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Citizen Science and Food: A Review

March 2020

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Executive summary

Citizen science is an innovative participatory research method that actively involves citizens in scientific enquiry to generate new knowledge or understanding. There is no one definition of the method but citizen science projects essentially involve engaging with communities and seeking their participation in a form of data collection and co-creation. As such outputs are varied but commonly result in a large data set or detailed individual/household data or new insights. The method has been endorsed by the European Commission for Research, Science and Innovation as a method well suited for policy issues and is a key part of their Science with and for Society work programme (SWAFS 2020).

As part of their commitment to exploring innovative methods and their application to priority research areas, the Food Standards Agency are keen to explore citizen science methods and increase capability in this area. This document is a rapid evidence review of citizen science methods, focusing on how they can be applied to the FSA priority areas. The desired impact of this review is to target and facilitate more systematic engagement with UK (and global) research communities to harness citizen science methods to address key research questions and themes of the FSA.

Adopting citizen science methods as part of the FSAs methodological toolkit could be transformative to the FSA and the communities it serves. The literature reviewed in this document highlights that citizen science benefits the research community, citizens of diverse socioeconomic and cultural backgrounds, policy makers and wider society. In particular, citizen science can help the FSA increase public awareness about (food) science, and create a feeling of wider ownership of FSA policies. Citizen science also has the potential to help the FSA and other policy makers formulate informed and targeted policies; monitor implementation and compliance with regulations; and it can enable faster and evidence-informed reactions to events.

What is citizen science? How do we define a method as such?

At its broadest, citizen science is taken to mean the involvement of volunteer (non-professional) scientists in scientific research or monitoring or (quantitative or qualitative) data collection. Common features of citizen science approaches have been identified in the European Citizen Science Association’s (ECSA) 10 Principles for Citizen Science. In particular, projects should seek to:

- Generate new knowledge or understanding and have a genuine scientific outcome (Principles 1 and 2).
- Be mutually beneficial for both professional and volunteer scientist participants (Principle 3) and give feedback to participants (Principle 5),
- Make data openly available where this is possible (Principle 7) and
- Acknowledge participants in project outputs (Principle 8).

Citizen science applies to a wide range of approaches that differ depending on their scale, discipline, cultural context and overall aims. One useful classification of citizen science projects is based on the stage of the scientific process participants are involved in and can be categorised as being contributory, collaborative, or co-created citizen science.

Why should citizen science be used to better understand issues around food policy?

Citizen science approaches have the potential to help investigate and better understand complexity in the food system and thereby inform nuanced policy. For example citizen science can contribute to understanding tensions between different actors in the system, or how one part of the food system views or effectively interacts with other parts. Improved understanding of how different parts of the complex food system interact or how system change can be achieved in various ways:

- Monitoring and quantifying issues
- Building understanding of issues
- Educating and communicating. This may include encouraging better and safer food practices.
- Leading to action; by the individual (encourages deep learning, agency), and by decision-makers, (drawing on evidence collected through citizen science)

How has citizen science been applied to FSA research interests?

The literature on 'citizen science', related to the food, and food systems, is concentrated in a few key areas on health and food production; but has the potential to help address many grand challenges related to food and agriculture. This review demonstrates that citizen science can be used to help answer questions within the FSA's areas of research interest, and 11 research themes. We found examples of existing citizen science projects in the UK (as well as global initiatives) in a range of priority areas and others that could be adapted for use across the other FSA's areas of research interest (Figure 2), with many ready to be deployed now. As such, it is clear that the FSA does not have to reinvent the citizen science wheel.

PRIORITY ONE: Food Hypersensitivity & Allergy

1. How can the FSA protect the UK consumer from the health risks posed by food hypersensitivity (including allergies and intolerance)?

Whilst there are no direct formal citizen science research studies, there are existing crowdsourcing initiatives and community forums led by NGOs/charities. Due to this wide range of public interest and engagement from allergy sufferers and their families there are already a number of citizen science approaches that could be adapted or expanded to sit within this research theme. We highlight that citizen science approaches can use social media to recruit groups, facilitate interactions, co-create projects, monitor food environment, and educate communities.

PRIORITY TWO: Assuring Food Safety and Standards

2. How can the impact of chemical contaminants (including nanomaterials and microplastics) in food be assessed and minimised?

There are multiple examples of projects which address this research theme, with citizens sending in samples to be analysed - or by acting as field monitors/sensors and analysing the samples themselves (if the monitoring can be carried out with domestic technology).

3. How can the FSA better understand and reduce the impact of foodborne pathogens?

There are various examples of monitoring networks that use citizens as monitors and collectors of information, producing data that have enabled a better understanding of foodborne pathogens.

4. How can the FSA improve the evidence base concerning Antimicrobial Resistance (AMR) and food?

There are a number of studies that engage citizen science with AMR concepts, including a “Swab and send” project for citizen scientists to send swabs from their environment to contribute bacteria or fungi, which may produce antimicrobial products against a range of bacterial and fungal indicator strains.

5. What is the role of food safety and standards in nutrition and health?

Citizen science has been used in multiple food, nutrition and health related studies. This Citizen science approach has included engaging schools as well as wider community groups. Current research formats used in nutrition and health studies could be adapted to create new research projects for food safety and standards. Likewise there are other health related study topics (such as gut microbiome) that use citizen science methods, and could investigate the impact of food safety on health and nutrition integrated into them.

PRIORTY THREE: Innovation in Food Regulation

6. What role does consumer and Food Business Operator behaviour and perception play in ensuring food safety and standards?

A number of projects have explored household food handling using citizen science methods. However, no studies on safety and regulation published in the scientific literature have been found deploying citizen science methods in a food industry setting. Researchers have examined trust and safety perceptions by citizens of different food production methods. Other work has looked at post purchase food safety, including cooking turkeys and factors affecting microbiological safety and risk.

7. How can data and digital innovations be used to create a safer food system?

Projects have used citizen crowdsourced data to explore food safety issues. Citizens as consumers are well placed to help crowdsource information which can be easily collected digitally in out of home eating environments. There is already more than one US based project that collects information from citizens about incidents of food poisoning; DineSafe and BarfBlog.

8. How can the FSA remain at the cutting-edge when developing and implementing food regulations?

While no direct studies have explored this research theme, there are examples in the published literature that could be easily applied to this area and help the FSA to remain at the forefront of developing, and implementing food regulations, as well as monitoring compliance of food businesses. This includes introducing/trialling emerging technology for food testing with a wide citizen audience, and monitoring trust in current food safety testing methods.

PRIORITY FOUR: Future Food Systems

9. How can the FSA remain responsive to emerging challenges and opportunities in the UK food system including unprecedented challenges such as those associated with Covid-19?

Citizen science has the potential to be rapidly deployed and scaled through communities if correctly used. As such the correct, and prompt, application of such methods to relevant areas is one way the FSA can remain responsive. Citizen science methods were rapidly deployed to explore challenges arising from COVID 19 (e.g. Patient Led Research, 2021, The Covid Symptom Study) and a number of responsive citizen science projects have addressed food related challenges including, mapping invasive mussel species, disease in dairy cattle and historical anthrax outbreaks in rural Minnesota. These food related examples emphasize 1) the suitability of these methods for helping the FSA remain responsive to a wider variety of challenges, and 2) the need to establish citizen science projects, and engage relevant communities in advance. Examples of citizen science investigating Covid-19 include patient led research into recovery symptoms include Patient Led Research, 2021, The Covid Symptom Study, and long Covid. See Callard and Perego (2021) for a review of studies.

10. What is the impact of novel and non-traditional foods, additives and processes on the UK consumer?

Citizen science is well placed to help the FSA understand the reception of new foods, how they are used and consumed, and their impacts on communities and citizens. However, due to development in this research theme being fast moving, there is limited citizen science literature specifically addressing the impact of novel foods.

11. What is the impact of crime in the UK food supply chain, including food fraud, and how can it be better detected and monitored?

A limited number of citizen science projects have addressed this theme, and all relate to the fish/seafood sector. Citizen science has the potential to complement existing detection and monitoring methods to help the FSA understand (and educate citizens about) the impact of food crime and food fraud.

What can the FSA do to ensure engagement with developments in citizen science and it's application to food policy areas?

This review demonstrates that citizen science can be a useful research method in the inventory of a food focused government department. To remain engaged with the developments in citizen science and generate policy relevant evidence, there are multiple actions that the FSA can take. These include:

1. Build on existing FSA areas of research interest with pilot citizen science projects.
2. Engage wider with citizen science community
3. Host and coordinate bespoke events.
4. Collaborate with funding providers, and other government departments, to engage with and support a wider range of citizen science projects.

What is citizen science?

Definitions of citizen science

Citizen science involves the production of knowledge outside traditional scientific institutions (Strasser and Haklay, 2018). At its broadest, it is taken to mean the involvement of volunteer scientists in scientific research or monitoring. While volunteer engagement in scientific research is not a new concept (Miller-Rushing et al., 2012), the use of the term citizen science has risen in popularity over the past two decades. It encompasses a wide range of approaches. In fact, the term itself was coined twice, independently, in the mid-1990s with two quite different meanings. Alan Irwin (Irwin, 2002) used it to call for science that is more democratic and participatory and better reflects the needs of citizens. Separately, Rick Bonney used the term in reference to the contributions bird watchers make to ecological research through their voluntary observations (Bonney, 1996). Because of the dual origins of this term, along with a rapid increase in its use, and the wide variety of approaches and disciplines to which it has been applied, there has been some debate around and a continued evolution of what is meant by citizen science (Eitzel et al., 2017).

While there are still points of discussion around what is and what is not citizen science (something that is classed as citizen science by one person may not be seen as citizen science by another, (Haklay, 2020)), some common features of citizen science approaches have been identified. Box 1 shows the European Citizen Science Association's (ECSA) 10 Principles for Citizen Science (ECSA, 2020a) which, along with ECSA's Characteristics of Citizen Science (ECSA, 2020b), seek to define good practice in citizen science and distinguish it from other forms of research or outreach with members of the public, while seeking to be as inclusive as possible to a wide variety of approaches and disciplines.

Citizen science projects, for example, should seek to generate new knowledge or understanding and have a genuine scientific outcome (Principles 1 and 2). This distinguishes citizen science from other forms of science education and engagement which are more focussed on disseminating research results or one-way "education" of participants. Related to this, non-scientist participant engagement in (quantitative or qualitative) data collection, processing or analysis is seen as a "common denominator to citizen science projects" (Cooper and Lewenstein, 2016) which also distinguishes it from other participatory approaches such as participatory design, action planning, participatory rural appraisal, where data, new knowledge or understanding are not generated.

There is also widespread agreement amongst citizen science communities that citizen science should seek to be mutually beneficial for both professional and volunteer scientist participants (Principle 3). This distinguishes citizen science from extractive forms of scientific research involving members of the public, such as questionnaires or interviews, where participants do not engage in research 'work' but are the subjects of research.

Distinct from citizen scientists, research subjects are participants who may be integral to but are passive. For example research subjects may be interviewed for information or may be given experimental treatment in a medical trial. People can be the subjects of research within citizen science projects but to be classed as citizen scientists, their involvement should be moved beyond solely this (ECSA, 2020b).

Box 1: ECSA's 10 Principles for Citizen Science

1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project.
2. Citizen science projects have a genuine science outcome. For example, answering a research question or informing conservation action, management decisions or environmental policy.
3. Both the professional scientists and the citizen scientists benefit from taking part. Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence e.g. to address local, national and international issues, and through that, the potential to influence policy.
4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process. This may include developing the research question, designing the method, gathering and analysing data, and communicating the results.
5. Citizen scientists receive feedback from the project. For example, how their data are being used and what the research, policy or societal outcomes are.
6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for. However unlike traditional research approaches, citizen science provides opportunity for greater public engagement and democratisation of science.
7. Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format. Data sharing may occur during or after the project, unless there are security or privacy concerns that prevent this.
8. Citizen scientists are acknowledged in project results and publications.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities

Mutual benefits to scientists and non-scientists also extends to giving feedback to participants (Principle 5), making data openly available where this is possible (Principle 7) and acknowledging participants in project outputs (Principle 8). However, it is important to note that different projects can have very different aims, drivers and designs. Thus while projects should strive to ensure both scientists (or other project leaders) and non-scientist participants benefit, the balance between these will differ depending on the aims of the projects. As such, it is important to be open and transparent with participants about the nature and intended outcomes of their contributions (ECSA, 2020b).

Citizen science approaches are used in many different research disciplines and settings, including physics (particularly astronomy (Lintott et al., 2008)), environmental science (Silvertown, 2009)), healthcare (Fiske et al., 2019), molecular biology (Koepnick et al., 2019), agriculture (van Etten, 2019), natural disasters (Bossu et al., 2018), amongst others.

Types of citizen science projects

As mentioned above, citizen science applies to a wide range of approaches that differ depending on their scale, discipline, cultural context and overall aims. While citizen science projects can involve volunteer scientists at all stages of the scientific process (Shirk et al., 2012); ECSA principle 4), not all projects do so. One useful classification of citizen science projects is provided by West and Pateman (2017), who classify projects as contributory, collaborative, or co created, depending on the stage of the scientific process where participants are involved. This is shown in figure 1 where shaded boxes indicate which stage of the process each classification of citizen science project covers.

Contributory projects are projects where, data collection is the primary activity of participating citizens. Contributory projects can be active, where people actively make an effort to collect data (e.g. making species observations), or passive (e.g. data collection and submission that is done via a mobile sensor and app and does not require active engagement). Professional scientists set research questions and methods, and volunteers are engaged in processing or collecting and submitting data. This approach is in-line with Bonney's original definition of citizen science and it was this approach that rose to prominence in the 2000s. Contributory citizen science projects have been facilitated by technological advances, including internet accessibility and the increasing availability of smart phones and low cost sensors (Bonney et al., 2014). Within contributory projects, some people question whether passive data collection is "citizen science" and in these cases it is particularly important to be transparent with participants about their contributions and to adhere to best practice in citizen science (ECSA 2020b). In **collaborative** projects, volunteer involvement extends to additional stages of the scientific process including data analysis and dissemination of findings.

Figure 1: Stages of the scientific process non-scientist participants are involved in according to type of citizen science project. Based on (West and Pateman, 2017)

Setting research questions →	Developing methods and material →	Collecting or processing data →	Analysing data→	Sharing results
		CONTRIBUTORY		
		COLLABORATIVE		
		CO-CREATED		

Co-created projects are those which involve participants at all stages of the scientific process, from setting the research questions right through to communicating findings. Individual participants may be involved in one or all of these stages. In addition, some projects are entirely led by an individual or community of non-professional scientists, with limited or no involvement of professional scientists. Projects where participants have more in-depth engagement throughout the scientific process are often thought to have more of participant or societal benefits (see next section) than data-driven or contributory style projects. However, it is increasingly recognised that, with good design, these benefits, including democratisation of science, can be achieved in data-driven projects (Cooper and Lewenstein, 2016).

A further category which is less common is “extreme” citizen science (Haklay, 2020, ExCiteS 2021), where all stages of the scientific process are carried out by citizens without the support of professionally employed scientists. Although some of these projects will likely include individuals who are highly scientifically educated.

Unique benefits of citizen science

As discussed above, citizen science approaches have some common principles and can be distinguished from other approaches to public engagement and research. In this section, we explore the unique benefits citizen science offers compared to other approaches. Table 1 shows some pathways to impact from citizen science projects. Three key aims or drivers of citizen science projects (contributions to science or decision-making, citizen engagement and bringing citizens and scientists together) are mapped against some of the immediate (or first order) outcomes from citizen science (column 2), followed by second order outcomes (column 3). Third order (or longer term, column 4) outcomes show the long term impacts that may result from citizen science projects. It should be noted that the further away from the initial project that outcomes are, the more difficult it is to attribute these to the project itself as a range of other influences will be present (Earl et al., 2001) It should also be noted that while the benefits of citizen science described below are widely discussed in the literature, the strength of evidence for many of these is weak (Bio Innovation Service, 2018).

Scientific drivers for using citizen science approaches (first column in table 1), often relate to collecting or processing data that would not be possible if professional scientists were working alone. This may relate to the fact that by working with volunteers, large volumes of data can be processed (Lintott et al., 2011); data can be collected across wide geographic areas and in fine detail (Amano et al., 2016); and/or data can be collected at high frequencies or for long periods of time (Pocock et al., 2015). Data can also be collected from areas that are otherwise difficult to access for professional scientists, such as within the home or on private land (Gittleman and Jordan, 2012). Citizen science approaches can also be quickly deployed in response to sudden events or emerging issues, as has been demonstrated recently with its application in tracking and understanding the Covid-19 pandemic (e.g. The Covid Symptom Study, 2021).

Citizen-collected data are used in research publications, which number in the thousands (Kullenberg and Kasperowski, 2016), contributing to increased environmental and scientific understanding. In addition, in their review of the policy-relevance of citizen science projects in Europe, (Turbé et al., 2019) found that policy-makers had used citizen science data in all stages of the policy cycle (problem definition, policy formation, policy implementation, compliance assurance and policy evaluation) and suggest that the collection of large amounts of data over broad spatio-temporal scales means that policy-makers can utilise this evidence base for multiple purposes. They also found evidence of citizen science projects being specifically designed to address policy data gaps; for example, the SeaSearch project emerged in response to a need for marine species distribution data in order to designate marine protected areas (Turbé et al., 2019). Long term volunteer monitoring data have also been used as the evidence base for official reporting (e.g. UK Biodiversity Indicators, (Hayhow et al., 2019)) and citizen science approaches are increasingly being discussed as a way to fill data gaps in Sustainable Development Goal reporting (Fritz et al., 2019).

In addition to these national or international scale efforts, smaller scale citizen science projects can also engage volunteers in generating an in-depth understanding of an issue at a local scale. Such projects provide the opportunity to incorporate local, often place-based, knowledge into the scientific process (Bäckstrand, 2003; Cigliano et al., 2015; Kimura and Kinchy, 2016; Lisdskog, 2008; Ramirez-Andreotta et al., 2015). Local knowledge is particularly important for ensuring science is relevant to people's lives and can lead to local action (see Lidskog, 2008 for some examples), in contrast with 'normal science' that aims to create findings with a high degree of validity and reliability in very specific contexts, which may not be applicable in the real world (Lidskog, 2008). Findings from such projects can be used to support decision making and action at a local level (Ballard et al., 2017; Rome and Lucero, 2019).

Table 1: Pathways to impact from citizen science projects

Project drivers	1st order outcomes	2nd order outcomes	3rd order outcomes
Science and decision making	• More and/or better data	• Research publications and other dissemination • Improved understanding of topic	• Scientific advances
Citizen – scientist collaboration	• Citizens understand relevance of science to their lives • Participant knowledge incorporated into science • Scientists open to citizens' research questions	• Locally relevant & democratic science • Trust & buy-in to science & outcomes • New partnerships form	• Policy or decision-making change • Local action
Citizen engagement	• Citizens gain knowledge and skills • Citizens gain scientific literacy and critical thinking skills • Opportunities for citizens to meet people	• Community building Citizen advocacy • Changes in values and perspectives • Increased employability	• Citizen behaviour change

Citizen science projects should also aim to benefit volunteer participants (fourth row in Table 1) (ECSA, 2020a). Well-designed projects have shown increased knowledge of participants (Bonney et al., 2016; Evans et al., 2005; Jordan et al., 2011; Phillips et al., 2019; Stepenuck and Green, 2015), increased skills (Stedman et al., 2009), and better understanding of scientific processes (Bonney et al., 2016; Merenlender et al., 2016; Trumbull et al., 2000).

Individuals gaining knowledge, skills and scientific literacy can lead to a number of second order outcomes (column 3), including greater employability, behavioural changes (Ballard et al., 2017; Bonney et al., 2016; Couvet and Prevot, 2015; Dickinson et al., 2010;

Fernandez-Gimenez et al., 2008) and advocacy (Danielsen et al., 2014; Johnson et al., 2014; Minkler et al., 2008). Individual benefits can include people spending time outdoors and with other people, improving their health and wellbeing (Coventry et al., 2019), sense of place (Evans et al., 2005) and supporting new relationship development (West et al., 2020). Community benefits can include supporting stable communities with the potential for social learning, whereby people learn from each other via observation and imitation (Becker et al., 2005; Dickinson et al., 2010; Fernandez-Gimenez et al., 2008).

A multitude of benefits also arise from bringing together scientists and members of the public within citizen science projects (row 3 in Table 1), including increased understanding of the relevance of science (Brouwer and Hessels, 2019), increased trust about science (Bäckstrand (2003), and challenges to traditional expert-citizen hierarchies, thereby opening scientists' eyes to novel questions and considerations (Burke and Heynen, 2014). Bringing diverse voices into the scientific process and having diversity in expert knowledge is a desirable goal, especially given the complexity of many of the environmental challenges we currently face (Bäckstrand, 2003). Innovation, invention and creativity are more likely to occur where people of diverse backgrounds are brought together (Dickinson et al., 2010; National Academies of Sciences, Engineering, and Medicine, 2018; Woolley et al., 2010).

Challenges with citizen science

There are, however, challenges with using citizen science approaches. Like any scientific endeavour, quality assurance processes need to be carefully considered, otherwise there can be issues with data quality. While many projects have demonstrated that citizen collected data can be of the same quality as that collected by professional scientists (Cooper et al., 2015), others have reported problems with data quality and concerns about data quality in citizen science projects is still a major barrier to its use (Kosmala et al., 2016, Lukyanenko et al., 2016).

Another challenge is that citizen science participants are typically not representative of wider society (Pandya, 2012). How recruitment strategies and projects may be designed to widen participation should be considered, noting that these are also often more time and resource intensive (Brouwer and Hessels, 2019). How the demographics and characteristics of participants affect data collected and the conclusions that can be drawn from it should also be assessed.

As with all research, projects should carefully consider the legal and ethical implications (for humans and the environment) of their proposed activities. Some additional considerations are needed for citizen science compared with other research activities. According to ECSA's characteristics of citizen science, to be considered citizen science, participant involvement should be consensual and fully understood and so project aims should be clearly and openly communicated with participants and other stakeholders. All those involved should be aware of and adhere to agreed ethical and research quality standards (ECSA 2020b). Co-design of these standards between scientists and participants could be considered to establish shared expectations and foster inclusion

(Rasmussen and Cooper, 2019). Citizen science projects may also have additional ethical and legal considerations when it comes to data management because of the collaborative way in which data are generated. These include issues around data ownership, data sharing, confidentiality and participant privacy (particularly when participants are also the subjects of the research), as well as copyright and intellectual property (ECSA 2020a,b). Other issues include appropriate recognition of participants in outputs from research and whether compensation for participation is required (Rasmussen & Cooper 2019). Finally, citizen science is not suited to all research questions and consideration should always be given to whether other approaches are more appropriate.

Citizen science is not always the “cheap option” it is often seen to be. Recruiting and retaining participants in projects is essential for their success but can be **costly and time consuming** (West and Pateman, 2016). In order to keep participants engaged and contributing to projects, they need to be given feedback and encouragement (see Box 1) and this can be resource intensive. There may also be costs associated with processing or analysing data or buying equipment. Securing funding for projects, particularly in the long term, can be very challenging but often the value of citizen science for monitoring particular issues or creating change in participants and communities only comes from long term engagement.

Why should citizen science be used to better understand issues around food policy?

Food is a universal connection between people. What and how we eat, farm, cook, and produce affects us on individual, community and societal levels. Supplying safe, secure, affordable, and nutritious food is a major global challenge that unites many different parts of the local and global food system. Food is also ubiquitous and mundane, with many day to day food practices carried out as an unconscious routine. Food is deeply cultural, historic, and appeals to a range of potential values, anxieties, and personal motivations. This universality and ubiquity makes food - and the many aspects of the food system - an ideal range of topics with which to engage citizens and communities.

Likewise, the everyday nature of food means that studying certain behaviours and practices can be difficult in household settings (with self-reported practices different from observed or direct measurement). Citizen science can be a bridge to co-collect (more) robust information on household behaviours and understand priorities for citizens based on their lived experience (e.g. around allergies, cooking, etc.). As in all citizen science studies, the co-design of this type of citizen science research within the communities in question is of utmost importance.

Citizen science lends itself to food related issues that span the public and private domains where data would be less comprehensive without engaging citizens i.e. to collect data from inside the home. A good example of the potential of citizen science to assist in providing higher quality data collection is to more accurately quantify household food waste (see Pateman et al. 2020).

Citizen science is also useful beyond the home. Citizens interact with all the multiple stages of the food system (e.g. retail, hospitality, consumption, disposal). Aside from the general public, farmers and food industry workers are citizens (not professional scientists) and are potentially valuable groups with which to engage. Citizen science approaches can help to form the basis of collaborative partnerships between a range of stakeholders, perhaps to investigate the tensions between them, or to understand how one part of the food system views or effectively interacts with other parts, enabling a better understanding of how different parts of the complex food system interact.

In summary, citizen science can help with:

- Monitoring and quantifying issues
- Building understanding of issues
- Educating and communicating. This may include the propagating of better, safer practice.

- Leading to action; by the individual (encourages deep learning, agency), and by decision-makers, (drawing on evidence collected through citizen science).

Many different citizens, actors and communities can be involved:

- Producers
- Processors
- Distributors
- Retailers
- Households/consumers

Many actors are already involved in citizen science projects around food; with many food policy issues already being explored using citizen science methods. However there is much room for expansion of methods, project scope, and number and type of citizens engaged. Regardless of where in the food system citizen science is deployed the principles of engagement (as outlined in the above section) would be the same.

How has citizen science been applied to FSA research interests?

The FSA has flagged four priority research areas as part of their current areas of research interest or ARIs. Within these 4 areas there are 11 research themes as detailed in Box 2. This review found over 40 studies that directly relate to the ARIs (see Annex A for method).

Box 2: FSA Areas of Research Interest

Priority ONE: Food Hypersensitivity & Allergy

1. How can the FSA protect the UK consumer from the health risks posed by food hypersensitivity (including allergies and intolerance)?

Priority TWO: Assuring Food Safety and Standards

2. How can the impact of chemical contaminants (including nanomaterials and microplastics) in food be assessed and minimised?
3. How can the FSA better understand and reduce the impact of foodborne pathogens?
4. How can the FSA improve the evidence base concerning Antimicrobial Resistance (AMR) and food?
5. What is the role of food safety and standards in nutrition and health?

Priority THREE: Innovation in Food Regulation

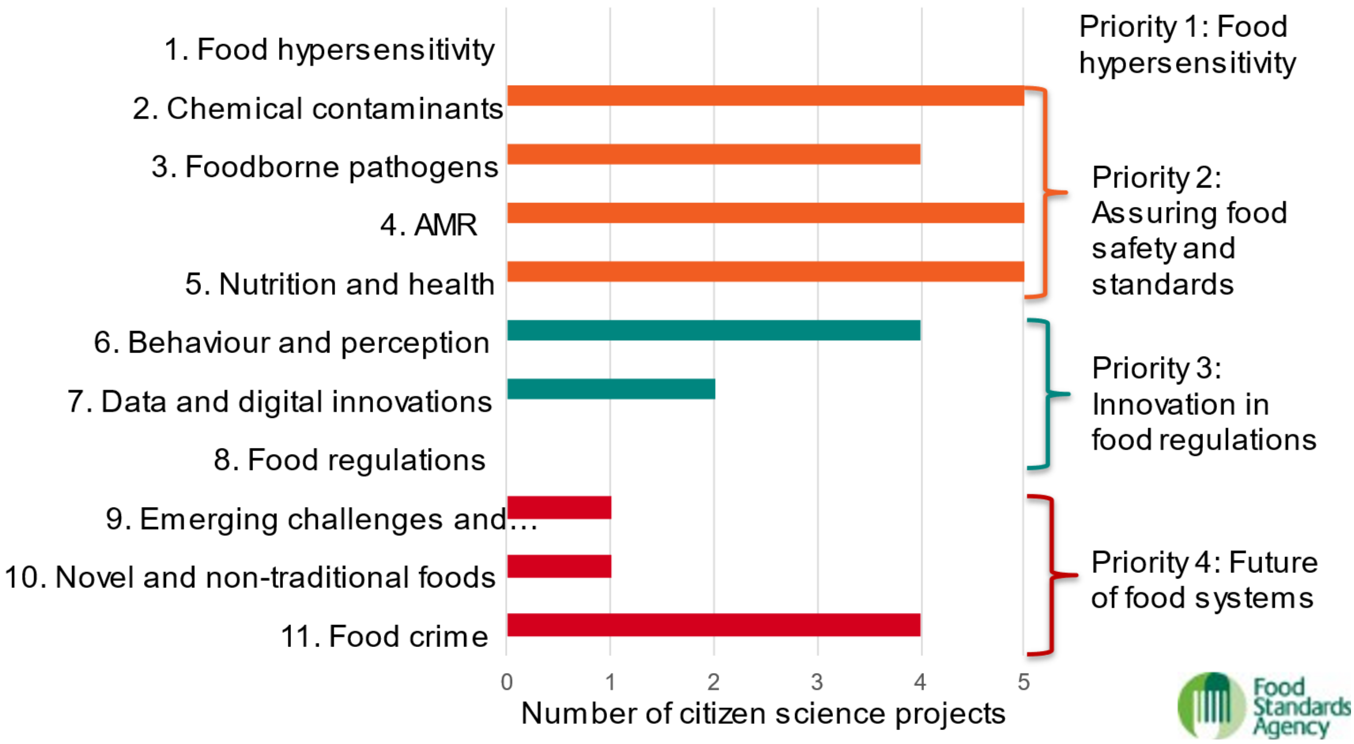
6. What role does consumer and Food Business Operator behaviour and perception play in ensuring food safety and standards?
7. How can data and digital innovations be used to create a safer food system?
8. How can the FSA remain at the cutting-edge when developing and implementing food regulations?

Priority FOUR: The Future of Food Systems

9. How can the FSA remain responsive to emerging challenges and opportunities in the UK food system including unprecedented challenges such as those associated with Covid-19?
10. What is the impact of novel and non-traditional foods, additives and processes on the UK consumer?
11. What is the impact of crime in the UK food supply chain, including food fraud, and how can it be better detected and monitored?

The literature on ‘citizen science’, directly relating to the FSA ARIs, is concentrated in a few key areas (as summarised in Figure 2) but has the potential to help address many grand challenges related to food and agriculture (Pateman et al., 2020; Ryan et al., 2018). As stated in the above sections, citizen scientists enable researchers to gather more data, with a wider geographic spread and over longer periods than possible otherwise (Strasser and Haklay, 2018). The long history of participatory public health, including research on the impact of (usually urban) food environments on diets is rich with ideas, that map on to the wider food system, as well as specific FSA priorities. For instance, engaging with members of the public to assess food fraud, food safety, or stimulate local food production could be fruitful areas of collective investigation. Such studies are becoming a possibility as a result of advances in remote forensic and sensing technologies (Dehnen-Schmutz et al., 2016).

Figure 2. Citizen science projects that relate to the FSA ARIs



Research priority one: Food Hypersensitivity and Allergy

1) How can the FSA protect the UK consumer from the health risks posed by food hypersensitivity (including allergies and intolerance)?

Food hypersensitivity and health risks (including allergies and intolerance) are an issue concerning a wide proportion of the UK population. Indeed, 3% of the UK population have IgE-mediated food allergy and are at risk of potentially life-threatening allergic reactions; while a wider proportion of the population have food intolerances.

The FSA are involved in the development of allergen management thresholds for use by industry and regulators, and in identifying risk factors associated with the development of food allergy so that appropriate information can be provided for consumers. In addition the FSA also focuses on understanding consumer attitudes to food allergies and intolerance and its labelling; leading to FSA allergy guidance and Food allergen labelling.

Due to this wide range of public interactions there are already a number of citizen science approaches that could be adapted or expanded to sit within this research theme though no studies are directly relevant. One pre-existing resource that could be adapted to citizen science methods is social media.

Investigators can work with citizens to crowdsource information via social media, (Vandevijvere et al., 2019) ran a project to help use citizen feedback to promote healthier local food environments, see [Foodback 2015] alongside other stakeholders. Mammen et al., (2019) was another public health project that utilised a participatory action research (community action research) approach to develop specific health messages for a rural low-income community. This messaging included food security concepts. Others projects recruit citizen groups (Collins et al., 2020), or facilitate interactions and co-create projects for example engaged an Urban Black and Hispanic community in New York in designing marketing (including social marketing) to promote heath messages, that might combat endemic diabetes and obesity (George et al., 2016). We highlight that participatory or community action research methods are additional methodological categories for applied research. They intersect with citizen science methods in terms of engagement, and they are focused on being contributory, collaborative, and co-created (Baum et al., 2006, Burns et al., 2011).

Future projects relevant to FSA priorities may be working with citizens to crowdsource information about provision for allergy sufferers alongside other stakeholders such as NGO's, healthcare professionals, HCP professional bodies, food service. There are many existing social media groups with different purposes: for people with allergies and families to share information (including documenting instances of good provision of alternatives for those with allergies), while other groups document instances of good and bad allergen labelling. Two existing organisations involved in working with allergy sufferers and their families already use crowd sourcing in this way are Coeliac UK (Coeliac UK, 2021) and Anaphylaxis Campaign (Anaphylaxis Campaign, 2019). We highlight that citizen science requires engagement and collaboration with communities to successfully use social media platforms to collect data related to a specific research priorities. This means that "scraping" or "mining" of social media text or images is not by itself citizen science. This is due to the passive nature of the research (lack of engagement), as well as the ethical implications of this type of research. However, if a citizen community was involved categorisation, tagging, etc. of images or text, and the research this led to, this type of activity could then be part of a wider citizen science project.

Research priority two: assuring food safety and standards

2) How can the impact of chemical contaminants (including nanomaterials and microplastics) in food be assessed and minimised?

The FSA are responsible for making sure that chemicals are not present in food at levels that would be of concern to health. Examples of chemical contaminants include mycotoxins, heavy metals (lead and mercury), organic pollutants, dioxins, and acrylamide. The most obvious form of citizen science related to this research theme would be citizens sending in samples to be analysed - or acting as field monitors/sensors and analysing the samples themselves, if the monitoring can be carried out with domestic technology (such as smart phones, or other accessible electronic equipment).There are multiple examples of these types of projects, which are predominantly from the environmental literature on citizen science.

Soy Beans and allotment vegetables

In Würschum et al., (2019), citizen scientists (growers) in the "1000 gardens" study contributed soy bean samples for genotyping and to examine the effects of localised growing conditions on different cultivars of soy. These were then used as samples for a cadmium monitoring study (Franzaring et al., 2019). It was found that cadmium levels were higher in produce grown in post-industrial and urban areas. A similar UK study, the My Harvest Project (Edmondson et al., 2019) is monitoring heavy metal contaminants in soils and allotment produce, along with levels of local community food production.

Mussels

Lanksbury et al., (2013) used citizen volunteers coordinated by the Washington State Department of Fish and Wildlife (USA) with multi agency involvement to conduct ecological monitoring. Volunteers participated in the field work portion of the program.

Farmed mussels (cleaned and catalogued were sited at different points within the geography to be evaluated at 108 sites. Volunteers for 30 organisations and some citizen scientists carried out the field work. Some government funding (60sites) and private sponsorship (48 sites) supported the work. Study analysis controlled for skill level of field workers. The contaminants mussel tissues are tested for are 20 heavy metals and 150 organic compounds. These included persistent organic pollutants.

Honey and neonicotinoids

Citizen scientists across the globe provided over 300 honey samples for research into the presence of 5 distinct neonicotinoids (Mitchell et al., 2017). The work was led by a collaboration between citizens and a team including University of Neuchâtel and the Botanical Garden of Neuchâtel, Switzerland. The researchers measured neonicotinoids concentrations in 198 of the samples and found 75% of samples contained quantifiable amounts of at least one neonicotinoid 45% contained between two and five, and 10% contained four or five. Although concentrations were below safe levels for human consumption the co-existence of multiple nicotinamides and pesticides' presents significant risk to pollinators.

Food and radioactivity.

Following the Fukushima nuclear disaster in Japan, because of a lack of information and mistrust in government reporting of radiation levels during the aftermath, a citizen scientist network began monitoring radiation levels in contaminated food (Kimura 2016, Kenens et al., 2020). 'Citizen Radioactivity Monitoring stations' were varied in nature but they were self-organised, efficient and practiced open source data sharing. The professionalism of the network (with many participants having degree-level scientific training) was perceived as a threat by the radiological protection establishment (Reiher, 2016). Indeed, Reiher discusses the political dismissal of scientific literacy, and reviews the lack of information and mistrust in the aftermath of the disaster which contributed to citizens setting up their own monitoring stations. Reiher comments that this may have been in part due to the safe radiation levels of food in Japan being set by specialist committees without reference to lay people. This issue of public trust of (possibly non-transparent) government data and standards, led to the Citizen Radioactivity Monitoring stations' publicly available data forming an alternative knowledge base which has, because of the attitudes of some users and government officials, become subversive in nature.

However, citizen science food safety projects could be viewed positively (and harnessed) by policy makers and professional scientists to reinforce food safety and trust. Indeed, public confidence and trust in food systems and policy makers is needed to accelerate transformations toward a healthy sustainable food system. Rapidly developing technology, citizen expertise and scientific literacy can allow higher levels of citizen participation. Policy makers and professional scientists could engage with citizen scientists and emerging technology to rapidly improve public health and trust in the food system.

Wider food safety

Trust in food safety, and distributed testing of food are key areas where citizen science may play a role. Currently there are multiple commentary articles that discuss the role of citizen science in trust and distributed testing. We highlight that both EFSA and French Agency for Food, Environmental and Occupational Health & Safety (ANSES) are reported to be thought leading. We provide summaries of these in Annex B.

3) How can the FSA better understand and reduce the impact of foodborne pathogens?

The annual personal, social and economic cost/burden of foodborne illness in the UK in 2018 was £9bn, with the 13 main foodborne pathogens in the UK contributing to around £3bn of these costs. Citizen science methods can offer a way to understand and reduce the impact of foodborne pathogens through using networks of citizens to monitor and educate.

There are various examples of monitoring networks that use citizens as monitors and collectors of information. These could be used to understand and track the impacts of foodborne pathogens. One such monitoring project is the Local Environmental Observer (LEO) Network, an environmental observation platform based within a social network originating in the Alaskan Arctic but now globally active. Mosites et al., (2018) describes the LEO network as organised around a network of hubs that allow individuals in the network to interact and to discuss observations with topic experts. This is based on the 'One Health' paradigm which seeks to monitor environment, human activity, flora and fauna. LEO is relevant to food and pathogens, as the LEO Network team identified a pattern of a potential human pathogen in a food source (fish). "Phaeohyphomycoses infections in fish are considered an emerging disease which result from metabolic factors, stress, poor water quality, trauma, or other infections". The LEO community also conduct permafrost monitoring. Monitoring the warming of permafrost to help provide early warning of risks to local household or community food storage facilities. This is interesting in terms of food safety and provides and is an example of what can be achieved in a community non-temperature controlled storage facilities that would benefit from weather monitoring to predict spoilage rates.

Other examples of citizen science monitoring and sample gathering include the multiple studies conducted as part of the Wild Sourdough project or the various "Super Yeasts" projects (e.g. at Aston University and the University of Tokyo). In the first project communities of bakers sampled their environments, sour dough starters, and hands for yeast types, bacteria and fungi (Reese et al., 2020). While in the latter projects environments were sampled for yeasts. Though not directly related to pathogens, these projects show the wide capacity for citizen science to collect sample materials and identify yeasts, bacteria, fungi and other pathogens with an engaged community. These methods could be easily pivoted to focus more on foodborne pathogens.

Future projects within this field of foodborne pathogens might include leveraging environmental citizen science projects to act as early warning of contamination in wild caught food species. Examples of citizen science that fit this include Musselwatch and the Local Environmental Observer Network.

4) How can the FSA improve the evidence base concerning Antimicrobial Resistance (AMR) and food?

Antimicrobial resistance (AMR) is when antimicrobial drugs, such as antibiotics, stop working effectively on the bacteria they are designed to kill, or prevent them from growing and multiplying. Resistant bacteria can be spread to humans in the food chain through cross-contamination, animal slaughtering processes, manure, and contaminated water. Tackling AMR is a high priority area for the FSA as well as a concern worldwide. Until recently AMR research has largely focused directly on farm animal and human health. However there are many studies that engage citizen science with AMR concepts.

One study relates most directly to food and reported (as a conference proceedings) the mapping of a livestock related strain of MRSA in Tyrolian high school staff and pupils (Oberhauser and Lutz-Nicoladoni, 2020). Participants collected nasal swabs and carried out some lab testing (cultures). The project partner, Section for Hygiene and Medical Microbiology (Innsbruck), identified the different MRSA strains through this engagement.

Other AMR related citizen science is not specific to food systems but does provide some examples of how citizen science has been used to learn more about AMR. Redfern et al. (2020) describes the UK Microbiology Society's 'Antibiotics Unearthed' citizen science project, developed as an approach for improving awareness and scientific literacy relating to AMR. Specific initiatives included "Swab and Send" (Roberts, 2020) and "Agar Art". These campaigns included the 'Seriously' campaign, which was used to educate university students on the importance of correct use of antibiotics that linked with Antibiotic Guardians. However, in the cited examples, the authors note neither the projects impact nor success of particular CS approaches are reported. When designing future projects collection of impact data should be built in.

Jørgensen et al., (2017) provide a commentary on combating AMR, They mention citizen science in the context of multilevel governance. They highlight citizen sciences' potential when combined with the availability of easier to use testing formats that may allow monitoring of personal and environmental microbiome.

A selection of citizen science and participatory research papers are also concerned with microbiomes or bacteria, viruses and other microbial life in various environments including the Mycobiome. These include The Oxford Interdisciplinary Microbiome Project (IMP) (Greenhough et al., 2020); 'Science Solstice' and 'Summer Soil-stice' (Shelton et al., 2020), and a pre-print study that used citizen science for household mycobiome sampling (Martin-Sanchez et al., 2020). These examples indicate that citizen science methods allow AMR projects to expand their sample size and depth, integrate interdisciplinary methods, and improve project engagement and impact beyond what might be expected from traditional research methods.

5) What is the role of food safety and standards in nutrition and health?

Food safety, and nutrition are closely linked. Unsafe food creates a vicious cycle of disease and health issues, particularly effecting infants, young children, elderly, and other at risk groups. What we eat has a profound effect on our gut and our health. Citizen science has been previously used in multiple food, nutrition and health related studies to understand and document these issues.

Waddingham et al., (2018) engaged children as key informants to examine children's food choices in school environments. Participatory action research was used to discover what motivated children's food choices. Theoretical concepts that emerged in the study came from the children engaged in the research via group discussion and consensus (rather than researchers). The investigators suggest the findings can help create healthier supporting food environments for children. This type of study could be adapted and the scope broadened to food environment interactions with food safety.

Dolejšová and Kera (2017) provide a report on "extreme" citizen science (ExCiteS, 2021) communities, using the example of the user community of Soylent - a powdered food substitute, originally developed by software developer Robert Rhinehart. There is an official product Soylent (uppercase), however the recipe for generic soylent (lowercase) was released as an open source asset as a soylent base recipe. Although many users buy the official Soylent product, some "nutritional hobbyists" and extreme citizen scientists practice health directed self-experimentation with custom versions of the powdered food. These extreme citizen scientists, like users of the official product, self-monitor their health and the impact of soylenton their health. Refinement of the soylent recipe is practiced with reference to the experimenter's health. Experimenters use varying tests and measures to evaluate physiological health. Dolejšová and Kera (2017) used ethnographic methods [1] to evaluate the soylent experimenter/practitioner scene over a two-year period. The practitioners were found to be motivated by health and self-determination, all self-reporting an increased nutritional knowledge. The investigators tested the level of nutritional expertise to gauge if self-reported high degree of nutritional literacy was realistic/accurate. Practitioners supported one another via social media

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[1] Methods included: participant observation at the 3 main community platforms; interviews with selected users; content analysis of user journals; public workshops and tasting probes to gather data about the practices of the soylent hobbyists. Note that this was understood to be "extreme" due to being bottom-up and participant led, and involving self-experimentation. Dolejšová and Kera, (2017) were inspired by University College London Extreme Citizen Science (ExCiteS) research group. ExCiteS define Extreme Citizen Science as a "situated, bottom-up practice that takes into account local needs, practices and culture and works with broad networks of people to design and build new devices and knowledge creation processes that can transform the world". (ExCiteS 2021)

forum however, there were some risks and criticisms that emerged through the analysis of the online community and online infrastructure:

- in-group bias and lack of critical appraisal of the diet or safety issues e.g. participants may not be critical of if a diet or specific food safe for long-term consumption, or suitable for them due to their own possible underlying health conditions.
- Lack of self-experimentation guidelines/reference or standardised data sharing.
- Unsecure data and health information handling, often linkable to personal identifiers.

These shortcomings in information management user support, and scientific process may be potentially detrimental to the practitioners' process and safety and health.

Dolejšová and Kera (2017) recommend a number of strategies to help ensure safe and effective extreme citizen science projects between networks of individuals. These would be useful to adapt to any future citizen science project with cross over between food safety and food consumption.

Data on food/health/safety can also be gathered through citizen science methods - while also educating citizens. Spitz et al., (2018) describes a citizen science project using crowdsourcing and gamification methods (game-design elements and game principles in non-game contexts). In this project citizens input and retrieve information on commercially available food products that contain ingredients associated with an increased risk of cancer and other diseases. Through this game/play based experience, (Spitz et al., 2018), are crowdsourcing an open database of potentially unhealthy food products, while also raising awareness among citizens about the risks of certain artificial additives

Citizen science is used frequently to enable gut microbiome studies (Grieneisen and Blekhman, 2018; Miyoshi et al., 2020; Visconti et al., 2019). Grieneisen & Blekhmana (2018) in particular describes sampling methodology challenges, and also challenges to getting a diverse cohort of CS to take part in a US gut microbiome project called 'Crowdsourcing Our National Gut' project. Likewise, Del Savio et al. (2017) discusses the motivations of British citizen scientists in gut microbiome project as being prosocial and not for profit. These studies also make clear that large numbers of participants are key to finding out more about the complexity of the organisms in our gut, with citizen science well placed to help with this.

Citizen science methodologies have also been used to demonstrate that altering fibre intake even in the short term is significant (Klimenko et al., 2018). However, the authors suggest a longer study would allow better characterisation of the long-term effects and changes in the kinds of microbes commonly found in the gut of individuals with high fibre intake.

Research priority three: innovation in food regulation

6) What role does consumer and Food Business Operator behaviour and perception play in ensuring food safety and standards?

Citizen Science is well placed to give insight into consumer behaviour, and also potentially food businesses where trustful relationships are key for business engagement. Numerous projects (Armstrong and Reynolds, 2020; Armstrong et al., 2020a, 2020b) have used the Zooniverse citizen science platform and online surveys as pilot methods of food citizen research to measure citizen perceptions of images of food. These perceptions related to concepts such as carbon footprint, energy content, animal welfare, and food risk. In Armstrong and Reynolds (2020) this was extended to include how country of origin and ethical information altered consumer perceptions of food in a post COVID-19 food system. It was found that UK citizen perceptions of food safety, animal welfare, purchase intention, deliciousness and carbon footprint were all influenced by origin and ethical status information. Chicken from the USA and China was perceived to be higher risk and have lower animal welfare standards. Apples from the USA and China were perceived to be higher risk. Pasta from China was perceived to be higher risk. However, this type of crowdsourced citizen perception research may need further engagement (and co-design) with citizens to be fully called true “citizen science”.

Home food handling has already been investigated using citizen science methods. Two of the most notable studies are (Duong et al., 2019, turkey thermometers) (Lorimer and Hodgetts, 2017, Good Germs Bad Germs). However this review did not find any literature that discusses deploying citizen science methods in a food industry setting to understand safety and regulation. We were also unable to find commercial studies, with these likely to be commercially sensitive and unpublished as a result.

Duong et al. (2019) used citizen science methods for data collection, to investigate whole turkey thermometer usage behaviours in the home. In this study, high school students were recruited and instructed on thermometer placement, correct cooking practices and internal carcass temperatures. Students were then asked in the subsequent thanksgiving break, to input data on an online form about thermometer usage and end point cooking temperature. Students were instructed to take a picture as evidence of thermometer placement and also to describe and note how they knew the turkey was ’done’. An innovation of this study was that it used a combination of internet, web form and citizen science methods to train the participants – which is novel in a food safety context. The authors highlighted the importance of existing networks in recruiting schools and some failures in the training process (of teachers, their use of training materials and carving out space for the training in the curriculum.

Lorimer et al.,(2019) used citizen science to examine communities of microbiota in people’s kitchens. The citizen led experiments were a form of “Kitchen microbe safari” to examine which microbes lived in particular kitchen locations. The professional scientists helped design initial trial experiments, these were followed by citizen scientist designed and led experiments, facilitated by the professional scientists. After the citizen science experiments the professional scientists reviewed what was interesting (to the citizens), and why, and examined the sociocultural components of the projects. This review provides “important insights into peoples’ hygiene practices and understandings in a world characterized by both ‘good’ and ‘bad’ microbes. After all, the public policy message has, for generations, been to vilify all germs; but increasingly, such messages are becoming less tenable.” (Lorimer et al., 2019).

Citizen science approaches to promoting awareness of home food safety could engage and inform citizens about practices such as fridge safety, use-buy vs best-before or cooking practices for meat, as examples. Stakeholders might include school teachers pupils families, retailers/processors, WRAP and microbiology organisations.

7) How can data and digital innovations be used to create a safer food system?

There are multiple projects that used citizen crowdsourced data to engage with food safety. Citizens as consumers are well placed to help crowdsource information which can be easily collected digitally in out of home eating environments. Examples include DineSafe, a foodborne illness reporting platform that links to social media, and the Citizen Food Safety project, which allows for anyone to post photos of good or bad food-safety practices to Twitter and Instagram with the tag #citizenfoodsafety. This project could be classed as citizen social science for food system safety communication, regulation and governance.

Citizen science within this priority could link together stakeholders including citizens, restaurant associations, and other food service organisations to crowdsource information about food poisoning incidents to target food safety resources food safety education or training.

8) How can the FSA remain at the cutting-edge when developing and implementing food regulations?

Citizen science approaches can also help the FSA to remain at the forefront of developing and implementing food regulations, and monitoring how compliant food businesses are with current regulations. This includes introducing and trialling emerging technology for food testing with wide citizen groups and monitoring trust in current food safety testing methods. Due to these technologies being relatively new, there is little peer reviewed literature on these topics and methods. In Annex C, we provide examples of cutting-edge reviews on what could be used by citizen scientists in relation to food safety, and gather data to help inform wider FSA policy.

Research priority four: the future of food systems

9) How can the FSA remain responsive to emerging challenges and opportunities in the UK food system including unprecedented challenges such as those associated with Covid-19?

Citizen science has the potential to be rapidly deployed and scaled through communities if correctly used. The previously mentioned Armstrong and Reynolds (2020) survey (examining how country of origin and ethical information altered consumer perceptions of food in a post COVID-19 food system) was able to be deployed rapidly in the first weeks of the 2020 UK COVID-19 lockdown after being based on the citizen science methods and foundations of Armstrong et al (2020). Likewise emerging challenges can be responded to in relatively short timeframes due to engaging with communities using citizen science methods to co-create knowledge. Kanankege et al. (2020) review multiple case studies linking stakeholder engagement in health and environment research to the benefits and limitations for mapping and identifying risk hotspots. Case studies include spatial dynamics of invasive mussel species, disease in dairy cattle and historical anthrax outbreaks in rural Minnesota. These food related examples emphasize 1) the suitability of these methods for helping the FSA remain responsive to a wider variety of challenges, and 2) the need to establish citizen science projects, and community engagements in advance.

The COVID-19 pandemic is a good example of the need for rapid response. Examples of citizen science investigating COVID-19 include: patient led research into recovery symptoms Patient lead research into recovery symptoms, The COVID Symptom Study and Long Covid. See Callard and Perego (2021) for review of studies.

Future citizen science approaches could include the rapid co-development of behavioural modification strategies to monitor and mitigate emergent zoonotic diseases (linked to ARI4). This is shown in Morgans et al., (2020), where farmer peer to peer support networks were created to promote better antimicrobial practices through co-creation of an Action Plans. Morgans et al., (2020) highlights the ability of citizen science to lead to behavioural and technical changes for prevention and early warning of disease over large geographic areas.

10) What is the impact of novel and non-traditional foods, additives and processes on the UK consumer?

Novel foods refers to those foods which have not been widely consumed by people in the UK or EU before May 1997 (FSA, 2020). This means that the foods do not have a 'history of consumption'. Novel foods include: traditional foods eaten elsewhere in the world, foods produced from new processes, and non-traditional new foods produced by existing processes for example, phytosterols and phytostanols used in cholesterol-reducing spreads. The FSA are responsible for ensuring that novel foods coming on to the market are safe for consumers. Citizen science is well placed to help the FSA understand the reception of new foods, how they are used and consumed, and their impacts on communities and citizens. Because this is a fast moving area, there is limited citizen science literature available directly on novel food safety. However, there are many examples of citizen science assisting in increasing research speed outside of food/safety. For instance, (Wannemacher and Grillmayer, 2016) used observational data from citizen scientists to develop a computational analysis method to reduce the workload of experts/scientists and allow large or complex datasets to be analyzed with speed. If applied to food/safety domains, we could envisage citizens helping to 1) screen the impacts of novel foods, 2) contribute their observations to build a stronger dataset for expert researchers, 3) analyse the data with researchers.

Citizen scientists have been engaged through gamification of data collection and knowledge sharing awareness raising about unhealthy foods and ingredients. A crowdsourcing game app 'Dyet - do you eat this?' (Spitz et al., 2018) allowed gamers to explore which food products contain ingredients associated with increased risk of cancer and other diseases. The gameplay allows the creators to crowdsource an open database of potentially unhealthy products, which has the potential to inform both the citizen (while shopping) and public health professionals (to monitor the product ecosystem). Awareness among consumers about the risks of certain components in new food products is increased by participation in the game.

11) What is the impact of crime in the UK food supply chain, including food fraud, and how can it be better detected and monitored?

Food crime can occur in various ways throughout the food system. It can range from isolated acts of dishonesty by individual offenders to organized illegal activity coordinated by criminal networks. Citizen science may complement existing detection and monitoring methods to help the FSA understand (and educate citizens about) the impact of food crime and food fraud. The three studies below provide examples of this in fish fraud where value differences between species with similar characteristics can be significant (Note: our review found that fraud in other industries was not well researched). A possible reason for this interest is that fish fraud sits between where food system and conservation issues directly intersect and is likely fertile ground for citizen science to be employed in gaining understanding about fraud in food systems.

Mitchell et al. (2019) describes how citizen science (carried out by high school students) was used for species identification using DNA analysis of processed seafood. The study demonstrated 7-10% of samples tested (n68 of 50 different common names) were mislabelled when matched to publicly available DNA sequences stored within the Barcode of Life Data System (BOLD) This paper highlights the benefits of citizen science in science extension classes and for wider science education. Mitchell et al (2019) also 1) discusses the usefulness of DNA labelling techniques; 2) highlights the potential for independent verification of standards in retail or food service using similar methods; 3) discusses the usefulness and limits of publicly available data; and 4) the role of regulators and statutory authority for developing food standards for labelling. The paper does not however discuss how data was communicated to relevant authorities, or if there was cooperation with regulators as part of the research design.

Warner et al. (2019) describes a similar citizen science project in the USA, which examined seafood fraud and was coordinated by the conservation group Oceana. However, Warner et al (2019) provides the context of long and opaque seafood supply chains that hide fraud and human rights abuses. The study was developed using iterative design principles with user feedback included. The citizen scientists were recruited from the organisations existing network of supporters, with 55,000 people contacted as potential data collectors, and 1,058 agreeing to participate and subsequently mailed testing kits. The response rate of 1.9% of those contacted was comparable with other studies as was the percentage of kits received back – a third of those sent out. The study uncovered high rates of mislabelling in the first wave of recruitment. The publicity about initial findings from this project in the local and national media likely aided later waves of recruitment. This paper illustrates well how citizen science can generate high-quality scientific findings, with applicability across multiple research and regulatory bodies.

Bénard-Capelle et al. (2015) is another study to examine rates of fish mislabeling, but in this case, in France. Fish samples were collected by participants. This was a collaborative citizen science project which was initiated by non-scientists who brought in professional scientists to ensure scientific voracity of the study. Once the study plan was made, a larger group of citizen scientists were engaged for fish sample collection. The study demonstrated that there was a high degree of substitution for expensive fish species, such as blue fin tuna.

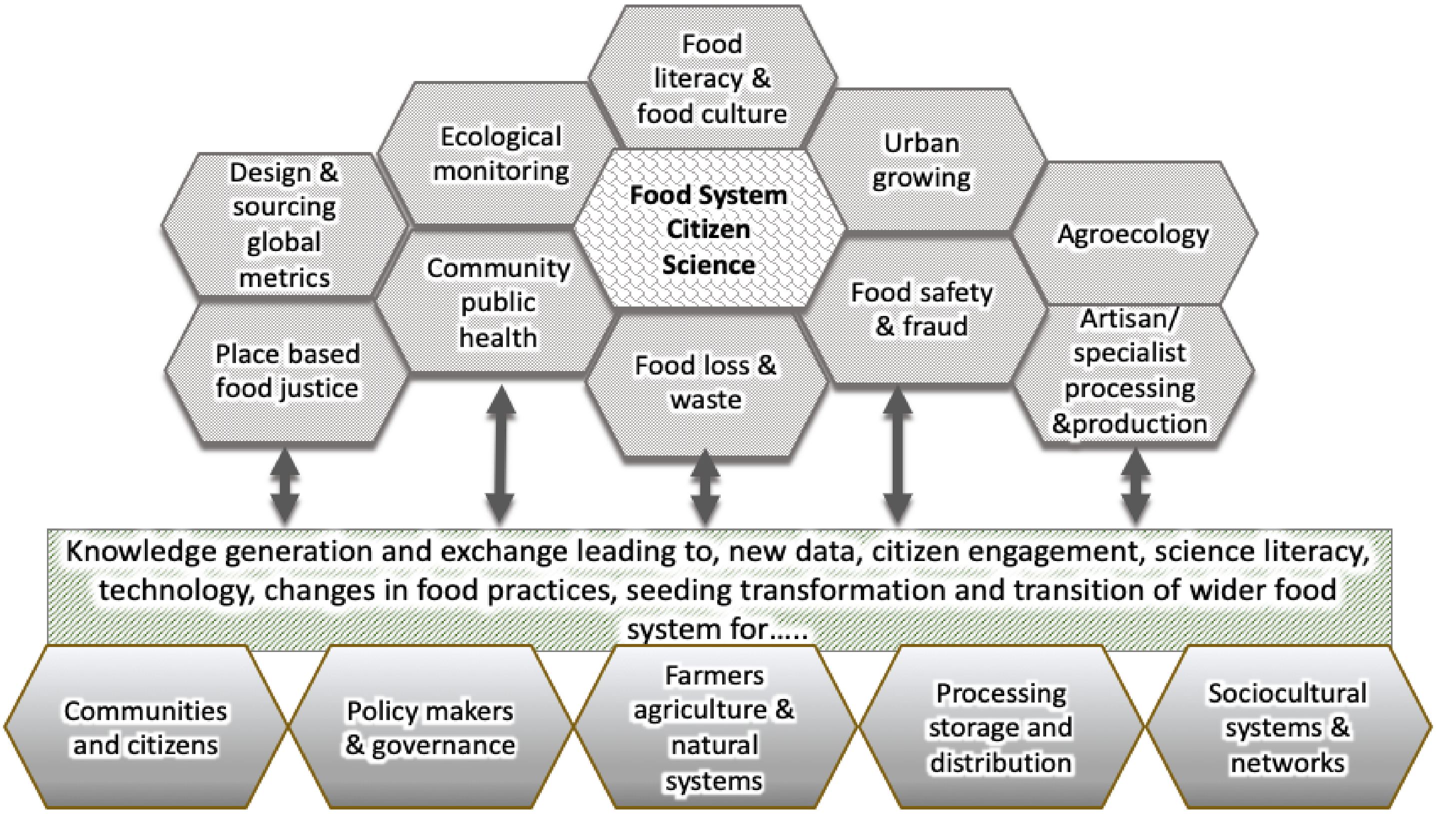
A feasibility study working with an individual citizen scientist to use DNA barcoding as a tool to identify mushrooms, tested samples of dried and fresh mushrooms bought from retailers in New York (Jensen-Vargas and Marizzi, 2018). The authors described their pilot as successful, with the citizen scientist readily able to correctly conduct tests on the samples. They did not find mislabeling in the limited (10) samples tested.

The kind of community detective work described could bring a number of benefits in detecting food fraud for high value items such as meat or fish. It could bring schools and colleges into a community science projects that use and familiarises them with genetic testing methods. There is also potential to for such a program to have a large or comprehensive geographic reach and it could provide information to alert FSA and trading standards to potential incidences of food fraud.

Food and citizen science research: wider examples

Citizen science can be applied across the various domains of the food system. Oakden et al. (2021) categorised citizen science studies as they related to ten food domains (see figure 3). Citizen science studies and methods are particularly applicable to research and development in complex systems, where transdisciplinary approaches are beneficial, and understanding human behaviour is integral. Our review has found citizen science methods deployed along the whole food chain and throughout the food system. A selection of studies, that may have relevance for the FSA remit, but not directly covered under the ARIs, are described below.

Figure 3. A pictorial summary of citizen science engagement with the food system and impact pathways from Oakden et al. (2021)



In farming and food production, citizen science approaches have been used to develop new practices and engage communities to propagate change (Rosset and Val, 2018; Rosset et al., n.d.) and to manage use of anti-microbials (Morgans et al., 2020). Facilitated participatory methods (such as citizen science) can lead to real change in practices where top-down technical solutions may not sufficiently capture nuances in everyday practice.

Focusing near the end of the chain, retail and Canteens have hosted food citizen science projects. Pomeroy et al. (2018) explored citizen science approaches to 1) survey the healthiness of local retail food environments and 2) empower citizens. The study used a pre-existing Promotoras network (the Spanish term for female community health workers) to connect researchers with the community. The current EU project SU-EATABLE LIFE focuses on mass catering (in Italy and the UK) and plans to reach 50,000 people and actively engage around 5,000 citizen scientists to propagate behaviour change by “reducing GHG emissions and achieve water savings in the EU via citizen education and active engagement.”

In the field of health, nutrition and obesity, participatory approaches are often employed help to engage specific or multiple stakeholders or target groups (Chrisinger and King, 2018; Díez et al., 2018; Findholt et al., 2011; Harper et al., 2017). When interrogating particular social contexts an 'our voice' or 'photovoice' methodology is typical (Sutton-Brown, 2014). In these methods citizen scientists are given training and equipment to film, photograph and record their environment and surroundings and are integral to, or lead in the analysis of the data they generate. We highlight that these methods are used beyond citizen science; but that they can be used in contributory, collaborative, and co-created projects to generate rich experiential qualitative data that can be analysed by citizens and researchers (depending on project design).

The photovoice/one voice approach may be used to engage and empower communities. Citizen scientists can then analyse data and feed back into the wider community group and to other health education stakeholders, informing action or future interventions. Change processes can include revision of overarching policy or local policy implementation e.g. training for store owners in the health corner store network (Chrisinger and King, 2018) or discovering specific information about food practices and health behaviours, such as poor eating habits and inadequate nutrition that are situated in specific sociocultural environments. Such studies reveal that broader stakeholder engagement alongside structural and policy changes are required to drive change and empower communities toward better health (Kovacic et al., 2014).

Photovoice methods have been used to study urban school food systems and food justice i.e. access to healthy affordable and nutritious food. Harper et al. (2017) conducted a study on food justice including an element of youth development. The authors described the benefits of the approach to shift power relations but cautioned that adequate stakeholder engagement, awareness of power structures, transparency and allocation of resources are crucial when citizen science aims include change to policy or practices.

In a community based action research project to improve chronic disease management in an in mid-Atlantic African American community, local solutions were developed (Rogers et al., 2018). The potentially successful implementation of the local but limited solutions, was heavily reliant on the pre-existing community networks in the setting, so community based change programs would require existing networks or for such networks to be built and nurtured.

Adequate support for citizen science activities is important through facilitated participation by supplying resource (time and money) in poor communities. In Chrisinger and King (2018), the aforementioned New Jersey study on healthy corner stores), participants were given nominal payments of $25 (for a guided walk around the food environment) plus $25 (for attending community meeting). This highlights that participation in citizen science can be costly and needs to be compensated. We highlight that the issue of remuneration is contentious, with remuneration in some instances influencing participation and the quality of data collected (Riesch and Potter, 2014; Robinson 2019; Wright et al., 2015).

Food citizen science can also require collaboration and engagement between multi-stakeholder groups, to drive change in behaviour or practices. Project SoL (Mikkelsen et al., 2018) was a collaborative intervention to increase activity and healthy eating in families with young children. Based in in Bornholm Denmark, this project was notable due to the wide engagement of local food system actors, including: media, researchers (from multiple organisations), supermarkets, schools, food producers (e.g. fishermen), childcare organisations, NGOs, action groups and local government, including school and social services administrators. The professional researcher's involvement was scaled back over time and local ownership of the scheme promoted, increased and supported through a community-based coordinator (based at a local NGO). The main project report (in Danish) states that the scheme did not run for long enough to demonstrate significant changes in the BMI of children in participating communities but intervention did produce positive changes, such as families making healthier food purchases and increased community awareness of healthy eating. Further success of the scheme can be evidence by 86% of the local population being aware of the scheme by the time of project assessment.

Citizen science projects have also focused on food security and healthy eating. In (Henderson and Slater, 2019) ethnically diverse participants were enrolled in the community newcomer nutrition program. Participants shared information about their local food practices and learned to cook healthy wholefood Canadian recipes. Nutrition and cookery skills weren't formally taught but discussed in the classes in relation to healthy Indigenous and Canadian foods. Both Canadian and home cultures were respected and healthy 'new' recipes and foods were practiced by the participants in the classes and at home. A variant on this collaborative method could be used to generate information about current and novel, food, as well as kitchen practices where the FSA wants to understand risk, behaviour, and social context, and how these interconnected issues might have a negative impact on food safety.

What can the FSA do to ensure engagement with developments in this method and application to food policy areas?

This review has demonstrated that citizen science can be a useful research method in the inventory of a food focused government department. We have shown that citizen science can be used to help answer questions within the FSA's areas of research interest, and it's 11 research themes. As such it is clear that the FSA does not have to reinvent the citizen science wheel. There are many existing UK and global initiatives that can be adapted for use in the food-safety domain, or are ready to be deployed now. To remain engaged with the developments of citizen science and generate policy relevant evidence, there are multiple actions that the FSA can take. These include:

1. **Build on existing FSA areas of research interest with pilot citizen science projects**. There are examples of pilot projects that could be undertaken within

each of the FSA's Research Themes. Pilot funding for citizen science should include funded time for reflection on what elements of pilot projects that work well and which do not.

2. **Engage more widely with citizen science communities**
The European Citizen Science Association (ECSA) hosts a large community of citizen scientist practitioners, holding annual conferences, maintaining a mailing list and hosting working groups. Likewise there are citizen scientist practitioners within the NERC Public Engagement, SciComm, and British Ecological Society communities The FSA would benefit from engaging with this wider citizen science community. We also encourage engagement with global food safety communities and international policy-makers on similar citizen science research. With the aim to adapt to existing programmes to UK and devolved situations. Our review found that ANSES/EFSA are already running citizen science projects, these groups should be contacted to understand potential synergies.

   We also highlight that citizen forums and workshops can contribute directly into FSA activities such as horizon scanning, preparation for emerging opportunities and to mitigate against threats or risks.

3. **Host and coordinate bespoke events and networks.** Citizen-science events and networks can be a key way to connect with researchers and organisations working in these areas. The FSA could develop a UK citizen science food-focused research group. This would give the FSA priority access to the best researchers and cutting edge citizen science methods. This could extend to hosting conferences and meetings to allow the Citizen Science community to present to the FSA. Parallel workshops of industry representatives and citizen science practitioners could raise awareness of the potential of the method and kick-start novel collaborations.

4. **Collaborate and co-fund with funding providers and other government departments, a wider range of larger citizen science projects**. Our review has found that many food citizen science projects are more effective when run over the longer term and at scale. However, the wider literature indicates that citizen science research have difficulties obtaining mainstream science funding. To continue to produce high quality results over a long time period, at a (inter)national scale with impact, there needs to be an ambitious funding call. In addition, this call needs to include funding for academic and non-academic partners to engage with the projects (as lack of funding is a major barrier to non-academic partners engaging in research). Recognising 1) the economic implications and budgetary limitations of post-COVID UK recovery, 2) the potential of citizen science approaches to provide effective community centred research at scale (with high value for money); we recommend co-funding a larger call with other aligned government departments. We recommend that this co-funding extends to delivering of training to enable best practice research (this should go beyond the 2021 EU-Citizen.Science Call). This training for citizen science leaders and

facilitators could be linked within a funded bid process; and could be followed by further funding support for leaders and facilitators in funded citizen science projects. Funding calls and funded research programs should also include strategies for maximising diversity and inclusivity.

To conclude, we highlight that citizen science has potential to help address many grand challenges related to food and agriculture, and that citizen science could be transformative to the FSA's research portfolio. Most (9 of 11) FSA's areas of research interest have been explored by citizen science initiatives, with our review identifying existing programmes that can be easily adapted to the remaining areas of research interest.

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Annex A: Method

This report is based on the results of multiple rapid literature reviews for food and citizen science research projects (Pateman et al 2020, and Oakden et al, under review 2021). Further searching related to the FSA Research Themes was conducted in December 2020, as some of these terms were outside the original remit and search keywords.

In Oakden et al a rapid literature review was used to explore the terms used to describe participatory citizen science methods. Preliminary literature searching (Scopus, Google) included search terms relating to knowledge co-creation and non-expert research participation included the terms: citizen science, participatory research, community research, action research, co-production.

These hits were interrogated for “food system” and related terms including: food, diet, obesity, nutrition, agriculture, farming, urban growing/farming, fish, food and safety, and variants of these terms. From this initial search further papers were reviewed if cited within relevant papers or if they referenced them (snowball method). This was conducted in March to June 2020. Further searching using Google Scholar was carried out in December 2020 using additional food system search terms antimicrobial resistance/AMR, food safety, food pathogens, food additives.

- Pateman, R.M., de Bruin, A., Piirsalu, E., Reynolds, C.J. and West, S.E., (2020). Citizen science for quantifying and reducing food loss and food waste. *Frontiers in Sustainable Food Systems*, *4*, p.247.

- Oakden, Bridge, Armstrong, Reynolds, Wang, Panzone, Schmidt Rivera, Kause, Ffoulkes, Krawczyk, Miller, and Serjeant, (under review 2021) " The importance of citizen scientists in the move towards sustainable diets" *Frontiers in Sustainable Food Systems*.

Both articles are part of a special issue of *Frontiers in Sustainable Food Systems*: Agro-Food Systems, Citizen Science and the Sustainability Transition.

Annex B: Citizen science and food safety

Table B1: Concepts and thought pieces that discuss citizen science in food safety.

Paper	Topics
Nielen, (2019)	• Benefit and risk of utilising CS for distributed testing. • Poor data collection or communication may sow distrust in centralised (and distributed) testing and of food safety experts. • Suggests mitigation strategies (e.g. reviews of instrumentation capability and sensitivity and accuracy). • Benefits might include science literacy and improving acceptability of existing professional science community structures they operate in.
Naydenova et al. (2019)	• Changing role of publics in safety science. • Potential to inform process and policy. • Expected boundary shifts between traditional and extramural knowledge creators linked to technological shifts, so called, megatrends. • Mentions Cochrane Crowd community and Research Data Alliance as examples of citizen science in action. • CS supports stakeholder involvement. Crowdsourcing and citizen science. • Extramural education can be tools to enhance the public's trust in safety systems.
Olsen and Christensen (2015)	• Potential of crowd sourcing via social media. • Tool for gaining insights into food safety concerns of consumers for commercial entities. • Stress commercial usefulness not citizen involvement. *"May be useful to inform improvements to safety policies and process."*
Soon and Saguy (2017)	• Concept paper that discusses crowdsourcing for food safety and quality and safety including: - Improving businesses food hygiene. - Shelf life monitoring. - Communication and allergen management. - Managing risk (non-specific). - Safety (non-specific). • Crowdsourced big data could be used within a defined framework or control mechanism.
Smith et al. (2019) EFSA's 3rd scientific conference in September 2018	• Discussion paper on public communication of safety and risk. • Existing govt and regulatory body e.g. EFSA approaches to communication may not be sufficient. • Improving trust via new roles for intermediaries e.g. journalists Stakeholder involvement in risk assessment. • The concept that engagement can build trust in regulation by publics • (i) invest in effective tools and methods that support engagement; (ii) ensure balanced representation of interested parties; and (iii) periodically assess the extent of the resulting contributions to the scientific process

Annex C: Summary of commentaries on cutting-edge technology that can be used for food citizen science

Quesada-González and Merkoçi (2017) reviews the current use of specialist sensors attached to mobile phones that can be used by non-experts. In relation to food safety they highlight technologies in development for sensing E.-coli bacteria in beef samples and also for wider food allergen testing.

Nielen (2019) reviews the emerging smart-phone linked sensor technology for the detection of allergens. These projects use devices and technologies that allow citizen scientists to carry out their own tests without expert knowledge and with compact equipment that can be used outside specialised laboratories. This is very much a technical review of what may be feasible and features discussion of equipment emerging from research and onto the market, and of some systems that are already commercially available of varying and (some) questionable quality. The authors mention the possibility of this new technology alleviating testing burden for food processors and manufacturers. However, “if there is a push toward putting the onus for food safety on citizens this risks poor practices in food production, increasing risk for individuals with allergies”.

Ross et al. (2020) describes the prototype development of a miniaturised analytical chemistry laboratory, or so-called ‘lab on a chip’ device. The device is interesting because it includes the most scientifically challenging component for processing solid samples into solution or suspension in liquid to allow specific identification for food contaminants, in this case peanut and hazelnut allergens, using a biochemical method called lateral flow immunoassay; (a method used in off the shelf pregnancy tests). The prototype was tested with citizen science participants who did not know the device’s usability and effectiveness. This was one test for a prototype. The authors estimate the cost of the materials for each device unit to be relatively low at <$1USD, showing that “low cost lab on chip technology is feasible” however, "production and further development costs would need to be mapped”(Ross et al. 2020). Ross et al. (2020) continues to highlight that the particular chemical components need to be selected and developed so that they could be “reliably measured without risk to consumers of false negatives”. This last comment is key as there is significant risk of harm including death from false negative tests. Further, unless the entirety of a food were sampled it is difficult to envisage how such tests would not guarantee that the food did not contain the allergen in an un-sampled section. Due to the risk of false negatives such crowdsourced and citizen science projects would require further exploration before wider experiments could take place.

Nelis et al. (2020) provides a systemic review of smart phone based devices, along with a discussion of limitations associated with newly developing technology. In a different narrative to the above papers, Nelis et al. speculate that it is more likely that devices will appear for commercial use to make testing in production handling of food easier (rather than consumer targeted devices). This is worth bearing in mind when thinking about the potential scaling and cost of this technology for citizen scientists when compared to environmental health officers.

For enquiries about this publication, contact the Food Standards Agency.

Project reference: FS900108

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