrist (2016) argued for the importance of distinguishing passive and active components of acceptance regarding innovative food technologies. Here, passive acceptance refers to the formation of a generally favourable attitude towards the attitude object, while active acceptance refers to the translation of that passive acceptance into decisions or behaviours showing support for the attitude object. Specific GM food applications with distinct traits can activate concrete thinking, including about the risks and benefits these applications may present (Bearth & Siegrist, 2016; Trope & Liberman, 2010). Measuring the active acceptance of specific GM food applications should better capture people's cognitive and behavioural decision processes.

5.2.6 Framework of acceptability

Hypotheses 1-5 in Table 5.1 were proposed to develop a framework for predicting attitudes towards GM food applications (Figure 5.1). The bold text in Table 5.1 and Figure 5.1 denotes that the hypotheses were developed in relation to previously inconsistent results or in relation to potential relationships that had not been empirically tested in previous studies.

No.	Hypotheses	Evidence
H1a	The perceived benefit of a GM food application has a positive effect on the acceptability of the application.	
H1b	The perceived risk of a GM food application has a negative effect on the perceived benefit of the application.	**Section 5.2.4**
H1c	The perceived risk of a GM food application has a negative effect on the acceptability of the application.	
H2a	The perceived unnaturalness of a GM food application has a negative effect on the perceived benefit of the application.	
H2b	The perceived unnaturalness of a GM food application has a negative effect on the acceptability of the application.	**Section 5.2.3**
H2c	The perceived unnaturalness of a GM food application has a positive effect on the perceived risk of the application.	
H3a	Perceiving a GM food application to be tampering with nature has a negative effect on the perceived benefit of the application.	
H3b	Perceiving a GM food application to be tampering with nature has a negative effect on the acceptability of the application.	
H3c	Perceiving a GM food application to be tampering with nature has a positive effect on the perceived risk of the application.	**Section 5.2.3**
H3d	Perceiving a GM food application to be tampering with nature has a positive effect on the perceived unnaturalness of the application.	
H4a	Positive affect evoked by a GM food application increases the perceived benefit of the application.	
H4b	Positive affect evoked by a GM food application increases the acceptability of the application.	
H4c	Positive affect evoked by a GM food application reduces the perceived unnaturalness of the application.	**Section 5.2.1**
H4d	Positive affect evoked by a GM food application reduces the perceived tampering with nature of the application.	
H4e	Positive affect evoked by a GM food application reduces the perceived risk of the application.	
H5a	A positive prior attitude towards GM food has a positive effect on the affect invoked by a specific GM food application.	
H5b	A positive prior attitude towards GM food has a positive effect on the perceived benefit of a specific GM food application.	
H5c	A positive prior attitude towards GM food has a positive effect on the acceptability of a specific GM food application.	
H5d	A positive prior attitude towards GM food has a negative effect on the perceived unnaturalness of the application.	**Section 5.2.2**
H5e	A positive prior attitude towards GM food has a negative effect on the perceived tampering with nature of the application.	
H5f	A positive prior attitude towards GM food has a negative effect on the perceived risk of the application.	
H6a	The positive effect of perceived benefit on the acceptability of a GM food application is stronger among people with more positive (cf. negative) prior attitudes towards GM food.	**Section 5.2.4**
H6b	The negative effect of perceived risk on the acceptability of a GM food application is stronger among people with more negative (cf. positive) prior attitudes towards GM.	

Table 5. 1: Research hypotheses

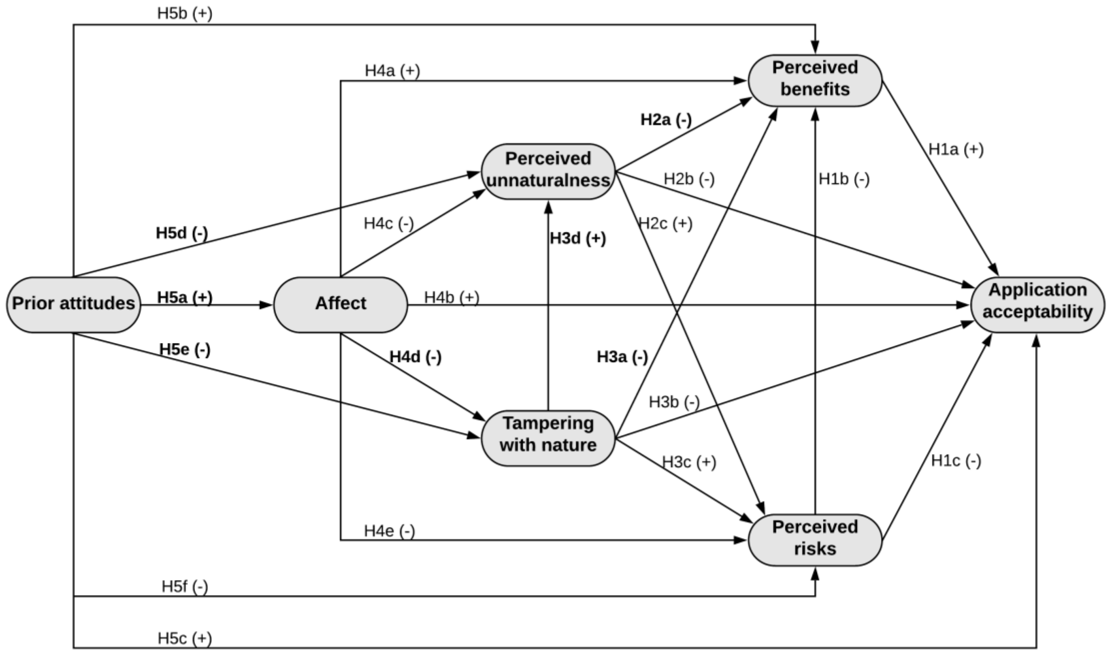

Figure 5. 1: Framework of attitude formation towards GM food applications

5.3 Methodology

5.3.1 Survey design

The survey included items measuring respondents' prior attitudes towards GM food, and their affect invoked by different applications, perceived risks and benefits, perceptions that GM food applications tamper with nature, the perceived unnaturalness of these GM food applications, and their acceptability, followed by the demographic questions. The survey design was based on similar measures used in previous research (Frewer, Scholderer, & Bredahl, 2003; Poortinga & Pidgeon, 2005; Siegrist, 2000). In addition, focus groups were conducted with Chinese participants (see Chapter 4) in order to help adapt the linguistics of the questionnaire to the vocabulary typically used by the target sample.

A national survey showed that 89% of Chinese citizens are unfamiliar with GM technology (Cui & Shoemaker, 2018). Therefore, we presented respondents in this study with a brief introduction to GM technology, which was aimed at assisting them with answering the subsequent questions (see "Brief introduction to GM", Appendix C Table A). In order to minimise its influence on respondents' general attitudes towards applying GM technology to food production, the introduction was written in a neutral manner, did not emphasise the benefits or risks of the technology, and provided no examples of GM application within the agri-food sector. Three items were used to measure participants' prior attitudes towards GM technology applied to food production, each of which used a five-point Likert response scale (1 = "strongly disagree" to 5 = "strongly agree"). The items were "*GM applied to food production is acceptable to me*", "*GM applied to food production is good for society", and "GM applied to food production should be encouraged"*. These items were adapted from previous studies (Costa-Font & Gil, 2009; Frewer, Scholderer, & Bredahl, 2003; Poortinga & Pidgeon, 2005).

Questions about plant-, microbe- and animal-based GM agri-food applications were included in the survey. These applications included GM yeast for producing vitamins (Hancock, Galpin, & Viola, 2000), an insect-resistant GM soybean (Gatehouse, Ferry, Edwards, & Bell, 2011), and a GM pig with improved cold weather adaptation and increased lean meat production (Zheng et al., 2017). An introduction to each application was provided, followed by a question measuring respondents' evoked affect associated with each application (open-ended response), "*What is the first thought or image that comes to your mind after you read information about this application?*" Then, respondents were asked to report the affect invoked by this first thought or image using a seven-point scale ranging from 1 = "extremely negative" to 7 = "extremely positive". These questions have been applied to elicit affect invoked by the information about novel food technologies such as GM technology and nanotechnology (Connor & Siegrist, 2011; Siegrist et al., 2007).

Respondents were asked to rate the extent to which they perceived the application to be tampering with nature ("*Using GM technology to create this GM yeast/soybean/pig tampers with nature*") and the extent to which they perceived the corresponding food products to be unnatural ("*Food products (i.e. vitamin/soy/pork products) based the GM yeast/soybean/pig are unnatural.*"). Questions about different benefits and risks of these GM applications were then asked (see "Perceived benefits" and "Perceived risks", Appendix C, Table A). There was no time limit for answering these questions, which gave the respondents the opportunity to engage in both affective and deliberative cognitive analysis. To measure the acceptance of different GM applications, respondents were presented with various statements (e.g. "*This GM yeast used to* *produce vitamins is acceptable to me*", "*I would consider eating foods containing vitamins produced by this GM yeast*", "*I would consider buying foods containing vitamins produced by this GM yeast*"; details of the other applications are shown in "Application acceptance" in Appendix C, Table A) and asked to respond using five-point Likert scales (1 = "strongly disagree" to 5 = "strongly agree").

5.3.2 Sampling and participants

The online survey was distributed by a survey company (Beijing Jishuyun Technology Co., Ltd) in 2020 in two Tier 1 cities (Shenzhen and Beijing) and two Tier 2 cities (Nanjing and Wuhan) in China. To determine the sample size, the following equation was used:

$$n = \frac{Z^2 \mathrm{p}(1-p)}{E^2} = \frac{1.96^2 \times 0.5(1-0.5)}{0.03^2} = 1067.11 \approx 1068$$

In this equation, "n" represents the required sample size, "p" represents standard deviation; "Z" is the value from the standard normal distribution for the selected confidence level; "E" represents the desired margin of error. We chose a 95% confidence level (i.e. Z = 1.96), 0.5 standard deviation, and a margin of error of ± 3%, indicating the need for a minimum of 1068 completed surveys. The survey was piloted with 142 respondents, and then administered to 1,500 respondents in September 2020 using quota sampling based on age distribution and gender in each city (National Bureau of Statistics of China, 2010). 1,411 responses remained after eliminating participants who provided inconsistent data. The sample's mean age was 34.69 (*SD* = 10.59), and 49% were female. Socio-demographic characteristics of survey respondents are shown in Table 5.2.

Sociodemographic attributes		**Number**	**Frequency**
Gender	Male	722	51%
	Female	689	49%
Age	18-24	314	22%
	25-34	435	31%
	35-44	318	23%
	45-54	268	19%
	>54	76	5%
City	Shenzhen	411	29%
	Beijing	295	21%
	Nanjing	398	28%
	Wuhan	307	22%

Occupation	Company employee	992	70%
	Government employee	86	6%
	Self-employed	114	8%
	Student	98	7%
	Others	121	9%
Highest Level of Educational Attainment	Secondary school or below	160	11%
	2-3 years of College	406	29%
	Undergraduate or above	845	60%
Personal monthly income (CNY)	<3,000	104	7%
	3,000-4,999	161	11%
	5,000–6,999	365	26%
	7,000–9,999	417	30%
	>10,000	364	26%

Table 5. 2: Sample characteristics

5.3.3 Data analyses

Descriptive analyses were first conducted to get an overall picture of respondents' responses to different GM food applications. The thoughts or images invoked by the information of these applications and the corresponding levels of affect were categorised into themes. Independent t-tests and one-way ANOVA between groups were conducted to compare respondents' responses to GM food in general and the selected applications across socio-demographic groups (gender, city, educational level, and personal monthly income). One-way ANOVA with repeated measures was used to compare respondents' acceptance between the applications. These analyses were conducted using IBM SPSS Statistics Version 24.

Partial least squares-structural equation modelling (PLS-SEM) was used to address research gaps and contribute to the development of a theoretical framework in this study. This method conserves robustness of estimations with less restricted requirements for constructs' measurement properties (e.g. allowing constructs with one or two items for measurement) compared with covariance-based equation modelling (CB-SEM) (Hair, Ringle, & Sarstedt, 2011). It also maximises the variance explanation for endogenous constructs within a complex context, representing a suitable tool for predicting and developing theories (Reinartz, Haenlein, & Henseler, 2009). PLS-SEM has been widely applied in the areas of marketing and management (Hair, Sarstedt, Hopkins, & Kuppelwieser, 2014). The analysis was facilitated by the software SmartPLS3 (Ringle, Wende, & Becker, 2015).

The reliability and validity of measurement models were ensured by meeting the internal consistency reliability (Cronbach's alpha $\alpha > 0.7$ and composite reliability $\rho > 0.7$), indicator reliability (retaining indicators with loadings > 0.7, removing loadings < 0.4, and removing loadings between 0.4 and 0.7 if the deletion can increase composite reliability to an acceptable level over 0.7), convergent validity (values of average variance extracted (AVE) > 0.5) and discriminant validity ((a) an indicator's outer loadings on a construct being higher than its outer loadings with other constructs; (b) Fornell-Larcker Criterion, i.e. the square root of the AVE of each construct being higher than its highest correlation with any other construct; and (c) the heterotrait-monotrait ratio (HTMT) < 0.9) (Hair, Jr., Ringle, & Sarstedt, 2017).

Previous research has adopted goodness of fit (GoF) as a model fit indicator for CB-SEM, which helped test the discrepancy between the empirical and the model-implied covariance matrix (Tenenhaus, Amato, & Vinzi, 2004). This approach, however, failed to distinguish valid models from invalid ones in PLS-SEM (Henseler & Sarstedt, 2013). The model fit of PLS-SEM focuses on the discrepancy between the observed or approximated values of dependent variables and the values predicted by the established model (Hair et al., 2017). This indicates the predictive capabilities are more suitable for evaluating the quality of models based on PLS-SEM. The assessment of the proposed framework in this research included five elements: the collinearity between constructs; the significance and relevance of model relationships; coefficients of determination using the R^2 values; an exogenous construct's contribution to an endogenous latent variable's R^2 value using the f^2 effect size; and the predictive relevance using Stone-Geisser's Q^2 value (Hair et al., 2017; Rigdon, 2012; Stone, 1974). The standardised root mean square residual (SRMR) of smaller than 0.08 was selected as a strict criterion for ensuring the model fit for PLS-SEM (Henseler et al., 2014; Hu & Bentler, 1998). As previous research has demonstrated the impacts of sociodemographic attributes (i.e. age, gender and education) on people's perceptions of GM food (Christoph, Bruhn, & Roosen, 2008; Cui & Shoemaker, 2018; Hallman, Hebden, Aquino, Cuite, & Lang, 2003), these variables were added to the model as control variables for all the other constructs, thereby testing the robustness of modelling results.

To test hypotheses 6a and 6b concerning the potential moderating effects of prior attitudes, a two-stage approach was selected. This accounted for the reflective constructs involved and the objective of revealing the significance of the moderating effects (Henseler & Chin, 2010). Two interaction terms were added to the model; one between prior attitudes and perceived benefits, and the other one between prior attitudes and perceived risks. Thereafter, the path coefficients, *t*-values and 95% confidence intervals and effect size (f^2) were calculated. The significance of the relationship between the interaction terms and the acceptability of GM applications was first tested using a *p*-value of smaller than 0.05, and the strength of the moderating effects was tested using f^2 values, where 0.005, 0.01, and 0.025 represent small, medium and large effect sizes, respectively (Hair et al., 2017).

5.4 Results

5.4.1 The acceptability of GM food applications

Overall, the survey respondents on average had slightly positive prior attitudes towards GM technology applied to food production (*M = 3.21, SD = 0.86*). reflecting that 44.9% of the respondents had either negative or neutral attitudes. Respondents' acceptance of different applications varied (Table 5.3): GM yeast (*M = 3.22 SD = 0.92*); GM soybean (*M = 3.31, SD = 0.94*); and GM pig (*M = 2.86, SD = 1.04*), indicating that the GM pig was the least acceptable and the GM soybean the most acceptable application. The highest levels of positive affect and perceived benefit were associated with the GM soybean. The highest levels of perceptions of tampering with nature, unnaturalness and risk were associated with the GM pig.

Constructs	**GM yeast**		**GM soybean**		**GM pig**	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***
Affect	4.15	1.20	4.36	1.29	3.72	1.43
PTN	3.08	1.16	2.97	1.15	3.34	1.19
PU	3.18	1.13	3.09	1.14	3.36	1.18
PB	3.23	0.78	3.40	0.77	3.09	0.84
PR	3.10	0.81	3.06	0.85	3.34	0.84
AA	3.22	0.92	3.31	0.94	2.86	1.04

Table 5. 3: Respondents' acceptance of GM food applications

Note: PTN = perceptions of tampering with nature; PU = perceived unnaturalness; PB = perceived benefit; PR = perceived risk; AA = acceptance of the application; and *SD* = standard deviation. Affect was rated using a seven-point scale ranging from 1 = "extremely negative" to

7 = “extremely positive”, and the others using five-point Likert scales (1 = “strongly disagree” to 5 = “strongly agree”).

The analysis identified ten, twelve and twelve thematic categories of images or thoughts invoked by information about the GM yeast, the GM soybean and the GM pig, respectively (Table 5.4a-c). The themes represented 89%, 86% and 87% of survey respondents’ first reactions to the applications. Four thematic categories (perceptions of safety and quality of the vitamin products using the GM yeast, regarding the GM yeast as an advanced technology, overall acceptance of the GM yeast, and health effects of eating the vitamin products produced by the GM yeast) accounted for over 50% of the responses in the GM yeast condition. These were connected to positive affect (the value of affect larger than 4) except in relation to the health effect (Table 5.4a). Similarly, of the six thematic categories (perceptions of the safety and quality of food products using the GM soybean, perceived increased productivity of the GM soybean and reduced price of relevant food products, overall acceptance, regarding the GM soybean as an advanced technology, health effects of eating GM soybean-based foods, and perceived capacity of the GM soybean to reduce pesticide use) that accounted for over 50% of the responses to the GM soybean, only the health effects of eating GM soybean-based food was associated with negative affect (the value of affect was smaller than 4) (Table 5.4b). In contrast, five thematic categories (perceived safety and quality of the GM pork, fear, worry or hesitation invoked by the GM pig, perceived health effects of eating GM pork, overall rejection of the GM pig, and ethical concerns) accounted for over 50% of the responses to the GM pig and were all associated with negative affect (Table 5.4c). The perceived safety and quality of food products based on GM applications and perceived health effects of eating these products represented the most dominant thoughts in response to three applications.

Respondents perceiving the GM yeast for producing vitamin products to be an advanced technology, and its potential in increasing productivity and reducing the price of vitamin products were associated with the highest levels of positive affect. The evoked fear, worry or hesitation and overall rejection of the GM yeast were related to negative affect. The perceived increased productivity and reduced price of the GM soybean, as well as its capacity to reduce pesticide use, were associated with positive affect. The overall rejection and the consideration of health effect and ethical issues (e.g. being unnatural and tampering with nature) were associated with the most negative affect. Perceptions that the GM pig could increase food production and reduce pork prices, and that the GM pig represents an advanced technology were associated with the highest levels of positive affect. Respondents' overall rejection, their fear, worry or hesitation, and consideration of ethical issues associated with the GM pig evoked the most negative affect.

No.	Themes	Affect	*SD*	Frequency
1	Perceptions of product safety and quality	4.2	1.2	17%
2	Regarding the GM yeast as an advanced technology	4.6	1.0	16%
3	Overall acceptance of the GM yeast	4.6	1.0	13%
4	Perceived health effect of eating vitamin products using the GM yeast	3.7	1.3	12%
5	Information seeking	4.1	1.1	9%
6	Overall rejection of the GM yeast	3.4	1.4	5%
7	Perceived increased productivity and reduced price of vitamin products using the GM yeast	4.9	1.1	5%
8	Ethical consideration	3.6	1.1	5%
9	Fear worry or hesitation	3.5	1.3	4%
10	Perceived environmental impacts of the GM yeast	4.1	1.2	4%

(a) GM yeast

No.	Themes	Affect	*SD*	Frequency
1	Perceptions of product safety and quality	4.4	1.4	11%
2	Perceived increased productivity and reduced price of food products using the GM soybean	5.1	1.2	10%
3	Regarding the GM soybean as an advanced technology	4.9	0.9	9%
4	Perceived health effect of eating GM soybean-based food	3.5	1.2	9%
5	Perceived capacity of the GM soybean to reduce pesticide use	5.0	1.0	8%
6	Perceived resistance of the GM soybean to pests	4.5	1.2	7%
7	Information seeking	4.2	1.1	7%
8	Overall acceptance of the GM soybean	4.7	1.0	10%
9	Fear worry or hesitation	3.7	1.4	5%
10	Overall rejection of the GM soybean	3.0	1.3	4%
11	Ethical consideration	3.5	1.2	3%
12	Perceived environmental impacts of the GM soybean	4.5	1.2	3%

(b) GM soybean

No.	Themes	Affect	*SD*	Frequency

1	Perceptions of product safety and quality	3.9	1.2	18%
2	Fear worry or hesitation	3.0	1.5	10%
3	Perceived health effect of eating GM pork	3.2	1.4	9%
4	Overall rejection of the GM pig	2.8	1.3	8%
5	Ethical consideration	3.0	1.1	7%
6	Perceived increased productivity and reduced price of GM pork	4.9	1.2	7%
7	Overall acceptance of the GM pig	4.5	1.1	6%
8	Information seeking	4.2	1.3	6%
9	Regarding the GM pig as an advanced technology	4.6	1.5	5%
10	Feeling weird or disgusting	3.2	1.2	5%
11	Perceived health status of the GM pig	3.9	1.3	4%
12	Perceived environmental impacts of the GM pig	3.9	1.5	4%

(c) GM pig

Table 5. 4: Affective responses to GM food applications

Note: Theme "information seeking" refers to respondents' invoked questions about more application/product details; affect values smaller than 4 represent negative affect, the smaller the more negative; affect larger values than larger than 4 represent positive affect, the larger the more positive; themes are ranked according to their percentages of all the different affective responses.

To test for significant differences in acceptance between different GM applications, normality checks were first carried out on the residuals of acceptance levels. The results showed that these were approximately normally distributed. A repeated-measures ANOVA with a Greenhouse-Geisser correction showed that the mean acceptance level differed significantly between applications [$F(1.821, 2565.759) = 194.581$, $p < 0.001$]. Post hoc tests using the Bonferroni correction revealed that the acceptance level of the GM soybean is 0.087 higher than that of the GM yeast ($p < 0.001$), 0.444 higher than that of the GM pig ($p < 0.001$), and that the acceptance level of the GM yeast is 0.357 higher than that of the GM pig ($p < 0.001$). There was no significant difference in prior attitudes towards GM food and the acceptability of specific applications across socio-demographic groups.

5.4.2 Model evaluation and moderation analysis

The criteria for evaluating the reliability and validity of measurement models were met for all GM food applications (see Appendix C, Table B and C). The estimated models had values of SRMR smaller than 0.08, representing a good model fit (Appendix C, Table D). All variance inflation factor (VIF) values were smaller than 5, indicating that there were no critical collinearity problems between constructs

(Appendix C, Table E1-3). The dependent variables' R^2 values were higher than 0.1 with the exception of the perceptions of tampering with nature associated with the GM yeast (Appendix C, Table F). As the research focused on explaining people's perceived benefit, perceived risk and acceptability of GM food applications, the results of R^2 values, represented an overall acceptable predictive power associated with the model (Falk & Miller, 1992). Stone-Geisser's Q^2 values of the dependent variables were larger than 0 (Appendix C, Table F), representing a satisfactory predictive relevance (Stone, 1974).

Standardised values of path coefficients β, their respective *t*-values, 95% confidence intervals and effect size f^2 are shown in Table 5.5. The t values > 1.96 (two-tailed tests, significance level = 5%) and p values < 0.05 represented a significant correlation between two variables. Hypotheses 3a and 3b were rejected across all the applications, suggesting that associating a GM application with tampering with nature has no direct impact on the perceived benefit and acceptance of that application. Hypothesis 2b was rejected for the GM yeast, showing that perceived unnaturalness of the GM yeast has no direct effect on respondents' acceptance (Figure 5.2). Hypothesis 2a was rejected for the GM soybean, indicating that the perceived unnaturalness of the GM soybean has no direct effect on respondents' perceived benefit (Figure 5.3). Hypotheses 5d and 5e were rejected for the GM pig, showing that prior attitudes have no direct effect on respondents' perceptions of tampering with nature and unnaturalness associated with the GM pig (Figure 5.4). Based on the moderation analysis (Table 5.6), Hypothesis 6a was rejected and Hypothesis 6b was supported across all the GM food applications, showing that prior attitudes only exert a moderation effect on the relationship between perceived risk and the acceptability of each application. The effect sizes f^2 values of moderating effects ranged from 0.004 to 0.008 across applications, implicating small moderating effects (Hair et al., 2017).

Hypotheses		GM yeast				GM soybean				GM pig			
		β	t values	f^2	95% CI	β	t values	f^2	95% CI	β	t values	f^2	95% CI
H1a	PB -> AA	0.428***	13.889	0.207	[0.376, 0.476]	0.414***	13.411	0.219	[0.353, 0.473]	0.384***	14.566	0.205	[0.333, 0.436]
H1b	PR -> PB	-0.101**	3.147	0.010	[-0.151, -0.047]	-0.102**	3.122	0.010	[-0.167, -0.039]	-0.134***	3.917	0.014	[-0.202, -0.067]
H1c	PR -> AA	-0.139***	4.601	0.022	[-0.190, -0.091]	-0.075**	2.693	0.007	[-0.131, -0.020]	-0.113***	4.025	0.014	[-0.169, -0.059]
H2a	PU -> PB	-0.054*	2.078	0.004	[-0.097, -0.013]	**0.047**^{ns}	1.640	0.003	[-0.010, 0.102]	**0.026**^{ns}	0.883	0.001	[-0.034, 0.083]
H2b	PU -> AA	**0.015**^{ns}	0.587	0.000	[-0.028, 0.057]	-0.067*	2.586	0.007	[-0.118, -0.016]	-0.100***	3.815	0.014	[-0.151, -0.049]
H2c	PU -> PR	0.358***	15.112	0.198	[0.318, 0.396]	0.32***	13.386	0.152	[0.273, 0.365]	0.378***	16.177	0.227	[0.332, 0.422]
H3a	PTN -> PB	**0.047**^{ns}	1.727	0.003	[-0.007, 0.098]	**0.012**^{ns}	0.400	0.000	[-0.044, 0.069]	**-0.010**^{ns}	0.352	0.000	[-0.066, 0.044]
H3b	PTN -> AA	**0.019**^{ns}	0.706	0.001	[-0.026, 0.063]	**-0.023**^{ns}	0.892	0.001	[-0.072, 0.028]	**-0.034**^{ns}	1.356	0.002	[-0.083, 0.015]
H3c	PTN -> PR	0.343***	14.337	0.182	[0.303, 0.381]	0.332***	13.106	0.161	[0.281, 0.380]	0.349***	15.280	0.205	[0.304, 0.393]
H3d	PTN -> PU	0.382***	14.023	0.171	[0.337, 0.425]	0.416***	15.448	0.204	[0.361, 0.467]	0.393***	14.612	0.194	[0.337, 0.444]
H4a	Affect -> PB	0.384***	14.552	0.224	[0.34, 0.427]	0.428***	16.237	0.251	[0.376, 0.478]	0.453***	17.228	0.247	[0.398, 0.500]
H4b	Affect -> AA	0.127***	4.585	0.023	[0.082, 0.173]	0.158***	5.701	0.035	[0.103, 0.214]	0.260***	9.688	0.091	[0.208, 0.314]
H4c	Affect -> PU	-0.092**	2.996	0.009	[-0.142, -0.042]	-0.131***	4.273	0.018	[-0.189, -0.069]	-0.263***	8.887	0.076	[-0.322, -0.205]
H4d	Affect -> PTN	-0.149***	4.488	0.020	[-0.207, -0.096]	-0.235***	7.640	0.051	[-0.295, -0.175]	-0.353***	12.075	0.121	[-0.412, -0.297]
H4e	Affect -> PR	-0.160***	6.487	0.040	[-0.200, -0.120]	-0.186***	6.973	0.052	[-0.236, -0.133]	-0.180***	6.690	0.053	[-0.234, -0.129]
H5a	PA -> Affect	0.434***	16.915	0.232	[0.391, 0.474]	0.449***	17.432	0.252	[0.395, 0.495]	0.405***	15.605	0.196	[0.353, 0.455]
H5b	PA -> PB	0.388***	15.099	0.229	[0.345, 0.430]	0.347***	13.316	0.175	[0.294, 0.397]	0.257***	10.509	0.099	[0.209, 0.305]
H5c	PA -> AA	0.245***	8.667	0.084	[0.199, 0.292]	0.247***	9.541	0.097	[0.195, 0.297]	0.114***	5.072	0.025	[0.071, 0.160]
H5d	PA -> PU	-0.127***	4.234	0.016	[-0.176, -0.077]	-0.082**	2.673	0.007	[-0.144, -0.023]	**-0.046**^{ns}	1.743	0.003	[-0.099, 0.005]
H5e	PA -> PTN	-0.207***	6.445	0.038	[-0.258, -0.153]	-0.182***	5.851	0.030	[-0.241, -0.118]	**-0.054**^{ns}	1.777	0.003	[-0.114, 0.006]

H5f	PA -> PR	-0.104***	3.913	0.017	[-0.147, -0.06]	-0.124***	5.040	0.024	[-0.174, -0.076]	-0.072**	3.201	0.010	[-0.116, -0.029]

Table 5. 5: Estimation results of the model across GM applications

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; β = path coefficients; 95% CI = 95% confidence interval; ns = non-significance; PA = prior attitudes towards GM food; PB = perceived benefit; PR = perceived risk; PU = perceived unnaturalness; PTN = perceptions of tampering with nature; AA = acceptance of the application. The β in bold and underlined refers to the rejection of corresponding hypothesis.

Hypotheses	**GM yeast**		**GM soybean**		**GM pig**	
	β	f^2	**β**	f^2	**β**	f^2
PA -> AA	0.239***	0.080	0.242***	0.093	0.114***	0.025
PA&PB -> AA	**-0.007**^{ns}	0.000	**-0.018**^{ns}	0.001	**0.035**^{ns}	0.003
PA&PR -> AA	0.054**	0.008	0.045**	0.006	0.040*	0.004

Table 5. 6: Moderating effects of prior attitudes

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; β = path coefficients; 95%; ns = non-significance; PA = prior attitudes towards GM food; PB = perceived benefit; PR = perceived risk; PU = perceived unnaturalness; AA = acceptance of the application; PA&PR = interaction term between PR and PA; and PA&PB = interaction term between PB and PA. The β in bold and underlined refers to the rejection of corresponding hypothesis.

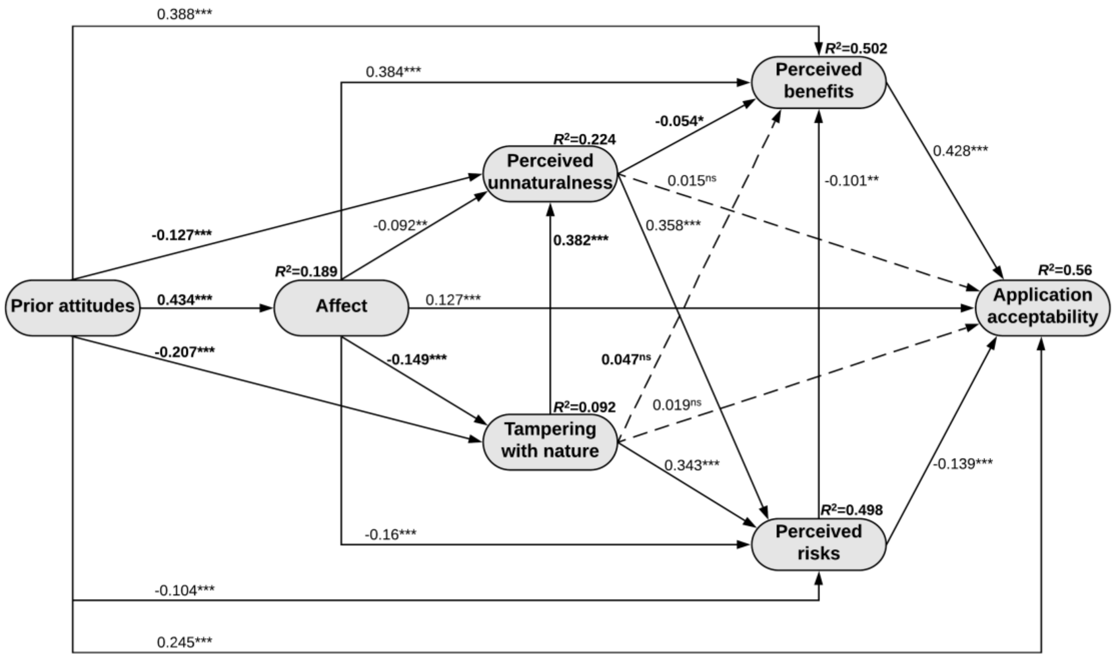

Figure 5. 2: Framework of attitude formation towards the GM yeast

Note: **p* < 0.05; ***p* < 0.01; ****p* < 0.001; ns = non-significance. The direction of the relationship is specified in parentheses.

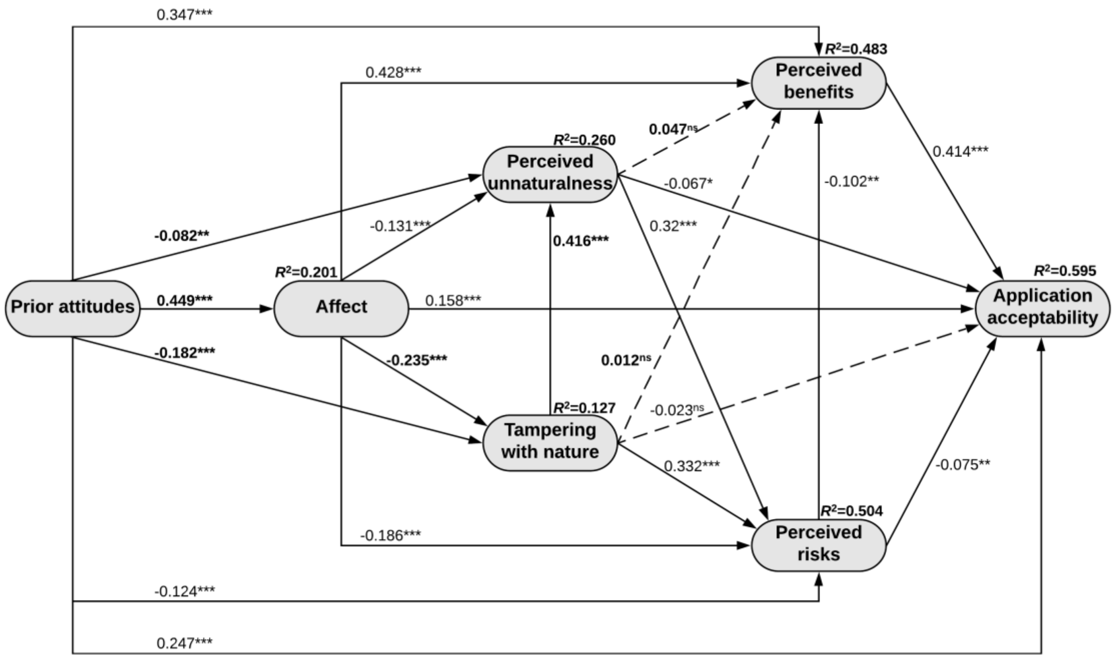

Figure 5. 3: Framework of attitude formation towards the GM soybean

Note: **p* < 0.05; ***p* < 0.01; ****p* < 0.001; ns = non-significance. The direction of the relationship is specified in parentheses.

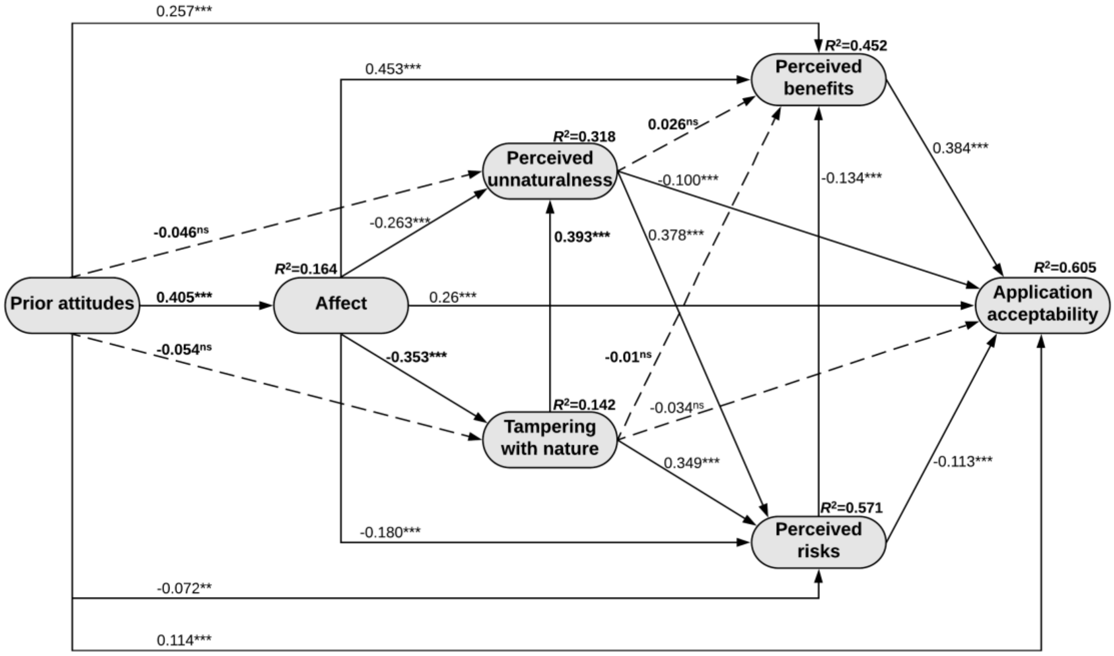

Figure 5. 4: Framework of attitude formation towards the GM pig

Note: $*p < 0.05$; $**p < 0.01$; $***p < 0.001$; ns = non-significance. The direction of the relationship is specified in parentheses.

5.4.3 Determinants of acceptability

The estimated models provided a moderate level of explanation for respondents' acceptance of GM food applications, with the R^2 values for the acceptability ranging from 0.560 to 0.605 (Appendix C, Table F). Cohen (2013) argued for effect size f^2 to indicate the effect of an exogenous construct on an endogenous construct, where the values of 0.02, 0.15 and 0.35 represent a small, medium or large effect size. This complemented the significance testing of correlations, further showing the strength of the relationship between two constructs. According to the effect sizes f^2 in Table 5.5, the perceived benefit had the strongest power in determining the acceptability, with medium effects (f^2 of the relationship ranging from 0.205 to 0.219). Both prior attitudes (f^2 ranging from 0.025 to 0.097) and affect (f^2 ranging from 0.023 to 0.091) had small effects on the acceptability of GM food applications. Prior attitudes played a more important role in the GM yeast and the GM soybean, while affect was more important for the GM pig. Table 5.5 shows that respondents' perceived risk exerts a very small effect on the acceptance of the GM yeast ($f^2 = 0.022$), and an almost negligible impact on the acceptance of the GM soybean ($f^2 = 0.007$) and the GM pig ($f^2 = 0.014$). Whilst there was a significant correlation for the GM soybean and the GM pig, the effect of perceived unnaturalness on application acceptance was very limited, given that all the f^2 values were smaller than 0.02. Perceptions of tampering with nature showed no significant effects on the acceptability of GM applications, given that all the p values were larger than 0.05.

Prior attitudes toward GM food had moderate positive effects on the affect invoked by the applications (f^2 ranging from 0.196 to 0.252). The two factors had the strongest power in determining the perceived benefit of these applications, which both showed positive impacts for the GM yeast (f^2 = 0.229 and 0.224, respectively) and GM soybean (f^2 = 0.175 and 0.251, respectively). Whilst the impact of affect on perceived benefit showed little change (f^2 = 0.247) for the GM pig, the effect of prior attitudes was small (f^2 = 0.099). Respondents' perceived risk had a negative effect on the perceived benefits of GM applications, despite the limited strength of the relationship (f^2 ranging from 0.01 to 0.014). Perceived unnaturalness (f^2 ranging from 0.001 to 0.004) and tampering with nature (f^2 ranging from 0 to 0.003) showed negligible or even no effects on the perceived benefits of GM applications. Perceptions of tampering with nature and unnaturalness had the strongest power in shaping risk perceptions, both exerting moderate positive effects. Affect showed a small negative effect on respondents' risk perceptions of different applications (f^2 ranging from 0.04 to 0.053). The negative impact of prior attitudes on respondents' perceived risk was small or sometimes even negligible (f^2 ranging from 0.01 to 0.024).

Associating GM applications with tampering with nature led to higher levels of the perceived unnaturalness of food products based on these applications, with a moderate effect being identified (f^2 ranging from 0.171 to 0.204). For the GM yeast, the GM soybean and the GM pig, f^2 values of the effects of prior attitudes on perceptions of tampering with nature were 0.038, 0.03, and 0.003, whilst those on perceived unnaturalness were 0.016, 0.007, and 0.003. The f^2 values of effects of affect on tampering with nature were 0.02, 0.051, and 0.121, whilst those on perceived unnaturalness were 0.009, 0.018, and 0.076. Prior attitudes and affect both had larger effects on perceptions of tampering with nature than on perceived unnaturalness across all applications. The smallest impact of prior attitudes and the largest impacts of affect on perceptions of tampering with nature and the perceived unnaturalness were observed for the GM pig. Prior attitudes had moderate positive effects on respondents' affect evoked by information about different GM food applications.

5.5 Discussion

The results of this study have demonstrated that, among a quota sample of the Chinese population, there are, overall, slightly positive attitudes towards GM food in general. There was no significant gender difference in both general and product-specific attitudes, which is consistent with previous research that has generally found gender does not determine Chinese people's overall attitudes towards GM food (Cui & Shoemaker, 2018; William Lin et al., 2006a; Zhang et al., 2010). While previous research has indicated that women are more likely to reject GM food than men in other cultural contexts such as Germany, Switzerland and Sweden (Christoph et al., 2008; Connor & Siegrist, 2010; Magnusson & Hursti, 2002), these gender differences may disappear when tangible benefits of GM food are presented to respondents (Frewer et al., 1996).

Bredahl (2001) and Connor & Siegrist (2010) found that people's strong reliance on prior attitudes towards GM food in forming product-specific attitudes (i.e. "top-down" attitude formation towards specific GM products) is independent of the application attributes. The results presented here suggest that prior attitudes towards GM food still play an important role in respondents' product-specific attitudes, and that more negative prior attitudes lead respondents to a higher dependence on risk perceptions in decision-making. Using attitudes towards GM food in general to inform decision-making about accepting or rejecting specific GM food applications may result in a systemic cognitive bias, which may subsequently reduce attitude change following communication about application attributes for people with negative prior attitudes (Haselton, Nettle, & Andrews, 2015). Nonetheless, significant differences in respondents' acceptance levels of GM food applications were identified, with the GM plant (i.e. the GM soybean) being the most and the GM animal (i.e. the GM pig) being the least acceptable (see also Frewer et al., 2013). Previous research also reported that stating the benefits of GM food, price discounts and increased production, results in people's increased negative responses (Hess et al., 2016; Mucci & Hough, 2004). In contrast, our respondents' association with the increased productivity and reduced prices of the selected applications was associated with positive affect. This can potentially be attributed to the recent increased prices of foods, especially non-GM pork, where the consumer price doubled in late 2019 in China (Haley & Gale, 2020). These findings imply a growing attitude formation towards different GM foods based on product characteristics among Chinese people, as well as the importance of considering contexts (e.g. application traits, social-cultural and economic attributes) when assessing public attitudes. Furthermore, developing products that have traits consistent with the public preferences may increase the acceptability of these products (Jin et al., 2019).

Here, prior attitudes and affect had a greater impact on benefit perceptions than on risk perceptions of GM food applications. This demonstrates that, despite the potential for analytical and experiential thinking to operate in parallel (Alhakami & Slovic, 1994), the perceived benefit of GM food applications may be more dependent on experiential thinking (e.g. affective/heuristic information processing and personal experience) compared to perceived risk (Fischer & Frewer, 2009). Attempting to increase the process and product acceptance by communicating the benefits alone is unlikely to represent an effective marketing strategy in the case of GM foods. This resonates with previous research in China, where Zhu and Xie (2015) found that provision of benefit information about GM food does not lead to attitudinal change, whilst provision of risk information decreases the acceptability. Reaction to benefit communication has also been shown to vary in different cultural contexts (Lusk et al., 2004). Given that food safety communication is predicated on a balanced presentation of benefits and risks, it is important to understand people’s preferred types of benefit as well as their ethical concerns and risk perceptions, how these arise in specific cultural contexts, and address these in targeted communication development. At the same time, the potential risks, and the mechanisms for risk mitigation and control, should be communicated to the public in a transparent manner (Frewer, Miles, Brennan, et al., 2002).

In general, research investigating whether risk or benefit plays a more important part in attitude formation towards novel food technologies has obtained mixed results (Amin et al., 2014; Bredahl, 2001; Chen & Li, 2007; Connor & Siegrist, 2010; Zhu & Xie, 2015). Here, the perceived benefit was found to be more influential than the perceived risk in determining the public acceptance of GM food applications. For example, while the respondents had a higher level of perceived risk than the perceived benefit associated with the GM pig (Table 5.3), the perceived benefit better predicted acceptability than the perceived risk (Table 5.5). It is possible, as Frewer (2003) has argued, that as long as the perceived risk is not beyond one’s tolerance, the perceived benefit will always play a more important role in shaping acceptance of food technology and its applications.

Previous research has also demonstrated a strong inverse correlation between risk and benefit perceptions of GM food in general (Costa-Font & Mossialos, 2007; Costa-Font & Gil, 2009; Poortinga & Pidgeon, 2005). However, controlling for people's general affective evaluation of GM food may render the relationship nonsignificant (Poortinga & Pidgeon, 2005). In our study, which focused on specific applications, factoring in prior attitudes towards GM food and affect evoked by three selected applications also substantially reduced the strength of the inverse correlation between risk and benefit perceptions[5]. Despite this remaining limited strength, the correlations were still significant for the selected applications. This suggests that prior attitudes towards GM food and affect evoked by specific applications greatly contribute to the inverse relationship. Hence, interventions to increase benefit perceptions and reduce risk perceptions of GM food products through building more positive prior attitudes and/or invoking more positive product-specific affect could be an effective strategy.

The respondents in the present study associated animal-based applications with the highest levels of tampering with nature and perceived unnaturalness of its food products. These two factors were also the strongest predictors of the perceived risks of the selected GM applications. However, the influence of these factors on the perceived benefit and acceptance of GM applications was limited, which differed to the findings of some previous studies (Hudson, Caplanova, & Novak, 2015; Subrahmanyan & Cheng, 2000; Tenbült, De Vries, Dreezens, & Martijn, 2005). Hoogendoorn, Sütterlin, and Siegrist (2020) suggested that perceiving a technology to be both tampering with nature and unnatural represents a consequence of human intervention, whilst tampering with nature, in addition, is linked to a negative attitude towards this intervention. However, the present study showed that when the respondents associated GM food applications with tampering with nature, this had no direct effect on acceptability, and that their perceptions of unnaturalness negatively affected their acceptance of the GM soybean and the GM pig. Hence, negative attitudes toward human intervention tend to exist in people's assessment of a food's unnaturalness rather than whether it is

[5] After factoring in prior attitudes and affect, β of risk perceptions on benefit perceptions reduced from -0.335 to -0.101 for GM yeast, from -0.367 to -0.102 for GM soybean, and from -0.358 to -0.134 for the GM pig, accounting for 70%, 72% and 63% of the inverse relationship, respectively.

considered to be tampering with nature *per se*, although perceptions that an application tampers with nature predicts greater perceived unnaturalness.

5.5.1 Implications for communications

The current study has provided a few insights that could be utilised to develop more effective communications. First, as well as people's risk and benefit perceptions, respondents' affective responses to specific applications need to be considered when developing GM products and relevant communications. For example, the product traits connected to positive and negative affect should preferably be incorporated and avoided in product development, respectively. Subsequently, information about the presence of desired traits and the absence of undesired traits needs to be included in relevant communications. Second, communication about GM food may in itself evoke affective responses, which have a direct impact on acceptance via the heuristic processing route. This may depend on how risks and benefits are presented in communications. Third, affective responses to information may be culturally and contextually dependent. For example, reference to increased productivity and reduced prices of GM food applications may evoke positive affect among Chinese consumers, but induce negative attitudes among consumers in Argentina (Mucci & Hough, 2004). This calls for more research considering, for example, social-cultural and -economic attributes when assessing public responses to GM foods so as to accommodate contextual variations in communication design. Finally, it should be considered that prior attitudes which have already formed towards GM food influence application acceptability and may result in a systemic cognitive bias, when developing communication about GM foods.

5.5.2 Study limitations

The respondent sample only included Tier 1 and two Tier 2 Chinese cities, which restricts the extent to which the findings can represent the whole population. In addition, associations identified in the survey should not be treated as cause-and-effect relationships. Other methods (e.g. experiments) can be used to more systematically investigate people's attitudes, decisions and behaviours, which will further contribute to the development of risk communications aimed at influencing individuals to form more evidence-based responses concerning GM applications.

5.6 Conclusion

In summary, this study contributes to the understanding of Chinese consumers' responses to GM food in several ways. First, perceived benefits are a major factor shaping people's GM product-specific acceptance, and perceived risk is not as influential as previous studies have suggested. Second, prior attitudes towards GM food and affective responses to specific applications have a greater influence on application acceptability than risk perceptions. People with negative prior attitudes may have more biased judgements of risks of, and attitudes towards, plant- and microbe-based applications compared to animal-based applications. Finally, preferences for, and concerns about, application traits are likely to vary cross-culturally. While these differences should be addressed in future product development and in the design of related risk communications, implications for global governance, regulation and food security policies need also to be considered, as universally acceptable development and implementation may be problematic.

Chapter 6. Public perceptions of SB applied within the agri-food sector: evidence for policy development

6.1 Introduction

SB is a multidisciplinary area of research that applies engineering principles to create new biomolecular components, networks and pathways, and uses these "bio-bricks" to "reprogram" organisms (Khalil & Collins, 2010). It has enabled the creation of a variety of applications at different development and commercialisation stages, which are anticipated to offer new and cost-effective ways of disease treatment, drug and clean energy production, waste recycling, and environment enhancement, among many others (Polizzi et al., 2018). SB innovations are being applied within agricultural and food production systems in relation to improved food security (e.g. to produce novel functional foods, create new crop variants, and improve livestock traits) (Bhat et al., 2017; Rogers & Oldroyd, 2014). As for all novel technologies, regulators and policy makers need to consider potential risks to human and environmental health, as well as benefits and ethical concerns associated with the technology (König et al., 2010). As part of these processes, it is useful to consider how SB food applications are *perceived* by different stakeholders, including by the general public, which can align the product development with social interest and help gain commercial success. Within this policy framework, it is also important to consider any ethical issues which may arise, including those perceived to be relevant by the public.

The early investigation and consideration of public responses in relation to concerns about emerging technologies is particularly important. This is because a failure to understand such concerns might lead to societal rejection of the technology and its applications, and to the *post hoc* production of complex and potentially unstable regulations and policies (Mehta, 2004). A closely related and often-cited example is GM food, where research into Europeans' reactions to GM foods primarily occurred subsequent to societal rejection. Indeed, as a result of the social amplification of the risk associated with particular GM foods, European attitudes crystallised and, thereafter, became less likely to be influenced by the availability of new information (Frewer, Miles, & Marsh, 2002). Such reactive policy development has been criticised on the basis that, although the public have been consulted in relation to technology development, consultation practices have been inadequate, particularly in Europe where they have been analysed extensively in relation to GM foods (Ahteensuu & Siipi, 2009). The same effect has been reported in other countries such as China, where the central government pledged more support for GM-related research in the agricultural sector in 2010 without investigation of the potential public responses (The Chinese Central Government, 2009). Subsequent negative media portrayals of GM food dramatically increased, resulting in online anti-GM food campaigns (Wang, 2015). Another limitation associated with the design of previous research into public perceptions was the dominant focus on GM food in general or on broad classifications of its applications, such as GM plants and GM animals, rather than more specifically introducing, for example, the endowed new functions or end products of certain applications. This limitation might impede the identification of public preferences for, or resistance to, certain application traits as well as the determinants of these attitudes (Frewer et al., 2013).

In the case of SB, it is possible that the public may express similar concerns to those associated with GM as both technological innovations involve deliberate changes to organisms at the genetic level (Steurer, 2015). The available evidence suggests that societal acceptance and rejection of SB might be linked to broad areas of application. For example, applications in energy and health may be more acceptable compared to those within the area of food production (Betten et al., 2018; Pauwels, 2013; Steurer, 2015). However, there is limited research into public responses to SB, particularly in relation to application within the agri-food sector and to specific food applications. Hence, this research investigates public perceptions of, and attitudes towards, three specific applications of SB under development within agri-food production system: SB yeast for producing milk proteins (Watson, 2020), drought-resistant SB soybean (Yang, Cushman, Borland, & Liu, 2020), and an SB pig with an improved immune function (Xu et al., 2020). The focus of the research is in China, where there is considerable research into developing SB applications in the agri-food sector and where there is a considerable end-user market for their future potential commercialisation (Jin et al., 2021). To the author’s knowledge, this is the first study to attempt to evaluate Chinese public perceptions of, and attitudes towards, SB food applications. Such a prospective analysis of Chinese public responses to SB within the agri-food sector has the potential to benefit future product development and policy making, thus avoiding the commercialisation, regulatory and policy problems associated with GM food that occurred late in their innovation trajectories. Understanding people's concerns at an early stage will also contribute to the development of effective risk-benefit communication, as the results of this research can inform that design of messages that align to people's fears, concerns, priorities and preferences for development (Frewer et al., 2016).

6.2 Theoretical background

In accordance with the existing literature on consumer responses to emerging food technologies, we developed a total of 21 hypotheses (Table 6.1). These hypotheses informed the development of a framework explaining attitude formation towards SB agri-food applications (Figure 6.1). The related literature and relevant knowledge gaps are discussed in sections 6.2.1 – 6.2.3 below.

6.2.1 Affect and risk and benefit perceptions

Affect, a person's positive or negative feelings about specific objects, ideas or images, can be employed as a mental "shortcut" in human judgement (Epstein, 1994; Slovic et al., 2004). It has been reported to have a strong impact on people's evaluation of risks and benefits associated with (potentially) controversial food technologies as well as consumer acceptance of the products of these technologies (Siegrist et al., 2007). There is evidence that both risk and benefit perceptions influence public acceptance of applications of novel food technologies, although benefit perceptions tend to be more dependent on experiential thinking compared to risk perceptions (Fischer & Frewer, 2009; Siegrist et al., 2007). Some researchers report an inverse relation between risk and benefit perceptions (Finucane, Alhakami, et al., 2000), which has been attributed to people's use of affective reactions to the stimulus item used to elicit risk and benefit evaluations. This inverse relationship can strengthen when an individual's reliance on affect as a heurisitc is enhanced, for example, when under time-pressure (Finucane, Alhakami, et al., 2000). Poortinga and Pidgeon (2005) reported that controlling for people's general affective evaluation of GM food substantially reduces the inverse relationship between risk and benefit perceptions, sometimes rendering it nonsignificant. As such, hypotheses about the relationships between affect, risk perceptions and benefit perceptions were assumed (see H1a-c, 4a, 4b and 4e in Table 6.1).

6.2.2 General attitudes towards SB food

An attitude can be defined as "*a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour*" (Eagly & Chaiken, 1993, p. 1). From this, general attitudes towards a food technology represent an individual's overall tendency to approve or disapprove of the application of a given food technology, which can affect their interpretation of the available information about the technology and specific applications. This, in turn, may influence an individual's affective responses, risk and benefit perceptions, and final acceptance (Bredahl, 2001; Jin et al., submitted). At present, the public are still unfamiliar with SB as an emerging area of research, and thus may "make sense" of SB applied to food production using GM as a "comparator" technology (Kronberger et al., 2012). Steurer (2015) reported that some people could regard SB as a technological "upgrade" of GM, with potential to raise more negative attitudes towards its application within the agri-food sector. In other words, an individual's prior attitudes towards GM food could potentially inform their general attitudes towards SB food and the acceptance of specific SB food applications. However, these studies had relatively small sample sizes, thereby limiting the generalisability (Kronberger et al., 2012; Steurer, 2015). Hence, further research is needed on the extent to which (i) prior attitudes towards GM food affect people's attitudes towards SB applied to food production in general and towards specific SB food applications, and (ii) attitudes towards SB food applications are derived from the attitudes towards novel food technologies in general. Therefore, relationships between prior attitudes towards GM food, general attitudes towards SB food, and applications acceptance, (see H5c, 6a, and 6b in Table 6.1), as well as those between general attitudes towards SB food and affect, risk perceptions and benefit perceptions were assumed (see H5a, 5b, and 5f in Table 6.1).

6.2.3 ***Perceptions of tampering with nature and perceived unnaturalness***

A technology considered to be "tampering with nature" could be related to perceived deliberate human intervention in nature as well as the resulting moral and ethical concerns. In turn, it might increase an individual's perceived "unnaturalness" and risk perceptions associated with this technology and its applications (Mielby et al., 2013; Rozin et al., 2012; Sjöberg, 2000). SB food was also considered to be tampering with nature or unnatural in some research (Betten et al., 2018). Dragojlovic and Einsiedel (2013) reported that the perceived unnaturalness of a SB food application could negatively affect associated benefit perceptions and acceptability of the application, in particular among those who view nature as sacred or spiritual, and under circumstances in which the selected application had a larger evolutionary distance between gene donor and host organisms. In addition, perceiving a GM food application to be tampering with nature or unnatural was found to be informed by one's prior attitudes towards GM food and their *ad hoc* affect evoked by the application (Jin et al., submitted). As such, the relationships between tampering with nature and unnaturalness (H3b), and their relationships with general attitudes towards SB food (H5d and 5e), affect (H4c and 4d), benefit perceptions (H2a), risk perceptions (H2c and 3a), and acceptability (H2b) were assumed (see Table 6.1).

No.	Hypotheses	Evidence
H1a	The perceived benefit associated with a SB food application has a positive effect on the acceptability of that application.	
H1b	The perceived risk associated with a SB food application has a negative effect on the perceived benefit of that application.	**Section 2.1**
H1c	The perceived risk associated with a SB food application has a negative effect on the acceptability of that application.	
H2a	The perceived unnaturalness of a SB food application has a negative effect on the perceived benefit of that application.	
H2b	The perceived unnaturalness of a SB food application has a negative effect on the acceptability of that application.	**Section 2.3**
H2c	The perceived unnaturalness of a SB food application has a positive effect on the perceived risk of that application.	
H3a	Perceiving a SB food application to be tampering with nature has a positive effect on the perceived risk of that application.	**Section 2.3**
H3b	Perceiving a SB food application to be tampering with nature has a positive effect on the perceived unnaturalness of that application.	
H4a	Positive affect evoked by a SB food application increases the perceived benefit of that application.	
H4b	Positive affect evoked by a SB food application increases the acceptability of that application.	
H4c	Positive affect evoked by a SB food application reduces the perceived unnaturalness of that application.	**Section 2.1 & 2.3**
H4d	Positive affect evoked by a SB food application reduces the perception that this application tampers with nature.	
H4e	Positive affect evoked by a SB food application reduces the perceived risk of that application.	
H5a	A positive general attitude towards SB food results in a positive effect on their affect evoked by a SB food application.	
H5b	A positive general attitude towards SB food results in a positive effect on the perceived benefit of a SB food application.	
H5c	A positive general attitude towards SB food results in a positive effect on the acceptability of a specific SB food application.	**Section 2.2 & 2.3**
H5d	A positive general attitude towards SB food results in a negative effect on the perceived unnaturalness of a SB food application.	
H5e	A positive general attitude towards SB food results in a negative effect on perceiving a SB food application to be tampering with nature.	
H5f	A positive general attitude towards SB food results in a negative effect on the perceived risk of a SB food application.	
H6a	A positive prior attitude towards GM food has a positive effect on the general attitude towards SB food.	**Section 2.2**
H6b	A positive prior attitude towards GM food has a positive effect on the acceptability of a SB food application.	

Table 6. 1: Research hypotheses

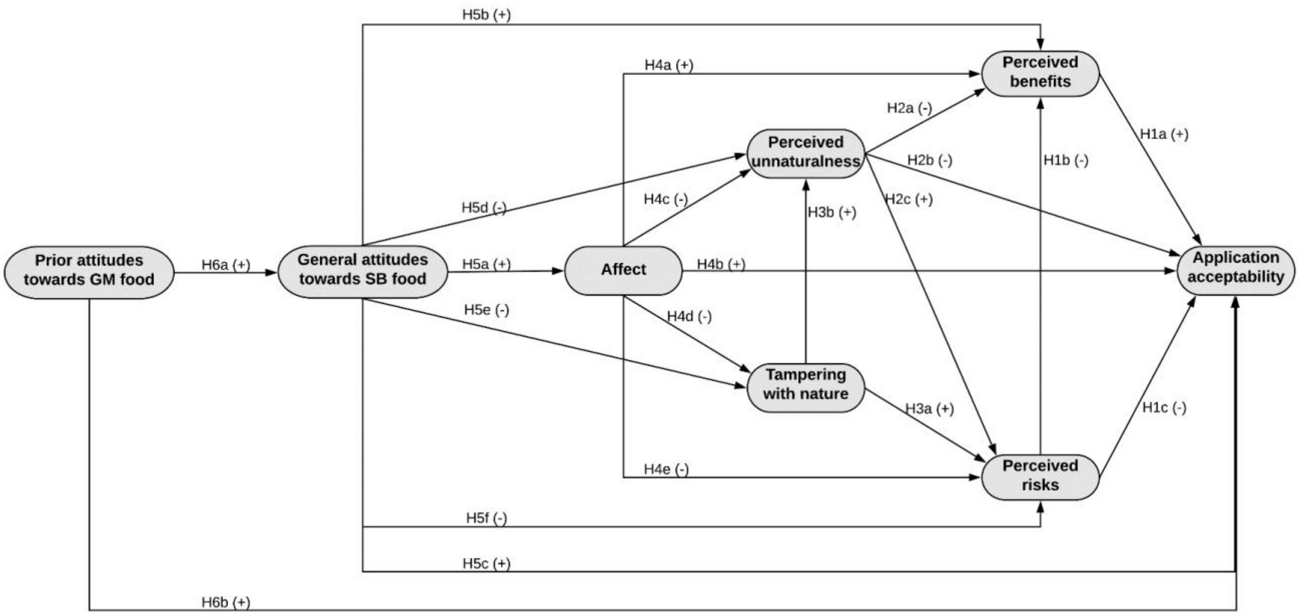

Figure 6. 1: Framework of attitude formation towards SB agri-food applications

6.3 Methodology

6.3.1 Questionnaire design

To address the research objectives, a questionnaire was developed to gather the required data. The design of the questionnaire was informed by the existing research into consumer attitudes towards GM food (Costa-Font & Gil, 2009; Dunlap, Van Liere, Mertig, & Jones, 2000; Frewer, Scholderer, et al., 2003; Poortinga & Pidgeon, 2005; Schnettler et al., 2017; Siegrist, 2000), as well as by focus group discussions conducted in Nanjing and Shenzhen (*n* = 32, three groups for each city). These focus groups were conducted to elicit Chinese people's habitual expressions regarding their opinions on SB (see Chapter 4). The questionnaire was designed to obtain data on the following constructs: prior attitudes towards GM food; general attitudes towards SB food; affect, risk perceptions, benefit perceptions and acceptance associated with evoked by the selected applications; food technology neophobia; and moralistic and dominionistic environmental worldviews (see Appendix D, Table A). All the constructs were measured by asking respondents to indicate the extent of their agreement or disagreement with different statements on five-point Likert scales (1 = "strongly disagree" to 5 = "strongly agree") except for affect. To elicit respondents' affective responses to these applications, respondents received introductory information about each application (see Appendix D, Table A), and were asked "*What is the first thought or image that comes to your mind after you read information about this application?*". Subsequently, they were asked to rate their levels of positive or negative affect associated with this first thought or image, based on seven-point scales (1 = "extremely negative" to 7 = "extremely positive"). The technique for eliciting affective responses has been used in previous research (Leiserowitz, 2006; Siegrist et al., 2007). Demographic information was also collected including gender, location, occupation, educational level and personal monthly income.

6.3.2 Sampling and Distribution

Ethical approval for this study was granted by the lead researcher's university in July 2019 (Ref: 13967/2018). The questionnaire was developed in English and then translated into Chinese. A pilot study was conducted using 130 respondents in China and a revised questionnaire was developed with minor refinements. The questionnaire was distributed online in two Tier 1 (Shenzhen and Beijing) and two Tier 2 (Nanjing and Wuhan) Chinese cities by a survey company (Beijing Jishuyun Technology Co., Ltd)[6]. Quota sampling based on gender, educational level and age distributions was informed by the Sixth National Population Census (National Bureau of Statistics of China, 2010). The questionnaire was administered online to 1,500 respondents in October 2020, of which 1,330 responses remained after removing incomplete responses. The mean age of respondents was 35 (*SD* = 11), and 48% of the respondents were female. The socio-demographic attributes of survey respondents are shown in Table 6.2.

Characteristics		**Number**	**Frequency**
Gender	Male	692	52%
	Female	638	48%
Age	18-24	267	20%
	25-34	412	31%
	35-44	319	24%
	45-54	260	20%
	>54	72	5%
City	Shenzhen	401	30%
	Beijing	303	23%
	Nanjing	359	27%

[6] Shenzhen and Beijing are Tier 1 cities, representing the most economically developed regions in China. Nanjing and Wuhan are capital cities at the provincial level and are Tier 2 cities that are fast developing.

	Wuhan	267	20%
Occupation	Company employee	889	67%
	Government employee	77	6%
	Self-employed	182	14%
	Student	82	6%
	Others	100	7%
Highest Level of Educational Attainment	Secondary school or below	175	13%
	2-3 years of College	380	29%
	Undergraduate or above	775	58%
Personal monthly income (CNY)	<3,000	73	6%
	3,000-4,999	110	8%
	5,000–6,999	300	23%
	7,000–9,999	404	30%
	>10,000	443	33%

Table 6. 2: Sample characteristics

6.3.3 Data analysis procedure

Descriptive analyses were initially conducted to get an overall picture of respondent responses to different SB food applications. The thoughts or images evoked by three SB applications that connected to different levels of affect were categorised into different themes by the lead author. Subsequently, a comparative analysis of the participants' responses to SB and its different applications were conducted. The Mann–Whitney *U* test and the Kruskal-Wallis test were used to compare respondent responses across gender and educational level, respectively. The paired sample t-test was used to compare respondents' attitudes towards GM food and SB food, and one-way ANOVA with repeated measures was used to compare respondents' acceptance of the three SB food applications. Finally, partial least squares-structural equation modelling (PLS-SEM) was employed to estimate the proposed framework. Data analysis was conducted using IBM SPSS Statistics Version 24 and SmartPLS3 (Ringle et al., 2015).

To ensure the reliability and validity of the measurement models, different criteria were used: Cronbach's alpha $\alpha > 0.7$ and composite reliability $\rho > 0.7$; values of average variance extracted (AVE) > 0.5; and an indicator's outer loadings on a construct being higher than its outer loadings with other constructs, the application of Fornell-Larcker Criterion (the square root of the AVE of each construct being higher than its highest correlation with any other construct), and the heterotrait-monotrait ratio (HTMT) < 0.9

(Hair et al., 2017). The structural model was evaluated by testing the collinearity between constructs, the significance and relevance of model relationships, coefficients of determination (R^2), an exogenous construct's contribution to an endogenous latent variable's R^2 value using the effect size f^2, and the predictive relevance (Stone-Geisser's Q^2) (Hair et al., 2017; Rigdon, 2012; Stone, 1974). A standardised root mean square residual (SRMR) being smaller than 0.08 was selected as a conservative criterion for ensuring the model fit for PLS-SEM (Henseler et al., 2014; L. T. Hu & Bentler, 1998). Individuals' food technology neophobia, moralistic and dominionistic environmental worldviews were added into the model as control variables in the relationships between prior attitudes towards GM food, general attitudes towards SB applied to food production, and application acceptance to assess the robustness of the impacts of prior attitudes towards GM food.

6.4 Results

6.4.1 Responses to SB and GM food

The results showed that the respondents had slightly positive attitudes towards GM food ($M = 3.13$, $SD = 0.83$) and towards SB food ($M = 3.27$, $SD = 0.81$). Attitudes towards SB food were significantly more positive according to the results of a paired sample t-test ($t = 6.59$, $p < 0.001$). In terms of different SB food applications, the SB soybean ($M = 3.41$, $SD = 0.87$) was associated with the highest level of acceptance, followed by the SB yeast ($M = 3.18$ $SD = 0.89$), and the SB pig ($M = 2.94$, $SD = 1.00$) was the least accepted, as was the case for all the GM applications (see Table 6.3). Given that the standardised residues of acceptance levels of SB food applications were approximately normally distributed, a repeated measures ANOVA with a Greenhouse-Geisser correction was conducted. This showed that mean acceptance levels differed significantly between three applications [$F(1.899, 2523.394) = 198.046$, $p < 0.001$]. Post hoc tests using a Bonferroni correction revealed that the acceptance level of the SB soybean was 0.234 higher than that of the SB yeast ($p < 0.001$), 0.472 higher than that of the SB pig ($p < 0.001$), and that the acceptance level of the SB yeast was 0.238 higher than that of the SB pig ($p < 0.001$). There was no significant difference in respondents' general attitudes towards SB food and their acceptance of the three SB food applications across gender and educational level.

The SB soybean evoked the most positive affect and was perceived to have the highest level of benefit and the lowest level of risk, tampering with nature and unnaturalness.

This was also the case for the GM soybean (Table 6.3). Both the SB and GM pigs evoked negative affect and were perceived to have the lowest level of benefit and the highest level of risk, tampering with nature and unnaturalness. However, while the GM yeast for producing vitamins evoked overall positive affect, the SB yeast for producing milk proteins evoked negative affect, to greater extent than the SB pig and the GM pig. This implies that besides the host organisms, other application attributes also play an important role in influencing affect.

6.4.2 Affective thoughts associated with SB applications

The images or thoughts evoked by the SB yeast, the SB soybean and the SB pig were categorised into nine, ten and thirteen themes (Table 6.4a-c), accounting for 91%, 86% and 86% of respondents' responses, respectively. The three most frequently evoked themes associated with the SB yeast were all categorised as evoking negative affect (i.e. the value of affect was smaller than 4), accounting for 52% of the responses. Of all the different themes, only "information seeking" and "the perceived increased productivity and reduced price of dairy products" were connected to positive affect (i.e. the value of affect was larger than 4), which accounted for 5% and 4% of the responses, respectively. The percentage of ethical considerations (13%) evoked by the SB yeast was more than twice that compared to the GM yeast for producing vitamins (5%), despite both using yeast as the host organism (see Jin et al., submitted re: the GM yeast).

In contrast, the four most frequently evoked themes associated with the SB soybean comprised 56% of the responses (see Table 6.4b), which were connected to positive affect. Only three themes (i.e. "the perceived health effect of eating SB soybean-based food", "regarding GM food as a similar kind of product" and "overall rejection of the SB soybean") were associated with negative affect, accounting for 13% of the response. The five most frequently evoked themes associated with the SB pig were all associated with negative affect, except for "the perceived increased productivity and reduced price of SB pork". Respondents' emotional reactions, "fear, worry or hesitation" (5%) and "feeling weird or disgusting" (1%), were associated with the highest magnitude of negative affect.

6.4.3 *Results of PLS-SEM*

All the reliability and validity criteria were met for the measurement models for each of SB food applications (see Appendix D, Table B and C). The values of SRMR were all smaller than 0.08, showing a good model fit across applications (Appendix D, Table D). All the variance inflation factor (VIF) values were smaller than 5, indicating that there were no critical collinearity problems between the assessed constructs (Appendix D, Table E). The model had a satisfactory level for explaining respondents' acceptance of SB food applications, where the R^2 values for acceptance were 0.555 for the SB yeast, 0.542 for the SB soybean, and 0.629 for the SB pig (Falk & Miller, 1992). Stone-Geisser's Q^2 values were larger than 0 (Appendix D, Table F), representing satisfactory predictive relevance (Stone, 1974).

Standardised values of path coefficients β, the respective *t*-values, 95% confidence intervals and f^2 were also obtained (see Table 6.5). Here, the t value > 1.96 (two-tailed tests, significance level = 5%) and p value < 0.05 represent a significant correlation between two variables. As such, Hypothesis 2a was rejected in the model across different SB applications because the results indicated that the perceived unnaturalness of these SB food applications had no direct effect on respondents' perceived benefit. Hypothesis 1b was rejected for the SB soybean because the results indicated that the perceived risk of the SB soybean had no direct effect on respondents' benefit perceptions. Hypothesis 5d was rejected for the SB soybean and SB pig because the results indicated that general attitudes towards SB food had no direct effect on respondents' perceived unnaturalness associated with food products developed using the SB soybean and the SB pig. Hypothesis 5f was also rejected for the SB pig as the results showed that general attitudes towards SB food had no direct impact on respondents' perceived risk of the SB pig. All the other hypotheses were supported.

The key findings of PLS-SEM across the three SB food applications are presented in Table 6.6. In order to better compare the power of different factors that could explain the respondents' perceptions and acceptance of different SB food applications, effect size f^2 was selected as a suitable indicator (Hair et al., 2017), where the values of 0.02, 0.15 and 0.35 represent a small, medium and large effect, respectively (Cohen, 2013).

Constructs	SB yeast		SB soybean		SB pig		GM yeast		GM soybean		GM pig	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Affect	3.53	1.08	4.50	1.20	3.71	1.38	4.15	1.20	4.36	1.29	3.72	1.43
Perceived tampering with nature	3.14	1.11	3.02	1.11	3.26	1.17	3.08	1.16	2.97	1.15	3.34	1.19
Perceived unnaturalness	3.28	1.08	3.15	1.13	3.38	1.14	3.18	1.13	3.09	1.14	3.36	1.18
Perceived benefits	3.27	0.74	3.51	0.72	3.11	0.79	3.23	0.78	3.40	0.77	3.09	0.84
Perceived risks	3.16	0.74	3.03	0.79	3.33	0.81	3.10	0.81	3.06	0.85	3.34	0.84
Acceptability	3.18	0.89	3.41	0.87	2.94	1.00	3.22	0.92	3.31	0.94	2.86	1.04

Table 6. 3: Respondents' acceptance of SB and GM food applications

Note: *SD* = standard deviation. Affect was rated using a seven-point scale ranging from 1 = "extremely negative" to 7 = "extremely positive", and the others using five-point Likert scales (1 = "strongly disagree" to 5 = "strongly agree"). The results of GM food applications were retrieved from (Jin et al., submitted).

No.	Themes	Affect	*SD*	Frequency
1	Perceptions of product safety and quality	3.6	1.0	27%
2	Ethical consideration	3.2	1.0	13%
3	Perceived health effect of drinking the SB yeast-based milk	3.2	0.9	12%
4	Regarding the SB yeast as an advanced technology	3.9	0.9	11%
5	Perceived similar products (e.g. traditional milk, yoghurt and GM food)	3.5	1.0	8%
6	Overall acceptance of the SB yeast	4	1.0	7%
7	Information seeking	4.2	1.1	5%

8	Overall rejection of the SB yeast	2.9	1.2	4%
9	Perceived increased productivity and reduced price of dairy products	4.2	1.1	4%

(a) SB yeast

No.	**Themes**	**Affect**	***SD***	**Frequency**
1	Perceived increased productivity and reduced price of food products using the SB soybean	5.0	1.0	20%
2	Overall acceptance of the SB soybean	4.8	0.9	14%
3	Regarding the SB soybean as an advanced technology	4.9	0.9	12%
4	Perceptions of product safety and quality	4.0	1.2	10%
5	Perceived impacts on the environment	4.8	1.1	6%
6	Perceived health effect of eating SB soybean-based food	3.7	1.3	6%
7	Information seeking	4.3	1.1	6%
8	Perceived drought-resistance of the SB soybean	4.9	1.2	5%
9	Regarding GM food as similar products	3.8	1.0	5%
10	Overall rejection of the SB soybean	3.2	1.3	2%

(b) SB soybean

No.	**Themes**	**Affect**	***SD***	**Frequency**
1	Perceptions of product safety and quality	3.8	1.3	22%
2	Ethical consideration	3.3	1.3	10%
3	Perceived health effect of eating SB pork	3.4	1.4	8%
4	Perceived increased productivity and reduced price of SB pork	4.7	1.2	8%
5	Overall rejection of the SB pig	2.6	1.3	8%

6	Information seeking	3.8	1.3	7%
7	Regarding the SB pig as an advanced technology	4.6	1.0	6%
8	Fear, worry or hesitation	2.6	1.3	5%
9	Overall acceptance of the SB pig	4.5	0.8	5%
10	Perceived health status of the SB pig	5.1	0.8	3%
11	Regarding GM food as similar products	3.4	1.6	2%
12	Feeling weird or disgusting	2.4	0.8	1%
13	Perceived environmental impacts of the SB pig	4.7	0.8	1%

(c) SB pig

Table 6. 4: Affective responses to SB food applications

Note: *SD* = standard deviation; affect was rated using a seven-point scale ranging from 1 = "extremely negative" to 7 = "extremely positive".

Hypotheses		SB yeast				SB soybean				SB pig			
		β	t values	f^2	95% CI	β	t values	f^2	95% CI	β	t values	f^2	95% CI
H1a	PB -> AA	0.407***	14.803	0.238	[0.353, 0.461]	0.379***	12.570	0.190	[0.319, 0.437]	0.343***	12.720	0.162	[0.291, 0.397]
H1b	PR -> PB	-0.137***	4.285	0.017	[-0.200, -0.075]	**<u>-0.034^{ns}</u>**	1.041	0.001	[-0.096, 0.031]	-0.122***	3.853	0.015	[-0.182, -0.060]
H1c	PR -> AA	-0.149***	5.637	0.029	[-0.199, -0.097]	-0.152***	5.272	0.029	[-0.207, -0.097]	-0.118***	4.617	0.019	[-0.167, -0.067]
H2a	PU -> PB	**<u>-0.008^{ns}</u>**	0.275	0.000	[-0.070, 0.050]	**<u>-0.05^{ns}</u>**	1.603	0.003	[-0.113, 0.012]	**<u>-0.020^{ns}</u>**	0.697	0.000	[-0.079, 0.035]
H2b	PU -> AA	-0.084**	3.053	0.010	[-0.142, -0.034]	-0.057*	2.120	0.005	[-0.108, -0.006]	-0.053*	2.232	0.005	[-0.099, -0.007]
H2c	PU -> PR	0.419***	18.489	0.277	[0.375, 0.463]	0.329***	13.176	0.173	[0.278, 0.376]	0.371***	14.614	0.217	[0.320, 0.420]
H3a	PTN -> PR	0.338***	15.030	0.178	[0.291, 0.380]	0.401***	17.014	0.251	[0.354, 0.446]	0.320***	12.663	0.166	[0.274, 0.372]
H3b	PTN -> PU	0.367***	13.455	0.154	[0.314, 0.421]	0.439***	16.162	0.233	[0.384, 0.490]	0.408***	15.165	0.206	[0.354, 0.459]

H4a	Affect -> PB	0.164***	6.380	0.037	[0.114, 0.215]	0.396***	14.663	0.199	[0.343, 0.448]	0.447***	16.869	0.258	[0.392, 0.496]
H4b	Affect -> AA	0.134***	6.233	0.035	[0.092, 0.176]	0.177***	5.998	0.044	[0.121, 0.235]	0.312***	12.427	0.140	[0.263, 0.360]
H4c	Affect -> PU	-0.116***	3.931	0.015	[-0.175, -0.059]	-0.120***	3.939	0.016	[-0.179, -0.060]	-0.231***	7.709	0.060	[-0.289, -0.174]
H4d	Affect -> PTN	-0.088**	2.893	0.008	[-0.147, -0.029]	-0.204***	6.249	0.039	[-0.271, -0.141]	-0.305***	10.042	0.092	[-0.364, -0.243]
H4e	Affect -> PR	-0.112***	5.068	0.022	[-0.154, -0.067]	-0.142***	5.827	0.035	[-0.190, -0.095]	-0.245***	9.359	0.100	[-0.296, -0.194]
H5a	GA -> Affect	0.248***	8.076	0.066	[0.188, 0.308]	0.387***	13.447	0.176	[0.327, 0.439]	0.377***	13.976	0.166	[0.323, 0.428]
H5b	GA -> PB	0.462***	17.126	0.289	[0.408, 0.514]	0.307***	11.393	0.124	[0.254, 0.359]	0.282***	10.932	0.129	[0.232, 0.335]
H5c	GA -> AA	0.157***	5.160	0.033	[0.097, 0.216]	0.137***	4.392	0.025	[0.076, 0.197]	0.119***	45.560	0.024	[0.068, 0.172]
H5d	GA -> PU	-0.091**	2.923	0.009	[-0.152, -0.030]	**-0.048**^{ns}	1.512	0.003	[-0.112, 0.014]	**-0.043**^{ns}	1.565	0.002	[-0.096, 0.010]
H5e	GA -> PTN	-0.242***	7.749	0.059	[-0.302, -0.182]	-0.169***	5.352	0.027	[-0.231, -0.106]	-0.123***	3.915	0.015	[-0.185, -0.060]
H5f	GA -> PR	-0.082***	3.493	0.012	[-0.127, -0.036]	-0.11***	4.575	0.021	[-0.158, -0.064]	**-0.021**^{ns}	0.954	0.001	[-0.066, 0.022]
H6a	PA -> AA	0.119***	4.258	0.021	[0.063, 0.172]	0.104***	3.900	0.016	[0.050, 0.156]	0.080***	3.485	0.011	[0.035, 0.125]
H6b	PA -> GA	0.530***	19.287	0.391	[0.472, 0.581]	0.529***	18.734	0.389	[0.470, 0.583]	0.531***	19.204	0.392	[0.474, 0.582]

Table 6. 5: Estimation results of the model across SB applications

Note: **p* < 0.05; ***p* < 0.01; ****p* < 0.001; β = path coefficients; 95% CI = 95% confidence interval; ns = non-significance; PA = prior attitudes towards GM food; GA = general attitudes towards SB applied to food production; PB = perceived benefit; PR = perceived risk; PU = perceived unnaturalness; PTN = perceptions of tampering with nature; AA = acceptance of the application. The β in bold and underlined refers to the rejection of corresponding hypothesis.

Relevant constructs	Expectations from literature	Results of this study	Difference across applications	Supplement
Affect, perceived benefit; perceived risk; application acceptance	Positive affect evoked by, and the perceived benefit of, a SB food application have positive effects on application acceptance, while the perceived risk has a negative effect.	The perceived benefit had medium positive effects for all three (f^2 ranging from 0.162 to 0.238), while affect (f^2 ranging from 0.035 to 0.140) and the perceived risk (f^2 ranging from 0.019 to 0.029) had small negative effects on the acceptability across three applications.	Despite the greater extent of negative affect evoked by the SB yeast, the largest influence of affect on respondents' acceptance was for the SB pig, indicating almost a medium impact (f^2 = 0.140), close to the impact of the perceived benefit (f^2 = 0.162).	Of the assessed factors influencing application acceptance, perceived benefit was the most important determinant across the three applications. The effect of affect evoked by different applications were second only to that of perceived benefit.
General attitudes towards SB food; perceived unnaturalness; application acceptance	A positive general attitude towards SB food has a positive effect, and the perceived unnaturalness of a SB food application has a negative effect, on application acceptance.	A general positive attitude towards SB food had small positive effects (f^2 ranging from 0.024 to 0.033) on application acceptance. While perceived unnaturalness had a negative effect on application acceptance, the strengths between the two constructs were very limited across applications (f^2 ranging from 0.005 to 0.01).	Not observed	

Prior attitudes towards GM food; general attitudes towards SB food; application acceptance.	A positive prior attitude towards GM food has a positive effect on the general attitude towards SB food and application acceptance.	A positive prior attitude towards GM food has a large positive effect on the general attitude towards SB food (mean value of f^2 is 0.39), and small positive effects on the acceptance of SB food applications (f^2 ranging from 0.011 to 0.021).	Not observed	Relationships between these constructs did not change much after adding food technology neophobia, and moralistic and dominionistic environmental worldviews in the models as control variables (see Appendix, Table G). This has excluded the potential confounding effects of people's attitudes towards novel food technologies and individual environmental values. Food technology neophobia and dominionistic worldviews were stable predictors of general attitudes towards GM and SB food, while they together with moralistic worldviews were not stable predictors of application acceptance (see Appendix, Table H).
General attitudes towards SB food, affect, perceived benefit; perceived risk	Positive affect evoked by a SB food application increases the perceived benefit but reduces the perceived risk of that application. A positive general attitude towards SB food has a positive effect on the perceived benefit, but a negative effect on the perceived risk, associated with a SB food application.	Positive affect evoked by SB food applications had small to medium positive effects on benefit perceptions (f^2 ranging from 0.037 to 0.258) and small negative effects on risk perceptions (f^2 ranging from 0.022 to 0.100). A general positive attitude towards SB food had small to medium positive effects on benefit perceptions (f^2 ranging from 0.124 to 0.289), but very small negative effects on the risk perceptions (f^2 ranging from 0.001 to 0.021), associated with the three applications.	The largest influence of affect on benefit and risk perceptions were observed for the SB pig. General attitudes towards SB food had very small negative effects on the risk perceptions associated with the SB yeast ($f^2 = 0.012$) and the SB soybean ($f^2 = 0.021$) and no direct effect on risk perceptions associated with the SB pig.	Both general attitudes towards SB food and affect evoked by different applications had stronger impacts on benefit perceptions than on risk perceptions.

Tampering with nature; perceived unnaturalness; perceived benefit; perceived risk	Associating a SB food application to be tampering with nature increases perceived unnaturalness and risk perceptions associated with that application. Perceived unnaturalness of a SB food application decreases perceived benefit, but increases perceived risk, associated with that application.	Associating the selected SB food applications to be tampering with nature had medium positive effects on perceived unnaturalness (f^2 ranging from 0.154 to 0.233) and risk perceptions (f^2 ranging from 0.166 to 0.251). Perceived unnaturalness of the selected SB food applications had medium positive effects on risk perceptions (f^2 ranging from 0.173 to 0.277) but no direct effects on benefit perceptions.	Not observed	Overall, benefit perceptions associated with specific SB food applications may be more informed by experiential thinking (e.g. affective/heuristic information processing and personal experience) compared to risk perceptions.

Table 6. 6: Key findings of PLS-SEM across SB applications

6.5 Discussion

The results showed that the application of SB to agri-food production evoked more positive consumer attitudes than GM food, and that Chinese consumers' general attitudes towards SB food were embedded in their prior attitudes towards GM food, which might potentially extend to their responses to other novel biotechnologies (e.g. genome editing) within the agri-food sector. Although some researchers have reported more negative public attitudes towards SB applications within the agri-food sector compared to the other sectors, such as energy and health (Pauwels, 2013; Steurer, 2015), the results of the research presented here suggest that acceptance or rejection of food applications is nuanced by specific application attributes. This aligns with previous research into consumer attitudes towards GM food, where greater consumer rejection was identified for animal-based food products compared to plant- and microbe-based products (Frewer, Coles, et al., 2014). This, however, is not a view held by Chinese scientists who have predicted the emergence of societal resistance to SB food in general (Jin et al., 2021). It implies that identification of information about societal preferences for products of SB in particular, and emerging food technologies in general, should occur early enough in the product development cycle to influence the final product design, and policy formulation. Product developers, including those within the scientific community, and policy makers should be trained in conducting or sponsoring relevant co-production methodologies, and the need to address societal priorities as well as technical possibilities, when considering the route to commercialisation of SB products.

An interesting finding in the present study was that more negative affect was evoked by the SB yeast for milk protein production compared to the SB pig with improved immune function and the GM yeast for producing vitamins. This might be because milk is often naturally produced by animals, whereas vitamin products are often human-made, which causes the yeast producing milk-related products to be perceived as a form of tampering with nature or unnatural food compared to the GM yeast producing vitamins. The negative affect might also relate to Chinese consumers treating dairy products-related innovations with caution due to the 2008 melamine in powdered milk scandal (Gossner et al., 2009; Kendall et al., 2019). Despite the evoked negative affect, Chinese consumers still perceived a higher level of benefits than risks to be associated with the same SB yeast and had positive intentions to drink its produced milk. In comparison, Swiss consumers perceived milk produced by the SB yeast to be of high risk and low benefit, leading to a very low level of acceptance (Egolf, Hartmann, & Siegrist, 2019). It has been reported that Europeans hold more negative attitudes towards GM food than Asian (Frewer et al., 2013). Thus, besides the technology *per se* and the employed host organisms, other traits of the applications, such as the derived products based on these applications, as well as cultural contexts should be considered in product development. In addition, the participants could have been primed by the labels used in the research (Egolf et al., 2019): “artificial milk” in the Swiss study versus “novel milk” in the research presented here. The label of “artificial milk” might have evoked a higher level of disgust and/or perceived unnaturalness (Rozin et al., 2004), thereby resulting in higher risk perceptions and lower acceptance. So, in research on consumer responses to specific SB food applications, the development of product/application information also needs to be cautious to avoid the unwanted framing effect.

In contrast to the results of previous research (Akin et al., 2017; Braman et al., 2008), respondent demographics did not differentiate their general attitudes towards SB food, nor those held in relation specific applications. Besides the different socio-cultural contexts in which the present and previous studies were conducted, the difference in research design might also contribute to the inconclusive findings. For example, when focusing on specific GM food applications with tangible benefits, attitudinal difference according to gender might disappear (Frewer et al., 1996). Some attributes of individuals (e.g. food technology neophobia and dominionistic environmental worldviews) were found to be stable predictors of general attitudes towards SB food in the present research, as was reported in previous GM food-related research (Hall & Moran, 2006; Vidigal et al., 2015). However, they failed to stably predict acceptability of specific SB agri-food applications, which could be due to application characteristics “overriding” the impacts of these individual attributes on the acceptance.

6.5.1 Theoretical implications

This research has contributed to developing a better understanding of the key factors that can drive public acceptance of novel food technologies. In particular, the research has examined the impacts of perceived unnaturalness and affective responses on acceptance, which are factors that have been infrequently investigated, particularly within China. Perceived unnaturalness was a strong predictor of Chinese consumers’ risk perceptions but not of their benefit perceptions and final acceptance. This was inconsistent with some of the findings from research conducted in Western countries (e.g. see Mielby, Sandøe, & Lassen, 2013; Siegrist, Hartmann, & Sütterlin, 2016; Tenbült, De Vries, Dreezens, & Martijn, 2005). Although it was suggested that perceived unnaturalness of a technology leading to higher level of perceived tampering with nature (Hoogendoorn et al., 2020), the present study showed that perceiving a SB food application to be tampering with nature increased consumers' perceived unnaturalness and its products in the Chinese context. Given the limited impact of general attitudes towards SB food on perceived unnaturalness, it is proposed here that perceived unnaturalness of a specific agri-food application could be more driven by perceptions of different application traits rather than the technology *per se*.

Previous research suggests that people's prior attitudes or beliefs associated with a technology and affect greatly contribute to people's risk and benefit perceptions. This is particularly the case for affective responses, which tend to become more pronounced under a time-pressure condition and when no extra information about the the technology is made availible (Alhakami & Slovic, 1994). In the present study, the impacts of prior attitudes and affect on risk perceptions associated with applications of SB were much smaller than those on benefit perceptions. This implies that risk perceptions are more likely to be derived from deliberative information processing but are less dependent on experiential thinking (e.g. affective/heuristic information processing and personal experience) compared to benefit perceptions. Also, despite the more negative affect evoked by the SB yeast than the SB pig, affect still played a more important role in shaping perceptions and acceptance for the SB pig (as was the case for the GM pig in Chapter 5), which might due to stronger moral concerns based on the perceived sentience of animals.

6.5.2 Policy implications

The results suggest that there is a need to establish more specific regulations for distinct SB agri-food applications, rather than all agri-food applications that are derived from GM, SB and genome editing being governed under a single regulation for GM (e.g., EU Directive 2001/18/EC[7] and 2009/41/EC[8], and "Regulations on Administration of Agricultural Genetically Modified Organisms Safety"[9] in China). Although such a

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[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32001L0018 (accessed 20 June 2021).
[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0041 (accessed 20 June 2021).
[9] http://www.moa.gov.cn/ztzl/zjyqwgz/zcfg/201007/t20100717_1601306.htm (accessed 20 June 2021).

blanket policy might enhance public sense-making of novel biotechnologies applied to agricultural and food production, it could also lead to misunderstandings and prejudices based on prior attitudes/belief associated with GM food rather than to evidence-based reasoning. Consequently, this could lead to stronger societal concerns, particularly within societies that tend to regulate food technologies on the basis of risk avoidance. Agri-food policy support should prioritise the research that intends to develop SB agri-food products in line with public preferences. This could potentially establish more positive public attitudes towards SB food in general, and in turn accelerate development and commercialisation of other SB agri-food products in the future. However, this requires rigorous risk analysis at different stages including early investigations of societal responses to SB food that consider specific application traits and the socio-cultural context in which applications are to be commercialised.

The findings of the present study could also inform policy-making in relation to future risk analysis, including communication with the public, which should be addressed at different stages of risk analysis of foods (König et al., 2010). First, understanding what characteristics consumers require from SB food, if any, will ensure effective collaboration between society and science in relation to agri-food technology development. This would help identify, and focus risk mitigation and communication strategies on, risks that are of public concern. For example, in China, research and development investment in the public and private sectors might prioritise developments that choose plants as host organisms rather than animals. Applications with direct and multiple benefits for consumers, or the environment, as opposed to the economy, might also be prioritised over those with economic benefits alone. Second, information provision appears to evoke deliberative information processing leading to risk perceptions (Zhu & Xie, 2015). This implies that the provision of information about risk mitigation strategies should be addressed in risk communication policy. Here, people's affective responses to specific applications needs to be considered in risk communication because the communication itself may evoke an affective response in the message recipient. This, in turn, could have an unintended impact on their risk and benefit perceptions and acceptance. Last but not the least, better communication mechanisms between consumers, scientists, industries, government representatives and other broader stakeholders should be established to co-develop not only the products but also the information for risk communication. In turn, this could help to improve the transparency, openness, and accountability of the risk and benefit management processes for SB agri-food applications. Again, this would require more case-by-case based analyses due to the potential influence of social contexts.

6.5.3 Study limitations

Caution is advised if generalising the findings to the whole Chinese population because the survey respondents were from Tier 1 and Tier 2 cities only. Nevertheless, the selected confidence intervals in this study have ensured 95% confidence that the sample means lie within the population means. More problematic is the extrapolation of the results outside of China, where different population groups have had different experiences with food safety risks, and regulatory approaches to risk analysis associated with technologies. However, we would argue that the mechanisms of attitude formation associated with SB in particular, and food technologies more generally, are broadly relevant at scale and across different populations. Hence, our conclusion that people's concerns need to be assessed at local and cultural levels, can still inform how best to operationalise policy for governments and industries. This could help in the development of more targeted, and, therefore, effective commercialisation trajectories and public communication strategies.

6.6 Conclusion

The long-term development of SB in the agri-food sector may be hindered due to a failure to fully understand societal acceptance of different applications. The factors that shape Chinese public acceptance of SB food applications were identified, of which benefit perceptions were the most influential. Affect evoked by applications had small effects on the acceptability, although its salience in decision-making was also informed by the target organisms involved. Respondents' general attitudes towards SB food were largely shaped by their prior attitudes towards GM food, and both had small but significant impacts on the acceptability of specific SB food applications. The findings of this study have implications for the development of policy that can effectively regulate and develop SB within the agri-food sector. At the same time, potential differences in consumer responses to SB agri-food applications across countries suggest that more international research and governance collaborations are needed to establish and implement governance and regulation of different SB agri-food products at a global scale, because SB, together with other technologies, represent a transboundary risk which cannot be contained within geographic or political regions.

Chapter 7. General discussion

7.1 Introduction

This chapter draws together the findings from the mapping review (Chapter 2), semi-structured interviews with scientists (Chapter 3), focus group discussions among Chinese citizens (Chapter 4), and two online surveys with Chinese people (Chapters 5 and 6). Based on these findings, both theoretical and policy implications were discussed, which would benefit future development and regulations of novel agri-food technologies and beyond. In addition, the research limitations in the thesis are discussed, along with recommendations for future research activities to address these limitations.

7.2 Consolidation of findings from the thesis

The thesis started with a mapping review of the existing literature into societal responses to SB and its applications including those within the agri-food sector (Chapter 2). The review indicated that, although some risk-related and ethical concerns were raised by the public, there was little evidence showing that people had an inherently negative perception of SB. The results demonstrated the importance of perceived benefits, perceived risks and ethical issues in influencing public acceptance of SB. Where analysis focused on specific applications, people tended to be more positive about medical and environmental applications compared to those in the agri-food sector. However, at present, the literature on public acceptance of SB is focused on it being used as an enabling technology, rather than on specific applications. Given that there is evidence presented in this thesis that people's attitudes varied by product types, more research on specific applications is needed to further investigate public attitudes, to co-develop SB agri-food products in line with societal preference, and to develop policy and regulations associated with SB and its application within the agri-food sector.

Given the important role of scientists in framing regulatory and implementation policies and commercialisation trajectories of novel technologies, semi-structured interviews were used in Chapter 3 to investigate Chinese and EU scientists' views on social implications associated with SB. Based on inductive thematic analysis, the results showed that both Chinese and EU scientists regarded SB as being high-benefit, low-risk and ethically acceptable, at the same time predicting its rejection by the general public.

The scientists in both regions attributed this to the public's knowledge deficit and "irrationality". Although EU research projects (e.g. EU Framework Programmes - Horizon Europe) increasingly emphasise the need to apply an RRI approach, engage a diverse range of stakeholders, and consider potential impacts on the environment and socio-economic functioning of society, both Chinese and EU scientists in this study endorsed the deficit model of science communication, increasing social acceptance of SB by transferring SB-related scientific knowledge to laypeople. However, in the case of GM food, an individual's scientific knowledge about GM technology was not a strong predictor of their attitudes (e.g. see Connor & Siegrist, 2010; Irani, Sinclair, & O'Malley, 2002). The results of the interviews with scientists suggested that a broader range of stakeholders need to be involved in SB technology and applications from the outset.

The focus of Chapter 4 relates to how Chinese people respond to different SB agri-food applications and whether it differs from responses to GM foods. Seven categories of factors that shaped research participants' attitudes towards SB agri-food applications were identified based on six focus groups in Tier 1 and Tier 2 cities. They included 1) perceptions of specific applications, 2) affect/emotions evoked by applications, 3) general attitudes associated with SB, 4) features or traits of application, 5) personal experience and values, 6) the social context of China, and 7) information to which individuals are exposed. Despite some participants "making sense" of SB from existing attitudes towards GM, Chinese people's general attitudes towards SB were less crystallised, and thus were more influenced by information compared to GM. Perceptions of ethical issues associated with SB using synthetic genes could also differ from GM which uses genes from other organisms. The results indicate that it is necessary to establish a more effective mechanism to engage interested stakeholders, including consumers, and co-develop socially acceptable SB agri-food products. It is also important to systemically consider the combined influence of multiple factors in specific cultural or socio-economic contexts when developing targeted communication strategies.

Chapter 5 used an online survey with Chinese citizens to explore how prior attitudes and affect (i.e. a person's positive or negative feelings about specific objects, ideas or images) interact and inform their responses to three GM food applications. These applications included three types of host organism (the plant, microbe and animal), and enabled quantitative comparisons with the selected SB applications in Chapter 6. Structural equation modelling was applied in Chapter 5, and the results of the analysis indicated that benefit perceptions were the most important factor in predicting application acceptability. Prior attitudes and affect both had larger impacts on acceptability compared to risk perceptions, with prior attitudes being in larger effect for the GM yeast and GM soybean and affect exerting a stronger influence for the GM pig. Prior attitudes also had a moderating effect on the relationship between risk perceptions and application acceptability, reinforcing the systemic cognitive bias that generalises prior attitudes-induced *a priori* judgements to all GM food applications. Respondents' perceptions that GM was linked to increased productivity and reduced prices were associated with to the highest levels of positive affect. When respondents associated GM applications with tampering with nature, perceived unnaturalness and risk perceptions both increased.

Chapter 6 aimed to understand societal responses to three SB food applications using an online survey with Chinese citizens, where plant- and microbe-based applications were more acceptable than the animal-based one, a similar result to the GM food-related findings of Chapter 5. The results of Chapter 6 showed that, despite being embedded in prior attitudes towards GM food, research participants' general attitudes towards SB food were slightly more positive compared to GM food. Benefit perceptions were the most predictive of application acceptance, while attitudes towards the food technology *per se*, affective responses and risk perceptions associated with specific food applications had smaller predictive capacities. The perceived unnaturalness of SB food applications was a strong predictor of risk perceptions but not of benefit perceptions and acceptability. All the findings have raised different theoretical and policy implications which will be explored more in detail in the following sections.

7.3 Theoretical implications

The theoretical implications from the thesis mainly relate to the limitation of "deficit model" in risk communication, and some factors that affect public responses to SB foods, including general attitudes towards SB food, perceiving SB agri-food applications to be tampering with nature or unnatural, and affect evoked by SB agri-food applications.

7.3.1 The limitation of "deficit model"

A few studies have shown that scientific knowledge is not a strong predictor of public acceptance and rejection of GM food (e.g. see Connor & Siegrist, 2010; Irani et al., 2002; Šorgo & Ambrožič-Dolinšek, 2010), and that using "deficit model" for public communication failed to reduce risk perceptions and increase social acceptance (Frewer et al., 2013). In addition, EU funded research programmes (e.g. EU Framework Programmes - Horizon Europe) have, in recent years, emphasised the need to engage diverse stakeholders for research and innovation co-development for ensuring the environmental and social benefits (European Commission, 2015; Ribeiro et al., 2017). However, this research has shown that this may not be the case in practice, with both the EU and Chinese scientists endorsing the "deficit model" for future public communication about SB, which may lead to non-positive effects on social acceptance of SB. Moreover, most scientists emphasised their known scientific evidence and evaluated risks associated with SB as being very low or even nil, without acknowledging the uncertainties. Such potentially confirmation bias might increase public concerns when it is learned by the public. This is an important research gap which needs to be addressed in the future. It is required to reach a consensus regarding how to estimate, evaluate and manage the risks, in the light of scientific uncertainty and ideally on a case-by-case basis; this also calls for better involvement of synthetic biologists, the public, and broader stakeholders, such as risk researchers and government representatives.

7.3.2 General attitudes towards SB food

Previous research has shown that prior attitudes towards GM food have a strong impact on product-specific risk perceptions, benefit perceptions and attitudes (Bredahl, 2001). Research has shown that the prior attitudes might even "over-ride" information about GM technology and/or products, and so the provision of any type of information did not result in research participants' attitude change (Scholderer & Frewer, 2003). However, some studies indicated that there are some GM food characteristics that people are more likely to accept, and others that people are more likely to resist (Hess et al., 2016; Mucci & Hough, 2004).

The study focused on GM food applications in the thesis indicated that Chinese people's product-specific attitudes could be affected by their prior attitudes towards GM food in general. However, the prior attitudes did not "override" the information about specific GM applications, where GM yeast for producing vitamins and an insect-resistant GM soybean were accepted, and a GM pig with improved cold weather adaptation and increased lean meat production was rejected, by research participants. This was mainly attributed to participants' case-by-case evaluations of applications, which evoked different levels of affect, risk and benefit perceptions and, in turn, shaped different product-specific attitudes.

In the research presented in this thesis which focused on SB food, Chinese people were unlikely to have a crystallised prior attitude or belief due to their being unfamiliar with SB. However, the prior attitude or belief associated with GM food could strongly affect people's general attitudes towards SB food, which, in turn, informed affect, perceptions and final acceptance of different SB agri-food applications. Despite so, people still had different attitudes across application types, with overall acceptance of SB yeast for producing milk proteins and drought-resistant SB soybean, and rejection of an SB pig with an improved immune function. As such, future research into public responses to SB and other novel biotechnologies (e.g. genome editing) should consider not only these technologies *per se* and their specific applications, but also the potential influence of prior beliefs or attitudes associated with GM food.

7.3.3 Perceived "tampering with nature" and unnaturalness

It has been proposed that perceiving a technology to be tampering with nature or unnatural could increase risk perceptions and reduce the acceptance overall (e.g. see Mielby, Sandøe, & Lassen, 2013; Siegrist, Hartmann, & Sütterlin, 2016; Sjöberg, 2000, 2004; Tenbült, De Vries, Dreezens, & Martijn, 2005; Wolske, Raimi, Campbell-Arvai, & Hart, 2019), while the impact of these constructs on benefit perceptions has been rarely studied. A recent systematic review suggested that the extent to which an individual perceived unnaturalness associated with a technology increases the perceptions that this technology is tampering with nature (Hoogendoorn et al., 2020). In this thesis, Chinese people expressed this as "*violating natural laws*" to express their perception that an application was "tampering with nature", which increased their perceived unnaturalness associated with this application and its products. Perceptions that an SB agri-food application was tampering with nature and the perceived unnaturalness associated with the application were strong predictors of risk perceptions but not of benefit perceptions and acceptability, as was the case for GM food applications.

7.3.4 Impact of affect on acceptability

There is little research available which has investigated the role of affective responses in shaping public perceptions of, and attitudes towards, novel food technologies in non-Western countries in the Global North, including within China. This research has shown that a positive general attitude towards SB food resulted in a positive effect on research participants' affect evoked by a SB food application, and that general attitudes and affect both had larger impacts on benefit perceptions than on risk perceptions. This implies the more important role of on experiential thinking (e.g. affective/heuristic information processing and personal experience) in shaping benefit perceptions compared to perceived risk associated with SB agri-food applications (Alhakami & Slovic, 1994; Fischer & Frewer, 2009). In addition to general attitudes towards SB food, the information which was presented about specific applications of SB also contributed to the affective responses evoked by SB applications, whether this was positive or negative. Here, positive affect tended to positively influence acceptability. A larger impact was identified for the animal-based application compared to microbe- and plant-based ones, as was the case for GM foods.

The medium impacts of affect on benefit perceptions but small impacts on risk perceptions associated with SB applications might partly explain why provision of benefit information about GM food in previous research led to no attitudinal change among Chinese people, while provision of risk information decreases the acceptability (Zhu & Xie, 2015). It has also raised the need to communicate potential risks and the mechanisms for risk mitigation and control to the public in a transparent manner. In addition, the presented application attributes and the way the information was communicated in itself could both contribute to the generation of affective responses, thereby influencing people's perceptions and attitudes. Therefore, on one hand, SB application attributes that are connected to positive or negative affect should be incorporated or addressed in product development and communication information-making; on the other hand, *how* the information is communicated can evoke more affect should be further explored in research, and considered in future communication activities by industry, policy-makers and researchers.

7.4 Policy implications

The findings from this thesis provide evidence upon which policy implications associated with SB agri-food applications can be developed, including those associated with understanding public preferences and incorporating these into product development, considering certain issues prior to commercialisation, and making effective regulatory framework and communications with the public. All these intend to prevent or mitigate potential risks, facilitate delivery of benefits for society, and align with societal priorities, preferences and expectations.

7.4.1 Development of socially preferred applications

It is always important to be socially beneficial and at the same time in line with public preference when developing SB agri-food applications. For example, plant- and microbe-based SB applications in the agri-food sector currently are more acceptable compared to animal-based ones in China. Some application attributes might relate more positive affect which could be incorporated into product development, such as the capacities of producing nutrients, reducing pesticide use, increasing the productivity and reducing price, and bringing direct benefits to the environment. Those applications with more positive attributes should be prioritised in product development as well as government research funding. In contrast, those applications that evoked strong social concerns should be avoided in product design before these concerns are addressed. Therefore, it is not an appropriate time to commercialise animal-based SB applications as food in Chinese market. The potential health risks and ethical issues, as well as social concerns in relation to different applications must be addressed before product commercialisation.

7.4.2 Considerations prior to commercialisation

Considering the influence of social contextual factors, it is not appropriate to promote potentially controversial food technologies and their applications where there is a high level of public food safety concern combined with a low level of social trust in regulatory institutions (see Chapter 4). In addition, prior to commercialisation, research into public responses to the products under development should be conducted, to provide information for "fine-tuning" product design as well as the commercialisation strategies (Raley et al., 2016). Also, the information transparency should be ensured, which requires effective labelling and traceability systems in place to ensure consumer autonomy associated with choosing SB products (Hansen, 2004; Ramjoué, 2007). As public food safety concern as well as their responses to food technologies might change over time, for instance, due to sudden food-related events that amplify or attenuate risk perceptions (e.g. see Frewer, Miles, & Marsh, 2002; Kendall et al., 2019; Li, Sijtsema, Kornelis, Liu, & Li, 2019), such investigations may need to be conducted regularly.

7.4.3 Effective regulatory and communication strategy-making

The current regulation of SB foods in China is covered by the regulatory framework of GM food (i.e. "Regulations on Administration of Agricultural Genetically Modified Organisms Safety"[10]). Given that Chinese people depended on prior belief or attitudes associated with GM food to form general attitudes towards SB food, a policy covering all aspects of GM, SB and genome editing might strengthen biased judgements of risks and benefits associated with SB food and weaken the evidence-based reasoning. Therefore, regulation of SB should be covered by a separate regulatory framework. In addition, as Chinese people have different levels of perceived risk, benefit, and acceptance across the selected SB applications, it is important to regulate SB applications on a more case-by-case basis to align with societal preferences.

Agri-food policy support should prioritise the research that intends to create socially beneficial SB agri-food products which are simultaneously in line with social preferences. Training about RRI approaches for product developers should be included in graduate curriculum and research funding programmes, which could help avoid strong social rejection of SB food in general due to any controversial SB application being created without considering potential social reactions. In addition, based on a case-by-case analysis, better communication mechanisms that can effectively involve different stakeholders, communicate relevant risks and benefits, reach consensus on risk mitigations, and co-develop products and information for benefit and risk communication, should be established. This could improve the transparency, openness, and accountability of the risk and benefit management processes for SB agri-food applications.

The factors that influence people's responses to SB agri-food applications should be systemically considered and addressed in future communication with the public. For instance, a high level of benefit perception, and a low level of risk perception, associated with a SB food product should be ensured in the whole process of product development. Here, based on the identified risk of public concern, effective risk mitigation and communication strategies should be developed which acknowledge

[10] http://www.moa.gov.cn/ztzl/zjyqwgz/zcfg/201007/t20100717_1601306.htm (accessed 20 June 2021).

societal preferences and requirements. Applications with direct and potentially multiple benefits for the public and/or the environment should be prioritised over those with economic benefits alone. As has been discussed in Section 7.3.4, people’s affective responses to specific applications also need to be considered in risk communication as communication may in itself evoke affective responses in the message recipient, which, in turn, informs their risk and benefit perceptions and acceptance.

7.5 Future research directions

This thesis has provided evidence of *how* Chinese people make decisions about accepting and rejecting SB agri-food applications, indicating promise in promoting the application of SB to the agri-food sector by addressing relevant factors systemically. Limitations to the research, which can be addressed in future studies, will now be discussed.

First, the empirical studies in the thesis which considered public responses to SB (and GM) food recruited participants primarily from focused on Tier 1 and Tier 2 cities. The populations of these cities may differ from those of the rest of China due to socio-economic and cultural differences (Cho, Jin, & Cho, 2010; Zhang & Xu, 2011). The direct generalisation of the results to the commercialisation and regulation of SB to the whole Chinese population may not be appropriate. Future studies targeting the Chinese public could be conducted in cities of other tiers as well as rural areas and should consider influential factors at local and cultural levels. Research focused on other countries should consider the cultural context and can compared findings with those from the current thesis. Both similarities and differences could contribute to deeper understanding about public responses to SB agri-food applications in particular those potentially posing transboundary risks (e.g. negative environmental impacts) (Polizzi et al., 2018). This can facilitate international collaborations in making more effective regional and global regulatory frameworks, and benefit in SB product development and commercialisation in the long term.

Second, the cross-sectional survey data in the thesis were analysed to explain participants’ attitudes based on regression analysis. The identified associations thus should not be treated as cause-and-effect relationships. In future research, other methods (e.g. experiments) can be employed to investigate people’s attitudes, decisions and behaviours, which will further contribute to the development of risk communications aimed at influencing individuals to form more evidence-based responses (De Wijk et al., 2016). The heterogeneity of people also needs to be explored in future, for example, identifying different segments (Verdurme & Viaene, 2003; van der Zanden, van Kleef, de Wijk, & van Trijp, 2015; Zhang, Huang, Qiu, & Huang, 2010), which can provide information for more targeted and effective communication and marketing strategy making for specific SB products.

Third, the thesis only paid attention to potential consumers and application developers (i.e. scientists) due to most SB food products being at an early development or commercialisation stage. This in a way has limited the potential of using findings from the thesis to facilitate the co-development of products and communication information. Thus, there is a need to engage a broader range of stakeholders such as government representatives, industries, and NGOs in future studies which preferably focus on promising new SB food products. This will help more effectively identify different stakeholders from a supply chain perspective and understand the relationships between different stakeholders, thereby facilitating collaborations between the stakeholders to achieve the success of product commercialisation (Kazadi, Lievens, & Mahr, 2016; Nudurupati, Bhattacharya, Lascelles, & Caton, 2015).

Finally, the acceptance measures in the thesis included both more passive (e.g. general support for different applications in Chapter 4) and more active components (e.g. intention to purchase or consume certain applications in Chapters 5 and 6) of acceptance. The latter could provide more information for predicting an individual's actual acceptance or even future behaviour associated with certain SB agri-food applications. However, a gap between the self-reported and actual behaviour about consuming specific SB food products may exist when those products are on the market. Research methodology which is more focused on understanding specific attributes of products and how these are traded (e.g. choice experiments) will be required in further investigations (Cardello, Schutz, & Lesher, 2007; Frewer, Howard, Hedderley, & Shepherd, 1997). Chapters 5 and 6 have used specific agri-food applications to gain understanding of societal responses, evoking more active components of acceptance. However, the information provided about the applications in themselves might have led to a framing effect, and in turn influenced respondents' decision making about accepting or rejecting different applications. This should be considered and addressed in future survey design.

7.6 Conclusion

The research aimed to understand Chinese people’s attitudes with a focus on SB applied to food production in general and specific agri-food applications in particular. Drawing together the findings from the qualitative and quantitative research, it showed that Chinese people had a slightly positive general attitude towards SB food and preferred plant- and microbe-based applications to animal-based ones. Also, the established model using structural equation modelling demonstrated a satisfactory level for explaining Chinese people’s acceptance of different SB agri-food applications, in which benefit perceptions most strongly predicted application acceptance compared to general attitudes towards SB food, and affect and risk perceptions associated with specific applications. When an individual perceived an SB application to be “tampering with nature”, this tended to increase the perceived unnaturalness of the application and/or its end products. The perceived “tampering with nature” and unnaturalness were strong predictors of risk perceptions but not of benefit perceptions and application acceptance. Social contextual factors were also found to influence people’s attitudes towards SB food, including the overall food safety concern and social trust in scientists and regulatory institutions. Findings have also highlighted several implications for developing more effective policy frameworks to benefit the development and regulation of SB within the agri-food sector in line with public preferences and to facilitate the commercialisation process in the long term.

Chapter 8. References

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Appendix A. Semi-structured interview materials

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Dear xxx,

We write to invite you to take part in a research project about understanding new developments of synthetic biology. We are asking you in our telephone interview for your views on the commercialization of synthetic biology especially in the agri-food sector, and the associated potential social, economic and ethical issues.

Synthetic biology offers the potential to deliver applications across a range of areas, including those within the agri-food sector. At the same time, the evolving regulatory and governance framework which guides how different applications of technology are applied encourages "socially responsible research and innovation" approaches to be adopted, such that science and technology delivers towards societally approved and, indeed, preferred outcomes. As part of this, it is important to consider the social, economic and ethical issues which are associated with different applications of synthetic biology.

The aim of this interview is fourfold: **First**, we are trying to find out what applications of synthetic biology might be ready for commercialisation in the next 15 years. We are particularly interested in applications within the agri-food sector, but also in understanding how close to commercialisation these applications are in relation to other sectors or domains. **Second**, we would like to know more about your views regarding any risks, benefits and ethical issues associated with different synthetic biology applications. **Third**, we would like to know whether different applications of synthetic biology will be linked to public concern, or consumer or societal demand (in general, and agri-food applications in particular). **Fourth**, we are interested in your views towards the existing and emerging regulatory and policy framework associated with the introduction of different applications of synthetic biology.

The main questions that we will ask during the interview are included on the following page so that you have time to think about your answers in advance. To arrange a convenient time for an interview, please contact Shan Jin (S.Jin13@newcastle.ac.uk), and to go through any further questions prior to the start of the interview.

Kind regards.

Shan Jin

In our interview, questions are set as below for fulfilling the fourfold aims:

1.	a) What applications of synthetic biology in general do you think will be ready for commercialization in the next 15 years?
	b) What applications of synthetic biology within the agri-food sector do you think will be ready for commercialization in the next 15 years?

2.	a) What are the benefits of the applications of synthetic biology you have mentioned?
	b) What are the risks of the applications of synthetic biology you have mentioned?
	c) Are there any potential ways of reducing these risks?
	d) Are there any potential ethical issues in relation to the applications of synthetic biology you have mentioned?

3.	a) Of different synthetic biology applications, which do you think will be priorities for the public?
	b) What factors do you think may drive the public acceptance?
	c) Which applications do you think will the public be more concerned about?
	d) What factors do you think may drive the public concerns?

4.	a) What do you think of the existing and emerging regulatory and policy framework(s) associated with synthetic biology?

5.	a) To what extent do you think the social opinions should be taken into account in terms of developing synthetic biology?

6.	a) Is there anything else you would like to add?

Appendix B. Focus group materials and data

———————————————————————————————

Section One. Focus Group Discussion Protocol

Part 1. Attitudes to GM

In this part, we will mainly introduce genetic modification (GM) and discuss your own attitudes towards it. Please follow the moderator's instructions and complete certain questions.

<u>Introduction to GM technology</u>

Most creatures are composed of cells, which have a large number of genes that determine different characteristics and functions. **GM** technology copies a piece of DNA from one organism to another so as to endow this organism with desired traits. This technology can be used in different sectors such as agriculture, food production and healthcare.

1. What do you think of GM technology in general?
2. What do you think of the following GM agri-food applications?

GM Applications	**Acceptability** ("1": Unacceptable; "2": Very unlikely to accept; "3": Probably not accept; "4": Not sure if accepting or not; "5": Probably accept; "6": Very likely to accept; "7": Fully acceptable.)
Crops (e.g. maize, rice and wheat) are genetically modified by inserting a piece of foreign genes so as to be resistant to different stresses, such as insects, drought and so forth.	**Score:** **Comment:** **Final score after discussions:**
Crops (e.g. maize, rice and wheat) are genetically modified by inserting a piece of foreign genes so as to produce higher content of nutrition.	**Score:** **Comment:** **Final score after discussions:**
Microbe (e.g. yeast) is modified to produce food additives, such as flavours and antioxidants.	**Score:** **Comment:** **Final score after discussions:**
Microbe (e.g. yeast) is modified by inserting some human genes to produce insulin.	**Score:** **Comment:** **Final score after discussions:**

Animals (e.g. chicken, pigs and fish) are modified to grow faster, thereby reducing the price.	**Score:** **Comment:** **Final score after discussions:**
Animals (e.g. chicken, pigs and fish) are modified to avoid certain disease and reduce the use of different medicine.	**Score:** **Comment:** **Final score after discussions:**

Part 2. Attitudes to SB

In this part, we will mainly introduce synthetic biology (SB) and discuss your own attitudes towards it. Please follow the moderator's instructions and complete certain questions.

<u>Introduction to SB</u>

"**SB** is a new area of research that combines biology and engineering to establish new biological functions and systems in cells. You may imagine cell as a computer, compromised of different parts, working together and providing different functions, and these parts are coded by DNA (or genes). Different from GM, SB can create new "bio-bricks" that do not exist in nature, either by synthesising and/or assembling DNA (or genes) so as to endow cells with new functions".

1. What do you think of SB in general?
2. What do you think of the following SB agri-food applications?

SB applications	**Acceptability** ("1": Unacceptable; "2": Very unlikely to accept; "3": Probably not accept; "4": Not sure if accepting or not; "5": Probably accept; "6": Very likely to accept; "7": Fully acceptable.)
Crops (such as wheat and rice) with reduced demands for inputs of different resources such as water, pesticides and fertilizer without compromising the productivity.	**Score:** **Comment:** **Final score after discussions:**
Crops that produce novel substances such as vitamins and carotenoid.	**Score:** **Comment:** **Final score after discussions:**
Synthetic yeast for producing novel food and food additives, such as milk protein, egg white and vanilla flavour.	**Score:** **Comment:**

	Final score after discussions:
Synthetic microbe sensing and degrading pollutants in the environment, such as heavy metals.	**Score:** **Comment:** **Final score after discussions:**
Synthetic pests whose offspring will lose fertility, which can be applied to decrease the agricultural pests without using pesticides.	**Score:** **Comment:** **Final score after discussions:**
Synthetic livestock with better traits such as faster growth and better immune system for reducing disease.	**Score:** **Comment:** **Final score after discussions:**

Part 3. Demographic information

The purpose of the following questions is to help gain an understanding of the profile of the participants. Answers are anonymous. Please indicate for the following:

Gender: Female / Male

Age: 18-25 ☐ 26-30 ☐ 31-39 ☐

40-49 ☐ 50-59 ☐ 60-65 ☐

Educational level:

College and below / Bachelor study / Master and above

Occupations:

Employed for wages / Self-employed / Homemaker / Student

Contact number:

Section Two. Focus group participants' attitudes towards GM and SB applications

(a) GM food

Group	Participant No.	GM crops				GM microbes				GM animals			
		Improved resistance		Enhanced nutrition		Food additives		Medicine production		Faster growth		Improved immunity	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
A	A1	6	7	6	6	5	5	5	7	3	3	2	4
	A2	7	7	3	3	7	7	1	3	2	3	5	3
	A3	6	5	3	3	3	3	5	6	2	3	4	4
	A4	6	6	4	4	7	6	6	5	4	4	5	6
	A5	5	6	5	6	3	3	3	3	2	3	3	3
	A6	5	6	5	3	3	3	5	6	4	3	3	2
	A7	6	6	6	6	6	6	6	6	3	3	3	3
B	B1	6	6	7	7	6	6	7	7	3	3	4	4
	B2	6	7	6	6	5	5	5	6	3	3	6	5
	B3	7	7	6	6	7	7	7	7	5	5	7	6
	B4	7	7	6	6	7	5	4	5	3	3	6	5
	B5	6	6	5	5	3	3	4	2	2	2	5	5
C	C1	5	5	6	6	3	3	6	6	2	2	3	3
	C2	7	7	7	7	7	7	7	7	6	6	7	7
	C3	4	7	7	7	5	5	7	7	1	6	7	7
	C4	7	7	5	7	5	3	7	7	3	1	5	6
	C5	7	7	7	7	2	5	7	7	1	1	3	2
D	D1	2	2	2	2	2	2	6	6	4	4	4	4
	D2	6	5	6	5	5	5	5	5	4	4	5	5

	D3	3	3	6	5	3	3	7	7	5	5	5	5
	D4	4	3	4	3	5	5	5	5	3	3	4	3
	D5	4	4	4	4	4	4	5	6	4	4	4	4
E	E1	7	7	7	7	7	7	7	7	7	7	7	7
	E2	2	3	5	6	5	6	3	3	2	3	6	6
	E3	5	5	5	5	6	6	6	5	3	2	3	5
	E4	3	5	3	3	6	7	7	7	3	3	3	3
	E5	4	5	4	3	4	5	5	5	2	1	5	3
F	F1	7	7	7	7	4	4	7	7	4	4	7	7
	F3	2	2	2	2	2	2	5	5	2	2	2	2
	F4	4	5	4	4	5	5	5	5	3	3	3	3
	F5	5	5	5	5	5	6	6	6	2	2	3	3
	F6	7	6	6	6	6	6	7	7	2	3	6	6
Average		5.25	5.50	5.13	5.06	4.78	4.84	5.56	5.72	3.09	3.25	4.53	4.41
SD		1.63	1.55	1.48	1.63	1.62	1.55	1.46	1.40	1.35	1.41	1.57	1.58

(b) SB food

Group	Participant No.	SB crops				SB microbes				SB animals			
		Reduced inputs		Enhanced nutrition		Food additives		Bioremediation		Pest management		Improved immunity	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
A	A1	6	7	6	4	5	6	4	6	4	7	5	7
	A2	7	7	3	2	7	6	7	7	6	5	2	3
	A3	2	3	3	3	7	5	7	4	1	1	2	3
	A4	4	4	3	6	5	5	7	7	4	4	6	6
	A5	5	5	5	5	3	5	6	6	6	6	3	5

	A6	6	5	5	5	5	5	5	5	3	3	1	3
	A7	6	5	6	6	5	6	6	5	1	1	5	5
	B1	5	5	7	7	6	7	7	7	4	4	3	4
	B2	5	6	5	7	5	6	7	7	6	6	6	5
B	B3	7	7	5	6	5	5	7	7	7	6	5	6
	B4	5	7	4	5	5	5	7	7	5	5	4	5
	B5	5	5	2	6	2	6	6	6	2	2	3	5
	C1	6	6	3	3	6	6	6	6	5	5	5	3
	C2	6	6	6	7	7	7	7	7	6	6	6	6
C	C3	7	3	3	6	5	5	5	5	6	6	7	7
	C4	2	5	2	6	5	5	3	5	6	5	5	5
	C5	7	7	4	6	5	5	4	5	4	4	2	3
	D1	4	2	2	2	2	4	6	6	4	3	2	4
	D2	4	4	4	4	4	4	5	5	4	5	4	5
D	D3	5	5	2	3	1	3	5	5	2	2	4	4
	D4	2	5	3	5	5	3	5	5	5	5	3	5
	D5	4	4	3	4	4	4	7	7	7	7	4	4
	E1	7	7	7	7	7	7	7	7	3	3	7	7
	E2	2	5	4	3	3	3	7	6	3	3	3	5
E	E3	5	6	5	6	6	6	6	7	5	5	3	5
	E4	5	5	3	2	5	5	7	6	5	6	5	6
	E5	3	5	3	5	2	2	5	5	3	2	3	5
	F1	7	7	4	4	4	4	7	7	7	7	4	4
F	F3	2	2	2	3	2	3	5	3	2	3	2	3
	F4	6	5	4	4	4	4	7	5	4	4	3	3

F5	6	5	2	6	4	3	7	7	2	1	5	5
F6	6	6	2	3	6	5	7	6	3	3	5	6
Average	4.97	5.19	3.81	4.72	4.59	4.84	6.06	5.91	4.22	4.22	3.97	4.75
SD	1.66	1.40	1.51	1.59	1.60	1.30	1.13	1.06	1.74	1.81	1.56	1.24

Appendix C. GM survey materials and data

	GM applied to food production		
Brief introduction to GM technology	GM technology inserts gene fragments of other organisms into the genome of a certain organism, so that the organism can acquire new characteristics or functions. It has been widely used in different fields, including agricultural food production.		
Prior attitudes towards GM food	GM applied to food production is acceptable to me. GM applied to food production is goof for society. GM applied to food production should be encouraged.		
	GM yeasts	**GM soybeans**	**GM pigs**
	By inserting genes from other microorganisms into the yeast genome, GM yeasts capable of producing vitamins can be obtained. After production, these vitamins can be used as dietary supplements and food additives.	By inserting a certain microorganism's gene into the soybean genome, GM soybeans can gain the ability to resist pests.	By transferring part of the mouse genes into the pig genome, it is possible to obtain transgenic pigs that are less likely to get sick in cold conditions and grow more lean meat than ordinary pigs.
Affect	What is the first thought or image that comes to your mind after you read information about this application? Do you think your first thought or image of this application is positive or negative?		
Perceived benefits	The quality of vitamins produced by GM yeasts is sufficiently high. The vitamins produced by GM yeasts are safe enough to take. GM yeast can provide consumers with cheap vitamins. The vitamins produced by GM yeasts can improve the nutritional level of our food. <u>GM yeasts can reduce environmental pollution caused by chemical synthesis of vitamins.</u> All in all, using GM yeasts to produce vitamins will bring many benefits.	GM soybeans can reduce the use of pesticides in ordinary soybeans. GM soybeans can improve food safety. GM soybeans reduce environmental pollution by reducing the use of pesticides. GM soybeans can provide consumers with cheaper products. All in all, GM insect-resistant soybeans will bring many benefits.	GM pigs can reduce the use of veterinary drugs. GM pigs can improve food safety. GM pigs can reduce environmental pollution caused by the use of veterinary drugs. GM pigs can grow more lean meat without feeding clenbuterol to meet consumer demand. All in all, GM pigs will bring many benefits.
Perceptions of tampering with nature	Using GM technology to create this GM yeast tampers with nature.	Using GM technology to create this GM soybean tampers with nature.	Using GM technology to create this GM pig tampers with nature.
Perceived unnaturalness	The vitamins produced by GM yeasts are unnatural.	Foods processed with GM soybeans are not natural.	Genetically modified pork is not natural.
Perceived risks	GM yeasts may have a negative impact on the environment. Taking vitamins produced by GM yeasts may have a negative impact on human health. GM yeasts may bring other unknown troubles to society. GM yeasts will benefit food companies, not ordinary consumers. All in all, the use of GM yeasts to produce vitamins poses a high risk.	GM soybeans may have a negative impact on the environment. Eating GM soybeans may be harmful to health. GM soybeans may bring some unknown troubles to society. GM soybeans are mainly to benefit farmers and food companies, not ordinary consumers. All in all, GM insect-	GM pigs themselves may have new health problems. GM pigs may have a negative impact on the environment. Eating genetically modified pork may have a negative impact on human health. GM pigs may bring other unknown troubles to society. GM pigs mainly benefit farmers and food companies, not ordinary consumers. I am worried that people may use this technology to transform humans.

		resistant soybeans pose a high risk.	All in all, GM pigs pose a high risk.
Application acceptance	The GM yeasts used to produce vitamins is acceptable to me. I would consider eating foods containing vitamins produced by GM yeasts. I would consider buying foods containing vitamins produced by GM yeasts.	GM soybeans are acceptable to me. I will consider eating foods processed with GM soybeans. I will consider buying food processed with GM soybeans.	GM pigs are acceptable to me. I will consider eating foods made from genetically modified pork. I will consider buying products made from genetically modified pork.

Table A. GM questionnaire

Note: The underlined item was removed due to the internal inconsistency problem.

(Table B1)

GM yeast	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.843	0.712	0.797	0.881
	PA2		0.828			
	PA3		0.859			
Perceived benefit	PB1	Reflective	0.757	0.534	0.781	0.851
	PB2		0.733			
	PB3		0.648			
	PB4		0.741			
	PB6		0.769			
Perceived risk	PR1	Reflective	0.718	0.538	0.785	0.853
	PR2		0.760			
	PR3		0.718			
	PR4		0.692			
	PR5		0.775			
Acceptance of the application	AA1	Reflective	0.825	0.681	0.766	0.865
	AA2		0.811			
	AA3		0.839			

(Table B2)

GM soybean	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.844	0.712	0.797	0.881
	PA2		0.829			
	PA3		0.857			
Perceived benefit	PB1	Reflective	0.731	0.515	0.765	0.841
	PB2		0.739			
	PB3		0.707			
	PB4		0.650			
	PB5		0.757			

	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Perceived risk	PR1	Reflective	0.758	0.562	0.805	0.865
	PR2		0.764			
	PR3		0.740			
	PR4		0.714			
	PR5		0.771			
Acceptance of the application	AA1	Reflective	0.839	0.706	0.792	0.878
	AA2		0.843			
	AA3		0.839			

(Table B3)

GM pig	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.834	0.711	0.797	0.880
	PA2		0.820			
	PA3		0.874			
Perceived benefit	PB1	Reflective	0.725	0.555	0.801	0.861
	PB2		0.779			
	PB3		0.679			
	PB4		0.734			
	PB5		0.801			
Perceived risk	PR1	Reflective	0.734	0.543	0.859	0.892
	PR2		0.742			
	PR3		0.787			
	PR4		0.746			
	PR5		0.687			
	PR6		0.685			
	PR7		0.772			
Acceptance of the application	AA1	Reflective	0.865	0.744	0.828	0.897
	AA2		0.860			
	AA3		0.863			

Table B. Internal consistency reliability, indicator reliability, and convergent validity of measurement models

***Note*:** PA = prior attitudes towards GM food; PB = perceived benefit of the application; PR = perceived risk of the application; and AA = acceptance of the application.

(Table C1)

a. Indicator Item Cross Loadings

GM yeast	PA	Affect	PU	PTN	PB	PR	AA
PA1	**0.843**	0.357	-0.249	-0.226	0.484	-0.316	0.514
PA2	**0.828**	0.365	-0.197	-0.231	0.486	-0.289	0.468
PA3	**0.859**	0.377	-0.238	-0.231	0.531	-0.315	0.523
Affect	0.434	**1**	-0.238	-0.239	0.592	-0.373	0.53
PU	-0.271	-0.238	**1**	0.439	-0.288	0.575	-0.276

PTN	-0.272	-0.239	0.439	**1**	-0.231	0.567	-0.249
PB1	0.435	0.5	-0.181	-0.178	**0.757**	-0.276	0.54
PB2	0.429	0.423	-0.27	-0.178	**0.732**	-0.306	0.512
PB3	0.383	0.339	-0.115	-0.117	**0.648**	-0.236	0.443
PB4	0.453	0.447	-0.235	-0.168	**0.741**	-0.307	0.493
PB6	0.465	0.441	-0.24	-0.197	**0.769**	-0.295	0.541
PR1	-0.223	-0.236	0.394	0.394	-0.247	**0.718**	-0.246
PR2	-0.272	-0.3	0.439	0.389	-0.32	**0.76**	-0.356
PR3	-0.232	-0.265	0.414	0.405	-0.233	**0.718**	-0.272
PR4	-0.289	-0.235	0.431	0.414	-0.281	**0.692**	-0.309
PR5	-0.309	-0.322	0.428	0.473	-0.334	**0.775**	-0.352
AA1	0.51	0.465	-0.232	-0.204	0.604	-0.361	**0.825**
AA2	0.462	0.419	-0.218	-0.163	0.548	-0.334	**0.812**
AA3	0.5	0.426	-0.233	-0.247	0.563	-0.35	**0.839**

b. Fornell-Larcker Criterion

GM yeast	AA	Affect	PB	PA	PR	PTN	PU
AA	**0.825**						
Affect	0.53	**1**					
PB	0.694	0.592	**0.731**				
PA	0.595	0.434	0.594	**0.844**			
PR	-0.423	-0.373	-0.39	-0.364	**0.733**		
PTN	-0.249	-0.239	-0.231	-0.272	0.567	**1**	
PU	-0.276	-0.238	-0.288	-0.271	0.575	0.439	**1**

c. Heterotrait-Monotrait Ratio

GM yeast	PA	Affect	PU	PTN	PB	PR	AA
PA							
Affect	0.486						
PU	0.303	0.238					
PTN	0.304	0.239	0.439				
PB	0.751	0.666	0.323	0.26			
PR	0.456	0.418	0.649	0.639	0.492		
AA	0.76	0.605	0.315	0.284	0.894	0.539	

(Table C2)

a. Indicator Item Cross Loadings

GM soybean	PA	Affect	PU	PTN	PB	PR	AA
PA1	**0.845**	0.364	-0.225	-0.258	0.480	-0.330	0.523
PA2	**0.829**	0.357	-0.202	-0.228	0.458	-0.324	0.488
PA3	**0.857**	0.413	-0.231	-0.242	0.485	-0.324	0.518
Affect	0.449	**1.000**	-0.299	-0.317	0.611	-0.442	0.583
PU	-0.261	-0.299	**1.000**	0.481	-0.224	0.567	-0.325
PTN	-0.288	-0.317	0.481	**1.000**	-0.260	0.580	-0.328

PB1	0.370	0.454	-0.131	-0.179	**0.731**	-0.250	0.474
PB2	0.458	0.468	-0.227	-0.198	**0.739**	-0.315	0.580
PB3	0.353	0.408	-0.131	-0.197	**0.707**	-0.248	0.470
PB4	0.357	0.344	-0.072	-0.123	**0.650**	-0.194	0.404
PB5	0.462	0.496	-0.210	-0.223	**0.757**	-0.369	0.557
PR1	-0.246	-0.311	0.401	0.426	-0.281	**0.758**	-0.305
PR2	-0.342	-0.326	0.434	0.427	-0.315	**0.764**	-0.341
PR3	-0.266	-0.305	0.455	0.447	-0.225	**0.740**	-0.304
PR4	-0.272	-0.336	0.424	0.425	-0.293	**0.714**	-0.331
PR5	-0.314	-0.374	0.414	0.448	-0.344	**0.771**	-0.412
AA1	0.509	0.527	-0.291	-0.294	0.601	-0.370	**0.839**
AA2	0.490	0.479	-0.251	-0.264	0.585	-0.389	**0.843**
AA3	0.524	0.461	-0.277	-0.267	0.580	-0.387	**0.839**

b. Fornell-Larcker Criterion

GM soybean	AA	Affect	PA	PB	PR	PTN	PU
AA	**0.84**						
Affect	0.583	**1**					
PA	0.604	0.449	**0.844**				
PB	0.7	0.611	0.563	**0.718**			
PR	-0.454	-0.442	-0.386	-0.392	**0.75**		
PTN	-0.328	-0.317	-0.288	-0.26	0.58	**1**	
PU	-0.325	-0.299	-0.261	-0.224	0.567	0.481	**1**

c. Heterotrait-Monotrait Ratio

GM soybean	AA	Affect	PA	PB	PR	PTN	PU
AA							
Affect	0.654						
PA	0.76	0.502					
PB	0.889	0.691	0.713				
PR	0.565	0.491	0.48	0.485			
PTN	0.368	0.317	0.322	0.293	0.646		
PU	0.365	0.299	0.291	0.245	0.633	0.481	

(Table C3)

a. Indicator Item Cross Loadings

GM pig	PA	Affect	PU	PTN	PB	PR	AA
PA1	**0.834**	0.325	-0.201	-0.147	0.377	-0.254	0.356
PA2	**0.820**	0.302	-0.156	-0.164	0.368	-0.227	0.364
PA3	**0.874**	0.389	-0.220	-0.184	0.452	-0.275	0.451
Affect	0.405	**1.000**	-0.429	-0.375	0.617	-0.502	0.656
PU	-0.230	-0.429	**1.000**	0.500	-0.318	0.646	-0.450
PTN	-0.197	-0.375	0.500	**1.000**	-0.300	0.620	-0.389
PB1	0.295	0.415	-0.199	-0.166	**0.725**	-0.260	0.428

PB2	0.402	0.517	-0.320	-0.307	**0.779**	-0.406	0.630
PB3	0.304	0.352	-0.179	-0.133	**0.679**	-0.241	0.365
PB4	0.347	0.441	-0.171	-0.180	**0.734**	-0.273	0.478
PB5	0.403	0.532	-0.279	-0.281	**0.801**	-0.369	0.600
PR1	-0.245	-0.395	0.474	0.472	-0.323	**0.734**	-0.404
PR2	-0.216	-0.344	0.461	0.448	-0.299	**0.741**	-0.348
PR3	-0.251	-0.410	0.538	0.496	-0.359	**0.787**	-0.437
PR4	-0.185	-0.372	0.490	0.445	-0.330	**0.746**	-0.416
PR5	-0.234	-0.325	0.434	0.422	-0.284	**0.687**	-0.344
PR6	-0.170	-0.316	0.438	0.423	-0.250	**0.685**	-0.322
PR7	-0.244	-0.415	0.490	0.484	-0.344	**0.772**	-0.436
AA1	0.437	0.609	-0.404	-0.352	0.610	-0.464	**0.865**
AA2	0.372	0.553	-0.367	-0.313	0.588	-0.444	**0.860**
AA3	0.396	0.532	-0.393	-0.342	0.585	-0.458	**0.863**

b. Fornell-Larcker Criterion

GM pig	**AA**	**Affect**	**PA**	**PB**	**PR**	**PTN**	**PU**
AA	**0.862**						
Affect	0.656	**1.000**					
PA	0.467	0.405	**0.843**				
PB	0.689	0.617	0.477	**0.745**			
PR	-0.528	-0.502	-0.301	-0.428	**0.737**		
PTN	-0.389	-0.375	-0.197	-0.300	0.620	**1.000**	
PU	-0.450	-0.429	-0.230	-0.318	0.646	0.500	**1.000**

c. Heterotrait-Monotrait Ratio

GM pig	**AA**	**Affect**	**PA**	**PB**	**PR**	**PTN**	**PU**
AA							
Affect	0.719						
PA	0.568	0.450					
PB	0.822	0.676	0.583				
PR	0.622	0.539	0.360	0.498			
PTN	0.427	0.375	0.219	0.319	0.668		
PU	0.494	0.429	0.255	0.344	0.695	0.500	

Table C. Discriminant validity of measurement models

Note: PA = prior attitudes towards GM food; PB = perceived benefit of the application; PR = perceived risk of the application; PTN = perceptions of tampering with nature; PU = perceived unnaturalness; and AA = acceptance of the application.

	GM yeast	GM soybean	GM pig
SRMR	0.052	0.056	0.053

Table D. standardised root mean square residual (SRMR) of the model across applications

(E1)

GM yeast	**AA**	**Affect**	**PA**	**PB**	**PR**	**PTN**	**PU**
AA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Affect	1.615	0.000	0.000	1.319	1.268	1.232	1.257
PA	1.625	1.000	0.000	1.322	1.300	1.232	1.279
PB	2.007	0.000	0.000	0.000	0.000	0.000	0.000
PR	2.014	0.000	0.000	1.994	0.000	0.000	0.000
PTN	1.529	0.000	0.000	1.525	1.290	0.000	1.101
PU	1.550	0.000	0.000	1.544	1.289	0.000	0.000

(E2)

GM soybean	**AA**	**Affect**	**PA**	**PB**	**PR**	**PTN**	**PU**
AA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Affect	1.761	0.000	0.000	1.408	1.339	1.252	1.315
PA	1.563	1.000	0.000	1.330	1.299	1.252	1.290
PB	1.933	0.000	0.000	0.000	0.000	0.000	0.000
PR	2.035	0.000	0.000	2.015	0.000	0.000	0.000
PTN	1.601	0.000	0.000	1.601	1.379	0.000	1.145
PU	1.562	0.000	0.000	1.558	1.352	0.000	0.000

(E3)

GM pig	**AA**	**Affect**	**PA**	**PB**	**PR**	**PTN**	**PU**
AA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Affect	1.895	0.000	0.000	1.519	1.443	1.196	1.342
PA	1.336	1.000	0.000	1.215	1.203	1.196	1.200
PB	1.830	0.000	0.000	0.000	0.000	0.000	0.000
PR	2.372	0.000	0.000	2.339	0.000	0.000	0.000
PTN	1.679	0.000	0.000	1.678	1.393	0.000	1.167
PU	1.805	0.000	0.000	1.804	1.470	0.000	0.000

Table E. Inner variance inflation factor (VIF) values

Note: PA = prior attitudes towards GM food; PB = perceived benefit of the application; PR = perceived risk of the application; PTN = perceptions of tampering with nature; PU = perceived unnaturalness; and AA = acceptance of the application.

Constructs	GM yeast		GM soybean		GM pig	
	R^2	Q^2	R^2	Q^2	R^2	Q^2
Affect	0.189	0.185	0.201	0.198	0.164	0.162
PU	0.224	0.216	0.260	0.256	0.318	0.315
PTN	0.092	0.088	0.127	0.123	0.142	0.138
PB	0.502	0.265	0.483	0.243	0.452	0.244
PR	0.498	0.264	0.504	0.280	0.571	0.307
AA	0.560	0.375	0.595	0.415	0.605	0.447

Table F. Predictive power and relevance of the model across applications

Note: PA = prior attitudes towards GM food; PB = perceived benefit of the application; PR = perceived risk of the application; PTN = perceptions of tampering with nature; PU = perceived unnaturalness; and AA = acceptance of the application.

Appendix D. SB survey materials and data

	GM applied to food production		
Brief introduction to GM	GM technology inserts gene fragments of other organisms into the genome of a certain organism, so that the organism can acquire new characteristics or functions. It has been widely used in different fields, including agricultural food production.		
Prior attitudes towards GM food	GM applied to food production is acceptable to me. GM applied to food production is good for society. GM applied to food production should be encouraged.		
	SB applied to food production		
Brief introduction to SB	SB uses engineering principles to artificially synthesize various genes and assemble them into fixed genetic parts, which can then be inserted into different organisms' genomes to allow them to acquire new functions. Some scientists can even use SB to artificially synthesize entire microorganisms (such as bacteria) from scratch. SB has been widely used in different fields, including agricultural food production.		
General attitudes towards SB food	SB applied to food production is acceptable to me. SB applied to food production is good for society. SB applied to food production should be encouraged.		
	SB yeasts	**SB soybeans**	**SB pigs**
Introduction to SB applications	By synthesizing and assembling the genes of different milk proteins, and then transferring them into the yeast genome, a synthetic yeast that can produce milk proteins is obtained. The milk protein produced is added with other ingredients to obtain a new type of lactose-free milk.	By synthesizing and assembling different genes, and then inserting them into the soybean genome, the drought-resistant soybeans are obtained. These soybeans can maintain yield even when the temperature rises, and the supply of fresh water is insufficient.	By synthesizing and assembling different genes and inserting them into the genome of pigs, a synthetic pig with improved immunity can be obtained.
Affect	What is the first thought or image that comes to your mind after you read information about this application? Do you think your first thought or image of this application are positive or negative?		
Perceived benefits	Using synthetic yeasts to produce milk can avoid veterinary drug residues in traditional dairy products. Using synthetic yeasts to produce milk can improve the safety of dairy products. Milk produced by synthetic yeasts can benefit consumers who suffer from lactose intolerance. Using synthetic yeasts to produce milk can reduce land use and carbon dioxide emissions, thereby benefiting the environment. Using synthetic yeasts to produce milk can reduce intensive dairy farming, thereby improving animal welfare. All in all, there are many benefits to using synthetic yeasts to produce milk.	Synthetic soybeans can reduce the consumption of fresh water resources. Synthetic soybeans can ensure a stable food supply in arid climates. Synthetic soybeans can reduce the negative impact of agricultural production on the environment. Synthetic soybeans can provide consumers with cheaper soybean products. All in all, synthetic soybeans will bring many benefits.	Synthetic pigs can effectively reduce the use of veterinary drugs. Synthetic pigs can improve food safety. Synthetic pigs can reduce environmental pollution caused by the use of veterinary drugs. Synthetic pigs can reduce veterinary drug residues, thereby providing consumers with safer pork. Synthetic pigs with improved immunity can benefit the welfare of farm animals. All in all, synthetic pigs will bring many benefits.

Perceptions of tampering with nature	Using SB to create the yeast for milk production tampers with nature.	Using SB to create the drought-resistance soybean tampers with nature.	Using SB to create the pig with improved immune function tampers with nature.
Perceived unnaturalness	The milk produced by synthetic yeasts is not natural.	Foods processed with synthetic soybeans are not natural.	The meat of synthetic pigs is not natural.
Perceived risks	The new milk produced by synthetic yeasts may be nutritionally insufficient. Drinking milk produced by synthetic yeasts can negatively affect health. The release of synthetic yeasts into the environment may cause ecological problems. The production of milk by synthetic yeasts may bring some unknown troubles to society. Artificial milk is mainly beneficial to food companies, not ordinary consumers. All in all, there is a high risk of using synthetic yeasts to produce milk.	Synthetic soybeans may have a negative impact on the environment. Eating synthetic soy products may have a negative impact on human health. Synthetic soybeans may cause some unknown troubles to society. Synthetic soybeans mainly benefit food companies, not ordinary consumers. All in all, synthetic soybeans pose a high risk.	Synthetic pigs may have some new health problems. Synthetic pigs may cause some negative effects on the environment. Eating synthetic pork may have a negative impact on human health. Synthetic pigs may bring some other unknown troubles to society. Synthetic pigs are mainly beneficial to food companies, not ordinary consumers. I am worried that someone might use this technology to transform humans. All in all, synthetic pigs pose a high risk.
Application acceptance	Using synthetic yeasts to produce milk is acceptable to me. I will consider drinking the milk produced by synthetic yeasts. I will consider buying the milk produced by synthetic yeasts.	Synthetic drought-resistant soybeans are acceptable to me. I would consider consuming foods processed with synthetic drought-resistant soybeans. I would consider buying processed foods made of synthetic drought-resistant soybeans.	Synthetic pigs with stronger immunity are acceptable to me. I would consider eating meat products made from synthetic pigs. I will consider buying meat products made from synthetic pigs.
Food technology neophobia	New foods are not healthier than traditional foods; The benefits of new food technologies are often grossly overstated; There are plenty of tasty foods around, so we do not need to use new food technologies to produce more; New food technologies decrease the natural quality of food; New food technologies are unlikely to have long term negative health effects; New food technologies may have long term negative environmental effects; It can be risky to switch to new food technologies too quickly; Society should not depend heavily on technologies to solve its food problems; There is no sense trying out high-tech food products because the ones I eat are already good enough.		
New Ecological Paradigm Scale	**Moralistic Worldview**: Humans must live in harmony with nature in order to survive; The balance of nature is very delicate and easily upset; When humans interfere with nature, it often produces disastrous consequences. **Dominionistic Worldview**: Humans have the right to modify the natural environment; Humankind was created to rule over the rest of nature; Plants and animals exist primarily to be used by humans.		

Table A. SB questionnaire

Note: The underlined items were removed due to the internal inconsistency problem.

(Table B1)

SB yeasts	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.797	0.637	0.716	0.841
	PA2		0.795			
	PA3		0.803			
General attitudes towards SB applied to food production	GA1	Reflective	0.838	0.703	0.788	0.876
	GA2		0.818			
	GA3		0.858			
Perceived benefits	PB1	Reflective	0.716	0.521	0.770	0.844
	PB2		0.770			
	PB3		0.679			
	PB5		0.685			
	PB6		0.756			
Perceived risks	PR1	Reflective	0.652	0.504	0.802	0.859
	PR2		0.769			
	PR3		0.671			
	PR4		0.740			
	PR5		0.668			
	PR6		0.752			
Application acceptability	AA1	Reflective	0.834	0.699	0.785	0.874
	AA2		0.832			
	AA3		0.842			

(Table B2)

SB soybeans	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.798	0.637	0.716	0.841
	PA2		0.798			
	PA3		0.799			
General attitudes towards SB applied to food production	GA1	Reflective	0.849	0.703	0.788	0.876
	GA2		0.815			
	GA3		0.850			
Perceived benefits	PB1	Reflective	0.748	0.522	0.695	0.813
	PB2		0.698			
	PB3		0.664			
	PB5		0.774			
Perceived risks	PR1	Reflective	0.742	0.554	0.799	0.861
	PR2		0.779			
	PR3		0.737			
	PR4		0.703			
	PR5		0.759			
Acceptance of the application	AA1	Reflective	0.831	0.692	0.778	0.871
	AA2		0.822			
	AA3		0.843			

(Table B3)

SB pigs	Items	Type	Loadings	AVE	Cronbach's alpha	CR
Prior attitudes towards GM food	PA1	Reflective	0.784	0.637	0.716	0.841
	PA2		0.789			
	PA3		0.812			
General attitudes towards SB applied to food production	GA1	Reflective	0.833	0.703	0.788	0.876
	GA2		0.817			
	GA3		0.864			
Perceived benefits	PB1	Reflective	0.715	0.535	0.827	0.873
	PB2		0.772			
	PB3		0.679			
	PB4		0.744			
	PB5		0.691			
	PB6		0.782			
Perceived risks	PR1	Reflective	0.764	0.549	0.862	0.895
	PR2		0.752			
	PR3		0.778			
	PR4		0.762			
	PR5		0.651			
	PR6		0.690			
	PR7		0.781			
Acceptance of the application	AA1	Reflective	0.861	0.746	0.830	0.898
	AA2		0.863			
	AA3		0.868			

Table B. Internal consistency reliability, indicator reliability, and convergent validity of measurement models

Note: **p* < 0.05; ***p* < 0.01; ****p* < 0.001.

(Table C1)

a. **Indicator Item Cross Loadings**

SB yeast	PA	GA	Affect	PU	PTN	PB	PR	AA
PA1	**0.797**	0.404	0.187	-0.226	-0.252	0.357	-0.268	0.404
PA2	**0.795**	0.416	0.157	-0.190	-0.155	0.301	-0.236	0.360
PA3	**0.803**	0.449	0.239	-0.229	-0.235	0.349	-0.296	0.382
GA1	0.433	**0.838**	0.191	-0.202	-0.235	0.458	-0.256	0.449
GA2	0.434	**0.818**	0.206	-0.147	-0.212	0.437	-0.199	0.428
GA3	0.465	**0.858**	0.227	-0.195	-0.216	0.472	-0.270	0.470
Affect	0.245	0.248	**1.000**	-0.193	-0.148	0.316	-0.263	0.387
PU	-0.269	-0.217	-0.193	**1.000**	0.409	-0.222	0.597	-0.356
PTN	-0.269	-0.264	-0.148	0.409	**1.000**	-0.257	0.547	-0.300

PB1	0.271	0.389	0.232	-0.115	-0.146	**0.715**	-0.207	0.443
PB2	0.322	0.435	0.252	-0.191	-0.226	**0.770**	-0.283	0.513
PB3	0.280	0.356	0.202	-0.151	-0.174	**0.679**	-0.196	0.416
PB5	0.271	0.347	0.205	-0.114	-0.150	**0.685**	-0.173	0.424
PB6	0.364	0.426	0.246	-0.216	-0.220	**0.756**	-0.276	0.539
PR1	-0.180	-0.145	-0.141	0.426	0.311	-0.196	**0.652**	-0.270
PR2	-0.278	-0.238	-0.215	0.470	0.457	-0.291	**0.769**	-0.360
PR3	-0.215	-0.175	-0.241	0.416	0.375	-0.145	**0.671**	-0.273
PR4	-0.219	-0.193	-0.191	0.447	0.372	-0.213	**0.740**	-0.334
PR5	-0.252	-0.219	-0.142	0.360	0.374	-0.262	**0.668**	-0.328
PR6	-0.272	-0.250	-0.188	0.423	0.427	-0.238	**0.752**	-0.341
AA1	0.416	0.457	0.319	-0.268	-0.248	0.566	-0.371	**0.834**
AA2	0.411	0.454	0.338	-0.315	-0.237	0.510	-0.377	**0.832**
AA3	0.374	0.434	0.313	-0.310	-0.268	0.558	-0.380	**0.842**

b. Fornell-Larcker Criterion

SB yeast	AA	Affect	GA	PA	PB	PR	PTN	PU
AA	**0.836**							
Affect	0.387	**1.000**						
GA	0.536	0.248	**0.838**					
PA	0.479	0.245	0.530	**0.798**				
PB	0.651	0.316	0.544	0.421	**0.722**			
PR	-0.450	-0.263	-0.290	-0.335	-0.319	**0.710**		
PTN	-0.300	-0.148	-0.264	-0.269	-0.257	0.547	**1.000**	
PU	-0.356	-0.193	-0.217	-0.269	-0.222	0.597	0.409	**1.000**

c. Heterotrait-Monotrait Ratio

SB yeast	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	0.437							
GA	0.681	0.279						
PA	0.639	0.288	0.705					
PB	0.831	0.359	0.694	0.562				
PR	0.564	0.293	0.359	0.438	0.395			
PTN	0.339	0.148	0.297	0.317	0.289	0.607		
PU	0.402	0.193	0.243	0.318	0.248	0.667	0.409	

(Table C2)

a. Indicator Item Cross Loadings

SB soybean	PA	GA	Affect	PU	PTN	PB	PR	AA
PA1	**0.798**	0.405	0.264	-0.218	-0.238	0.318	-0.272	0.381
PA2	**0.798**	0.416	0.256	-0.175	-0.216	0.303	-0.250	0.347
PA3	**0.799**	0.447	0.234	-0.234	-0.149	0.317	-0.256	0.337
GA1	0.433	**0.845**	0.326	-0.190	-0.231	0.418	-0.302	0.463
GA2	0.435	**0.818**	0.334	-0.127	-0.189	0.373	-0.255	0.395

GA3	0.464	**0.852**	0.313	-0.192	-0.202	0.418	-0.275	0.409
Affect	0.314	0.387	**1.000**	-0.257	-0.270	0.541	-0.377	0.540
PU	-0.262	-0.204	-0.257	**1.000**	0.484	-0.234	0.582	-0.335
PTN	-0.252	-0.248	-0.270	0.484	**1.000**	-0.265	0.626	-0.344
PB1	0.281	0.315	0.432	-0.141	-0.173	**0.745**	-0.208	0.452
PB2	0.201	0.323	0.336	-0.151	-0.168	**0.695**	-0.162	0.420
PB3	0.221	0.284	0.342	-0.147	-0.154	**0.663**	-0.194	0.411
PB5	0.393	0.445	0.438	-0.225	-0.254	**0.779**	-0.318	0.553
PR1	-0.224	-0.232	-0.238	0.448	0.482	-0.235	**0.742**	-0.314
PR2	-0.240	-0.246	-0.310	0.484	0.496	-0.221	**0.780**	-0.358
PR3	-0.215	-0.195	-0.222	0.422	0.462	-0.167	**0.738**	-0.275
PR4	-0.249	-0.270	-0.318	0.406	0.422	-0.217	**0.705**	-0.349
PR5	-0.277	-0.286	-0.308	0.402	0.465	-0.320	**0.756**	-0.370
AA1	0.365	0.420	0.483	-0.248	-0.264	0.576	-0.328	**0.827**
AA2	0.377	0.430	0.416	-0.288	-0.283	0.490	-0.405	**0.826**
AA3	0.369	0.411	0.447	-0.299	-0.312	0.537	-0.391	**0.843**

b. Fornell-Larcker Criterion

SB soybean	AA	Affect	GA	PA	PB	PR	PTN	PU
AA	**0.832**							
Affect	0.540	**1.000**						
GA	0.505	0.387	**0.838**					
PA	0.445	0.314	0.529	**0.798**				
PB	0.643	0.541	0.482	0.392	**0.722**			
PR	-0.450	-0.377	-0.332	-0.325	-0.314	**0.744**		
PTN	-0.344	-0.270	-0.248	-0.252	-0.265	0.626	**1.000**	
PU	-0.335	-0.257	-0.204	-0.262	-0.234	0.582	0.484	**1.000**

c. Heterotrait-Monotrait Ratio

SB soybean	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	0.612							
GA	0.644	0.436						
PA	0.597	0.372	0.705					
PB	0.863	0.642	0.637	0.537				
PR	0.569	0.420	0.415	0.428	0.406			
PTN	0.390	0.270	0.279	0.298	0.310	0.700		
PU	0.380	0.257	0.228	0.309	0.275	0.650	0.484	

(Table C3)

a. Indicator Item Cross Loadings

SB pig	PA	GA	Affect	PU	PTN	PB	PR	AA
PA1	**0.784**	0.403	0.244	-0.132	-0.188	0.324	-0.195	0.333
PA2	**0.798**	0.416	0.277	-0.146	-0.147	0.329	-0.232	0.349
PA3	**0.812**	0.449	0.313	-0.243	-0.237	0.380	-0.272	0.386

GA1	0.432	**0.833**	0.289	-0.191	-0.212	0.394	-0.231	0.404
GA2	0.435	**0.819**	0.319	-0.170	-0.154	0.407	-0.184	0.389
GA3	0.466	**0.862**	0.339	-0.206	-0.227	0.428	-0.270	0.440
Affect	0.350	0.377	**1.000**	-0.390	-0.351	0.624	-0.510	0.679
PU	-0.220	-0.226	-0.390	**1.000**	0.499	-0.336	0.631	-0.409
PTN	-0.241	-0.237	-0.351	0.499	**1.000**	-0.317	0.597	-0.379
PB1	0.286	0.332	0.420	-0.153	-0.169	**0.715**	-0.235	0.444
PB2	0.322	0.390	0.532	-0.353	-0.305	**0.772**	-0.415	0.595
PB3	0.281	0.273	0.340	-0.154	-0.119	**0.679**	-0.218	0.410
PB4	0.314	0.381	0.493	-0.289	-0.245	**0.745**	-0.361	0.527
PB5	0.294	0.339	0.402	-0.141	-0.196	**0.691**	-0.252	0.463
PB6	0.388	0.405	0.509	-0.318	-0.307	**0.782**	-0.393	0.590
PR1	-0.203	-0.198	-0.406	0.514	0.459	-0.330	**0.764**	-0.392
PR2	-0.194	-0.172	-0.379	0.472	0.450	-0.335	**0.752**	-0.364
PR3	-0.228	-0.229	-0.404	0.523	0.445	-0.340	**0.778**	-0.400
PR4	-0.220	-0.177	-0.386	0.465	0.454	-0.314	**0.763**	-0.397
PR5	-0.217	-0.211	-0.321	0.419	0.422	-0.347	**0.651**	-0.368
PR6	-0.197	-0.206	-0.318	0.394	0.399	-0.285	**0.690**	-0.328
PR7	-0.261	-0.228	-0.417	0.475	0.462	-0.329	**0.780**	-0.428
AA1	0.419	0.431	0.613	-0.357	-0.347	0.631	-0.446	**0.862**
AA2	0.359	0.416	0.577	-0.361	-0.327	0.585	-0.456	**0.862**
AA3	0.378	0.425	0.569	-0.342	-0.307	0.596	-0.439	**0.868**

b. Fornell-Larcker Criterion

SB pig	AA	Affect	GA	PA	PB	PR	PTN	PU
AA	**0.864**							
Affect	0.679	**1.000**						
GA	0.491	0.377	**0.838**					
PA	0.447	0.350	0.531	**0.798**				
PB	0.700	0.624	0.489	0.432	**0.732**			
PR	-0.518	-0.510	-0.274	-0.294	-0.440	**0.741**		
PTN	-0.379	-0.351	-0.237	-0.241	-0.317	0.597	**1.000**	
PU	-0.409	-0.390	-0.226	-0.220	-0.336	0.631	0.499	**1.000**

c. Heterotrait-Monotrait Ratio

SB pig	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	0.745							
GA	0.605	0.424						
PA	0.577	0.412	0.705					
PB	0.831	0.675	0.597	0.556				
PR	0.611	0.548	0.33	0.371	0.505			
PTN	0.415	0.351	0.266	0.282	0.335	0.642		
PU	0.449	0.39	0.254	0.257	0.352	0.678	0.499	

Table C. Discriminant validity of measurement models

Note: PA = prior attitudes towards GM food; GA = general attitudes towards SB applied to food production; PB = perceived benefits of the application; PR = perceived risks of the application; PTN = perceptions of tampering with nature; PU = perceived unnaturalness; and AA = acceptance of the application.

	SB yeast	SB soybean	SB pig
SRMR	0.052	0.057	0.052

Table D. standardised root mean square residual (SRMR) of the model across applications

(Table E1)

SB yeast	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	1.161				1.114	1.091	1.066	1.074
GA	1.692	1.000			1.134	1.139	1.066	1.129
PA	1.512		1.000					
PB	1.563							
PR	1.708				1.658			
PTN						1.250		1.083
PU	1.568				1.560	1.238		

(Table E2)

SB soybean	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	1.540				1.284	1.241	1.176	1.222
GA	1.635	1.000			1.234	1.211	1.176	1.207
PA	1.488		1.000					
PB	1.650							
PR	1.720				1.708			
PTN						1.366		1.108
PU	1.532				1.515	1.339		

(Table E3)

SB pig	AA	Affect	GA	PA	PB	PR	PTN	PU
AA								
Affect	1.870				1.483	1.349	1.166	1.273
GA	1.582	1.000			1.180	1.186	1.166	1.183
PA	1.493		1.000					
PB	1.954							
PR	1.972				1.933			
PTN						1.396		1.157

PU	1.685				1.684	1.435	

Table E. Inner variance inflation factor (VIF) values

Constructs	SB yeast		SB soybean		SB pig	
	R^2	Q^2	R^2	Q^2	R^2	Q^2
GA	0.281	0.196	0.280	0.196	0.282	0.196
Affect	0.062	0.058	0.149	0.149	0.142	0.141
PU	0.192	0.189	0.253	0.248	0.303	0.297
PTN	0.077	0.074	0.097	0.094	0.136	0.133
PB	0.349	0.179	0.384	0.196	0.477	0.249
PR	0.488	0.244	0.532	0.292	0.556	0.303
AA	0.555	0.385	0.542	0.371	0.629	0.464

Table F. Predictive power and relevance of the model across applications

Application	Hypotheses		Before				After			
			β	t values	f^2	95% CI	β	t values	f^2	95% CI
SB yeast	H6a	PA -> AA	0.119***	4.258	0.021	[0.063, 0.172]	0.113***	4.180	0.019	[0.060, 0.166]
	H6b	PA -> GA	0.530***	19.287	0.391	[0.472, 0.581]	0.497***	17.083	0.326	[0.439, 0.554]
SB soybean	H6a	PA -> AA	0.104***	3.900	0.016	[0.050, 0.156]	0.109***	4.026	0.017	[0.053, 0.160]
	H6b	PA -> GA	0.529***	18.734	0.389	[0.470, 0.583]	0.500***	17.261	0.332	[0.411, 0.555]
SB pig	H6a	PA -> AA	0.080***	3.485	0.011	[0.035, 0.125]	0.074**	3.165	0.010	[0.030, 0.122]
	H6b	PA -> GA	0.531***	19.204	0.392	[0.474, 0.582]	0.500***	17.436	0.333	[0.442, 0.555]

Table G. Relationship before and after controlling for variables

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; β = path coefficients; 95% CI = 95% confidence interval; GA = general attitudes towards SB applied to food production; PA = prior attitudes towards GM food; and AA = acceptance of the application.

Hypotheses	Cronbach's alpha	SB yeast				SB soybean				SB pig			
		β	t values	f^2	95% CI	β	t values	f^2	95% CI	β	t values	f^2	95% CI
FTN -> PA	0.797	-0.246**	8.283	0.063	[-0.300, -0.185]	-0.246***	7.846	0.062	[-0.302, -0.178]	-0.249***	8.275	0.065	[-0.304, -0.186]
FTN -> GA		-0.093***	3.300	0.010	[-0.139, -0.029]	-0.096**	3.314	0.012	[-0.150, -0.037]	-0.108***	3.858	0.015	[-0.158, -0.049]
FTN -> AA		-0.022^{ns}	0.867	0.001	[-0.069, 0.028]	**0^{ns}**	0.009	0.000	[-0.047, 0.049]	**0.003^{ns}**	0.129	0.000	[-0.033, 0.046]
MW -> PA	0.719	**0.062^{ns}**	1.053	0.004	[-0.055, 0.140]	**0.038^{ns}**	1.134	0.001	[-0.027, 0.101]	**0.024^{ns}**	0.677	0.000	[-0.040, 0.099]
MW -> GA		**0.089^{ns}**	1.46	0.01	[-0.067, 0.166]	0.123***	4.347	0.017	[0.067, 0.177]	0.113**	3.406	0.015	[0.045, 0.173]
MW -> AA		**0.032^{ns}**	0.84	0.002	[-0.027, 0.104]	**0.002^{ns}**	0.066	0.000	[-0.049, 0.048]	**-0.026^{ns}**	1.163	0.001	[-0.069, 0.019]

DW -> PA		0.168***	5.179	0.028	[0.110, 0.235]	0.173***	5.014	0.025	[0.101, 0.237]	0.154***	4.552	0.020	[0.084, 0.216]
DW -> GA	0.747	0.083*	2.445	0.009	[0.006, 0.138]	0.116***	3.826	0.014	[0.054, 0.173]	0.106***	3.528	0.013	[0.046, 0.164]
DW -> AA		0.048*	1.979	0.004	[0.006, 0.099]	**-0.028**^{ns}	1.230	0.001	[-0.074, 0.016]	0.065**	3.007	0.009	[0.023, 0.107]

Table H. Influence of FTN, MW and DW

Note: $*p < 0.05$; $**p < 0.01$; $***p < 0.001$; β = path coefficients; 95% CI = 95% confidence interval; ns = non-significance; PA = prior attitudes towards GM food; GA = general attitudes towards SB applied to food production; AA = acceptance of the application; FTN = food technology neophobia; MW = moralistic environmental worldview; DW = dominionistic environmental worldview; The β in bold and underlined refers to the rejection of corresponding hypothesis.