Consumer acceptance of and willingness to pay for food nanotechnology: a systematic review

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Author contributions

LJF conceived of the study, helped draft the manuscript and provided overall leadership for the research. ELG was responsible for data searching and sifting, data extraction and analysis, and drafting of the manuscript. BC was responsible for second sifting, and drafting of the manuscript. SK and CH were responsible for drafting of the manuscript. All authors critically commented on, and approved, the final version of the manuscript.

Competing financial interests

The authors declare that there are no competing financial interests.

Conflicts of interest

No conflicts of interest are reported by the authors.

ABSTRACT

Background

Consumer's attitudes to, and acceptance of, emerging technologies and their applications, are important determinants of their successful implementation and commercialisation. Understanding the range of socio-psychological, cultural and affective factors which may influence consumer responses to applications of nanotechnology will help "fine-tune" the development of consumer products in line with their expectations and preferences. This is particularly true of applications in the food area, where consumer concerns about technologies applied to food production may be elevated.

Objectives

This research applied systematic review methodology to synthesise current knowledge regarding societal acceptance or rejection of nanotechnology applied to agri-food production. The objective was to aggregate knowledge derived from different research areas to gain an overall picture of consumer responses to nanotechnology applied to food production.

Information sources

Relevant electronic databases of peer-reviewed literature were searched from the earliest date available, for peer-reviewed papers which reported primary empirical data on consumer and expert acceptance of agri-food nanotechnology, using a formal systematic review protocol.

Eligibility criteria

Inclusion criteria for papers to be included in the review were: empirical peer-reviewed papers written in English; a population sample of adults aged 18 years and over used in the research; a research focus on consumer and expert acceptance of agri-food nanotechnology; and research on attitudes towards, and willingness to pay for ,different applications of agri-food nanotechnology.

Study selection, appraisal and synthesis

Two researchers independently appraised the papers using NVivo 10 QSR software. Studies examining consumer and expert acceptance were thematically analysed, and key information collated. The results were

synthesised in order to identify trends in information relevant to consumer acceptance of nanotechnology applied to food production.

Results

Eight key themes were identified from the 32papers which were extracted from the literature. These themes were applied to understand the determinants of consumer acceptance of agri-food nanotechnology.

Conclusions

Nanotechnology is more likely to be accepted by consumers when applied to development of novel packaging with distinct benefits rather than when integrated directly into agri-food products. Trust and confidence in agri-food nanotechnology and its governance needs to be fostered through transparent regulation and development of societally beneficial impacts to increase consumer acceptance.

Keywords

Nanotechnology, consumer, acceptance, expert opinion, systematic review.

BACKGROUND

There has been extensive debate about the potential societal responses to (different) applications of nanotechnology primarily because consumer's attitudes towards, and acceptance of, emerging technologies and their applications are important determinants of their successful implementation and commercialisation, and without consumer acceptance the potential economic and social benefits of nanotechnology may not be realized (Burri and Bellucci 2008; Frewer et al. 2011; Gupta et al. 2011; Kim et al. 2014; Lowe et al. 1993; Macoubrie 2006; Pidgeon et al. 2011; Renn and Roco 2006; Roco 2003). Stakeholders (drawn from industry and policy communities) have identified applications in the agri-food sector as being the potentially most controversial as far as societal acceptance is concerned (Gupta et al. 2013; Matin et al. 2012). To some extent this reflects expert perceptions that the pattern of societal response to different applications of nanotechnology will be similar to those observed following the introduction of genetically modified (GM) foods (Gupta et al. 2015; Mehta 2004). To date however, there has been little evidence of consumer opposition to agri-food applications of nanotechnology, (George et al. 2014), nor has formalised opposition (for example, through activities linked to pressure groups) been as extensive as that associated with GM (Seifert and Plows 2014; van Broekhuizen and Reijnders 2011). It is also important to note that attitudes towards technology are unlikely to remain static in space and time, and the results of a single study are unlikely to reflect an aggregated analysis of multiple studies which use different methodologies, study populations, or applications, and which are embedded in different contexts. The aim of this study was to synthesise current knowledge regarding consumer and expert acceptance or rejection of nanotechnology applied to agri-food production, to identify emerging trends and patterns, and to assess gaps in knowledge.

While there have been systematic reviews of the regulatory situation surrounding nanotechnology (Grobe 2008), to the best of the authors' knowledge, no systematic reviews of research investigating consumer attitudes, perceptions and acceptance of agri-food nanotechnology have been conducted or registered on the PROSPERO[1] (PROPSERO 2012) database, nor the databases of the Centre for Reviews and Dissemination (Centre for Reviews and Dissemination 2012); (Besley et al. 2008) The systematic reviews that have been conducted to date

[1] Prospero is a well-known database of systematic reviews in health and social issues, ran by the CRD. The CRD produces three databases: Database of Abstracts of Reviews of Effects; NHS Economic Evaluation Database; and Health Technology Assessment Database. Whilst these databases are not wholly applicable to our review, they are the only databases of their kind to register systematic reviews, and thus was checked for thoroughness. Any other systematic reviews on a similar topic would have been returned in our searches of the main databases for relevant papers.

are in the general area of nanotechnology application (e.g. in relation to risk assessment) or have focused on specific food issues, such as vitamin D food fortification (Black et al. 2011). A systematic review of research into consumer's attitudes towards and acceptance of agri-food nanotechnology is timely and policy relevant, as simply considering attitudes to specific applications may not reflect general trends in attitudes and consumer priorities for development.

This review seeks to synthesize existing knowledge regarding consumer attitudes towards agri-food nanotechnology in order to provide policy makers, nanotechnology experts, and food manufacturers with robust and high quality evidence concerning consumer acceptance of nanotechnology applied within the agri-food sector. The results can be applied to providing evidence which will assist key stakeholders in their decision making, facilitate fine–tuning of policies, and enable an estimation of how consumers may react to future food products, in line with best practices in agri-food technology application (Cook and Fairweather 2007; Raley et al. In Press)

METHODS

A protocol (see Supplementary Data 1) for the review was compiled in full before searching commenced, and there were no substantive variations from protocol during the course of the study. Reporting of the review follows the Preferred Reporting Items for Systematic Reviews (PRISMA checklist) guidelines (see Supplementary Data 2:(Moher et al. 2009)

Information sources

Seven electronic databases of peer-reviewed literature were searched from the earliest date available (indicated in brackets) to October 2051. These were: CAB Abstracts (1910), EBM Reviews (1991), Embase (1980), Medline (1946), PsycINFO (1806), Scopus (1960) and Web of Science (1864). The search strategy combined relevant terms for 'nanotechnology', 'food' and 'consumer acceptance', and search strings were adapted as appropriate for each database. Examples of the search terms used are provided in Supplementary Data 3. Additionally reference lists of all papers meeting the inclusion criteria were also reviewed and citation searches of included papers were conducted using Web of Science. Endnote X6 was used to manage search results, with NVivo 10 QSR International software subsequently used for data analysis.

Eligibility criteria

Studies deemed eligible for inclusion were papers which reported primary empirical data on consumer and expert acceptance of agri-food nanotechnology. Only peer-reviewed papers, written in English, were included in this review in order to focus on high quality evidence on the acceptance of agri-food nanotechnology. The inclusion criteria are fully described in Table 1 and were established to answer the primary research question: How acceptable is nanotechnology to consumers and experts when applied to agri-food products?

Study selection, appraisal and synthesis

Papers were screened by two independent researchers (ELG and BC) in a three stage process in relation to the eligibility criteria. This was done at title, abstract and full text level. Any disagreements were resolved by face-to-face discussion. Due to reference lists and citation searches being conducted, some studies were included which contained the same population as previous studies (Brown et al. 2015; Yue et al. 2015b;Roosen et al. 2013). Where studies report the same data they are only reported once in the result i.e. there are 32 papers but only 29 stand-alone studies.

Quality assessment of included studies was carried out independently by two researchers (ELG & BC) with the Critical Appraisal Skills Programme Qualitative Research Checklist (Critical Appraisal Skills Programme 2013) used to assess qualitative research. To assess the quantitative papers the survey research tool by Petticrew and Roberts (Petticrew and Roberts 2006) was used. For the mixed methods papers, both tools were used for quality appraisal. Disagreements were resolved through discussion (ELG & BC).

The studies examining consumer and expert acceptance are presented in a tabular summary for narrative synthesis (see Table 2). They are described in terms of their aims, methods and study participants along with a brief summary of their key findings. Due to the plethora of findings, inconsistency in reporting styles and complexity, and mixed methods nature of the data, studies were deemed too heterogeneous for meta-analysis, a four stage thematic analysis approach was taken (Braun and Clarke 2006).

The first stage involved reading through the papers line-by-line and highlighting relevant data (e.g. a word or a paragraph), to which a code was assigned. These codes were either sociologically constructed. this means that a code was given to the data by the researchers (ELG and BC), which was either a word, sentence or paragraph, and which best reflected the meaning within the data (e.g. safety, lack of testing, too expensive) - or an ‘in vivo’ code – a code which directly copies what was published in the text (Barnett-Page and Thomas 2009). The

second stage of the coding process involved examining these initial codes to ensure all data had been thematically analysed (by ELG and BC). The third stage involved sorting the initial codes into broader categories. Here, the researchers (ELG and BC) reflected upon the array of codes and generated broader categories by merging some codes with others, creating new codes, or re-naming or deleting existing codes. The fourth stage involved assigning several themes, which essentially grouped the initial codes into major themes that would help address the research questions. Memo notes were made on how and why these analytical codes were generated by one researcher (ELG), with two further researchers (BC and SK) verifying them. These themes are presented in Table 5, and are discussed in the next section. They are illustrated using representative quotations to illustrate each theme.

RESULTS

Thirty two papers were included; 6 qualitative studies (Becker 2013; Brown et al. 2015; Brown and Kuzma 2013; Gupta et al. 2012; Gupta et al. 2015; Köhler and Som 2008), 23 quantitative studies (surveys and experiments) (Besley et al. 2008; Bieberstein et al. 2013; Capon et al. 2015; Casolani et al. 2015; Cobb and Macoubrie 2004; Conti et al. 2011; Cook and Fairweather 2007; Farshchi et al. 2011; Groves 2013; Gupta et al. 2013; Marette et al. 2009; Roosen et al. 2015; Roosen et al. 2011; Schnettler et al. 2013a; Schnettler et al. 2014; Schnettler et al. 2013b; Siegrist et al. 2007; Siegrist et al. 2009; Siegrist et al. 2008; Stampfli et al. 2010; Suhaimee et al. 2014; Yue et al. 2015a; Yue et al. 2015b), and three mixed methods papers (Handford et al. 2015; Simons et al. 2009; Yawson and Kuzma 2010) (see Table 2). During sifting, 17 papers were excluded because they were unavailable from Newcastle University, the Internet, or through inter-library loans, or they were unobtainable in English (Ahmadi and Ahmadi 2013; Cheng et al. 2009; Lin et al. 2011; Militaru and Ionescu 2013; Mir 2007; Rakia 1993; Rogers et al. 2013; Schiffeler 2014; Scholl 2013; Siegrist 2007; Stone 2009; Suerdem et al. 2013; Tanaka 1995; Teggatz 2013; Thoenes 1982; Thompson n.d.; Zimmer 2008), but which may have been potentially relevant. The qualitative empirical papers collected data using focus groups (n=2) (Brown et al. 2015; Brown and Kuzma 2013) and interviews (n=4) (Becker 2013; Gupta et al. 2012; Gupta et al. 2015; Köhler and Som 2008). The quantitative empirical papers largely utilised survey methodology (n=20) (Besley et al. 2008; Capon et al. 2015; Casolani et al. 2015; Cobb and Macoubrie 2004; Conti et al. 2011; Cook and Fairweather 2007; Farshchi et al. 2011; Gupta et al. 2013; Roosen et al. 2015; Schnettler et al. 2013a; Schnettler et al. 2014; Schnettler et al. 2013b; Siegrist et al. 2007; Siegrist et al. 2009; Siegrist et al. 2008; Stampfli et al. 2010; Suhaimee et al. 2014; Yue et al. 2015a; Yue et al. 2015b), one used a

192 survey as part of a Delphi methodology (Groves 2013), and a further three used experiments (Bieberstein et al.
193 2013; Marette et al. 2009; Roosen et al. 2011). The mixed methods studies combined a survey and interview
194 methods approach (Handford et al. 2015; Simons et al. 2009; Yawson and Kuzma 2010). Study populations
195 were mainly individual members of the public (consumers/shoppers) (n=23) (Bieberstein et al. 2013; Brown et
196 al. 2015; Brown and Kuzma 2013; Casolani et al. 2015; Cobb and Macoubrie 2004; Conti et al. 2011; Cook and
197 Fairweather 2007; Farshchi et al. 2011; Gupta et al. 2015; Marette et al. 2009; Roosen et al. 2015; Roosen et al.
198 2011; Schnettler et al. 2013a; Schnettler et al. 2014; Schnettler et al. 2013b; Siegrist et al. 2007; Siegrist et al.
199 2009; Siegrist et al. 2008; Simons et al. 2009; Stampfli et al. 2010; Suhaimee et al. 2014; Yue et al. 2015a; Yue
200 et al. 2015b), 'experts' in the area of nanotechnology (n=6) (Besley et al. 2008; Groves 2013; Gupta et al. 2013;
201 Gupta et al. 2012; Köhler and Som 2008; Yawson and Kuzma 2010), agri-food organisations (Handford et al.
202 2015),'commercializers' (*individuals who make deliberate efforts to increase the presence of products on the*
203 *market that employ nanotechnology or contain nanomaterials"*(Becker 2013); and one study surveyed
204 consumers, academic, business and government stakeholders (Capon et al. 2015).
205
206 Quality appraisal of the qualitative studies is shown in Table 3, and the quantitative studies in Table 4. For the
207 qualitative studies, all 6 papers included a clear statement of the aims of the research and employed a qualitative
208 methodology. The majority of studies had designs appropriate to the aims and objectives, used a suitable
209 recruitment strategy, collected data in a way that was appropriate to the research topic, and provided a clear
210 statement of findings. However, the majority of studies did not consider the impact of the relationship between
211 the researcher and the participants, and only 2 of them explicitly state how they had considered ethical issues.
212 For the experimental studies, a lack of information reported in the papers meant that many study attributes were
213 rated as 'unclear', most likely due to reporting restrictions in the respective journals. Finally for one of the
214 qualitative studies, information to demonstrate the rigour of the data analysis was not provided. All quantitative
215 studies employed a methodological approach appropriate to the research topic and most undertook appropriate
216 analyses, with the remaining 4 being unclear to exactly how they analysed the data. However, for the majority of
217 the studies it was not possible to determine whether a representative sample and objective measures (e.g.
218 validated survey questions) had been used, with only studies, typically the experimental ones, using quota
219 sampling to ensure samples were representative. Less than half of the studies justified their sample size or
220 reported the response rate during recruitment. Finally, in terms of the quality of the papers, it may be that key
221 methodological issues were not reported, rather than these being weak areas of study design, although this is

potentially interpretable as evidence of bias. In the absence of validated quality appraisal tools, a best match was used.

The results below present the main themes that were identified from the thematic analysis (see Table 5). We indicate the relevant supplementary data boxes which are pertinent to each theme throughout the next section.

Theme 1: type and applications of agri-food nanotechnology

Nanotechnology can be integrated into food products, can form part of the packaging of food, and/or can be used when processing food products. When considering these three types of application, overall, the majority of the studies (regardless of sample population) reported greater consumer acceptance of nanotechnology when it was applied to agri-food packaging and processing activities, compared to when it was integrated into agri-food products (see Supplementary Box 1).

Both consumer and expert opinion were divided on whether they found nanotechnology to be acceptable or unacceptable when used directly in foods as such. Experts appear to rate nanotechnology when applied to food and food products to be more acceptable than do consumers, but that could be because many of these experts worked in the nanotechnology field and hold some asymmetric information (i.e. greater knowledge and information about risk and benefit assessment which is not available to consumers).

Theme 2: benefits and risks of agri-food nanotechnology

Often agri-food related nanotechnology was considered acceptable by experts when clear benefits could be identified. Experts considered benefits in relation to food freshness and safety, and wider environmental and food manufacturing advantages. In particular, if nanotechnology could prevent food spoilage and enhance the shelf-life of the food, and reduce the amount of packaging that would need to be used, it was viewed as acceptable. Additional wider applications of nanotechnology included using nanotechnologies to reduce food shortages, and to improve (reduce) calorie content of food. Ultimately, if the perceived benefits were thought to outweigh the perceived risks then nanotechnology applied to agri-food production was acceptable (see Supplementary Box 2a).

The available evidence suggests that consumers view agri-food nanotechnology favourably, for example in comparison to other agri-food technology innovations recently introduced such as genetically modified (GM) foods. Moreover, if the technology results in cheaper consumer products, and when it could assist beneficial food modifications (such as improved taste and disease prevention), it was perceived as acceptable. As found in the expert studies, the consumer studies found that if the perceived benefits outweighed the perceived risks, then agri-food nanotechnology is more acceptable to consumers (see Supplementary Box 2b).

The 'commercializers' perceived agri-food nanotechnology to be societally acceptable, although this may be attributable to participant's professional roles in promoting such products (see Supplementary Box 2c). Ultimately, commercializers viewed agri-food nanotechnology to be novel, to pose a low risk to individuals in terms of health impacts, and to be societally acceptable given that there are "riskier" technologies within the marketplace (although it was not clear to which 'riskier' technologies participants were referring in the published research).

However, both experts and consumers expressed concerns about the potential risks associated with using nanotechnology to produce food and food products. Experts perceived a greater risk associated with nanotechnology applied to the production of food products directly as compared to food packaging (see Supplementary Box 2d).

Experts and commercializers noted that, even when nanotechnology was used in food packaging, there may be the potential for it to contaminate food with which it came into contact, increasing risks to consumers (see Supplementary Box 2e). The proximity of nanoparticles to the human body, and in particular ingestion of the particles, was viewed as high risk, and hence unacceptable by some experts.

Within the consumer studies, multiple concerns were raised. These included concerns about potential side effects, and beliefs that the technology could be misused; both of these concerns were underpinned by a fear of the unknown (see Supplementary Box 2f). Agri-food nanotechnology was also considered to be unacceptable because foods containing the technology are not perceived to be "natural" products. There was also a concern that nanotechnology is used for increasing profit, rather than for producing improved food products with discrete consumer benefits.

Theme 3: socio-demographic influences

The studies included in the review are heterogeneous in nature and so it is difficult to conclusively link opinions about agri-food nanotechnology to individual socio-demographic characteristics. However, there is some indication that certain population groups may be more accepting of agri-food nanotechnology than others (see Supplementary Box 3). In particular, white, male population groups perceive fewer risks to be associated with the application of nanotechnologies. In terms of expert opinion regarding perceived acceptance, Europeans and Australasians appeared to be less open to agri-food nanotechnology than other population groups. In addition, those who are traditional in their outlook may perceive greater risks to the use of agri-food nanotechnologies, compared to those who are open to new technologies. However, in most of these studies no explanation was provided to explain how and why these particular socio-demographic groups may influence levels of consumer acceptance of agri-food nanotechnology.

Theme 4: creating an informed and trusting consumer

The available evidence suggests that consumer acceptance of agrifood nanotechnologies may increase if there is clarity regarding who takes responsibility for creating and regulating safe nanotechnology products, as well as regarding who provides information about safety to the general public (see Supplementary Box 4a). Although regulations regarding the protection of human health is an obvious requirement for the effective commercialisation of any agri-food technologies, participants indicated that (harmonised) regulations are also required to facilitate trade of food products developed using nanotechnology across countries (see Supplementary Box 4b). Whether or not information should be provided through product labels, to inform consumers that particular products have been produced using nanotechnology, was a more contentious issue. It is unclear how much information consumers should be provided with, nor who should be responsible for educating and informing consumers about agri-food nanotechnology (see Supplementary Box 4c). Underpinning consumer acceptance (or rejection) of foods made using nanotechnology was the issue of trust. There is evidence that a higher level of trust in the nanotechnology industry was linked to greater acceptance of the technology (see Supplementary Box 4d). Consumers place a greater degree of trust in nanotechnology when it was used in food packaging compared to when it is integrated into food products.

Many studies indicated that consumers have limited knowledge about nanotechnology and how it can be applied to food products. For some consumers this may encourage early adoption of the technology, for others it can

311 create concerns. Low levels of knowledge about nanotechnology may translate into a lower willingness to
312 accept and purchase agri-food nanotechnology products because of a lack of understanding of how it is used in
313 the food (see Supplementary Box 4e).
314
315 Commercializers recognised that, in order to increase consumer acceptance of, and trust in, agri-food
316 nanotechnology, rigorous testing of products may have to be undertaken by companies who use nanotechnology
317 in their products (see Supplementary Box 4f). Being prepared for regulatory and labelling changes was deemed
318 important, to help increase consumer confidence in agri-food nanotechnology, even if there was some
319 scepticism about how well consumers would understand labelling of nanotechnology in agri-food products. (see
320 Supplementary Box 4g).
321
322 *Theme 5: characteristics of food nanotechnology*
323 Acceptance of agri-food nanotechnology appears to be partly determined by the technology underpinning
324 nanotechnology products, product characteristics and the cost of nanotechnology products (see
325 Supplementary Box 5a). Those who preferred foods to be produced using "natural" processing
326 methodologies, and who associated this with being healthy, perceived nanotechnology to be less
327 acceptable, due to greater perceptions of risk. If agri-food nanotechnology brings tangible and concrete
328 advantages to consumers (e.g. in relation to increased food security), then experts are more likely to rate
329 the different applications as acceptable (see Supplementary Box 5b). Consumers were however, not
330 willing to pay more for products developed using nanotechnology, independently of the benefits that will
331 be delivered through its application.
332
333 *Theme 6: link to historical agri-food technology concerns*
334 In some of the studies reviewed, consumers linked agri-food nanotechnology to GM foods. This may have
335 lowered the acceptability of agri-food nanotechnology if GM foods are perceived negatively (see Supplementary
336 Box 6). Where there was consumer uncertainty about the acceptability of agri-food nanotechnology, individuals
337 utlised their existing "reference points" to assess the risks and benefits arising from the technology. As one of
338 these reference points is potentially GM foods, this may have created lower consumer acceptance of agri-food
339 nanotechnology.
340

341 *Theme 7: marketing and commercialisation*

342 In order to encourage consumer purchases of agri-food nanotechology products, the role of marketing and, in
343 particular, branding is potentially an important topic of research. Highlighting the benefits to consumers via
344 marketing communications was rated important, as was the development of a "trustworthy brand". These
345 recommendations are not dissimilar to the role marketing plays for other types of products and services (see
346 Supplementary Box 7a).

347

348 It was recognised that encouraging increased repeat purchases of agri-food nanotechnology would inspire
349 confidence in other population groups and thus increase acceptance. Thus it was suggested that those consumers
350 who view agri-food nanotechnology to be most acceptable may "lead" in terms of technology adoption, which
351 may then open up the market for other agri-food nanotechnology products (see Supplementary Box 7b). It was
352 also reported that food packaging should be commercialised ahead of foods produced using nanotechnology, as
353 this would be more acceptable to consumers. Furthermore, informed expert opinion might usefully be utilised to
354 facilitate the formation of consumer opinions regarding agri-food nanotechnology and its potential acceptability
355 by consumers.

356

357 *Theme 8: future applications of agri-food nanotechnology*

358 Most recommendations for future research focused understanding the determinants of consumer acceptance of
359 food nanotechnology in different cultures. Comparing expert and consumer opinion was considered an
360 important research area, as there may be a mismatch between what experts would provide in terms of agri-food
361 nanotechnology and what would be accepted by consumers (see Supplementary Box 8a). This applied to future
362 developments as well as those currently well advanced in terms of their innovation trajectories.

363

364 When consumer characteristics were considered in the studies reviewed, there was a focus on demographic
365 characteristics rather than wider psychographic characteristics. Thus, moving beyond the focus on socio-
366 demographic characteristics and to consider other psychological and cultural determinants was also identified as
367 important (see Supplementary Box 8b). For example, consumers with an internal "health locus of control" (who
368 perceive that they are able to influence their own health status through their behaviours) may be more inclined
369 to adopt consumer products with distinct health benefits (Poínhos et al. 2014).

370

Exploring the drivers of social negativity towards new technologies, as well as risk aversion in the context of agri-food nanotechnology, were identified as future research priorities (see Supplementary Box 8c). Furthermore, there was a call for consumer acceptance research to use real nanotechnology products, rather than hypothetical scenarios, in order to provide study participants with a real experience of such products. This could help to provide a more realistic evidence base regarding consumer acceptance of nanotechnology, although it is clearly dependent on both the product innovation trajectory and regulatory approval of such products, in particular if they were consumed by study participants, or in some other way come into physical contact with consumers.

Finally, other key issues were identified that might influence consumer acceptance of agri-food nanotechnology. These considerations also related to the themes identified above, particularly providing clear and detailed information, involving multiple stakeholders in the debate on nanotechnology, and building consumer confidence and trust (see Supplementary Box 8d).

DISCUSSION

Statement of main findings

We believe that this is the first systematic review to explore empirical findings reporting on consumer and expert acceptance of nanotechnology applied to the agri-food sector. Included in this review are 32 empirical studies focused on consumer and expert opinions towards agri-food nanotechnology. The majority of these studies used a survey methodology to assess acceptance, although each survey asked very different questions of participants. In-depth empirical (i.e. qualitative research), or experimental research (for example, that which examined the impacts of information interventions on consumer attitudes) exploring consumer acceptance was limited, and it may be useful to follow this up in future research. The analysis of the research reported in the papers included in the review identified eight themes which appear relevant to understanding societal acceptance of agri-food nanotechnology. The consumer studies, and those involving expert assessment of consumer perceptions, suggested that the benefits and risks which consumers perceive to be associated with nanotechnology applied to food production and food products is likely to be an important determinant of consumer responses. In this respect, agri-food nanotechnology is likely to be accepted by consumers if the perceived benefits in some way outweigh the perceived risks and associated consumer concerns. In particular, nanotechnology was deemed more acceptable when it was used in food packaging and processing rather than as an integral part of food products themselves. It was also found that agri-food nanotechnology may be more

401 acceptable if it results in cheaper, safer, consumer products. i.e. a tangible and desirable consumer benefit is
402 delivered as a consequence of its application.
403
404 There is reasonable consistency in the literature regarding societal acceptance of agri-food applications of
405 nanotechnology. Although consumers express some concerns about nanotechnology applied to food production
406 *per se*, less concern is expressed about nanotechnology applied to innovative novel food packaging. However,
407 the consumer rejection of nanotechnology applied to food production, anticipated by some stakeholders, and
408 following consumer reaction to GM applied to food production in some parts of the world, has not been
409 supported by the evidence identified in this review. Increased inputs by consumers into the product
410 development, when concrete and tangible consumer benefits are being incorporated into specific products, is
411 required to ensure what is being developed is also what consumers want(Raley et al. In Press).
412
413 Our systematic review has also highlighted a major gap in the available literature which concerns research
414 which utilises theoretical approaches to understanding societal acceptance of nanotechnology applied to agri-
415 food production. Developing research which is theoretically-informed is potentially advantageous insomuch as
416 it may facilitate greater ability to predict consumer's requirements of nanotechnological innovation in the future.
417 Utilising theoretically driven approaches will also enable more systematic comparison of research outcomes
418 across studies (for example, between populations with different characteristics, with respect to societal
419 acceptance of different applications, and analysis of trends on consumer acceptance with time), in particular if a
420 common theoretical or methodological framework or approach is adopted. It is also notable that many of the
421 studies included in the review identified further exploration of the drivers of social negativity towards new
422 technologies, as well as social negativity and risk aversion as future research priorities. Given that one
423 conclusion of this systematic review is that perceived benefit is a relevant and important determinant of
424 consumer behaviour, it will also be important to understand drivers of acceptance and benefit acquisition. It
425 would be useful if future research systematically integrated both risk and benefit perception analyses in the
426 research design, not least because benefit information might usefully be applied to refining the product
427 development trajectory in the future. Commercial success will depend on consumers perceiving tangible and
428 concrete benefits to be associated with the application of nanotechnology to food products.
429
430 *Strength and weaknesses of studies included in the review*

The majority of the studies reviewed used quantitative survey methodologies. Often large – and sometimes nationally representative – samples were used. This facilitated comparative analysis of the acceptance of agri-food nanotechnology across different consumer segments but did not allow for exploration or in depth analysis of why these views were held by consumers, given the method used to collect the data. Three studies utilised experimental methodologies (i.e. choice experiments) to explore consumer preferences for (hypothetical) food nanotechnology products. Consumer experience (whether positive or negative) of foods produced using nanotechnology may influence subsequent choice behaviours, and as such limit the generalisability of findings from studies using choice experiments.

In addition, the application of formal quality appraisal indicated that studies were poor at reporting sampling and analytical procedures, and often ethical approvals for research which utilised human participants. However, the studies assessed acceptance of agri-food nanotechnology across a wide range of stakeholders, including representative groups of consumers, experts and commercializers, as well as reporting data from a cross-section of participants, from multiple countries and backgrounds. Therefore whilst the findings of this review highlight acceptance of agri-food nanotechnologies from the perspective of multiple stakeholders, further research is required to see how the gap can be narrowed between expert/commercializer opinions and consumer views, to ensure nanotechologies are acceptable to consumers, whilst being commercially viable to those who produce such technologies .

Strengths and weaknesses of this review

We believe that this systematic review has captured the available empirical evidence exploring consumer and expert opinion towards agri-food nanotechnology. Similar findings are reported across the included papers, and so we are confident that we have reached data saturation (Francis et al. 2009) regarding consumer and expert acceptance of agri-food nanotechnology. In particular, this systematic reviews affords those interested in commercialising nanotechnology with a quick reference guide to consumer and expert opinions towards nanotechnologies when applied to agri-food products and production methods. This review synthesises the factors that both help and hinder food nanotechnology commercialisation and provides suggestions for future research, legislation of nanotechnology, and consumer education. By synthesising all of the relevant literature in these areas, this systematic review allows those interested in the field to gain an oversight of these key issues much more quickly than would occur by reading individual papers. Aggregation of the literature in this

systematic review allows readers an opportunity to identify key issues, areas of concern and future developments in the field that would not be obtainable by reading individual papers in a standalone context.

While the authors are of the opinion that data saturation was reached, 17 papers were excluded because they were unobtainable in English and/or they were unavailable. Likewise, we have not reviewed the grey literature in this area, and so again, we may have missed relevant opinions that have not been published in English language peer reviewed journals. Some of the papers refer to grey literature, such as the Eurobarometer (European Commission 2010), do not discuss themes that are wholly different to the results of our systematic review.

A further weakness is that we have been unable to undertake a quantitative meta-analysis given the heterogeneity of dependent variables across the included papers. However, it may be feasible to revisit this review at a future date to conduct a meta-analysis, once there are a greater number of published empirical studies in this area which report suitable data.

Implications for policy and practice

A consistent finding was that acceptance depends on the perceived benefits of nanotechnology outweighing the perceived risks, although there is less consistency in reporting what constitutes a "desirable benefit" in terms of consumer perceptions. Benefits may refer to generic factors like (cheaper) prices or benefits specific to different agri-food applications. Systematic analysis of what these preferred benefits are, and which consumers want them, is needed. Policy makers and other stakeholders should also be aware that much of the research indicated that, for agri-food nanotechnology to be accepted in the marketplace, consumer confidence and trust in nanotechnology, food manufacturers, regulators and nanotechnology experts, must be developed and maintained. This might be achieved, for example, through good technology governance practice, (e.g. see (Bernstein et al. 2014; Marchant 2012), effective risk-benefit communication, (Binder et al. 2011; Frewer et al. 2015), and stakeholder and end-user involvement on technology development, in line with best practice in responsible Research and Innovation policies (de Bakker et al. 2014; von Schomberg 2013).

A focus on communicating the potential benefits and risks of nanotechnology, building on consumer concerns, and investigation of how food nanotechnology can be regulated in a way that inspires consumer confidence, will increase the likelihood of food nanotechnology purchases.

CONCLUSION

Nanotechnology is more likely to be accepted in food packaging rather than integrated into food products. Trust and confidence in agri-food nanotechnology needs to be fostered, to increase consumer acceptance. Providing information to consumers on the benefits of nanotechnology, and ensuring an informed public could help to reduce consumer concern and could inspire food nanotechnology purchases. However, research is needed to understand what consumers perceive as beneficial, as well as how they construe risks. Adopting theoretically underpinned approaches to understanding consumer perceptions and attitudes will facilitate comparative analysis across different groups of consumers, different food nanotechnology applications, and allow assessment of trends in consumer priorities and concerns with time.

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FIGURE LEGENDS

Figure 1. PRISMA Flow Diagram

TABLE LEGENDS

Table 1. Inclusion criteria

Table 2. Table of included studies

Table 3. Quality appraisal of qualitative studies

Table 4. Quality appraisal of quantitative studies

Table 5. Analytical themes

SUPPLEMENTARY FILES

Supplementary Data 1: Protocol

Supplementary Data 2: PRISMA checklist

Supplementary Data 3: Example search terms

Supplementary Data 4: Box 1 Quotations to illustrate the 'Type and applications of food nanotechnology' theme

Supplementary Data 5: Box 2 Quotations to illustrate the 'Benefits and risks of agri-food nanotechnology' theme

Supplementary Data 6: Box 3 Quotations to illustrate the 'Socio-demographic influences' theme

Supplementary Data 7: Box 4 Quotations to illustrate the 'Creating an informed and trusting consumer' theme

Supplementary Data 8: Box 5 Quotations to illustrate the 'Characteristics of agri-food nanotechnology' theme

Supplementary Data 9: Box 6 Quotations to illustrate the 'Link to historical agri-food nanotechnology concerns' theme

Supplementary Data 10: Box 7 Quotations to illustrate the 'Marketing and commercialisation' theme

Supplementary Data 11: Box 8 Quotations to illustrate the 'Future applications of food nanotechnology' theme

Table 1. Inclusion criteria

Study component	Inclusion criteria
Date range	All dates
Publication characteristics	English language , peer-reviewed journal article
Study design	Empirical, qualitative and/or quantitative primary data
Population	Adults aged 18 years and over
Focus	Must contain a discussion of consumer acceptance of food nanotechnology
Outcome	Must contain discussion of willingness to pay/intention to pay for food nanotechnology products

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Table 2. Table of included studies

Paper	Aim	Methods (n)	Participants	Country	Major conclusions
Becker 2013	To understand how the nanotechnology industry perceives the risks of nanotechnology.	Semi-structured, open-ended phone interviews (n= 17).	American individuals involved in the commercialization of Nanotechnology.	USA	Commercialisers acknowledged uncertainty to be inherent to the overall risk arising from nanotechnology and thus take a lot of precaution in ensuring the safety of their products. However, they claim that nanotechnology is neither novel nor risky.
Besley, Kramer and Priest 2008	To provide evidence regarding what American researchers, who have published research on nanotechnology, view as the most important potential benefits and risks of nanotechnology-oriented research, as well as views about the current state of government regulation, the	Survey (n = 177).	Nanotechnology American researchers.	USA	Researchers acknowledged the importance of a range of nanotechnologies across a diversity of areas. Health and technological benefits were perceived to be more important than environmental benefits. However, public health and environmental issues are argued to be areas where both risks and the need for regulation are greatest.

	current state of research and its future. It also explores which expert perceptions represent broadly a shared consensus and which provoke a range of individual opinions.				
Bierberstein et al 2013	To evaluate consumers' willingness to pay (WTP) for food nanotechnology focusing on: nano-fortification with vitamins and nano-packaging. Specifically, to evaluate the impact of information on consumer choice when nanotechnology may have important but uncertain consequences on health, environment and society.	(Choice) experiment based on sample of 143 German participants, and 152 French participants. Sample random sampling using quotas.	French and German consumers.	France and Germany	Most participants in this study expressed their reluctance to accept nanotechnology applications in food products. Food safety and its link to human health are very important when considering nano-foods. There are differences across the two countries with, French consumers being more reluctant to accept nano-packaging, whereas German consumers are more concerned about nano-fortification.

Brown, Fatehi and Kuzma 2015	To better explore and understand the public's perceptions of and attitudes toward emerging technologies and food products.	Focus groups (n-=7) 90 minutes in length and ranging in size from seven to 10 participants. Participants selected on the criteria an equal number of females and males in each group.	56 participants (citizens/public) across 6 US cities.	USA	Skepticism and altruism are two factors yet unrecognised as influential in the public's perceptions of nanotechnology. Hence, they may play an important role in explaining how and why perceptions are formed. These factors also provide a bridge between cultural-based theories and psychometric-based theories.
Brown and Kuzma 2013	To examine public attitudes toward food nanotechnology in conversational, focus group settings, in order to identify policy options for nanofood governance, particularly options for labelling.	Focus groups (n=7) 90 minutes in length and ranging in size from seven to 10 participants. Stratified random sampling. Quantitative worksheet responses, followed by post-group online survey (n=34).	56 participants (citizens/public) across 6 US cities.	USA	Participants required nanotechnology labels for all types of food and most of them were willing to pay a premium for labelling. However, labels alone are insufficient to help consumers to make informed choices.

Capon et al. 2015	To develop evidence regarding perceptions of labelling products made by nanotechnology.	Representative national cross-sectional household survey (n =1355) using computer assisted telephone interviewing landline and mobile phone technologies. Random-digit dialled sampling. A similar survey (N= 1850) with academic, business and government stakeholders.	Australian larger public, academic, business and government stakeholders	Australia	Support for labelling of nano-products is wanted by all stakeholders. However, the larger public are less likely to buy these products than any other stakeholders.
Casolani et al 2015	To examine consumers' acceptance of nanotechnology application in wine production.	Representative regional (face-to-face) survey (N =221) Conjoint and post-hoc segmentation analysis	Italian wine consumers from the Abruzzo region.	Italy	Consumers are relatively unfamiliar with applications of nanotechnology and possess an overall rejection of the concept of "nano-wine". However, nanotechnology becomes more acceptable when its specific application enhances wine attributes.

Cobb and Macoubrie 2004	To discover the status of US public opinion/concern or interest (knowledge, risk, benefits and trust) in nanotechnology.	Representative national phone survey (N =1536) Random-digit dialled survey.	Public/citizens - adults 18 years or older in the continental US.	USA	American citizens pay scant attention to science in general and nanotechnology in particular, and hence they have minimal knowledge about it. However, respondents who have heard about nanotechnology were more likely to associate it with potential benefits. Emotions (particularly the emotion of feeling hopeful) played an important role in explaining respondents' attitudes towards nanotechnology
Conti, Satterfield and Harthorn 2011	To assess public perceptions of nanotechnology by exploring perceived risks (risk versus benefit framings) and the specific social positions from which people encounter or perceive new technologies.	National phone survey (N = 1,100).	American public.	USA	Public's acceptance of nano-enabled products depends on a multitude of factors. Assessments of risks and benefits are strongly linked to the systematically manipulated psychometric qualities of various nanotechnology applications. With some exception, (social) justice plays an important role in the formation of risk perceptions related to nanotechnology.

Cook and Fairweather 2007	To provide an early assessment of key influences on intentions to purchase low fat lamb or beef made using nanotechnology.	Focus groups (N=40) to identify beliefs associated with the new food. National postal survey (N = 565).	New Zealand public.	New Zealand	Participants are more likely to purchase low fat lamb or beef made using nanotechnology. The intentions to purchase these products were influenced by self-identity, attitude and subjective norms.
Farshchi et al 2011	To examine public awareness and attitudes of Iranian people towards nanotechnology, including the role of affect and trust in shaping public opinion on this technology.	Survey (N = 759).	759 individuals demographically weighted to reflect general population of 16 years and more in Tehran.	Iran	The majority of participants were not familiar with the concept of nanotechnology. However, perceived benefits are more likely to outweigh perceived risks. Attitude towards nanotechnology particularly driven by hopes and expectations.
Groves 2013	To examine the prospects (difficulties and opportunities) of nanoscale science and technology commercialisation by implementing adaptive and/or anticipatory regulation and to identify potential	Policy Delphi (n=13)	A multi-stakeholder panel including individuals from central government and regulatory agencies, consultancies, natural and social academic	UK	The panel saw little prospect of a disruptive nanoscale science and technology (NST) future triggered by a radical new technical paradigm. At the strategic level, there is a need for trade-offs between flexibility and resilience. Benefits of NST are perceived particularly for luxury goods manufacturers

	challenges to its implementation.		science, and civil society organisations.		rather than society at large. Regulators, governments and industry are encouraged to avoid a 'fast, fragile and fragmented' future.
Gupta, Fisher and Frewer 2015	To elicit the factors that shape consumer perception of different applications of nanotechnology	Structured interviews (n= 18 participants) Repertory grid method in conjunction with generalized Procrustes analysis.	Consumers from a city (Newcastle upon Tyne) in the North East of England	UK	Consumers differentiate between applications of nanotechnology based on their perceived benefits. However, these may be off-set particularly by perceived risks of fear and ethical concerns.
Gupta et al 2012	To identify expert opinion on factors influencing societal response to applications of nanotechnology. Specifically, to compare different applications of nanotechnology and identify expert views regarding factors influencing societal acceptability.	Structured face-to-face interviews (n=17). Repertory grid methodology in conjunction with generalized Procrustes analysis.	Experts on nanotechnology engaged in diverse activities related to nanotechnology, across the North West of Europe.	North West of Europe (Germany, Ireland, UK and the Netherlands)	The societal response to different nanotechnology applications depends mainly on the extent to which these applications are perceived to be beneficial, useful and necessary and how 'real' and physically close they are to the end-user.

Gupta et al 2013	To examine differences in expert opinion regarding societal acceptance of different applications of nanotechnology within different technological environments, consumer cultures and regulatory regimes.	Online questionnaire designed and administered using Qualtrics software (n=67)	Experts from Northern America (N = 12); Europe (N = 21); India (N = 12); Singapore (N = 11) and Australasia (N = 11). Academia, industry, government, media and consumer representative groups.	Northern America Europe; India Singapore and Australasia	All experts agreed that perceived risk and consumer concerns regarding contact with nanoparticles are more likely to drive rejection, whereas perceived benefits influence acceptance, no matter the country. Encapsulation and delivery of nutrients in food was thought to be the most likely to raise societal concerns, while targeted drug delivery was most likely to be accepted. Social acceptance may be homogenous, independent of local contextual factors.
Handford et al. 2015	To assess awareness and attitudes of agri-food organisations towards nanotechnology.	Face-to-face and phone interviews (n=14) and an electronic questionnaires administered to a large database (n=1014)	Agri-food organisations	Ireland	Current awareness of nanotechnology applications in the Irish agri-food sector is low. Participants do not have strong (negative or positive) views regarding applications of nanotechnology to this sector.
Köhler and Som 2008	To examine whether innovators, the pioneers of the	Interviews (n=20) using structured questionnaires	Innovators/experts (researchers and	12 European	Innovators are less sensitive to early scientific warnings regarding risks of nanotechnology.

	technological advance in nanotechnology, are aware of the lessons that can be learned from adverse effects that have occurred following past innovation.	based on the relevant issues identified in the literature review. Most by phone plus some face-to-face questionnaire responses.	engineers involved in R&D on nanotechnology-based applications, at both universities and businesses). Nanotechnology application areas: "medical diagnosis", "food packaging" and "energy conservation and production"; marketing and regulating nanotechnology.	countries (no clear specificati on)	However, they hardly engage in risk communication and dialogue with stakeholders. Lack of public acceptance of nanotechnology is perceived as a barrier by innovators and many fear a 'backslash'. Innovators are confident that risks associated with nanotechnology are measureable and manageable.
Marette et al 2009	To evaluate the impact of information on consumers' choice (WTP) when nanotechnology may have important but uncertain	(Choice) experiment (n=97) randomly selected based on quota sampling.	German consumers.	Germany	The majority of participants are reluctant to accept nanotechnology in food products. Health information is a priority for consumers and the lack of it reduced considerably the WTP for these products.

	consequences on health, environment and society.				
Roosen et al 2015	To assess the impact of trust on the willingness to pay for nanotechnology food.	Online survey in Canada (N= 615) and Germany (N = 750) plus an economic laboratory experiment in Germany (n=143).	Larger public/consumers	Canada and Germany	Nanotechnology applications, related to food and drink (juice) and packaging, raise concerns in people's minds. Trust can lessen these concerns. WTP for nanotechnology increases with trust.
Roosen et al 2011	To evaluate the impact of different information sequences on participants' hypothetical WTP for food produced using nanotechnology that may have uncertain consequences for health, the environment, and society.	(Choice) experiment (n=143) randomly selected based on the quota method.	German consumers.	Germany	Information choice plays an important role in assessing impacts of food produced using nanotechnology. Health information clearly decreases WTP, whereas societal and environmental information have a lower effect on WTP. Consumer benefit depends on their perceptions regarding the safety of nanotechnology food products.
Schnettler et al 2013 (Food	To evaluate acceptance of nanotechnology applications in sunflower oil and in food	Survey (n=400). Simple random sampling.	Shoppers (people responsible for buying	Chile	Consumers' perception regarding new food should be considered from an early stage of the product development process. Brand is an

Science and Technology)	packaging by consumers in Temuco (Region of the Araucanía, Chile) and identify consumer segments according to their knowledge of nanotechnology, socio-demographic characteristics, and their level of satisfaction with food-related life.		food for their households).		attribute which matters relatively more than nanotechnology application in packaging and food. It is also more important than price.
Schnettler et al 2013 (Appetite)	To investigate the relationship between food neophobia, satisfaction with life and food-related life, and acceptance of the use of nanotechnology in food production.	Survey (n= 400).	Supermarket shoppers in southern Chile.	Chile	The study confirms the existence of a positive relation between satisfaction with life and satisfaction with food-related life. Four consumers groups were identified. Groups differ in their knowledge of nanotechnology, willingness to purchase foods involving nanotechnology, age, socioeconomic level and lifestyle. The degree of food neophobia is associated with

					satisfaction with life, with food-related life, as well as with the acceptance of nano-products.
Schnettler et al 2013 (Agr Ec)	To compare the acceptance of sunflower oil produced with nanotechnology with the acceptance of genetically modified and conventionally produced foods among consumers in Temuco (Region of the Araucanía, Chile), to differentiate market segments according to their acceptance of nanotechnology, and to characterize these segments according to their socio-demographic characteristics and level of food neophobia.	Survey (n= 400).	Supermarket shoppers in southern Chile.	Chile	The majority of respondents had no previous information on nanotechnology or knew its meaning. Brand and production technology were identified as the main attributes that influenced the decision to purchase sunflower oil. This was followed by price and the existence of a health certification seal.
Siegrist et al 2007	To investigate how lay people perceive nanotechnology	Survey (n=153). Convenience sample.	Shoppers (persons who are responsible for	Switzerland	Overall, participants were reluctant to buy nanotechnology foods or food with

	foods and nanotechnology food packaging, and examine the factors that influence willingness to buy (WTB) these products.		grocery shopping) from the German-speaking part of Switzerland.		nanotechnology packaging. However, packaging is perceived as more beneficial than nano-foods. Social trust in the food industry directly influences the affect aroused by these new products and WTP. The affect has an impact on perceived benefits and risks. The latter seems to be the most important predictor for WTP.
Siegrist et al 2008	To examine how lay people perceive various nanotechnology foods and nanotechnology food packaging and to identify food applications that are more likely and food applications that are less likely to be accepted by the public.	Mail survey (n = 337). Random sampling.	Person in the household next in line for their birthday and over 18 years in the German speaking part of Switzerland.	Switzerland	Affect and perceived control influence risk and benefit perception of nanotechnology food. Packaging seems to be less problematic than nanotechnology in foods. Naturalness in food products and trust are significant factors that influence the perceived risk and benefit of nanotechnology foods and nanotechnology food packaging.

Siegrist, Stampfli & Kastenholz 2009	To examine consumers' willingness to buy health-beneficial food products produced using nanotechnology.	Two representative mail surveys (n=255 & n=260). Random sampling.	Person in the household next in line for their birthday and over 18 years of age in the German speaking part of Switzerland.	Switzerland	Consumers were hesitant to accept nano-foods. They attribute a negative utility to nanotechnology foods, even when the food products had clear health benefits for the consumers. Perceived naturalness influences positively the willingness to buy functional foods. Health benefits due to natural additives had a higher utility compared with additives tailored using nanotechnology.
Simons et al 2009	To analyse the recognition, risk perception and acceptance of nanotechnology, and to address the problems of risk communication on nanotechnology.	In-depth interviews (n=50) plus a phone survey (n=1,000).	In-depth interviews: participants selected in line with the requirement to cover a broad range of ways of dealing with nanotechnology and information about it. Survey: people aged between 16 and 60 years,	Germany	In Germany, nanotechnology raises expectations and hopes for improvements, particularly in the fields of medicine and environment. The majority of participants are open to nanotechnology, and perceived risk associated with nanotechnology is low.

			registered in public telephone books that include cell phones, who were capable of understanding and answering questions in German.		
Stampfli, Siegrist & Kastenholz 2010	To examine factors that may influence the acceptance of nanotechnology products in the food domain. Specifically it investigates the influence of risk information on the acceptance of nanotechnology food and food packaging.	Representative mail survey (n = 514).	The person in the household next in line for their birthday and over 18 years of age.	Switzerland	Attitudes toward gene technology was the strongest variable in explaining the variance of perceived risk and perceived benefit of nanotechnology applications. Social trust had also a significant effect on perceived benefit and perceived risk. However, food and packaging applications containing nanoparticles are perceived differently with the latter receiving greater acceptance.

Suhaimee et al 2014	To evaluate the level of awareness and knowledge (including risks and benefits) about nanotechnology in Malaysia in relation to demographic profiles. The willingness to buy and use nano-based products was also identified specifically on food-related products.	Survey (n= 309). Random sampling.	Visitors of the Malaysia Agriculture, Horticulture and Agrotourism Exhibition 2012.	Malaysia	The level of awareness regarding nanotechnology is low in Malaysia relative to the developed countries. Most participants agreed that the perceived benefits exceed the risks and they were willing to buy nanotechnology-based products.
Yawson and Kuzma 2010	To examine and critically analyse the links between consumer acceptance of agrifood nanotechnology and factors such as trust, stakeholders, institutions, knowledge, and human	Meta-analysis of the risk perception literature plus experts' opinions to develop a systems map (n =21), via electronic surveys and/or phone interviews.	Experts in agrifood nanotechnology.	n/a	Consumer acceptance of agri-food nanotechnology involves a high level of complexity in which to model and understand how decisions are made. Building trust and confidence in an industry that may involve significant risks such as the agrifood nanotechnology industry, governance systems, especially regulatory

	environmental health risks, by using systems mapping.				aspects of governance systems, were pointed out as key factors in consumers' acceptance of nanotechnology.
Yue, Zhao and Kuzma 2015	To investigate heterogeneous consumer preferences for nano-food and genetically modified food.	Online survey (n=1117) and choice experiment to compare consumer preferences and willingness to pay (WTP) for GM good and nano-food (i.e. rice).	US consumers	USA	Nano-food is preferable to GM food across all participants. Safety benefits, nutrition, taste and environment are important attributes. However, consumers' preferences are heterogeneous.
Yue et al 2015	To explore the relationship between perceptual influences of consumers such as trust in government to manage technologies, risk and benefit attitudes and labelling preferences on consumers' willingness to buy (WTB)	Online representative survey (n=1145) conducted by a professional company (Qualtrics). Structural equation modelling.	US consumers	USA	Trust in government to manage GM and nano-foods does not influence labelling preferences. However, trust does influence attitudes towards food technologies. Labelling influences WTP for nano-foods but not GM foods.

	genetically modified and nano-food products.				

Table 3. Quality appraisal of qualitative papers

Study	Was there a clear statement of aims?	Is a qualitative methodology appropriate?	Was the research design appropriate to the aims?	Was the recruitment strategy appropriate to the aims?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participant been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?
Interviews									
Becker (2013)	Yes	Yes	Unclear	Yes	Yes	No	Unclear	Yes	Yes
Gupta, Fischer & Frewer (2015)	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes
Gupta *et al* (2012)	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes
Kohler & Som (2008)	Yes	Yes	Yes	Yes	Yes	No	Unclear	Unclear	Yes
Focus Groups									
Brown, Fatehi & Kuzma (2015)	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes
Brown & Kuzma (2003)	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes
Mixed Methods									
Handford et al (2015)	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes
Simons *et al* (2009)	Yes	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes
Yawson & Kuzma (2010)	Yes	Yes	Unclear	Unclear	Unclear	Unclear	Yes	Unclear	Unclear

Table 4. Quality appraisal of quantitative studies

Study	Was a survey appropriate for the aim?	What was the response rate?	Is the sample representative of the population?	Are the measures reported objective and reliable?	Was there a justification of the sample size?	Were appropriate statistical analyses performed?	Was there evidence of any other bias?
Surveys							
Arnold (2014)	Yes	Unclear	Unclear	Unclear	No	Unclear	Unclear
Besley *et al* (2008)	Yes	32.3%	No	Unclear	No	Yes	Yes
Capon et al (2015)	Yes	19-48%	Unclear	Yes	Yes	Yes	Yes
Cobb & Macoubrie (2004)	Yes	38-48%	Unclear	Unclear	Unclear	Yes	No
Conti *et al* (2011)	Yes	51.9%	Unclear	Unclear	Unclear	Unclear	Unclear
Cook & Fairweather (2007)	Yes	29.6%	No	Yes	No	Yes	No
Farschi *et al* (2011)	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear
Groves (2013)	Yes	71%	No	Unclear	No	Yes	Unclear
Gupta *et al* (2013)	Yes	32%	Unclear	Unclear	No	Yes	Unclear
Schnettler *et al* (2013)	Yes	Unclear	Unclear	Unclear	Yes	Yes	Unclear
Schnettler *et al* (2013) neophobia	Yes	68%	No	Yes	Yes	Yes	Yes
Schnettler *et al* (2014)	Yes	Unclear	No	Yes	Yes	Yes	Yes
Siegrist *et al* (2007)	Yes	Unclear	No	Unclear	No	Yes	Unclear
Siegrist *et al* (2008)	Yes	28%	Unclear	Unclear	No	Yes	Unclear
Siegrist *et al* (2009)	Yes	43%	Unclear	Yes	No	Yes	Yes

Study	Was a survey appropriate for the aim?	What was the response rate?	Is the sample representative of the population?	Are the measures reported objective and reliable?	Was there a justification of the sample size?	Were appropriate statistical analyses performed?	Was there evidence of any other bias?
Stampfli *et al* (2010)	Yes	41%	Unclear	Unclear	Unclear	Yes	No
Suhaimee *et al* (2014)	Yes	Unclear	Unclear	Unclear	No	Yes	Yes
Yue et al (2015)	Yes	86%	No	Yes	No	Yes	Unclear
Experiments							
Bieberstein *et al* (2013)	Yes	Unclear	Yes	Unclear	Unclear	Yes	No
Marette *et al* (2009)	Yes	Unclear	Yes	Unclear	Unclear	Yes	No
Roosen *et al* (2011)	Yes	Unclear	Yes	Unclear	Unclear	Yes	No
Conjoint Analysis							
Casolani et al (2015)	Yes	Unclear	Yes	Yes	No	Yes	Yes
Yue, Zhao & Kuzma (2015)	Yes	97.5%	Yes	Yes	No	Yes	Unclear
Mixed Methods							
Handford et al (2015)	Yes	8.67%	Yes	Yes	Yes	Yes	Unclear
Roosen et al (2015)	Yes	Unclear	Unclear	Yes	No	Yes	Unclear
Simons *et al* (2009)	Yes	Unclear	Yes	Unclear	No	Unclear	Unclear
Yawson & Kuzma (2010)	Yes	30%	Unclear	Unclear	No	Unclear	Unclear

Study	A1	A2	B1	B2	C1	D1	D2	E1	E2	F1	F2	G1	G2	G3	H1	H2	H3	H4
Bieberstein *et al* (2013)	Very Likely	Can't tell	Other	Yes, no description	No	Yes	Can't tell	Can't tell	Can't tell	No	n/a	80-100%	Can't tell	No	Individual	Individual	Yes	n/a
Marette *et al* (2009)	Very Likely	Can't tell	Other	n/a	n/a	Yes	Can't tell	Can't tell	Can't tell	No	n/a	80-100%	Can't tell	No	Individual	Individual	Can't tell	n/a
Roosen *et al* (2011)	Very Likely	Can't tell	Other	Yes, no description	n/a	Yes	Can't tell	Can't tell	Can't tell	No	n/a	80-100%	Can't tell	No	Individual	Individual	Yes	n/a

Table 5. Analytical themes

Theme 1	Type and applications of food nanotechnology
Theme 2	Benefits and risks of food nanotechnology
Theme 3	Socio-demographic influences
Theme 4	Creating an informed and trusting consumer
Theme 5	Characteristics of food nanotechnology
Theme 6	Link to historical food technology concerns
Theme 7	Marketing and commercialisation
Theme 8	Future applications of food nanotechnology

Supplementary Data 1: Protocol

Protocol

SAFRD, Newcastle University

27 November 2014

1. REVIEW TITLE

Review title

How acceptable is nanotechnology, when applied to food and food products, to consumers?

2. REVIEW TEAM CONTACT DETAILS

Named contact & organisational affiliation of the review

Named contact:

[removed for peer review]

Review team members & organisational affiliations

[removed for peer review]

Funding sources/sponsors

N/A.

Conflicts of interest

None known

Collaborators

Not applicable

3. REVIEW METHODS

Primary research question

How acceptable is nanotechnology to consumers, when applied to food and food products?

Additional research questions

1. What are consumer attitudes towards nanotechnology?

2. What are consumer and expert attitudes/perceptions towards nanotechnology when applied to food and food production? Including:
    a. Beliefs
    b. Values
    c. Risks/Benefits
    d. Concerns
3. What is the influence of consumer attitudes and perceptions on their intention to consume and purchase food-related nanotechnology applications?

Condition or domain being studied & context

Nanotechnology utilises scientific advancements in the study of "molecules, compounds, or particles at the extremely small scale of about a millionth of a millimetre" (Cook and Fairweather, 2007). Its uses can vary; including in cosmetics, medicine, electronics, IT, textiles, and for environmental solutions, military use and space exploration (Economic and Social Research Council [ESRC], 2003). In particular relation to food, food production and food packaging, nanotechnology can be applied in the processing of commodities, such as in flour milling, or in functional foods whereby bioactive compounds are added to foods to create foods with additional physiological benefits (Sozer and Kokini, 2008). Nanoparticles can also be used in food packaging, to make packaging that is biodegradable and more environmentally friendly (Sozer and Kokini, 2008).

That said, nanotechnology in food products, processes and packaging presents numerous safety concerns, as well as "environmental, ethical, policy and regulatory issues" (House of Lords, 2010: 1). Whilst there are toxicological tests which are available to monitor the risk of nanotechnology in food, there are still concerns that the 'standard' tests are unable to detect very small effects (House of Lords, 2010). Due to such safety (amongst other) concerns, food consumers are often sceptical of nanotechnology in food (ESRC, 2003; Siegrist et al, 2009; Frewer, 2003). Whilst the picture is mixed, studies have found that consumers are unwilling to accept nanotechnology in foods, even if the health benefits are obvious, although there is a greater acceptance towards nanotechnology in food packaging (Siegrist, 2009). It is argued that greater public engagement with food nanotechnology may help to ease consumer concerns around its use, but that limited research has to-date been undertaken that can link risk assessment, consumer concerns, public engagement and nanotechnology in the food arena (Kuzma et al, 2008).

Consumer acceptance of nanotechology in food is important, considering that it can help to combat pressing global concerns, such as food shortages (ESRC, 2003). That said, whilst there has been some attempt to conduct systematic reviews of the regulatory situation surrounding nanotechnology (Grobe et al, 2008), systematic reviews exploring consumer attitudes, perceptions and acceptance of nanotechnology in relation to food is less common. Searching the PROSPERO database - a database containing registered systematic reviews in health and social care (PROSPERO, 2012) - and the databases of the Centre for Reviews and Dissemination (Centre for Reviews and Dissemination, 2012) does not indicate directly applicable systematic reviews in the areas of consumer acceptance, expert opinion, food and nanotechnology (Besley et al, 2008). The systematic reviews that have been conducted are in the general area of nanotechnology or focus on specific food issues, such as vitamin D food fortification (Black et al, 2011). Thus, it can be suggested that this area is under-researched.

This research seeks to provide policy makers, nanotechnology experts, and food manufacturers with a systematic review of the evidence concerning societal acceptance of nanotechnology and food. By undertaking this systematic review, we will offer policy makers and industry with all of the available evidence surrounding consumer acceptance of food nanotechnology. This will assist them in their decision making, risk assessment approaches, and will be prudent since they will have an indication of how consumers may react to future products, rather than waiting for the 'aftermath' to occur after food nanotechnology products are released (Cook and Fairweather, 2007).

Overview of the search strategy

Research reports for inclusion in the review will primarily be found through database searches, using search engines. There will be no systematic hand searching of journals or conference proceedings.

Inclusion criteria

Peer-reviewed papers will be included in the review if they meet all of the following criteria:

- Language: English.
- Date range: All dates.
- Study design: Empirical study including both qualitative and quantitative data.
- Population: Adults (aged 18 years or over).

- Intervention: Must contain a discussion of nanotechnology in relation to agri-food, risk perceptions, consumer acceptance, policy implications and research applications.
- Outcome measure: Discussion of stakeholder attitudes towards nanotechnology applied to food and food production.

Search strategies

Peer reviewed literature will be included in the systematic review. The following sources will be searched to identify published literature:

- Electronic databases of peer-reviewed journal articles; Scopus, Web of Knowledge, CAB Abstracts, PsychInfo, Medline, and Embase.
- The reference lists of all studies that meet the inclusion criteria, as well as relevant reviews will be scanned to identify further relevant publications.

The search strategy will take the general form of: nanotechnology AND terms for consumer acceptance, risk, and agri-food, and will be developed with the help of a specialist librarian. The search term will be adapted for use in each electronic medium.

Screening

After importing search results into EndNote and removing duplicates, screening will be conducted in three independent phases. Firstly, titles will be screened by two researchers (ELG and BC) independently to identify publications that do not meet the inclusion criteria. These publications will then be excluded with brief notes taken on the reasons for their exclusion. In cases of doubt, publications will be included for further discussion.

Secondly, the abstracts of publications that were included in the first screening round will be screened again by the same two researchers, to identify those that definitely do not meet the inclusion criteria. In any cases of doubt, or where an abstract is not present, publications will be included. Reasons for exclusion will again be noted.

Finally, the full text of publications that were included following the second screening will be screened by the same two researchers. On this occasion the assessment will be whether publications meet the inclusion criteria,

with notes made on whether they meet all of the criteria. Any disagreements at this stage will be resolved by discussion. Only papers that meet all of the inclusion criteria will be kept, with tables of excluded studies prepared, detailing when exclusion occurred and reasons for exclusion.

Primary outcome(s)

Debate on consumer acceptance of nanotechnology as it is applied to food and food production.

Secondary outcome(s)

We include here all additional variables of interest: risk perceptions of food and nanotechnology, political discussion on food and nanotechnology, and research applications in the area of food and nanotechnology.

Data extraction (selection and coding)

A coding framework will be developed using Nvivo software, and will include: participant characteristics, the research method, year of data collection, sample size and method, location of research data collection, and quality assessment. Data will be extracted by one reviewer and checked by a further two reviewers. Any disagreements will be resolved by discussion.

Where publications lack details required for quality assessment or full data extraction, authors will be contacted to request further details.

Risk of bias/quality assessment

The quality of all studies that meet the inclusion criteria will be formally assessed and will be assessed by researchers working independently using the Petticrew and Roberts and CASP tools for quantitative and qualitative data.

Strategy for data synthesis and reporting

We will begin by describing the range of debate in the area (both consumer and expert opinions), the theoretical and empirical rationales used to guide the debate in the area, population characteristics, and the political and research outcomes that have been studied. Finally, we will prepare a Table of Included Studies.

4. GENERAL INFORMATION

Type of review

Systematic review with possible meta-analysis.

Language

English

Country

United Kingdom

Dissemination plans

In order to disseminate our findings to the academic community, we will write up and submit our results for publication in a peer-review journal (e.g. Nature Nanotechnology).

Keywords

Systematic review, nanotechnology, consumer acceptance, risk perceptions, agri-food, food and food production.

Details of any existing review of the same topic by the same authors

None.

Supplementary Data 2: PRISMA checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2-3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-7
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5-6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Supp. Data 3

Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6-7
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	6-7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	6-7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6-7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5-7
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	5-7
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5-7
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias	19	Present data on risk of bias of each study and, if available, any	8-9

within studies		outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	n/a
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	n/a
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8-9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	n/a
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	14-16
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16-17
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	18
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	1

Supplementary Data 3: Example search terms

TI=(**consumer** OR lay OR **public** OR **customer** OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer information** OR **consumer panel**) AND (**nano** OR **nanotechnology** OR **"nano material"** OR **nano products**) AND (**food** OR **food product** OR **product** OR **consumption** OR **purchase** OR **preparation** OR **storage**)

TI=(**accept*** OR **perception** OR **thought** OR **view** OR **belief** OR **factor** OR **idea**) AND (**society** OR **public** OR **group**) AND (**nano** OR **nanotechnology** OR **nanomaterial** OR **nano products**) AND (**food** OR **food product** OR **food production** OR **health**) AND (**consumer** OR lay OR **public** OR **customer** OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer behavior** OR **consumer information** OR **consumer panel**)

TI=(accept* OR perception OR thought OR view OR belief OR factor OR idea) AND (nano OR nanotechnology OR nanomaterial OR nano products) AND (consumer OR lay OR society OR public OR group OR customer OR expert OR stakeholder OR citizen OR people OR individual OR consumer attitude OR consumer behaviour OR consumer behavior OR consumer information OR consumer panel)

TI=(**attitude** OR **value** OR **anxiety** OR **risk** OR **benefit** OR **concern** OR **impact** OR **accept*** OR **perception** OR **thought** OR **view** OR **belief** OR **factor** OR **idea**) AND (**nano** OR **nanotechnology** OR **nanomaterial** OR **nano products**) AND (**consumer OR society** OR **public** OR **group** OR **public** OR **customer** OR lay OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer behavior** OR **consumer information** OR **consumer panel**) AND (**food** OR **food product** OR **food production** OR **health**)

TI=(**attitude** OR **value** OR **anxiety** OR **risk** OR **benefit** OR **concern** OR **impact** OR **accept*** OR **perception** OR **thought** OR **view** OR **belief** OR **factor** OR **idea**) AND (**nano** OR **nanotechnology** OR

nanomaterial OR **nano products**) AND (**consumer** OR lay OR **public** OR **customer** OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer behavior** OR **consumer information** OR **consumer panel OR society** OR **public** OR **group**) AND (**food** OR **food product** OR **food production** OR **health**) AND (**buy** OR **purchase**)

TI=(**accept*** OR **perception** OR **thought** OR **view** OR **belief** OR **factor** OR **idea**) AND (**nano** OR **nanotechnology** OR **nanomaterial** OR **nano products**) AND (**food** OR **food product** OR **food production** OR **health**) AND (**consumer** OR lay OR **public** OR **customer** OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer behavior** OR **consumer information** OR **consumer panel OR society** OR **public** OR **group**)

TI=(accept* OR perception OR thought OR view OR belief OR factor OR idea) AND (nano OR nanotechnology OR nanomaterial OR nano products OR technology OR engineering OR modified) AND (consumer OR public OR customer OR lay OR expert OR stakeholder OR citizen OR people OR individual OR consumer attitude OR consumer behaviour OR consumer behavior OR consumer information OR consumer panel OR society OR public OR group)

TI=(**consumer** OR **public** OR **customer** OR lay OR **expert** OR **stakeholder** OR **citizen** OR **people** OR **individual** OR **consumer attitude** OR **consumer behaviour** OR **consumer behavior** OR **consumer information** OR **consumer panel**) AND (**nano** OR **nanotechnology** OR **"nano material"** OR **nano products OR technology OR engineering OR modified**) AND (**food** OR **food product** OR **product** OR **consumption** OR **purchase** OR **preparation** OR **storage**)

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Supplementary Data 4: Box 1 Quotations to illustrate the 'Type and applications of agri-food nanotechnology' theme

Box 1:
"Participants were more willing to use nanotechnology food applications involving packaging…than either food additives...or processing" (Brown and Kuzma 2013)

Supplementary Data 5: Box 2 Quotations to illustrate the 'Benefits and risks of agri-food nanotechnology' theme

Box 2a:

"The use of nanoclay polymer-composites in food packaging would better protect food freshness, delay spoilage, and enhance the shelf life of packaged foods." (Köhler and Som 2008)

"The scientists surveyed generally rate the risks of nanotechnology substantially lower than the benefits." (Besley et al. 2008)

"… with some aspect of addressing starvation, food supply, or food quality, with the top three sub- themes emerging as ''Food preservation, spoilage prevention, and storage'' … ''Food distribution and production'' … and ''Better/enhanced nutrition or crop yields''…" (Brown et al. 2015)

"…nanotechnology that reduced calorie content …" (Casolani et al. 2015)

"The complexity of participant views is illustrated by this participant's comment: the focus was on using technology to adjust food production methods, in order to expand general food production and improve nutrition, while preserving the ability of the environment to support food production and ensuring that the benefits go to not only the very rich." (Brown et al. 2015)

Box 2b:

"Our data suggest that from Iranians' view, the … [largest] *benefit of nanotechnology to achieve is new ways to detect and treat human diseases and the second high scored benefit is cheaper, longer lasting consumer products.''* (Farshchi et al. 2011)

"Descriptive analysis showed that most of the people agree that nanotechnology is beneficial to them as it could modify foods based on nutritional needs or tastes." (Suhaimee et al. 2014)

Box 2c:

"Interviewees responded that some nanomaterials and nanotechnologies were novel, and some were not. But overall, there was an insistence from subjects that nanotechnology has 'been around forever', and that what is new is our more complete understanding and control of matter at this small scale." (Becker 2013)

"For these subjects, this was the case because of their belief that either (1) the small volume of production and exposure to nanoproducts made them less risky, (2) all individual nanomaterials agglomerate before coming into contact with humans, (3) nanotechnology is relatively less risky than other technologies currently on the market, such as genetically-modified organisms (GMOs) and organics, (4) nanotechnology's risks are comparable to ultra-fine particles (UFPs), (5) or that most nanomaterials on the market have been embedded within matrices so as to limit consumer exposure."(Becker 2013)

"Some emphasized the normalcy of risks accompanying newly developed technologies." (Becker 2013)

Box 2d:

"People don't think about nanoparticles when it is in their [tennis] rackets and sports equipment, but they start to think of risks if these particles are in food." (Gupta et al. 2012)

Box 2e:

"Others pointed out that nanoparticles could potentially migrate from the packaging into the food and then pose a health risk." (Köhler and Som 2008)

"Some subjects mentioned that, because of their small size, some nanomaterials are able to be taken up by cells and absorbed through the skin and that this presents a health risk." (Becker 2013)

Box 2f:

"When it comes to food, in particular, the overwhelming majority of the population is against nanotechnology. Therefore, it is obvious that nanotechnology and food makes the majority feel at least uncomfortable and that it does not enjoy acceptance." (Simons et al. 2009)

"In the context of food, nanotechnology is not natural, and hence, it goes against the common belief that natural is good and unnatural is bad." (Simons et al. 2009)

"Finally, in terms of nanoenabled food, the robustness of bodily invasion in our experiments indicates that [nano]-food may trigger particularly strong reactions and concerns because it is consumed intentionally, but possibly unknowingly." (Conti et al. 2011)

"…the main reasons for unwillingness to use nano-products were limited knowledge about the product and merely the fact that the product is new." (Brown et al. 20115)

Supplementary Data 6: Box 3 Quotations to illustrate the 'Socio-demographic influences' theme

Box 3:

"We find that whites and more educated respondents are more likely to perceive benefits exceeding risks." (cobb and Macoubrie 2004)

"Consistent with the white male effect, white and male participants perceived the benefits of nanotechnology as outweighing the risks as compared to women and non-whites." (Conti et al. 2011)

"Men are significantly more likely than women to think that benefits outweigh risks. And individuals who have greater knowledge of nanotechnology are far more likely to say that the benefits will outweigh the risks, and those who have no knowledge of the technology are more likely to say that the risks will outweigh the benefits." (Simons et al. 2009)

"Older respondents perceived nano-outside applications as significantly more beneficial than younger respondents. No significant age effect was observed for nano-inside applications. Females perceived significantly less benefits associated with both nano- outside and nano-inside applications than males." (Siegrist et al. 2008)

"Experts also indicated that agri-food applications of nanotechnology would be more acceptable in Northern America, Singapore and India and less so in Europe and Australasia." (Gupta et al. 2013)

"The second segment … labelled "traditionalist displayed a strong negative utility for nano-technology produced wine" (Casolani et al. 2015)

"[Those] prone to nanotechnology… assigned greatest importance to the type of nanotechnology application in the food…" (Schnettler et al. 2014)

Supplementary Data 7: Box 4 Quotations to illustrate the 'Creating an informed and trusting consumer' theme

Box 4a:

"Generally, responsibility for safe development was perceived as something shared by multiple parties. But there was a strong tendency for interviewees to emphasize their own company's responsibility or industry's responsibility for making safe products." (Becker 2013)

"A couple of subjects indicated that consumers were under-protected because there was insufficient knowledge about the safety of some nano-products entering the market." (Becker 2013)

Box 4b:

"As might be expected, respondents see a need for regulation most clearly in those areas where they see the most risk, including issues related to human and animal health and protection of the natural environment…Health (human and animal), environmental, and privacy concerns were seen as the areas with the least adequate regulations, but not by a wide margin…With regard to regulations, it appears that many of the scientists involved see a need to appropriately manage potential risks. The priority for regulation seems to be in the areas of health and environmental regulation, with scientists also indicating that current regulations in these areas may not be adequate." (Besley et al. 2008)

"International harmonisation of regulations would simplify international trade." (Gupta et al. 2013)

Box 4c:

"Yet as long as regulatory agencies lack the immediate funds to research the implications of nanotechnology extensively on their own, they will need to pass the burden on to industry to build a coherent body of knowledge about these implications. But such requirements could easily exceed the amount that industry is generally willing to contribute. Such disagreement will undoubtedly be played out in the form of a power struggle between agencies and industry." (Becker 2013)

"The main reason given by supporters of labeling was that the consumer has a right to know, with one subject declaring, 'If it's a nano-scale material, people should know, hands down.''' (Becker 2013)

"Labeling is an unusually contentious issue for the domain of nanotechnology, with much disagreement about whether or not products containing nanomaterials should be labeled as such, and what information, if any, should be included on a label. The European Union has already enacted labeling requirements for nanotechnology ingredients in cosmetics. But in the United States, it is still undecided how much ought to be known before accurate labels can be produced. But what is perhaps most contentious is if the need for highly accurate labeling trumps the consumer's ''right to know'', given that consumers are increasingly coming into contact with nano-enabled products. Still, the question may be posed, if only a vague label is given, what information do consumers really have?" (Becker 2013)

"In the present study, we tested consumers' acceptance of hypothetical food concepts. The formulation of the scenario was not constrained by current regulations. Regulations are constantly changing. For middle or long term planning, industry and NGO's should know under which conditions the public accepts nanotechnology in food products. Currently, the use of nanotechnology encapsulation methods does not have to be labeled in the USA or the EU. The case of GM food demonstrates, however, that pressure from interest groups may result in new regulations. GM food must be labeled in the EU and in Switzerland, for example. Labeling of nanotechnology food products is discussed in various countries (Burri and Bellucci, 2008). It is important for the food industry, therefore, to have some knowledge of the conditions under which nanotechnology is accepted by consumers. Otherwise, the food industry will not be well prepared for possible future regulations related to nanotechnology." (Siegrist et al. 2009)

Box 4d:

"Respondents with high levels of trust perceived more benefits associated with the nanotechnology applications compared with respondents with low levels of trust." (Siegrist et al. 2008)

"Social trust (trust in sciences/consumer protection agencies) had a significant effect on the perceived risks of nano-outside applications but had no effect on the perceived risk of nano-inside applications." (Siegrist et al. 2008)

Box 4e:

"Familiarity with nanotechnology is found to play a role in accepting nanotechnology." (Bieberstein et al. 2013)

"Consumer choice and the right to be informed were reasons for desiring the label and were typically invoked in these exchanges. The label therefore acted as an enabler of consumer choice from their perspective." (Brown and Kuzma 2013)

Box 4f:

"… commercializers interviewed here focused on carrying out subjective risk/benefit analyses by performing in-house testing and utilizing common sense to come to an understanding of the risks." (Becker 2013)

Box 4g:

"However, even though they were not familiar with the technology behind the products, they were not scared. In contrast, grasping their own boundaries can foster interest in and fascination with nanotechnology." (Simons et al. 2009)

"The more that negative affect and the less that control was associated with a nanotechnology food application or nanotechnology food packaging, the higher the perceived risk….The more that negative affect and the less that control was associated with a nanotechnology food application, the lower the perceived benefit." (Siegrist et al. 2008)

"Skepticism about their ineffectual nature stemmed from concerns about correctly interpreting a label or that labels simply do not motivate behavioral change…"
(Brown et al. 2015)

Supplementary Data 8: Box 5 Quotations to illustrate the 'Characteristics of food nanotechnology' theme

Box 5a:

"In sum, people who preferred natural and healthy food associated more risks and fewer benefits with nanotechnology food products compared to people who did not put emphasis on those food qualities." (Stampfli et al. 2010)

"…consumers are more sensitive to technologies directly modifying the product." (Marette et al. 2009)

Box 5b:

"Experts were of the opinion that people will distinguish between applications on the basis of the personal advantages that would accrue to an individual, and how real or close to reality these applications will appear to the public." (Gupta et al. 2012)

"For example, nanotechnology is promoted widely as a technological solution to enhance food security, which is a more pressing problem in the developing world…" (Gupta et al. 2013)

"More specifically, participants were most willing to use nanotechnology food packaging for the beneficial functions of enhancing nutrition…, reducing spoilage …, and leading to cheaper production..." (Brown and Kuzma 2013)

Supplementary Data 9: Box 6 Quotations to illustrate the 'Link to historical agri-food technology concerns' theme

Box 6:

"We can show that a high- risk perception of GM food correlates with lower WTP [willingness to pay] *of nano-food and nano-packaging, both in France and in Germany."* (Bieberstein et al. 2013)

"It was assumed that a new, still unknown technology with high levels of uncertainty, as is the case for nanotechnology food applications, may make consumers rely on previous evaluations of other already known food technologies, such as genetic modification in food. In both countries and for both products, higher risk judgements of GM food are linked to a significantly lower WTP for the nano-food and nano-packaging." (Bieberstein et al. 2013)

"In the interview, "negative public perceptions" were a particular concern due to misinformation and "bad press" from comparisons to GM foods. There were fears that misinformation could result in mistrust by the consumers, which in turn could have serious implications for the agri-food industry, like in the recent example of the horsemeat scare. This was replicated in the survey, with the main challenges regarding the use of nanotechnology in agri-food being "information and knowledge deficits", "public acceptance", and "long term health implications" (Handford et al. 2015)

Supplementary Data 10: Box 7 Quotations to illustrate the 'Marketing and commercialisation' theme

Box 7a:

"In the area of promotion, consumers must be informed of the risks and benefits associated with nanotechnology, as the public appreciates receiving information that can facilitate the decision to buy traditionally produced foods or foods produced with new technologies..." (Schnettler et al. 2013b)

"This indicates that the brand helps reduce uncertainty and the perception of risk when purchasing foods produced with new technologies such as GM and nanotechnology." (Schnettler et al. 2013a)

Box 7b:

"Increase number of consumers that are purchasing or consuming agrifood nanotechnology products will ultimately lead to increase R&D [research and development] *investment rate, more products in R&D, increase in the rate of commercialization, and more agrifood products on the market."* (Yawson and Kuzma 2010)

"...that people would expect water filtration and food packaging to be commercialised sooner than most other applications." (Gupta et al. 2013)

"Assuming that experts shape the process of innovation, one might anticipate that the first products introduced into the (European) market will be those which experts perceive will be viewed as most beneficial and least related to societally less acceptable application in, for example, the agrifood sector." (Gupta et al. 2012)

Supplementary Data 11: Box 8 Quotations to illustrate the 'Future applications of agri-food nanotechnology' theme

Box 8a:

"Future studies may wish to examine how consumers react to different descriptions of nanotechnology. Moreover, further research should identify factors that augment or hinder the acceptance of nanotechnology foods and should also examine possible cultural differences." (Siegrist et al. 2009)

"Comparison between expert and public opinion is therefore needed in order to determine whether what is technically possible from implementation enabling technologies such as nanotechnology aligns with societal preferences." (Gupta et al. 2013)

Box 8b:

"Future studies may wish to examine how consumers react to realistic nanotechnology foods." (Siegrist et al. 2007)

"However, these results suggest that when investigating the acceptance of nanotechnology applications, a large number of consumer-related variables should be considered, such as their psychographic and psychological characteristics, and should not be confined solely to their demographic characteristics." (Schnettler et al. 2014)

Box 8c:

"This suggests that experts speculate that social negativity will arise as nanotechnology is commercialised, in particular within the agrifood sector, and that at this stage in implementation understanding why this occurred with genetic modification may be useful when determining how nanotechnology might be commercialised." (Gupta et al. 2012)

"Future research could adopt a more nuanced focus both on application domain and the social contexts in which they will be encountered and understood by social groups and persons in different social locations." (Conti et al. 2011)

"In step with most of the past research, we investigated willingness to buy new food products

and not the actual behavior. Respondents did not taste the food. Results of past studies suggest that taste is an important factor influencing consumers' willingness to use functional foods (Verbeke, 2006). Future studies may wish to examine how consumers react to different descriptions of nanotechnology." (Siegrist et al. 2009)

Box 8d:

"Handling public education of different stakeholder groups, public engagement in the governance and regulatory process, and involvement of consumers in proactive debate on risks and benefits of agrifood nanotechnology." (Yawson and Kuzma 2010)

"Public engagement has a dual role in consumer acceptance of agrifood nanotechnology and public engagement will lead to increased consumer awareness which will enable consumer acceptance or rejection of agrifood nanotechnology to be based more on facts than on suspicions or speculative claims and engaging the public will enhance the depth of interaction and confidence and trust among those involved in the research, development, governance, and regulation of agrifood nanotechnology, the public, and NGOs (Mantovani et al. 2009). This is crucial if satisfactory trade-offs of risks and benefits of agrifood nanotechnology are to be defined appropriately." (Yawson and Kuzma 2010)

"So it is crucial to involve trusted agencies and even specified NGOs in risk communication process. Sooner or later bad news on nanotechnology will become available for the uninformed general public, so it is wisdom to take risk communication actions as soon as possible." (Farshchi et al. 2011)

"Special emphasis ought to be given to transparency and accountability in communication." (Köhler and Som 2008)