Social Dimensions of Synthetic Biology in the Agrifood Sector: The Perspective of Chinese and EU Scientists

Authors

Shan Jin [a]*, Beth Clark [a], Wenjing Li [ab], Sharron Kuznesof [a], Lynn J. Frewer [a]

[a] School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom

[b] School of Economics and Management, Huazhong Agricultural University, 430070, P.R. China

***Corresponding Author**

Name: Shan Jin

Address: Agriculture Building, Newcastle University, Newcastle upon Tyne, NE1 7RU.

Email: s.jin13@newcastle.ac.uk; Tel: +44 (0) 784 923 4549.

Abstract

Purpose

Scientists' perceptions of societal needs and priorities will shape the innovation trajectories of synthetic biology (SB). In turn, these will be shaped by the funding and regulatory environments in which their research is conducted. This study intends to investigate scientists' perspectives on co-innovation with the public regarding the implementation of pathways associated with SB including its agrifood applications.

Design/methodology/approach

Semi-structured interviews were conducted with Chinese and EU scientists (*N*=9 and 13, respectively). Six prominent themes emerged from the interviews using the thematic analysis method.

Findings

Both Chinese and EU scientists regarded SB as being high-benefit, low-risk and ethically acceptable, and predicted its rejection by the general public and attributed this to the public's knowledge deficit and irrationality. They endorsed the deficit model of science communication, independent of greater emphasis on responsible research and innovation (RRI) in EU research projects. The findings raised concerns that public fears might intensify once they have learned about scientists' biased risk perceptions of SB; this calls for better involvement of broader stakeholders.

Research limitations/implications

As the sample size is relatively small, the generalisation of research findings needs to be cautious. However, we believe the findings have provided some insights that support increasingly RRI associated with SB.

Originality/value

This study has presented scientists' misunderstandings of societal responses to SB and science communication. It has also provided information to understand how SB-related issues and agenda can be better shaped in future.

Keywords: Synthetic biology; social dimension; risk uncertainty; deficit model; agrifood.

1. Introduction

It has long been observed that emerging technologies including those within the agrifood 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 agrifood technology development in order to allow the co-production of technological innovations in line with societal priorities and preferences (Li et al., 2020).

Synthetic biology (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 agrifood) (Polizzi, Stanbrough, & Heap, 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).

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 agrifood 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 agrifood technologies, for instance, food products using genetic modification (GM) technology and nanomaterials (Tyagi et al., 2016; van Putten et al., 2006). 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).

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, Biller-Andorno, & Deplazes-Zemp, 2017; Starkbaum, Braun, & Dabrock, 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, Broerse, & Kupper, 2018; Kronberger, Holtz, & Wagner, 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, Mandel, & Kahan, 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.

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 agrifood 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 paper 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:

1) What are scientists’ perceptions of social dimensions pertinent to SB in particular its applications in the agrifood sector? Is the precautionary or proactive principle more in alignment with scientists’ cognitive structures?
2) What are the similarities and differences between the EU and Chinese scientists with respect to their perceptions of social dimensions?
3) What are scientists’ understandings of the potential public response to SB?
4) 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?
5) What are the implications for future research into SB?

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).

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, covering the following topics: the potential applications for commercialisation including those within the agrifood sector; benefit and risk perceptions; understanding of public response; and attitudes towards regulation and public opinion (**Figure 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).

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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**

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.

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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.

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).

3.1 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)

3.2 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 agrifood, environment, energy, and healthcare sectors and as advanced experimentation tools (see **Table 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)

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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)

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 agrifood 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 agrifood 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)

3.5 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[1], 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)

3.6 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

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

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)

"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)

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 applications across different sectors (see **Table 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 2**).

Compared with the numerous benefits, only a limited number of risks were mentioned, which were in reference to specific applications (see **Table 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 often found a 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 (e.g. IRGC Framework) 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, as the involvement activities associated with SB are limited (Inglesby, Cicero, Rivers, & Zhang, 2019). 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 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 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 our 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.

5. Limitations of the study

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 more diverse 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.

6. Conclusion

SB has seen much progress in creating novel tools and agrifood 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 agrifood 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.

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Declarations of Interest Statement

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Figure 1. Schematic overview of the research methodology

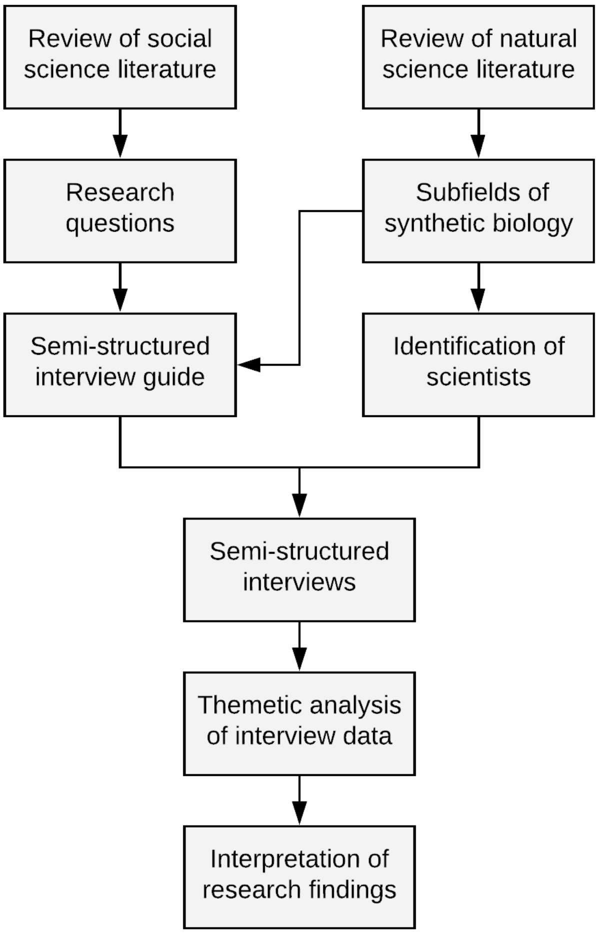

Table 1. Interview sample characteristics

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	University	Plant SB
	C9	Male	Research institute	Plant & Microbial SB

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

Table 2. Scientists' anticipated applications and benefit/risk perceptions

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 energy with reduced environmental impacts.	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		

	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